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Evaluation of occupational and patient radiation doses in orthopedic surgery

A. Sulieman^{a,b,*}, K. Alzimami^c, B. Habeeballa^b, H. Osman^d, I. Abdelaziz^b, S.A. Sassi^e,
A.K. Sam^{f,g}

^a Radiology and Medical Imaging Department, College of Applied Medical Sciences, Salman bin Abdulaziz University, P.O. Box 422, Alkharj, Kingdom of Saudi Arabia

^b College of Medical Radiologic Sciences, Sudan University of Science and Technology, P.O. Box 1908, Khartoum, Sudan

^c Radiological Sciences Department, College of Applied Medical Sciences, King Saud University, P.O. Box 10219, Riyadh 11433, Saudi Arabia

^d Radiology Department, College of Applied Medical Science, Taif University, Taif, Saudi Arabia

^e Department of Medical Physics, Prince Sultan Medical City, Riyadh, Saudi Arabia

^f Radiation safety institute, Sudan Atomic Energy Commission, Khartoum, Sudan

^g Radiometrics Section, International Atomic Energy Agency Environment Laboratories, 4, Quai Antoine 1er, 98000 Monaco

HIGHLIGHTS

- Occupational exposure was evaluated during two intervention orthopedic procedures.
- Radiation doses were measured using a calibrated TLD GR200A.
- The radiation dose to orthopedic surgeons was shown to be well below the limits for prevention of tissue reactions.
- The radiation dose per hip procedure is low compared to previous studies.

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ABSTRACT

This study intends to measure the radiation dose to patients and staff during (i) Dynamic Hip Screw (DHS) and (ii) Dynamic Cannula Screw (DCS) and to evaluate entrance surface Air kerma (ESAK) dose and organ doses and effective doses. Calibrated Thermoluminescence dosimeters (TLD-GR200A) were used. The mean patients' doses were 0.46 mGy and 0.07 mGy for DHS and DCS procedures, respectively. The mean staff doses at the thyroid and chest were 4.69 mGy and 1.21 mGy per procedure. The mean organ and effective dose for patients and staff were higher in DHS compared to DCS. Orthopedic surgeons were exposed to unnecessary radiation doses due to the lack of protection measures. The radiation dose per hip procedure is within the safety limit and less than the previous studies.

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1. Introduction

Interventional fluoroscopy presents a tremendous advantage over invasive surgical procedures, because it requires only a very small incision, which substantially reduces the risk of infection and allows for shorter recovery time compared to surgical procedures (Miller, 2009). These interventions are used by a rapidly expanding number of health care providers in a wide range of medical specialties. An increasing number of medical specialists are using fluoroscopy outside imaging departments without full

consideration of radiological protection coverage of fluoroscopy machines. Radiation protection and dose evaluation are important for orthopedic staff during the intervention since they are usually at close proximity to the patient during procedures. As a consequence, areas of the body not protected by the lead apron may receive significant radiation doses from scattered X-rays (Kim et al., 2008; Bedetti et al., 2008; Rehani and Ortiz-Lopez, 2006; ICRP, 2010; UNSCEAR, 2000; ICRP^b, 2007; Trianni et al., 2005; Delichas et al., 2003; Barry, 1984; Hynes et al., 1992; Miller et al., 2010; Radford et al., 1993). Thus, they are potentially at risk of developing radiation-induced cataracts, and complexity of invasive procedures (Rehani et al., 2011; Jacob et al., 2013; ICRP, 2012; Vano et al., 1998; Worgul et al., 2007; Ainsbury et al., 2009; Haskal and Worgul, 2004; Kleiman, 2006). Moreover the risk that

* Corresponding author.

E-mail address: abdelmoneim_a@yahoo.com (A. Sulieman).

orthopedic surgeon develop cancer (e.g. thyroid carcinoma) is significantly higher than that of a non-orthopedic professional and eight times more than that of an unexposed worker (Heeckt, 2011; Giannoudis et al., 1998). Lack of radiological protection training in radiation science or protection measures for those working with fluoroscopy outside imaging departments can increase the radiation risk to staff and patients (ICRP, 2010). The radiation dose of a surgeon depends on many factors, including the exposure time, the distance from the beam's central axis, the orientation of the fluoroscopic beam relative to the patient, the position of the surgeon within the operative field and the use of protective shields (Bone and Hsieh, 2000). In addition, the radiation exposure is dependent on the unit's design: input screen sensitivity of image intensifier, conversion factor, x-ray generator type and irradiation geometry. The radiation doses delivered to patients in most orthopedic procedures under normal conditions will not cause effects such as skin injury (IAEA, 2010).

Measurement of the occupational and patients radiation doses in interventional procedures are recommended (ICRP, 2010); however, there are only a few studies published regarding the radiation doses received by the patients and staff during orthopedic intervention compared to its frequency (Osman et al., 2011; Bahari et al., 2006; Osman et al., 2013; Osman et al., 2012; Rampersaud et al., 2000; Blattert et al., 2004; Arnstein et al., 1994; Jones and Stoddart, 1998; Moore and Heeckt 2011; Theocharopoulos et al., 2003). These studies show wide differences in terms of dose, fluoroscopic time, number of radiographic images, equipment and inter-examiners variability, suggesting that patient dose optimizations methods have not been accomplished yet. Furthermore, there is a need of information concerning the doses received by radiosensitive organs, dose optimization and the related risks. Reference dose levels for orthopedic procedures have not yet been adopted either in national or international levels in terms of entrance surface air kerma (ESAK), according to our knowledge. This study evaluates radiation dose during orthopedic fracture fixation. The objectives of the current study are to measure the radiation dose to patients and staff during four surgical interventional orthopedic procedures (i) Dynamic Hip Screw (DHS) (ii) Dynamic Canula Screw (DCS); to estimate the risk of the aforementioned procedures and to evaluate entrance surface dose (ESD) and organ dose to specific radiosensitive patients' organs.

2. Material and method

2.1. Patient population

A total of 76 patients in Medical Corps Hospital, Sudan were investigated (56 patients, 73.7% for DHS and 20 patients, 26.3% for and DCS procedures). Ethics and research committee approved the study and informed consent was obtained from all patients prior to the procedure. The collection of patient exposure parameters data was done using standard data collection sheet prepared for collection of patient exposure-related parameters.

2.2. TL dosimetry

Radiation dose measurements were made for patients using TL dosimeters GR-200A TLDs (LiF: Mg, Cu, P (FIMEL, France)). All TLD dosimeters shared the same thermal history. A calibrated X-ray machine Toshiba, model DRX-1603B was used under reproducible reference conditions to deliver a known absorbed dose to the TLDs. For the TLD and chamber irradiation, a polymethylmethacrylate (PMMA) calibration test bed was constructed having dimensions $30 \times 30 \times 10 \text{ cm}^3$, which simulates the patient's lateral and backscatter conditions (Martin et al., 1998; Sulieman

et al., 2007). The first PMMA slab was used to accommodate the TLD chips in an array of slots 10×10 . Each TLD was identified by its position in the array. Individual calibration factors were obtained by irradiating the entire group to the same dose. The measured signal of each TLD was divided by the mean signal of the group. This process was repeated three times to reduce the effect of statistical variations and to determine the stability and reproducibility of the signal.

The TLD signal was read using PCL3 TLD automatic reader (FIMEL, France) which allows fast readings of a large number of TLD samples with a reproducibility of $0.3 \pm 0.5\%$. A set of measurements were performed using (PTW-CONNY II) ionization chamber with dimensions of $180 \times 100 \times 45 \text{ mm}^3$, applicable to cardiology, radiology and mammography. After completing the calibration process, any chips that exceeded the 5% error were excluded from the study. The irradiated chips were read out at a 55°C preheat temperature and the signal was acquired from 55°C to 260°C with heating rate of 11°C/s . All TLDs were annealed in annealing oven (TLDO, PTW: Freiburg, Germany) at 240°C for 10 min, followed by fast cooling. The mean background signal for un-irradiated TLDs was subtracted before any calculation. The linearity of the TLD's response for the range of dose used in this study was verified.

2.3. X-ray machine

All procedures were performed using a C arm machine at Medical Corps Hospital, a Siremobil 2000 (Siemens, Germany) with a total filtration of 2.5 mm Al and equipped with automatic brightness control, footswitch and last image hold. The machine was installed in 2009.

2.4. Staff dose measurement

Three orthopedists performed all procedures at the five departments. Groups of 3 TLDs were packed in transparent plastic envelopes and were attached with surgical tape to five sites on the operator body: the forehead, the neck, the chest, over the lead apron, the hand and the leg. Surgeons' wore a rubber lead apron of 0.5 mm lead equivalent as protection from scattered radiation (Fig. 1). No lead rubber cola was worn during any of the procedures. At each department, a single operating team was chosen to perform all the procedures, in order to avoid inter operator variations that could result from the different skills and experiences of the orthopedists. The effective dose to the organs and tissues has been calculated using the methodology and tissue weighting

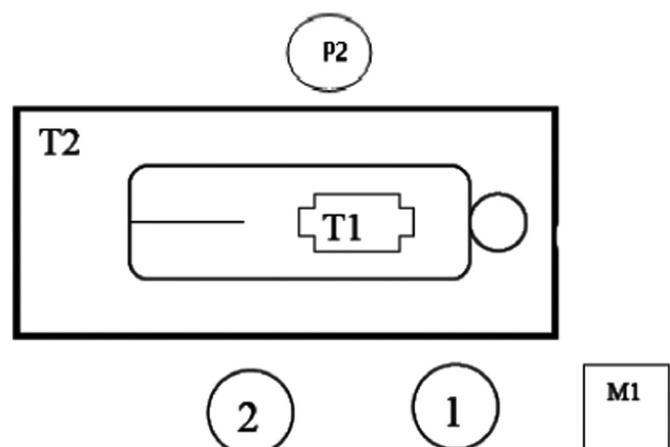


Fig. 1. Patient setup, staff positions during orthopedic surgery procedures. (1) Orthopedist; (2) assistant; (3) technologist; (M1) fluoroscopic monitor; (T1) X-ray tube and (T2) table.

factors reported at NCRP (1995) and ICRP (2007), respectively. A computer program was developed, allowing calculation of the dose to 14 organs and tissues (Sulieman et al., 2007).

2.5. Patients dose measurement

ESAK (mGy, a physical quantity) is defined as the air kerma to air measured on the central X-ray beam axis at the position of the patient or phantom surface, including the contribution of the back scatter radiation (ICRU, 2005). The ESAK is related to the incident air kerma (K_i) by the backscatter factor, B , thus:

$$ESAK = K_i B \quad (1)$$

Organ dose is the absorbed dose averaged over an organ. Equivalent dose to an organ or tissue (mSv, a derived quantity) is the organ dose corrected by a radiation weighting factor (w_R) that takes account of the relative biological effectiveness of the incident radiation in producing stochastic effects. The determination of the organs dose is difficult in the patient. Therefore organ doses are estimated using software based on Monte Carlo simulation and ESAK dose. Patients ESAK were evaluated using one envelope with three TLDs chips in a plastic envelop made of transparent polyethylene plastic foil (to protect the TLDs from any contamination) mounted on patient skin at midpoint of radiation field at a part of interest of the central axis beam and secured in the required position using adhesive tape.

2.6. Organ and effective dose estimation

The organ equivalent dose (mSv) is given by

$$H_T = \sum_R w_R D_{T,R} \quad (2)$$

where $D_{T,R}$ is the mean absorbed dose to tissue (T) from radiation (R) and w_R is the radiation-weighting factor from the recent ICRP recommendations (ICRP, 2007).

Effective dose (E , mSv) is a quantity that has been introduced to give an indication of risk from partial or non-uniform exposure to risk from an equivalent body exposure. The effective dose is calculated by determining the equivalent dose to each organ irradiated and then multiplying this equivalent dose by a tissue-specific weighting factor for each organ or tissue type. This tissue-organ-specific weighting factor accounts for the variations in the risk of cancer induction or other adverse effects for the specific organ.

An effective dose is given by the following equation (ICRP, 2007):

$$E = \sum_T w_T H_T \quad (3)$$

where H_T is the equivalent dose to tissue T and w_T is the weighting factor representing the relative radiation sensitivity of tissue T .

ESAK was used to estimate the organ equivalent dose (H) using software provided by the National Radiological Protection Board (NRPB-SR279) (Hart et al., 1998).

3. Results

A total of 76 procedures were investigated. Table 1 presents measured patients' doses in terms of mean and the range of ESAK (mGy) values for both patients groups along with the exposure factors per procedures. Patient organ dose per procedure were presented in Table 2. The orthopedist radiation doses (mGy) per procedure for both groups are presented in Table 3.

Table 1

Patient radiation dose (ESAK, effective dose) and exposure factors during orthopedic procedures.

Procedure	Tube voltage (kV)	Tube current-time product (mAs)	ESAK (mGy)	Effective dose (mSv)
DHS	84 (76–92)	4.2 (3.6–4.8)	0.46 (0.18–2.8)	0.03 (0.01–0.18)
DCS	84 (76–92)	4.2 (3.6–4.8)	0.07 (0.03–0.8)	0.005 (0.002–0.05)

Table 2

Mean and range of organ radiation dose (mSv).

Organ	Organ equivalent dose per procedure	
	DHS	DCS
Testicles	0.15	0.02
Urinary bladder	0.12	0.02
Uterus	0.07	0.01
Active bone marrow	0.01	0.001
Ovaries	0.06	0.01

Table 3

Staff doses radiation doses during DHS and DCS procedures.

Organ dose	DHS	DCS
Forehead	0.16 (0.12–0.24)	0.16 (0.01–0.10)
Thyroid	4.69 (0.04–16.95)	1.21 (0.01–0.17)
Chest	1.21 (0.02–3.30)	0.07 (0.05–0.01)
Hand	0.25 (0.18–0.30)	0.02 (0.01–0.20)
Leg	0.21 (0.15–0.22)	0.03 (0.01–0.10)

4. Discussion

Orthopedic interventional procedures result in unavoidable radiation dose to patients and staff due to fluoroscopic and radiographic exposure. The mean patient ESAK was found to be 0.46 mGy and 0.07 mGy for DHS and DCS procedures respectively. The mean doses for DHS procedures are almost six times higher compared to the DCS procedures. No significant variation was noticed between the two procedures in exposure parameters. Patient doses in both procedures showed wide variation (Table 1). These variations can be attributed to patient BMI and duration of procedure (related to complexity of the procedure), imaging related factors such as fluoroscopy mode, imaging technique and orthopedist's experience. In this context, Botchu and Ravikumar that the radiation dose and screening time during fixation of a hip fracture were almost three times more with surgeons and trainees with less than 3 years of operative experience when compared with that of the surgeons with more than 10 years of surgical experience (Botchu and Ravikumar, 2008). The maximum dose for both procedures (Table 1) was found to fall below the tissue reaction of radiation (ICRP, 2010). This can be attributed to the long fluoroscopic exposures due to the complication of the procedures. DHS procedures required special concern because it is more common than the DCS procedures because the high incidence of hip fractures resulting from the ageing of the population. The frequency of DHS fixation procedures exposes staff to the high portion of the occupational exposure to high radiation dose. The mean values of the patient effective doses for both procedures were estimated to be 0.03 mSv and 0.005 mSv for DHS and DCS, respectively (Table 1). In comparison between effective doses from previous studies, these values are also lower. The effective dose value from the literature ranged between 1.0 mSv and 1.2 mSv (Osman et al., 2012; Crawley and Rogers, 2000). DHS and DCS

involve direct irradiation of the pelvic and adjacent organs; therefore organ doses were estimated to the testicles, ovaries, uterus, bladder and bone marrow (Table 2). Testicles and urinary bladder were imposed to higher doses compared to other organs outside the primary beam. Therefore, shielding the testicles is important in situation of prolonged radiation exposure. Table 3 shows wide variation of staff doses during the procedures. Unprotected organs and tissues received considerable radiation dose especially when additional protection is not used for eye lens and thyroid. Staff radiation exposure doses are principally due to scattered radiation, and leakage from the X-ray tube housing. Despite of the fact that scatter radiation is only a small fraction of the dose that patient receives, it become significant over the working life and under high workload circumstances as the case in Sudan. The effective dose per procedure for the orthopedic surgeons for DHS and DCS were estimated to be 174 μ Sv, and 10.0 μ Sv, in that order. The orthopedic surgeon was exposed to higher radiation dose during DHS than the DCS procedure. The radiation dose per hip procedure is low compared to previous studies (Theocharopoulos et al., 2003; Osman et al., 2012; Crawley and Rogers, 2000). Theocharopoulos et al. (2003) reported a dose value of 5.0 mGy per procedure. The staff dose is also low compared to the recommended limits by the ICRP (ICRP, 2007). In 15% of procedures it was reported that the surgeon's hand had been caught in the fluoroscopy beam (Jones and Stoddart, 1998). Hafiz et al. reported that the orthopedic surgeon finger may exposed to exposure to the primary beam during surgical protocols. Although surgeons and members of surgical teams are aware that their hands should never be exposed to primary radiation, it is not unusual for fingers to be accidentally caught in the beam (Hafez et al., 2005). Although, it is well known that wearing protective shields will reduce the radiation dose, the orthopedic surgeons as well as other operators believe that the use of lead glasses impairs vision and so increases the exposure time and that lead gloves are inconvenient. Optimization of protection requires that exposure of patients be the minimum necessary to achieve the required diagnostic and therapeutic objective of the interventional procedure without a compromise to clinical information and outcome. Almost all of the measures to reduce patient dose will also result in a reduction of staff dose. The amount of radiation exposed to individual surgeons is independent of the skills of the surgeons; previous studies attributed the increase in radiation dose to the fact that staff have always to stand close to the patient, and hence, the primary beam for procedures like placement of interlocking screws in order to manipulate the procedure (Blatter et al., 2004). Botchu and Ravikumar (2008) summarized the factors that influence the exposure as patient dependent, equipment dependent and procedure dependent factors. Patient related factors include: body mass or body thickness in the beam, complexity of the lesion and anatomic target structure. Equipment dependent factors include setting of dose rates in pulsed fluoro- and continuous fluoro-mode, appropriate quality control, last image hold, acquisition, and virtual collimation. The main procedure related factors are: number of radiographic frames per run, collimation, fluoroscopic and radiographic acquisition modes, fluoroscopy time, wedge filter, magnification, distance of patient to image receptor (image intensifier or flat panel detector), distance between X-ray tube and patient, and tube angulations (IAEA, 2010). These include the type and difficulty of the surgical procedure, patient's position, and radiation protection measures used.

5. Conclusions

Orthopedic surgeons are exposed to unavoidable radiation dose. The mean patient ESAK and effective dose for DHS

procedures are almost six times or more high compared to the DCS procedures. Patient ESAK, organ and effective doses in both procedures showed wide variation. The radiation dose per hip procedure is within the safety limit and less than the previous studies. The orthopedic surgeon was exposed to higher radiation dose during DHS than the DCS procedure. Shielding the testicles is important in situation of prolonged radiation exposure to reduce the probability of cancer effect. Accurate use of radiation protection measures will reduce the dose and hence the probability of cancer risk for staff and patients and reduces the probability of the cancer effect in the light of the current practice.

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