Evaluation of Radiation Protection in Interventional Orthopedic Procedures in Khartoum State

By:

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Evaluation of Radiation Protection in Interventional Orthopedic Procedures in Khartoum State

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Date of Exam: 26/06/2013
Dedication

To

My parents for their patience and encouragement.

My brothers and sister for their help and support.

My friends, teachers and colleagues.

I dedicate this work
Acknowledgment

My full thanks to God in every thing.
My great and deep gratitude to my supervisor Mr. Mamdouh Yassin for his invaluable guidance, fruitful discussions and comments throughout this work. Also thanks for orthopedics procedures staff in Khartoum state.
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Abstract

In this study an evaluation of radiation safety and protection in interventional orthopedic procedures for the staff in three theatres in Khartoum state was conducted. To evaluate radiation protection program and staff knowledge with regard to radiation protection a questionnaire was designed and distributed among the staff there. Integrity check was conducted on the available radiation protection tools (lead aprons) to ensure that they provide optimal protection when positioned appropriately. Also dose rate was measured around the theatre to evaluate the level of leakage radiation. Finally the absorbed dose to orthopedic specialists was measured during several procedures.

The study showed the absence of most of the radiation protection and safety procedures that ensure the protection of workers and lack of worker awareness about radiation protection, which in turn is due to the absence of radiation protection program.

The integrity check conducted on lead aprons showed unacceptable crack in about 24% of the checked aprons. And in spite of this, there was no action taken to withdraw those faulty aprons or to replace them due to the acute shortage of the aprons available in the three centers and this will cause unjustified radiation exposure to the staff.

The level of radiation around the theatres was found to fall within the acceptable limit according to the current occupancy factor and the workload. Also, the average absorbed dose to orthopedic specialists falls within the acceptable limit according to the international commission of radiation protection (ICRP) recommendations. However, other more complex procedures may carry radiation risk to both patients and workers in this situation.

Lastly, the study includes some recommendations that – if implemented – could improve the status of radiation protection in interventional orthopedic procedures. The important recommendations are to establish a single regulatory authority in Sudan independent from any user or promotion of radiation as well as to conduct periodically training courses for orthopedic staff on radiation protection in orthopedic interventional procedures.
ملخص البحث

تناولت هذه الدراسة تقويم الأمان والحماية من الأشعاع في عمليات العظام التدخلية للعاملين في ثلاثة مراكز داخل ولاية الخرطوم حيث تم تصميم إستبان بهذا الخصوص وتم توزيعه على العاملين لتعرف على برامج الوقاية من الأشعاع المتعبة وهمي معرفة العاملين بالمخاطر الإشعاعية، ومعظم أدوان الوقاية من الأشعاع المتوفرة (المعاطف الرصاصية) للتأكد من أنها تؤدي وظيفتها بصورة جيدة، وتقوم معدل الجرعة الإشعاعية حول غرف العمليات لمساوي مستوى التشرب الإشعاعي، وكذلك تم قياس الجرع الإشعاعية للإخصاصي في المراكز باعتبارهم أكثر تعرضاً للإشعاع.

أوضح هذه الدراسة غياب الكثير من إجراءات الأمان والوقاية الإشعاعية في الأقسام الثلاثة التي تضمن الحماية لعاملين، وكذلك أوضحت الدراسة عدم معرفة العاملين بسلاس الوقاية من الإشعاع، وذلك بسبب عدم وجود برامج الوقاية من الإشعاع.

الفحوصات التي أجريت على المعاطف الرصاصية أوضحت وجود شكوك غير مقبولة في حوالي 42% من المعاطف التي تم اختبارها، وبالرغم من ذلك فإنه لا يوجد قرار بسحبها وإستبدالها بأخرى وذلك نسبة للنقص الشديد في عدد المعاطف المتوفرة بالمراكز وسيؤدي ذلك إلى تعرض إشعاعي غير مبرر للعاملين.

القياسات الإشعاعية للتسرب الإشعاعي حول غرف العمليات أوضحت أنه داخل النطاق المسموح به وفقاً لمعايير الاحتياط، وعدد ساعات العمل الحالية، وكذلك فإن قياس الجرعة الإشعاعية في الإخصاصي أوضح أن متوسط جرعة الإشعاعي من العمليات يقع داخل نطاق المسموح به وفقاً لوصايا اللجنة الدولية للوقاية من الإشعاع، ولكن ربما تكون عمليات أخرى أكثر تعقيداً مخاطر إشعاعية للعاملين والمريض.

أخيراً تضمنت هذه الدراسة بعض التوصيات التي إذا تم تنفيذها قد تحسن من مستوى الوقاية من الإشعاع في أقسام الإشاعة التدخلية. من أهم تلك التوصيات هو إنشاء جهاز رقابي وحد مستقل بالبلد ويجيب أن يكون تابعاً لجهة مستخدمة أو موجه لاستخدام الإشعاع، وكذلك تنفيذ بشكل دوري دورات تدريبية للعاملين حول الوقاية من الإشعاع في العمليات التدخلية للعظام.
Chapter One

Introduction
Chapter One

Introduction

1-1 Introduction:

The assessment of the radiation doses that the staff received in Interventional Radiology is extremely important because the irradiation in such procedures is not uniform and the received radiation doses could be substantially high. During the procedure, the radiation control is complex and there are several reasons for the high exposure levels. It is necessary to perform dosimetric assessments to the interventional radiology staff and checking radiation protection tools. By analyzing this information it is possible to determine the probable causes and to provide recommendations, aiming to optimizing the radiological protection.

1-2 Problem of the study:

The awareness of radiation workers of the basic principles of radiation protection is not adequate and this lead to unjustified exposure to radiation of staff and patient during interventional orthopaedic procedures.

1-3 Hypothesis:

Appropriate safety precautions at the facilities should be followed during interventional orthopedic procedure as described by the regulatory authority and international radiation safety guidance.

1-4 Overall objective:

The main objective of this study was to evaluate the level of radiation protection to staff during interventional orthopedic procedures and to lay down practical recommendations to maintain radiation doses as low as reasonably achievable (ALARA) during such procedures.
1-5 Specific objectives:

1- To assure that radiation protection tools e.g. lead aprons, thyroid protector, lead glass etc. provide optimal protection when positioned appropriately.
2- To estimate staff doses during interventional orthopedic procedure.
3- To monitor leakage radiation around the theatre.

1-6 Methodology:

Type of the study: field study

Study area: several orthopedic procedure theatres in Khartoum state

Source of data: Direct measurement, interviews, questionnaire.

1-7 Materials and methods:

- Pocket dosimeter to estimate staff doses
- Staff managing interventional orthopedic procedure as sample
- Survey meter to measure dose rate around the theatre
- Questionnaire.

1-8 Scope:

- Chapter-1 Introduction
- Chapter-2 Theoretical Background
- Chapter-3 Radiation Protection in Interventional Orthopedic Procedures
- Chapter-4 Materials and Methods
- Chapter-5 Results and Discussions
- Chapter-6 Conclusion and Recommendations.
Chapter Two

Theoretical Background
Chapter Two

Theoretical Background

2-1 Radiation quantities and units:

2-1-1 Physical quantities:

2-1-1-1 Photon fluence and energy fluence:

These quantities are usually used to describe photon beams and may also be used in describing charged particle beams.

- The photon fluence $\Phi$ is the quotient $dN$ by $dA$, where $dN$ is the number of photon incident on a sphere of cross-sectional area $dA$:

$$\Phi = \frac{dN}{dA} \tag{2-1}$$

The unit of photon fluence is $m^{-2}$.

- The energy fluence $\Psi$ is the quotient of $dE$ by $dA$, where $dE$ is the radiant energy incident on a sphere of cross-sectional area $dA$:

$$\Psi = \frac{dE}{dA} \tag{2-2}$$

The unit of energy fluence is $J. m^{-2}$.

2-1-1-2 Kerma:

Kerma is defined as the mean energy transferred from the indirectly ionizing radiation to charged particles (electrons) in the medium $dE_{tr}$ per unit mass $dm$:

$$K = \frac{dE_{tr}}{dm} \tag{2-3}$$

The unit of kerma is joule per kilogram ($J/kg$). The name for the unit of kerma is the gray (Gy), where 1 Gy = 1 J/kg.
2-1-1-3 The absorbed dose $D$:

It is defined as the mean energy $\dot{\varepsilon}$ imparted by ionizing radiation to matter of mass $m$ in a finite volume $V$ by:

$$D = \frac{d\dot{\varepsilon}}{dm}$$  \hspace{1cm} (2-4)

$d\dot{\varepsilon}$ is the mean energy imparted to matter of mass $dm$.

- The SI unit for absorbed dose is J/kg and its name is the gray (Gy).
- The older unit of absorbed dose is the rad, representing 100 erg/g, i.e., $1 \text{ Gy} = 100 \text{ cGy} = 100 \text{ rad}$.

2-1-2 Radiation protection quantities:

2-1-2-1 Organ dose:

Organ dose $D_T$ is defined as mean dose in a specified tissue or organ $T$ of the human body, given by:

$$D_T = \int D \, dm = \frac{\varepsilon_T}{M_t}$$  \hspace{1cm} (2-5)

- $M_t$ is the mass of the organ or tissue under consideration.
- $\varepsilon_T$ is the total energy imparted by radiation to that tissue or organ.

2-1-2-2 Equivalent dose:

Equivalent dose $H_T$ in tissue or organ $T$ is defined by the organ dose $D_{T,R}$ multiplied by a radiation weighting factor $W_R$ to account for the effectiveness of the given radiation in inducing biological detriment or harm:

$$H_T = W_R \times D_{T,R}$$  \hspace{1cm} (2-6)
- $D_{T,R}$ is the absorbed dose delivered by radiation type $R$ averaged over a tissue or organ $T$.
- $W_R$ is the radiation weighting factor for radiation type $R$.
- The unit of equivalent dose $E$ is J/kg and its name is the sievert (Sv) (1).

Table (2-1) shows radiation weighting factors for some types of radiation

(ICRP Report No. 103) (2)

<table>
<thead>
<tr>
<th>Type of radiation</th>
<th>Weighting factor (WR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photons</td>
<td>1</td>
</tr>
<tr>
<td>Electrons and muons</td>
<td>1</td>
</tr>
<tr>
<td>Protons and charged pions</td>
<td>5</td>
</tr>
<tr>
<td>Alpha particles, fission fragments, heavy ions</td>
<td>20</td>
</tr>
<tr>
<td>Neutrons</td>
<td>A continuous function of neutron energy</td>
</tr>
</tbody>
</table>

2-1-2-3 Effective dose:

Effective dose $E$ is defined as the summation of tissue equivalent doses, each multiplied by the appropriate tissue weighting factor $W_T$, to indicate the combination of different doses to several different tissues in a way that correlates well with all stochastic effects combined.

$$E = \sum W_T X H_T$$  \hspace{1cm} (2-7)

- $W_T$ tissue weighting factor
- The unit of effective dose $E$ is J/kg and its name is the sievert (Sv) (1).
Table (2-2) Shows tissue weighting factors for some types of tissues
(ICRP report No. 103) (2)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Weighting factor (Wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone marrow (red), Colon, Lung, Stomach, Breast, Remainder Tissues.</td>
<td>0.12</td>
</tr>
<tr>
<td>Gonads</td>
<td>0.08</td>
</tr>
<tr>
<td>Bladder, Oesophagus, Liver, Thyroid</td>
<td>0.04</td>
</tr>
<tr>
<td>Bone surface, Brain, Salivary Glands, Skin</td>
<td>0.01</td>
</tr>
<tr>
<td>Total</td>
<td>1.00</td>
</tr>
</tbody>
</table>

2-1-3 Operational quantities

Organ dose $D_t$, equivalent dose $H_t$ and effective dose are not directly measurable quantities. No standards are available to obtain traceable calibrations for radiation monitors using these quantities.

The ICRU has defined a set of measurable operational quantities for radiation protection purposes based on ICRU reference spherical (30 cm diameter) phantom made of tissue equivalent material with a density of 1 g/cm$^3$.

2-3-1 Ambient dose equivalent (for area monitoring):

Ambient dose equivalent $H^* (d)$ at a point in a radiation field is defined as the dose equivalent that would be produced by the corresponding aligned and expanded field in the ICRU sphere at a depth $d$ in millimeters on the radius opposing the direction of the aligned field.

- Recommended value for $d$ for penetrating radiation is 10 mm and the ambient dose equivalent is designated as $H^* (10)$. 
2-1-3-2 Directional dose equivalent (for area monitoring):

\(H'(d, \Omega)\) at a point in a radiation field is defined as the dose equivalent that would be produced by the corresponding expanded field in the ICRU sphere at depth \(d\) on a radius in a specified direction.

- The directional dose equivalent is generally defined for area monitoring of weakly penetrating radiation:
  - Recommended depth of \(d = 0.07\) mm.
  - \(\Omega\) Angle is the angle between the beam direction and the radius of the ICRU sphere on which the depth \(d\) is defined.

2-1-3-3 Personal dose equivalent (for personnel monitoring):

Personal dose equivalent \(H_p(d)\) is defined for both strongly and weakly penetrating radiations as the equivalent dose in soft tissue below a specified point on the body at an appropriate depth \(d\):

- \(d\) is 10 mm for penetrating radiation.
- \(d\) is 0.07 mm for skin and 3 mm for the eye lens (1).
Chapter Three

Radiation Protection in Interventional Orthopedic Procedures
Chapter Three

Radiation Protection in Interventional Orthopedic Procedures

3-1Historical perspective:

Although x-rays have been used since the early 20th century to image bones and joints, the use of fluoroscopy for orthopedic imaging did not gain popularity until much later. In the 1980's, fluoroscopy gained a prominent foothold in the orthopedic trauma community where it was championed as a valuable tool during femoral nailing and hip pinning. Now, nearly every discipline of orthopedics has adopted the use of fluoroscopy to meet its various needs (3).

The foremost body dealing with matters of radiation protection is International Commission on Radiological Protection, (ICRP). This was established in may 2011 under its former name Radiological Protection in fluoroscopically guided procedures performed outside the imaging department through the work of its specialist committees the ICRP continues to issue recommendations on many aspects of radiation safety in fluoroscopically guided procedures (3).

The European Council Directive on 30 June 1997 on “health protection of individuals against the danger of ionizing radiation to medical exposure and repealing directive 84/466 euratom” identified interventional radiology as specialist practice requiring special attention to be given to quality assurance programmers’, quality control measurement and patient dose assessment (4).

The last code of practice regulates the work in radiology department in Sudan issued by Sudan Atomic Energy Commission on 2007 (5).

3-2Some interventional orthopedic procedures:

3-2-1Fracture supported by dynamic hip screw:

Dynamic hip screw (DHS) or Sliding Screw Fixation is a type of orthopedic implant designed for fixation of certain types of hip fractures which allows controlled dynamic sliding of the femoral head component along the construct. The idea behind the dynamic compression is that the femoral head component is allowed to move along one
plane; since bone responds to dynamic stresses, the native femur may undergo remodeling and proper fracture healing.

Figure (3-1) Shows fracture supported by dynamic hip screw(6)

3-2-2 Interlocking nail:

Interlocking Nails are a refinement of the original Kuntscher Nail. An Interlocking Nail is basically an intramedullary pin secured in position by proximal and distal transfixing screws which engage the bone to the nail to provide axial bending and torsional stability. This procedure, in man, generally involves power reaming and insertion by closed technique on a distraction table under fluoroscopic control.

Figure(3-2) Interlocking nail (7)

3-2-3 ORIF

ORIF means Open Reduction-Internal Fixation. It refers to the treatment of a fractured bone, often of the femur - the thigh bone which is the longest bone in the body. ORIF can be (and is) used to refer to fractures in other bones in the body.
3-3 Radiopathology and radiation risk:

Exposure of tissues to x-ray can result in development of both inflammatory and cell killing effects or induction of malignancy. The probability of inflammatory cell killing effects, of which skin desquamation and ulcers are on type, is dose related once the body exceeds a significant threshold. This threshold for skin is relatively high, but can be exceeded in orthopedic procedure. Malignancy may occur even at low doses, but the exact dose is not accurately known. Associated threshold doses are given below showing the potential effect of fluoroscopy on the reaction of the skin and lens of the eye.
Table (3-1) shows potential effects of fluoroscopic exposure on the reaction of the skin and eye. Adapted from Wanger and Archer (1998) with reference to Hopewell (1986) (9).

<table>
<thead>
<tr>
<th>Effect</th>
<th>Approximate threshold dose (Gy)</th>
<th>Time of onset</th>
<th>Minute of fluoroscopy at typical normal dose rate of (.02 Gy/min)</th>
<th>Minute of fluoroscopy at typical high dose rate of (.2 Gy/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early transient erythema reaction</td>
<td>2</td>
<td>2-24 hours</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Main erythema reaction</td>
<td>6</td>
<td>1.5 weeks</td>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>Temporary epilation</td>
<td>3</td>
<td>3 weeks</td>
<td>150</td>
<td>15</td>
</tr>
<tr>
<td>Permanent epilation</td>
<td>7</td>
<td>3 weeks</td>
<td>350</td>
<td>35</td>
</tr>
<tr>
<td>Dry desquamation</td>
<td>14</td>
<td>4 weeks</td>
<td>700</td>
<td>70</td>
</tr>
<tr>
<td>Moist desquamation</td>
<td>18</td>
<td>4 weeks</td>
<td>900</td>
<td>90</td>
</tr>
<tr>
<td>Secondary ulceration</td>
<td>24</td>
<td>&gt;6 weeks</td>
<td>1200</td>
<td>120</td>
</tr>
<tr>
<td>Late erythema</td>
<td>15</td>
<td>8-10 weeks</td>
<td>750</td>
<td>75</td>
</tr>
<tr>
<td>Ischaemic dermal necrosis</td>
<td>18</td>
<td>&gt;10 weeks</td>
<td>900</td>
<td>90</td>
</tr>
<tr>
<td>Dermal atrophy (1st phase)</td>
<td>10</td>
<td>&gt;52 weeks</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>Telangiectasis</td>
<td>10</td>
<td>&gt;52 weeks</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>Dermal necrosis (delayed)</td>
<td>&gt;18</td>
<td>&gt;52 weeks</td>
<td>750</td>
<td>75</td>
</tr>
<tr>
<td>Skin cancer</td>
<td>None known</td>
<td>&gt;15 years</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Lens opacity (detectable)</td>
<td>&gt;1.2</td>
<td>&gt;5 years</td>
<td>&gt;50 to eye</td>
<td>&gt;50 to eye</td>
</tr>
<tr>
<td>Lens cataract (debilitating)</td>
<td>&gt;5</td>
<td>&gt;5 years</td>
<td>&gt;250 to eye</td>
<td>&gt;250 to eye</td>
</tr>
</tbody>
</table>

11
Without known the actual dose rate(s) of various modes of operation, an interventionist inadvertently reach the threshold. Columns 4 and 5 show the impact of typical (realistic) dose rate in term of minutes required to reach the threshold. Emphasizes the importance of knowing the dose rates being delivered by specific equipment. Any role of thumb e.g. 100 minutes should not be used, unless it represent the actual dose rate (9).

3-4 Categories of radiation exposures:

3-4-1 Occupational exposure:

All exposures of workers incurred in the course of their work, with the exception of exposures excluded from the Basic Safety Standard (BSS) and exposures from practices or sources exempted by the Standards.

3-4-2 Medical exposure:

Exposure received because of the benefit of a diagnosis or treatment. E.g.: Chest Radiography.

3-4-3 Public exposure:

Other exposures. Their justification (for those of non natural origin) is the general benefit brought by the use of ionizing radiation in Medicine, Industry etc (10).

3-5 General principles of radiation protection

3-5-1 Time, distance and shielding:

Form the key aspects of general protection principles as applicable to the situations within the scope of this document.

A-Time:

Minimize the time that radiation is used (it can reduce the radiation dose by a factor of 2 to 20 or more). This is effective whether the object of minimization is fluoroscopy time or the number of frames or images acquired.

B- Distance:

Increasing distance from the x-ray source as much as is practical (it can reduce the
radiation dose by a factor of 2 to 20 or more).

**C-Shielding:**

Shielding is most effective as a tool for staff protection. Shielding has a limited role for protecting patients' body parts, such as the breast, female gonads, eyes and thyroid in fluoroscopy (with exception of male gonads).

**3-5-2 Justification:**

The benefits of many procedures that utilize ionizing radiation are well established and well accepted both by the medical profession and society at large. When a procedure involving radiation is medically justifiable, the anticipated benefits are almost always identifiable and are sometimes quantifiable. On the other hand, the risk of adverse consequences is often difficult to estimate and quantify. In the ICRP Publication 103, Commission stated as a principle of justification that Any decision that alters the radiation exposure situation should do more good than harm. Also the Commission has recommended a multi-step approach to justification of the patient exposures in the Publication 105. In the case of the individual patient, justification normally involves both the referring medical practitioner (who refers the patient, and may for example be the patient's physician/surgeon) and the radiological medical practitioner (under whose responsibility the examination is conducted).

**3-5-3 Optimization:**

Once examinations are justified, they must be optimized: can they be done at a lower dose while maintaining efficacy and accuracy? Optimization of the examination should be both generic for the examination type and all the equipment and procedures involved. It should also be specific for the individual, and include review of whether or not it can be effectively done in a way that reduces dose for the particular patient (ICRP, 2007b) (3).

**3-5-4 Dose Limitation**

There are radiation dose limits for staff and public recommended by the International Commission on Radiological Protection (ICRP) that most countries tend to adopt. Currently the limit for radiation workers is 20 mSv/year average over 5 consecutive
years (100 mSv in 5 years not to exceed 50 mSv in any one year). For public the dose limit was set to 1mSv per year. Other dose limits are shown in table below.

This dose limit is based on the calculation of radiation risk over a full working life from the age of 18 years to 65 years (47 years) at the rate of 20 mSv per year, amounting to 20x47 = 0.94 Sv and resulting in an excess cancer risk of 1 in 1000 (10).

---

**Table (3-2): Recommended dose limits by ICRP (10)**

<table>
<thead>
<tr>
<th>Dose quantity</th>
<th>Occupational</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective dose</td>
<td>20 mSv/year averaged* over 5 years</td>
<td>1 mSv in a year</td>
</tr>
<tr>
<td></td>
<td>Lens of eye 150 mSv/year</td>
<td>15 mSv/year</td>
</tr>
<tr>
<td>Annual equivalent dose to</td>
<td>Skin 500 mSv/year</td>
<td>50 mSv/year</td>
</tr>
<tr>
<td></td>
<td>Hands &amp; Feet 500 mSv/year</td>
<td></td>
</tr>
</tbody>
</table>

---

3-6 **Objective of radiation protection and safety in interventional orthopedic:**

The prime objective of radiation protection and safety in interventional orthopedic are to ensure that:-

- Optimal image quality is achieved with the minimum radiation dose to patients (the dose within guidance levels)
- The workers in interventional orthopedic procedure have safe working environment, subject to safe working rules and do not receive radiation dose exceed the dose limit ( 100 mSv averaged over 5 years ( dose per year does not exceed 50 mSv )
members of the public who work near the interventional orthopedic operation room do not receive radiation dose exceed 1mSv per year.

3-7Factors affecting dose to the staff:

3-7-1Radiation protection tools:

A-Lead apron:

The foremost and most essential component of personal shielding in an x-ray room is the lead apron that must be worn by all those present in the fluoroscopy room. Clinical staff taking part in diagnostic and interventional procedures using fluoroscopy wear lead protective aprons to shield tissues and organs from scattered x-rays. Transmission will depend on the energies of the x-rays and lead equivalent thickness of the aprons. The attenuation of scattered radiation is assumed to be equal to that of the primary (incident) beam and this provides a margin of safety (3).
Attenuation measured with lead aprons

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Lead Thickness</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 kV; 100%</td>
<td>0.5 mm</td>
<td>2 - 3%</td>
</tr>
<tr>
<td>100 kV; 100%</td>
<td>0.25 mm</td>
<td>8 - 15%</td>
</tr>
</tbody>
</table>

Figure (3-5) A and B provide the relative penetration value as percent of incident beam intensity with lead of 0.5 and 0.25 mm. (Figure courtesy of E. Vano) (3).

For procedures performed on thinner patients, in particular many children, a lead apron of 0.25 mm lead equivalence will suffice, but for thicker patients and with heavy workload 0.35 mm lead apron may be more suitable. The wrap-around lead aprons of 0.25 mm lead equivalence are ideal that provide 0.25 mm on back and 0.5 mm on front. Two piece, skirt type help to distribute weight. Heavy weight of aprons can really pose a problem for staff who have to wear these for long spans of time. There are reports of back injuries because of weight of lead aprons with staff who wear these for many years (NCRP, 2011). Some newer aprons are light weight while maintaining lead equivalence. Also they are designed to distribute weight through straps and shoulder flaps (3).

B- Thyroid protector:

With the high radiation doses and dose rates during interventional radiology procedures, the specialist medical practitioner should use thyroid protection (10).

C- Lead glass:

In some interventional radiology procedures, it is possible for the lens of the operator's eyes to receive annual radiation doses which approach or might exceed 150 mSv. Lead protective glasses should be used in these cases but must also have protection at the sides (10).
D- Mounted shielding:

These can be table mounted lead rubber flaps or lead glass screens mounted on pedestal that are mobile. Manufacturers are encouraged to develop detachable shielding flaps to suit situations of practice in operating theatres. Lead rubber flaps should be used as they provide effective attenuation being normally impregnated with 0.5 mm lead equivalence (10).

G- Ceiling suspended shielding:

Shielding screens are very effective as they have lead equivalence of 0.5 mm or more and can cut down x-ray intensity by more than 90%. There are practical problems that make use of radiation shielding screens for staff protection more difficult but not impossible in fluoroscopy machines in operating theatres. Manufacturers should develop shielding screens that can be effectively used for staff protection without hindering the clinical task (10).

Proper use of a suspended protective barrier between the patient and the interventionist may reduce the need for separate eye and thyroid protection.

3-7-2 Practical aspect:

- Scattered dose rate is higher near the area into which the X-ray beam enters the patient.

![Figure(3-6) The effect of angle on the dose rate (10)]
- Scattered dose rate is higher when field size increases

![Figure (3-7) The effect of field size on the dose rate (10)]

- Scattered dose rate is lower when distance to the patient increases

![Figure (3-8) The effect of the distance on the dose rate (10)]
• Tube under couch position reduces, in general, high dose rates to the specialist’s eye lens

![Diagram showing the effect of under couch on dose rate at eye lens level.](image)

Figure (3-9) The effect of under couch to dose rate at eye lens level (10)

• patient size increases the staff dose increases
• Change from normal fluoroscopy mode to high dose rate mode
• The use of anti scatter grid
• Number of series (IMAGES)
• Performance of the x-ray system used (10).
Chapter Four
Materials and Methods
Chapter Four

Materials and Methods

4-1 Introduction:

This study has been conducted in three orthopedic theatres in Khartoum state (Khartoum Teaching Hospital, East Nile Model Hospital, Heraa Hospital). The main purpose of this study was to evaluate the safety precautions in interventional orthopedic procedure which aims to reduce the dose received by staff. It is known that the radiation exposure received by an individual staff usually related to the position of staff, available protection tools and its condition, workload, the type of procedure being performed, the techniques employed, standard performance of the image intensifier and x-ray system used. The study was included four main fields:

4-2 Integrity check of radiation protection tools:

This conduct by inspecting each item for kinks and irregularities and examine the entire item using the fluoroscope for suspect areas looking for breaks in the lead lining and assessment its storage condition.

4-3 Monitoring of leakage radiation around the theatre:

A survey meter “Polimaster” with the following characteristics:

- Model: PM 1703 M-01,
- serial number 286084,
- manufacture: Polimaster Instrument
- energy range: 0.033 – 3MeV
- dose rate range: 0.01 – 9999 μSv/h

was used to measure the dose rate around the theatre at specific points at area occupied partially by member of staff or public.
4-4 Estimation of staff doses during orthopedic procedure

This was conducted by using two pocket dosimeter (Thermo electronic corporation, model Mk 2.3, calibrated on 8-4-2011 in the Secondary Standard Dosimetry Laboratory (SSDL) of the Sudan Atomic Energy Commission (SAEC) ) with the following characteristics:

- Direct readout of personal dose equivalents \( Hp(10) \) (penetrating/deep/whole body) and \( Hp(0.07) \) (superficial/shallow/skin)
- Dose display and storage \( 0\mu Sv \) to \( >16Sv \) (0.0 mrem to \( > 1600 \) rem) auto Ranging
- Resolution for dose display \( 1\mu Sv \) (0.1 mrem) at levels up to \( 10mSv \) (1 rem)
- Resolution for dose storage \( 1/64\mu Sv \)

worn by a member of staff one of them at collar level over lead apron and the another one under the lead apron at chest level.

- The effective dose \( E \) was calculated using the equation:

\[
E = 0.5 H_w + 0.025 H_n
\]  
(4-1)(10)

where:

- \( H_w \) : dose at chest level under the lead apron
- \( H_n \) : dose recorded by a dosimeter worn at neck level over lead apron.

4-5 Questionnaire:

It was used to evaluate radiation protection program in interventional orthopaedic theatres and includes 6 areas:

- Responsibilities
- Training of workers
- Radiation protection tools
- Follow up of patient and staff
- Personnel radiation monitoring
- Quality control of x-ray machine.
Chapter Five
Results and Discussion
Chapter five

Results and Discussion

5-1 Results

5-1-1 Evaluation of radiation protection tools:
A: Khartoum Teaching Hospital:

Table (5-1) Shows results of integrity check of radiation protection tools

<table>
<thead>
<tr>
<th>Tools</th>
<th>Serial Number</th>
<th>Lead Equivalent mm</th>
<th>Integrity Check</th>
<th>Storage Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Apron</td>
<td>08987</td>
<td>0.5</td>
<td>fail</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>08781</td>
<td>0.5</td>
<td>fail</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>08990</td>
<td>0.5</td>
<td>fail</td>
<td>Bad</td>
</tr>
<tr>
<td>N.A</td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td>N.A</td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td>N.A</td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td>N.A</td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
</tbody>
</table>

*N.A (not available)
**B-East Nile Model Hospital:**

Table (5-2) Shows results of integrity check of radiation protection tools

<table>
<thead>
<tr>
<th>Tools</th>
<th>Serial Number</th>
<th>Lead Equivalent mm</th>
<th>Integrity Check</th>
<th>Storage Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Apron</td>
<td>N.A</td>
<td>0.25</td>
<td>fail</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.25</td>
<td>fail</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.25</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.25</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.25</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.25</td>
<td>fail</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.25</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.5</td>
<td>Pass</td>
<td>Bad</td>
</tr>
</tbody>
</table>

N.A=not available
C- Heraa Hospital:

Table (5-3) Shows results of integrity check of radiation protection tools

<table>
<thead>
<tr>
<th>Tools</th>
<th>Serial Number</th>
<th>Lead Equivalent mm</th>
<th>Integrity Check</th>
<th>Storage Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead apron</td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>N.A</td>
<td>0.5</td>
<td>pass</td>
<td>Bad</td>
</tr>
</tbody>
</table>

*N.A (not available)*
Figure (5-1) The result of integrity check of the lead aprons as percentage of the three hospitals.

Figure (5-2) Result of integrity check of the lead aprons of three hospitals.
5-1-2 Dose measurement around the theatres result:

A: Khartoum Teaching Hospital:

Corridor

Figure (5-3) Diagram of theatre and the most probable location of the staff
- S = surgeon, T = technologist, A = anesthetist, N = nurse, As = assistant

Table (5-4) Radiation dose rate around the theatre during the procedure

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Reading (μSv/h)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Corridor</td>
<td>0.015</td>
<td>Background level</td>
</tr>
<tr>
<td>B</td>
<td>Corridor</td>
<td>0.015</td>
<td>Background level</td>
</tr>
<tr>
<td>C</td>
<td>Corridor</td>
<td>0.015</td>
<td>Background level</td>
</tr>
<tr>
<td>D</td>
<td>Entrance</td>
<td>7.000</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Theatre</td>
<td>0.015</td>
<td>Background level</td>
</tr>
</tbody>
</table>
B-East Nile Model Hospital:

Figure (5-4) Diagram of theatre on the first floor and the most probable location of the staff

- S= surgeon, T= technologist, A= anesthetist, N= nurse, As= assistant

Table (5-5) radiation dose rate around the theatre during the procedure

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Reading in (µSv/h)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Corridor</td>
<td>0.015</td>
<td>Background level</td>
</tr>
<tr>
<td>B</td>
<td>Entrance</td>
<td>6.000</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Theatre</td>
<td>0.015</td>
<td>Background level</td>
</tr>
</tbody>
</table>
C- Heraa Hospital:

Figure (5-5) Diagram of theatre and the most probable location of the staff

- S= surgeon , T= technologist , A= anesthetist , N= nurse , As= assistant
5-1-3 Estimation of effective dose to orthopedic specialist:

Table (5-6) Specialist average effective dose during several procedures in (μSv)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose over lead apron (thyroid level) (μSv)</th>
<th>Dose under lead apron (chest level) (μSv)</th>
<th>Effective dose (μSv)</th>
<th>Average effective dose (μSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHS</td>
<td>76.32</td>
<td>0</td>
<td>1.908</td>
<td>0.668</td>
</tr>
<tr>
<td></td>
<td>38.16</td>
<td>0</td>
<td>0.954</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.6</td>
<td>0</td>
<td>0.265</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.18</td>
<td>0</td>
<td>0.0795</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.35</td>
<td>0</td>
<td>0.133</td>
<td></td>
</tr>
<tr>
<td>ILN</td>
<td>64.66</td>
<td>0</td>
<td>1.617</td>
<td>1.096</td>
</tr>
<tr>
<td></td>
<td>61.48</td>
<td>0</td>
<td>1.537</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.35</td>
<td>0</td>
<td>0.134</td>
<td></td>
</tr>
<tr>
<td>INT</td>
<td>1.7</td>
<td>0</td>
<td>0.043</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>2.14</td>
<td>0</td>
<td>0.054</td>
<td></td>
</tr>
<tr>
<td>Elastic nail</td>
<td>6.36</td>
<td>0</td>
<td>0.159</td>
<td>0.159</td>
</tr>
</tbody>
</table>

* INT interlocking nail for tibia.
5-1-4 Questionnaire result:

Table (5-7) The answer of participants in percentage

<table>
<thead>
<tr>
<th>Items</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Is there a radiation protection officer in your department?</td>
<td></td>
</tr>
<tr>
<td>Have you attended an appropriate radiation safety courses?</td>
<td>23.5%</td>
</tr>
<tr>
<td>Refresher radiation safety training is provided periodically?</td>
<td></td>
</tr>
<tr>
<td>Are there enough radiation protection tools (lead apron, thyroid protector etc) in the operating room?</td>
<td></td>
</tr>
<tr>
<td>Do you use lead apron</td>
<td>94.1%</td>
</tr>
<tr>
<td>Do you use thyroid protector</td>
<td></td>
</tr>
<tr>
<td>Do you use eye protector</td>
<td></td>
</tr>
<tr>
<td>Do you ensure that the protected tools functioning well</td>
<td>18.1%</td>
</tr>
<tr>
<td>Have you or any of your colleagues encountered any health problem you think is related to radiation?</td>
<td>27.3%</td>
</tr>
<tr>
<td>Have any of your patients encountered any health problem related to his/her exposure to radiation?</td>
<td></td>
</tr>
<tr>
<td>Is there a program for radiation protection in your department?</td>
<td></td>
</tr>
<tr>
<td>Is there a program for personnel radiation monitoring?</td>
<td></td>
</tr>
<tr>
<td>Is there a clear procedure to identify pregnant patients?</td>
<td>82.4%</td>
</tr>
<tr>
<td>Are quality control measurements performed on x ray machines?</td>
<td></td>
</tr>
</tbody>
</table>
5-2 Discussion:

This study has been conducted in three orthopedic theatres in Khartoum state. The main purpose of this study was to evaluate the safety precautions in interventional orthopedic procedures which aim to reduce the dose received by staff.

To achieve the above-mentioned objectives direct measurement of dose rate from scatter radiation were carried out during the procedure in two centers (Khartoum Teaching Hospital, East Nile Model Hospital). Results shown in table (5-4) and table (5-5) reveal that the dose rate around the theatres falls within the acceptable limit accordingly to occupancy factor and the workload. In all of the measurements around the theaters the dose rate did not exceed the background level. Higher dose rate was detected at the entrance of the theaters where there were no doors. At these points only radiation workers would be expected to be.

With regard to integrity check of radiation protection tools the tables (5-1), (5-2), (5-3) showed that percentage of lead aprons that passed this test was 63% (5 out of 8), 70% (7 out of 10) and 100% (7 out of 7) in Khartoum Teaching Hospital, East Nile Model Hospital and Heraa Hospital respectively. That brings the total percentage of lead aprons that passed this test to 76%. It was noted that - due to shortage in lead aprons - the faulty lead aprons were in use. In fact that was the first occasion that those lead aprons have been tested. International recommendations state that all radiation protection tools should be at least tested every 18 months or even at a shorter period depending on the workload and lead aprons conditions. In all three theatres the storage conditions were found to be bad e.g. lead aprons were not on hangers and most of them were folded, this would – over time – lead to create cracks which in turn would reduce the useful life of the lead apron and cause unjustified radiation exposure to the staff.

On the other hand the absence of very effective radiation protection tools were noted such as thyroid protector, lead glass, table lead curtain, suspended ceiling and this also caused unjustified exposure to radiation in very sensitive part of the staff body such as lens of the eye and thyroid gland.
With regard to assessment of staff doses the dose received by specialist was measured during 11 procedure performed in the three centers using pocket dosimeters. The average staff doses were found to fall within the acceptable limit recommended by the ICRP in light of the current load. The maximum staff dose was found to be equal to about 1.1 μSv. The maximum number of interventional procedure per month and per staff is about 10 that would bring the average monthly staff dose to 11 μSv i.e. about 0.7% of the dose limit. In fact, most orthopedic surgeons using radiation protection devices and tools will have a radiation dose below typically 2 mSv/year.(10) However it should be emphasized that such measurements were carried out in a limited number of interventional procedures, doses to staff could be much higher in some other more complex procedures. There is no personal radiation monitoring for the staff, this is mainly because of the absence of such service in the country for the time being and because of the lack of radiation protection program.

The evaluation of radiation protection program aspect carried out using questionnaire covered 6 areas in radiation protection and the answer of 31 participants (6 orthopedic specialists 15 orthopedic registrars 10 technologist) showed that:

- In all of the three hospitals, there is no radiation protection program or a radiation protection officer.
- All of the staff in the three hospitals claim that there is a known specific procedure (though not documented) regarding pregnant patients.
- No radiation safety training (regular, formal, refresher, etc) program are conducted, only 23.5% of participant attended such training events. and some of the technologist indicated that they had been exposed to the subject of radiation protection as part of their graduate or post graduate studies.
- Staff participated in the questionnaire admitted the absence of an adequate radiation protection tools, the absence of personal monitoring program and that they are unaware of any quality control test performed on radiation protection tools or on x ray machines.
- about 27.3% of participants indicated that some of their colleagues suffer from healthy problem expected to be caused by their exposure to radiation, but because of
absent of record regard to their exposed to radiation such claims can not be confirmed. Generally speaking it is unlikely for the staff in interventional orthopedic procedures to get adverse health effect due to the level of radiation doses expected in such procedures.

- 45.5 of the participants said that they are not aware of any radiation related health effects of their patient; however it is not certain that a follow up program is in place to monitor such effects.
Chapter Six

Conclusion and Recommendations
Chapter six
Conclusion and Recommendations

6-1 Conclusion

The Hypotheses of this study assumed that appropriate safety precautions at the facilities are followed during interventional orthopedic procedures in Khartoum state orthopedics theatres. The data that was collected and analyzed from the results revealed that this is not strictly true. There are many violations of the current radiation protection regulation issued by SAEC1998. Such violations have and will inevitably lead to increase doses to patient, staff and public. Also the probability of accidents will be increased. The main problems found in the three centers under this study are absent of responsibility due to absent of the radiation protection program and Poor knowledge of workers about the radiological hazards and ways to prevent them for themselves and for their patient.

6-2 Recommendations:

The major recommendations that can – if implemented – help in improving the level of radiation safety and protection in orthopedic procedures or the interventional radiology as general.

• Interventionist and the technologist work in interventional radiology department must conduct adequate training in radiation protection in interventional radiology as a requirement to be licensed by the regulatory body.

• A proper radiation protection officer (RPO) should be appointed to lie down and oversee a radiation protection plan (RPP) in the interventional radiology departments. The RPO must be given the full authority and the adequate time to enable him to discharge his duties effectively.

• Establishment within the country one regulatory authority independent from any use or promotion of radiation to replace the current two regulatory authorities available in the country.

• More studies and research should be conducted to assess the protection level with respect to patient, and workers in interventional radiology department.
References:


3. ICRP, annals ref 4834-1783-0153, *Radiological protection in fluoroscopically guided procedures performed outside the imaging department*; May 18, 2011


9. ICRP, publication 85, *avoidance of radiation injuries from medical interventional procedures*; September 2000.

10. IAEA, training course material in diagnostic and interventional radiology, 2011.

