Asian Journal of Medical and Clinical Sciences Review Article

Orthopedist and patient radiation exposure: state of art and future prediction

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Abstract

Interventional radiology has many important clinical uses and can provide significant benefits. Concerns have been raised about how imaging facilities administer medical imaging exams that use radiation: wide variations have been observed among radiation doses associated with particular types of medical imaging procedure. This paper involves a literature review on radiation dose levels for orthopedist and patient during interventional procedures from 1986-2011. It highlights the importance of the equipment design, accurate dose measurement and measured the various methods applied to radiation dose optimization; the various techniques used are presented. These include: Thermoluminsence dosimeters (TLDs), Dose area product (DAP) and Electronic Personal Devices (EPD).The mini C-arm has universally less radiation exposure than the standard C-arm in the clinical configurations tested. The orthopaedic surgeons may be more likely to develop thyroid carcinoma if not protected from this radiation exposure. Efforts should be made to reduce radiation exposure to orthopedist, surgery staff and patients.

Key Words: Review Orthopedicist, Patient Radiation Dose , Electronic Personal Devices (EPD), Dose area product (DAP).

Received :1 Mar 2012 Accepted : 25 Mar 2012 Published: 10 May 2012

INTRODUCTION

Radiologists and radiologic technologists are among the earliest occupational groups exposed to radiation. It was the observation of the earliest radiologists that led to the recognition of radiation-induced skin cancer (the first solid cancer linked to radiation) in 1902 [1]. In the 1940s and 1950s, excess mortality from leukemia among radiologists was recognized [2,3], and this, together with the rising concern about the effect of chronic radiation exposure led to, among others, two landmark studies of radiologists—one in the United Kingdom [4] and another in the United States [5].

Interventional procedures represents a tremendous advantage over invasive surgical procedures, because it requires small incision wounds , substantially reduces the risk of infection and allows for shorter recovery time compared to surgical procedures. However, many of these specialists have little training in radiation science or protection measures[6].
In an era of an increasing number of invasive procedures in orthopedic surgeries particular attention to radiation exposure and protection measures for patients and staff is warranted. Ionizing radiation accounts for risk-dose-dependent, cancer effects (no threshold dose) and dose-dependent, tissue reaction (threshold dose). The effective dose (E) is a weighted sum of equivalent doses delivered to various organs or tissue to assess the cancer risk (stochastic risk) the former, whereas the latter tissue effect (deterministic effects) are related to the entrance dose [7].

In spite of the current task, still few workers follow the safety procedures, and the increase number of invasive procedures in the orthopedic field, therefore a review of literature is important in order to evaluate the current practice and predict the future.

The aim of the present review is (i) to evaluate radiation dose to interventional orthopedist surgeons as well as patients in the orthopedic theater and to (ii) evaluate the usefulness of radiation measuring devices and protection tools.

Study plan

Available studies from 1986 up to 2011[6-46] were reviewed in order to quantify the radiation dose in different orthopedic surgeries procedures. However, only few studies [12, 14, 15, 23, 25, 30, 31, 36, 39, 40-46] have investigated the exposure risks to the orthopedic surgeon in the

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operation theatre from different surgeries. Therefore this study will cover most of imaging procedures, techniques and different dosimeters.

Dosimeters

Radiation dosimeters used with literature are classified into two main categories active devices (DAP, EPD) and passive devices (TLD).

Dose area product (DAP)

In the field of fluoroscopy and radiography, the DAP or kerma-area product (KAP) have been introduced. The DAP is the product of the cross section of an X-ray beam and the air kerma averaged over that cross section, and represents the amount of radiation that the patient receives. DAP can be measured at any point between the housing of the X-ray tube and the patient, The unit of this quantity is the Gray-square centimeter ($Gycm^2$) [7].

Thermo luminescence dosimeter (TLD)

TLD have different types ,the most common types are (i) (TLD-100) of lithium fluoride (LiF: Mg, Ti) chips doped with magnesium and titanium or (ii) (TLD 200) LiF:Mg,P,Cu(GR: 200) , which is more sensitive than the former , minimum detection limit of the TLD and uncertainty of TLD should be established, to avoid any fluctuation. The TLDs should be calibrated under reproducible reference conditions using typical diagnostic x-ray beam qualities according to the protocol reported by Sulieman et al (2007) [32].

The majority of the studies reviewed (29, 78%) used TLDs to assess either staff radiation dose or patient dose, three studies used DAP to assess patient dose (3, 8%) and five studies used other dosimeter (5, 14%). Table 1 compares different dosimeter encountered in measurements of radiation doses during orthopedic procedures.

Different procedures involved during this study by different authors, which include (i) upper limbs, (ii) lower limbs and (iii) vertebrae, so accordingly to this fact this review study have been classified.

Orthopedists hand doses

Madan et al (2002) [12] stated that the hands of the surgeon are most likely to be directly exposed to ionising radiation during intraoperative fluoroscopic screening. The study performed by Goldstone et al, (1993) [13] in the United Kingdom for surgeons within 44 procedures with similar dosimeter, the total radiation dose received to the hands per surgeon ranged from 0.048 – 2.3 mSv. Similarly, Muller, et al. (1998) [14] evaluated the radiation

Table 1: Advantages and disadvantages of dosimeters used in radiology for doses estimation.

Detector	Radiology Application	Advantages	Disadvantages
Ionization chamber	Calibration of output	High precision, gold standard	Cables ,high voltages
TLD	Monitoring doses for patient and staff	Accurate ,TLD 100 for patient doses and TLD 200 for staff doses ,easy to use , reusable for accumulation doses passive dosimeter	Time lengthen easy attached to skin
EPD	Staff doses for interventional radiology	Real time reading ,active dosimeter un suitable for patient doses	less sensitive in low energy field, dose rate evaluation
Radiographic film	Image quality assessment	High spatial resolution	Not reusable, require development ,variability ,energy and dose rate dependence
Scintillator Detectors	Entrance surface dose for interventional radiology	High spatial resolution ,online measurements ,good stability ,water equivalence ,high efficiency	Cables ,small temperature dependence , expensive and complicated reading
Dose area product DAP	Monitoring of DAP for patient	Online measurements	Does not directly measurement entrance surface dose

dose to the hands during 41 procedures of intramedullary nailing of femoral and tibial fractures, and found that the average dose of radiation to the dominant hand of the primary surgeon is 1.27 mSv and 1.19 mSv to the first assistant. Levin et al, (1997) [15] also used TLD rings to study the radiation dose to the orthopaedic surgeon during 30 close interlocking intramedullary nailing procedures. They reported an average of 0.23 mSv to the orthopaedic surgeon hands of exposure during insertion of the intramedullary nail and proximal locking screw.

Orthopedist thyroid dose

Thyroid cancer is of concern after radiation exposure. It accounts for approximately 6% to 12% of the mortality attributed to radiation-induced cancers (Bushberg, et al. 2002) [16] , The dose response data for thyroid cancer fits a linear, non-threshold dose response relationship (Dowd et al 1999)[18]According to Balter, (1996) [17] the increased numbers of thyroid cancers are related to:

Chronic iodine deficiency during the years preceding the Chernobyl disaster in the children living in regions contaminated with radiation and, (B) Genetic predisposition to developing thyroid malignancy after radiation exposure in some subgroups of exposed population Shore, et al. 1985 and Ron, 1990 [19-20] have shown small excesses of thyroid cancer beginning within 5 years after low dose irradiation, which became more pronounced by 10-15 years after irradiation. Statkiewicz, et al (1998) [21]concurred with Shore, et al. (1985) [19] and Ron, (1990) [20] by stating that the approximate time for the appearance of such radiation-induced thyroid malignancies is usually between 10 years and 20 years after low dose exposure. In 1996, a preliminary survey of the membership of the Australian Orthopaedic Association (AOA) suggested an increased incidence of thyroid carcinoma in orthopaedic surgeons, due to the used of fluoroscopic image (Dewey et al, 1997) [22]. This perception is the subject of on going investigation. Dewey et al (1998) [23] reported that the perceived increase in the incidence of thyroid carcinoma in orthopaedic surgeons prompted an assessment of the use and value of thyroid shields in the operating theatre. They used TLDs to monitor the orthopaedic registrars" thyroid, in addition, thyroid function, thyroid-stimulating hormone (TSH), free thyroxin (T_4), free triiodothyronine (T_3)., antimicrosomal antibody, and antithyrolobulin antibody tests were performed to exclude any abnormality related to radiation exposure. The radiation exposure measured on the TLD monitor ranged from of 0.01 to 0.4 mSv. The authors found that the thyroid function results were within normal limits, however the higher TSH levels occurred in trainees with the longest service. The orthopaedic surgeons may be more likely to develop thyroid carcinoma if not protected from this radiation exposure.

Schneider et al. (1993) [24] investigated the dose the examiner received over a period of one year, during coronary angiographies, both with and without thyroid protection, and the study revealed that without thyroid protection the examiner received a dose 30 times higher than with thyroid protection. Muller, et al. (1998) [14] found that the radiation dose to the thyroid without a lead shield is 70 times higher than with a thyroid shield.
A study performed by Theocharopoulos, et al. (2003) [25] concluded that the use of thyroid protection leads to a further 2.5- fold decrease of radiation dose than without thyroid protection.

Madan et al (2002) [12] performed a study to estimate the radiation hazard to the patient's gonads and orthopaedic surgeon's hands during intramedullary nailing of the femur, but did not calculate the radiation dose to the thyroid of the orthopaedic surgeon. Therefore a study, which investigated the radiation dose to the thyroid of the orthopedics' surgeons is necessary.

Bahari et al (2006) [26] evaluated radiation exposure of the hands and thyroid gland during percutaneous wiring of wrist and hand procedures reported that the hand dose for surgeon and assistant is 0.80 and 0.87 mSv respectively. And thyroid dose for surgeon and his assistant when shielded and not shielded is 0.21, 0.22, 0.67 and 0.69 mSv respectively.Theocharopoulos et al (2003) [25] calculated eye lens and surface face dose to surgeon using anthropomorphic phantom and DAP during hip and lumber spine (AP and lateral), the study reported that the effective dose, eye lens dose, and face skin dose to an orthopaedic surgeon wearing a 0.5-mm lead-equivalent apron will not exceed the corresponding limits if the dose area product of the fluoroscopically guided procedure is <0.38 Gy m ^{2}. When protective eye goggles are also worn, the maximum permissible dose area product increases to 0.70 Gy m ^{2}, while the additional use of a thyroid shield allows a workload of 1.20 Gy m ^{2}. The effective dose to the orthopaedic surgeon working tableside during a typical hip, spine, kyphoplasty procedure was 5.1, 21, and 250 µSv, respectively, when a 0.5-mm lead shield is wearing Comparison between mini c-arm and standard c-arm Edward et al (2010) [27] compared radiation dose and screening time between mini C-arm and standard fluoroscopy machines in elective foot and ankle surgeries during 55 procedures for mini c-arm and 72 procedures for standard c-arm , they revealed that there was a statistically significant reduction in mean DAP using the mini C-arm, 3.46 Gy cm^2 vs. 7.43 Gy cm^2 ($P = 0.0013$). There was no difference in screening time. Athwal et al (2005) [27] studied the radiation exposure in hand surgery: mini versus standard C-arm they reported, that the mean in-beam radiation exposures with the use of the mini and standard C-arms were 3,720 mR/h and 6,540 mR/h, respectively. The mini C-arm had universally less radiation exposure than the standard C-arm in the clinical configurations tested.

Tsalafoutas et al (2007) [29] estimated radiation doses to patients and surgeons from various fluoroscopically guided orthopaedic surgeries, for the most often performed procedures (intramedullary nailing of peritrochanteric fractures, open reduction and internal fixation of malleolar fractures and intramedullary nailing of diaphyseal fractures of the femur), the respective mean fluoroscopy times were 3.2, 1.5 and 6.3 min while the estimated mean ESDs were 1.83, 2.1 and 3.31 mGy, respectively. The estimated dose rates for the hands, chest, thyroid, eyes, gonads and legs of the operating surgeon were on average to 0.103, 0.023, 0.013, 0.012, 0.066 and 0.045 mGy min^{-1}, respectively, and compare well with the literature.

Brian et al (2007) [30] studied exposure to direct and scatter radiation with use of mini-C-arm fluoroscopy. The surgical team was exposed to minimal radiation during routine use of mini-c-arm fluoroscopy, except when they are in the direct path of the radiation beam.

William et al (2009) [31] evaluated reduction of radiation exposure in intra-medullary nailing procedures: Intra-medullary endo-transilluminating (iMET). The authors reported that a visible light source was inserted into the medullary bone cavity in order to detect the distal interlocking screw holes.. The average time to finish the insertion of one distal interlocking screw was 4.1± 1.8 min. It was extrapolated that 13–41% of previous radiation exposure levels could be saved. The non-fluoroscopic approach thus decreases the health hazards that the patients are experiencing as well as those of the surgical team who need to perform such intra-medullary nailing operations on a routine basis.

Screening time

The orthopaedic surgeon spends a significant amount of time working in close proximity to x-rays during one procedure and through their working life. Screening time gives a useful idea of the amount of time that the image intensifier machine is operating, but not of the radiation dose to the surgeons. Sutherland et al (1998) [33] performed a study to evaluate the relationships between screening time and radiation dose to the 45 orthopaedic surgeons during fluoroscopic procedures. The study concluded that the reduction of the time that the machine is operating should reduce the potential exposure to harmful radiation. Jones et al (1998) [34] stated that the prolonged exposure time per patient might be required during operational procedure, resulting in increased exposure of orthopaedic surgery theatre staff. The addition of a stored image facility to a basic fluoroscopy machine reduces screening time by a factor of four, while a more modern digital image facility results in a further eightfold reduction. Therefore, the radiation dose to the orthopaedic theatre staff and patient will be decreased.

Wallace, et al (1987) [35] quantified the radiation dose to the orthopaedic registrars hands, thyroid and whole body, and to quantify the average operation and screening times during fluoroscopic internal fixation of the lower limbs, during three-month period Furthermore to determine the maximum number of internal fixations of the lower limbs that can be performed by an orthopaedic registrar per year before exceeding the ICRP recommended level of radiation to the hands.

Table 2 and 3 summarizes the screening times for the most commonly carried out operations for consultants and trainees. Although the consultants had shorter times for the insertion of cannulated hip screws, the trainees had shorter times for the other four procedures. Although the numbers of patients are often small, a more detailed analysis by operator showed differing mean screening times for different consultants and trainees, and has led to a re-evaluation of practice. For other procedures there were insufficient numbers of patients operated on by both trainees and consultants for meaningful interpretation. There was no apparent difference between the radiographers involved.

Patient dose during orthopedic surgery

The radiation beam in interventional fluoroscopy procedures is typically directed at a relatively small patch of skin for a substantial length of time. This area of skin receives the highest radiation dose of any portion of the patient's body. The dose to this skin area may be high enough to cause a sunburn-like injury, hair loss, or in rare cases, skin necrosis (Mettler 2002) [36].

Sundaram et al (2007) [37] have studied the radiation dose to patient undergoing orthopedic surgery they reported that more than 600 patients underwent trauma & orthopaedic surgery that required an image intensifier at the time of surgery. The mean screening DAP of the patients undergoing spinal surgery and other common procedures are as follow Lumbar fusion 23 , Disc replacement 10, Discogram 4.9, Foraminal injection 4.4, DHS 1.86, intramedullary hip screw IMHS 1.33, open reduction of internal fixation ORIF Ankle 0.89, manipulation under anesthesia MUA k-wire wrist 0.04,(Gray/cm^2). The four surgical procedures

Table 2: Procedures and dosimeters used in literatures

Authors	Procedure type or organ	Dosimeter
Goldstone et al (1993)[13] Zaka Ullah et al (2006) [38]	Dynamic hip screw (DHS)	TLD
William et al (2009) [31] Goldstone et al (1993) [13]	Intramedullary nailingintra-medullary endo-transilluminating	TLD
Asghar et al (2008) [41]	DHS and DCS	Didose and gamma scout meter
Badman .et al (2005) [42]	Ankle and forearm surgeries	Ion chamber type radial industries (MDH)
Brian et al (2007) [30]	Upper extremity	Luxel luminescence dosimeter
Michael et al (2001) [43]	Upper extremity	Ion chamber Keithley Model-35000
AbuAshab et al (2006) [44]	Internal fixation of femur and tibia	TLD
Laxman et al (2004) [45]	Metacarpal and humerus manipulation	DAP
Radhi et al (2006) [46]	Tibia interlocking nail	TLD

Table 3: Screening times for the most commonly carried our operations for consultant and trainees [33]

	Mean screening time (minutes)	
Procedure	Consultant	Trainee
Dynamic hip screw	0.47	0.33
Cannulated hip screws	0.36	0.51
K-wire fracture fixation	0.23	0.18
Fracture manipulation	0.13	0.11
Intramedullary nailing	1.15	0.89

which required the most radiation were spinal procedures. Patients undergoing spinal surgery can receive as much radiation exposure as those undergoing procedures such as barium swallow or standard lumbar spine films.

Zaka Ullah et al (2006) [38] have investigated radiation dose to patient during DHS they concluded that, the total (DAP) was 96.42cGy/cm^2 with an average of 0.860cGy/cm^2. The authors have determined a local DRL for DHS fixation which can be used as a guideline for this procedure. We recommend that DRL be set for other orthopedic procedures done under Fluoroscopic guidance, especially procedure involving younger patient.

Table 4 : Patients dose reductions techniques during orthopedic interventionnel proedures

Imaging parameters	Equipment settings characteristics	Orthopedic procedure
Increase tube voltage	Reduction of image intensifier patient distance	Experienced examiners
Reduce fluoroscopic time	Under couch configuration	Well patient positioning and focusing prior the procedure
Reduce number of fluro grab taken	Fluoroscopy time with alarm	Radiation barriers
Intermittent fluoroscopy	Last image hold with digital features	Wear wrap-around lead aprons
Storing fluoroscopic images	Adequate filtration	Examiners radiation safety training
Selection of the low dose fluoroscopic mode	Pulsed fluoroscopy	Examiners and patient dose monitoring
Avoid magnification	Radiation control from inside the room	Dose reference levels(DRL)
Radiation field Collimation	Automatic Brightness control (ABC)	Thyroid shields
	Mobile C-arm	ALARA principles (As Low As Reasonably Achievable)

Optimization and dose reduction

During orthopedics and any other interventional radiologic procedures several major parameters influence dose are: number of images taken, fluoroscopy time, field size and overlap of fields (Miller 2002) [39].Tube filtration, generator voltage and current, reduced-dose pulsed fluoroscopy versus continuous fluoroscopy (Wagner 2000) [40], distance between the X-ray tube and the patient and between the patient and the image receptors and patient body habitus .Radiation dose is optimized when imaging is performed with the least amount of radiation required to provide adequate image quality and imaging guidance. Optimizing patient radiation dose also provides a direct benefit to the operator and assistants: scattered radiation in the room is directly proportional to the patient dose. If patient dose is reduced, so is the dose to the operator.Table 4 summarize steps to be followed to reduced radiation risk to both patients, surgeons and other staff .

CONCLUSION

The mini C-arm had universally less radiation exposure than the standard C-arm in the clinical configurations tested. The orthopaedic surgeons may be more likely to develop thyroid carcinoma if not protected from this radiation exposure. Digital fluoroscopic system with last frame hold should be encouraged.Efforts should be made to reduce radiation exposure to orthopaedic patients, and operating surgeons especially those undergoing spinal surgery. Well training, continuous monitoring and rich knowledge about hazard among orthopedist are starting steps to reduce radiation risk.

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