Radiation protection and standardization

O.P. Lakhwani ^{a,*}, Vipin Dalal ^b, Mohit Jindal ^c, Ashok Nagala ^d

^a Professor, and Head of Department Orthopedics, ESI Postgraduate Institute and Medical Sciences, New Delhi, India

^b Senior resident, Orthopedics, ESI Postgraduate Institute and Medical Sciences, New Delhi, India

^c Assistant Professor, Kalpana Chawala Medical College, Karnal, Haryana, India

^d Consultant Orthopedics, SAIMS, Indore, India

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ABSTRACT

X - Rays has become integral and indispensable part of health care diagnosis and intervention. Intervention procedures in Orthopedics surgery now mostly performed under image intensifiers (C-Arm) which involve the risks of occupational overexposure of radiation to the patients and health care personnel. The principles of radiation protection are helpful in keeping radiation exposure just adequate for diagnostic and intervention procedures. Regular surveillance of protective apparel is necessary for longevity of safety. It is responsibility of all OT personnel to know and implement radiation safety. Each situation involving X-ray radiation should include justification of the procedure, minimum radiation exposure just adequate for diagnostic and interventional procedures.

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1. Introduction

Since the discovery of X-ray by Wilhelm Conrad Röntgen¹ (1845–1923) in 1895, it has become integral and indispensable part of health care diagnosis and intervention. X-rays are used in single frame radiographs, computed tomography (CT), radiotherapy and interventional fluoroscopy. It is estimated² that, each year, more than 2500 million diagnostic radiological examinations, 32 million nuclear medicine examinations and 5.5 million radiotherapy sessions are performed worldwide. There may be a risk of cumulative effect at low doses as well.^{3–7} Interventional procedures like Orthopaedic surgery procedures utilizing fluoroscopy image intensifier (C-Arm) involve the risks of occupational overexposure of radiation, both to the patients and health care personnel. Hence knowledge of preventive measures and use of protective devices are mandatory to keep radiation as low as reasonably achievable (ALARA).⁸ (see Fig. 1).

2. Radiation sources and measurement

Natural radiation sources, including cosmic rays and terrestrial radon gas, account for approximately 85% of the exposure to

humans. The remaining exposure comes primarily from diagnostic radiography.^{9,10} Risk of the Occupational exposure to Orthopaedic surgeons and health care personnel are mainly from scatter radiation exiting from the patient and not from the primary beam itself.

Radiation exposure dependent on time functions and is expressed as dose per unit time i.e. gray per hour (Gy/h) or Sievert per hour (Sv/h). The unit of energy for radiation is usually given as electron volt(s). One eV is defined as the energy of an electron that has been accelerated through an electron potential of 1 V.

Gamma-rays and X-rays, unlike alpha or beta particles are made up of individual packets of energy called photons. Gamma rays are emitted from the nucleus of a radioactive atom while X-rays are emitted when high speed electrons are slowed down or their direction is changed, in a strong electric field. The energy of X-rays are greater than 5 keV and ranges from 40 to 100 keV.

The quantity of radiation energy absorbed in a unit of mass of material is measured in international standard unit (SI unit) as Gray (Gy) and 1 Gy is equivalent to 100 rad. SI unit for equivalent and effective dose is Sievert (Sv). Equivalent Dose is a measurement of the biological effects of the radiation on a specific tissue or organ exposed to specific type of radiation. It is dependent on the type of radiation absorbed in a particular time duration. The radiation-weighting factor for X-ray in standard unit is expressed as Sievert (Sv). (Old unit: rem (roentgen equivalent man). 1Sv = 100 rem). Effective Dose is a measurement of the whole body dose based on the total equivalent dose received by all organs. Each organ contributes with a tissue-weighting factor. It has the same units of

* Corresponding author. Professor and Head Orthopedics Department, ESI - Postgraduate Institute and Medical Sciences, New Delhi - 110015, India
E-mail address: orth365@gmail.com (O.P. Lakhwani).

Fig. 1. Image intensifier targeting device increase accuracy of exposure reducing radiation and surgical time (source courtesy - OP Lakhwani¹², Radiation Safety & Protection Use of Image Intensifier Targeting Device May- Medical Equipment & Automation, vol.5; no. 4 pg 40–41, June 2012).

measure as the equivalent dose.

3. Radiation exposure and safety

The Radiation exposure^{13–15} depends on the triad of “Time-Distance-Shielding”. Reduction of the exposure time, increasing the distance from source and proper shielding are important for protection. The International Commission for radiation protection¹¹ (ICRP) and other organization has recommended measures to mitigate the exposure (see Table 1).

Time - Time is related to exposure time and exposure rate. Optimum technique including use in high KV and low mAs mode, beam collimation, beam filtration anti scatter grids, high speed films and processing are necessary.

Tube current or mA determines the quantity of the photons and KV determines the energy of photons; collectively both contributes to patient dose. The use of high frequency generators, which generate high KV beam will decrease the mAs required to produce diagnostically adequate X-rays thus reducing radiation dose. It is mandatory that console have a set reminder with audible alarm, which warns when a significant radiation dose (at 5 min cumulative time), beyond which local harmful effects such as radiation

burns may arise. Exposure time can be further reduced by increasing accuracy of radiographs by laser targeting devices¹² and correct positioning of the subject.

Distance – Radiation exposure is inversely proportionate to the square of the distance. When the distance is doubled, the exposure is reduced by a factor of four.

The International Commission for radiation protection¹¹ (ICRP) and National council for Radiation protection (NCRP) recommended a safe distance of 2 m from the source of radiation in Image Intensifier fluoroscopy setup, so exposure cord of at least 2 m length or remote control switch should be used for exposure. At a distance of 2 m, exposure is 0.025% of the direct beam intensity.¹¹ The minimum source-to-skin distance for a stationary fluoroscopy tube should not be less than 38 cm (15 inches) and for a mobile C-arm, should not be less than 30 cm (12 inches). However, increased surgeon distance can compromise surgical technique.¹²

Shielding - Attenuation of radiation exposure by protective devices between the source of radiation and the exposed individual. It includes personnel shielding and patient shielding of organs not under investigation. Personnel shielding devices includes lead apron, lead goggles, gonad shields, thyroid masks and gloves.

4. Lead aprons

Lead can effectively attenuate certain kind of radiations because of its high density and high atomic number (82); principally, it is effective at stopping gamma rays and X-rays. It is used as thyroid collar shield, gonadal shield, apron and other forms to provide the secondary barriers to protect wearers from secondary or scatter radiation (see Fig. 2).

Standard lead apron must provide at least 0.5 mm of lead or equivalent structural barriers (ie, a 0.2 mm lead equivalent = 1.2 mm of steel, 2.5 mm of glass, 5.9 mm of gypsum, 33 mm of wood). Lead aprons of 0.5 mm thickness have been shown to shield approximately 99% of potential radiation dose.^{11,13} Lead apron must cover the front of the body from the throat to within 10 cm of the knees, as well as the sides of the body from the shoulder to below the buttocks. A single piece apron is easy to use and appropriate for a short procedure, Two-piece lead apron have a vest and skirt. Special aprons that contain elements like barium and iodine in combinations with lead and plastic struts, provide protection equivalent to lead but reduce the overall weight of apron hence reducing the stress over shoulder and spine and can be used

Table 1

General Principle in operation theatre IITV to reduce radiation exposure.

Principles
1. Risk of the Occupational exposure are mainly from scatter radiation exiting the patient.
2. Radiation exposure dependent on triad of “Time-Distance-Shielding”.
3. Optimum technique use in high KV and low mAs mode, beam collimation, beam filtration anti scatter grids, high speed films processing are necessary.
4. Tube current or mA determines the quantity of the photons and KV which determines the energy of photons; collectively contribute patient dose.
5. Mandatory to have a set reminder with audible alarm on console which warns when a significant radiation dose.
6. Increasing accuracy of radiographs by laser targeting device ³ and correct positioning.
7. Distance – Radiation exposure inversely to proportionate to the square of the distance. When the distance is doubled the exposure is reduced by a factor of four.
8. A safe distance of 2 m from the source of radiation hence exposure cord of at least 2 m length or remote control switch should be used.
9. Minimum source-to-skin distance for a stationary fluoroscopy tube should not be less than 38 cm (15 inches), and for a mobile C-arm not less than 30 cm (12 inches).
10. Lead apron are secondary barriers to protect from secondary or scatter radiation.
11. Standard lead apron must provide at least 0.5 mm of lead or equivalent barriers.
12. Lead apron must cover the front of the body from the throat to within 10 cm of the knees, as well as the sides of the body from the shoulder to below the buttocks.
13. Thyroid shield can decrease the amount of effective dose by 2.5 fold and almost 50% reduction in total exposure.
14. Lead aprons defect is greater than 15 mm ² in areas close to critical organs areas. Thyroid shields with defects greater than 11 mm ² should be replaced.
15. If only one dosimeter is worn it must be worn at the collar outside the lead apron.
16. Neck receives 10–20 times more radiation than the trunk which is protected by lead.
17. Protect of patients thyroid, breast and gonads in children and young adults.
18. Placement of shield should be based on the direction of the tube during the procedure.
19. Best time to image females child bearing age is in the 10 day period following the onset of menstruation.

Fig. 2. Testing of lead apron integrity by image intensifier exposure.

for longer procedure.

THYROID SHIELD - Although lead gown is routinely worn as a part of c-arm assisted orthopaedic procedures, it does not cover the neck (thyroid) area. The consistent neglect in the use of thyroid shield¹⁴ is a matter for concern. Exposure to radiation over many years may promote development of thyroid carcinoma. The thyroid shield can decrease the amount of effective dose by 2.5 fold and almost 50% reduction in total exposure.¹⁴

5. Storage of lead apparels

Care of the lead apparel is must to keep the lead integrity. Frequent falling, dropping, piling, improperly storing can lead to internal fracture of the lead layer, affecting the integrity and protective capability. Hence proper storage and checking is required for its optimum use.

Lead apron, side shields, thyroid shields, gloves shields and other protective apparel should either be kept flat or on hangers in properly designed racks or to prevent defects such as internal cracks and tears.

6. Standardization testing and rejection procedure of lead apparels

All the lead aprons and radiation protection appliances at the time of purchase should be uniquely identified with an identification number and date of first use. Records must be kept which should include the identification number, date of purchase, lead equivalence, testing dates and test results.

Annual examination should include visual inspection and tactile evaluation to detect any defects such as holes, cracks or tears, perforations and thinning of Velcro belt etc. Aprons are usually covered with a non-shielding protective cover, which must be tested fluoroscopically, as underneath protective lead layer may be faulty. This Fluoroscopic examination should be done using manual settings (60–80 kVp). Defects will appear light, while shielded will be dark.

7. Rejection criteria¹⁶

Lead aprons usually serve about 5 years and defects may appear early, depending on use and care. Considering the costs, a lead

apron may have to be replaced if the defect is greater than 15 mm² in areas close to critical organs. Thyroid shields with defects greater than 11 mm² should be replaced. Other areas in lead apron, at the back or along the seams, having defect greater than 670 mm² needs replacement.²⁹ Use of the lead apron may be continued, if an apron has defects that do not meet the rejection criteria. Record of defect characteristics like size, location should be maintained. Lead apron should be checked twice in a year to monitor the defects.

7.1. Radiation protection survey and programme

Every hospital must have a radiation protection program with a Radiation Safety Committee (RSC) and a Radiation Safety Officer (RSO). It is recommended by NCRP that the RSC should comprise of a radiologist, a medical physicist, a nuclear medicine personnel, a senior nurse and an internist. It is the duty of RSC to perform a regular radiation protection survey and monitor radiation safety measures.

8. Monitoring of radiation exposure^{17,18} and safety limits

Measuring Patient Dose – Patient radiation exposure¹⁹ dose (Entrance skin dose) can be measured by placing a dosimeter in the field of exposure. For instance a standard chest x-ray has a skin exposure dose of 10–20 mrad and a gonadal exposure of about 1 mrad.

It would be a good practice if after every fluoroscopic procedure, the radiation dose received by the patient is mentioned in the report. This would help patients to remain informed on how safe the procedure was and the risk likely to be incurred in a subsequent radiological investigation.

Personnel Dosimeter: It detects and measures the dose of radiation to individuals who are exposed to radiation during the course of their work over a period of time. It is usually measured at about 3 months. Two types of dosimeter are usually used –

Film Badge dosimeter - it uses the small x-ray films sandwiched between several filters to help detect radiation.

Thermo luminescent dosimeter (TLD) - which uses the property of certain materials such as lithium fluoride (LiF), lithium borate (Li₂B₄O₇), calcium fluoride (CaF₂), and calcium sulfate (CaSO₄). When these crystals are exposed to radiation, they become heated and emit the light. The amount of light emitted is measured and it is

proportional to the radiation dose. It is recommended that ideally two dosimeters should be worn, one at the collar level outside the lead apron and other at the trunk level underneath the lead apron. The outer one gives estimate of radiation dose to the unprotected regions of head and neck and underneath one gives estimate of radiation dose to the protected region. If only one dosimeter is worn it must be worn at the collar outside the lead apron, because, the neck receives 10–20 times more radiation than the trunk, which is protected by lead.

9. Radiation protection to surgeon/surgical team

The safety of the physician and healthcare team^{18,19} is also important. As orthopaedic surgery becomes more reliant on fluoroscopy, due to the percutaneous nature of newer, minimally invasive procedures, surgeons should be cognizant of safety recommendations.

Studies have recommended that surgeons and others in the radiation field wear 0.5 mm lead-equivalent aprons during fluoroscopy. Since thyroid is very sensitive to ionizing radiation, thyroid shields should be worn anytime fluoroscopy is used.

Personnel who are wearing leaded glasses should orient their heads to avoid exposing the sides to the radiation. When hands are directly exposed to the radiation beam, exposure is markedly increased, so surgeons should always attempt to keep their hands out of the field of view, when using the fluoroscope. If the surgeon's hands must be exposed, leaded gloves or bismuth-based x-ray attenuating hand creams can provide some protection. Female surgical personnel, who are pregnant should not hold the patient and/or X-ray cassette.

Closing the collimator down increases the concentration of exposure to the patient's skin but also reduces the surface area of exposed skin and decreases scatter from the fluoroscope.

Most C-arms have ABC (automatic brightness control) to control voltage (KvP) and current (mA) automatically as per image quality. The machine should be used in ABC mode only, as much as possible. Automatic image quality adjustment and direct surgeon control of fluoroscopy can also significantly reduce exposure time.^{5,16}

Low-dose or pulsed fluoroscopy (rather than extended exposures) should be used to obtain an adequate quality image, which has been shown to dramatically reduce the exposure to ionizing radiation.

A mini C-arm¹⁹ fluoroscopy unit can be used in lieu of a standard C-arm for intraoperative extremity fluoroscopy when feasible, which releases a lower dose of ionizing radiation.¹⁷ Laser grids help the technician to focus the image well and bring down the radiological wastage.

Digital zooming (for distal locking), in monitor, should be preferred over zooming the image in C-arm which increases radiation exposure enormously. Placing leaded shields on stands or hanging them from the ceiling, when possible, can decrease radiation exposure to the patient, the surgeon, and other personnel.

The generator (X-ray tube) should be positioned as far as possible, away from the patient, surgeon and C-ARM operator, to reduce the exposure. To avoid scatter radiation OT personnel should stand on the image-intensifier side of the fluoroscope, not the generator side. The direction of X-ray beam should be from bottom to top by keeping X-ray tube to bottom side, to decrease scatter radiations. Effective dose received can be dramatically reduced if personnel stand atleast 36 inches away from the beam.¹⁸ Frequent calibration of the fluoroscope can ensure the smallest effective radiation dose (see Fig. 3).¹⁹

Using computer-assisted surgery (CAS) technologies^{20–22} in reducing radiation risk is another method, which uses digitized

Fig. 3. Component of image intensifier IITV.

images of patient's anatomy to enable surgical navigation in an improved virtual environment.²⁴ Stored radiographic images are utilized during navigation, eliminating the need for additional radiographs and unnecessary exposure.^{20–23} Studies have shown that navigation can further reduce fluoroscopy time during spine surgery when pedicle screw instrumentation is performed.^{24,25}

The O-arm imaging system provides complete multi-dimensional surgical imaging and neuro-navigation in a seamless manner and provides surgeons with real-time, 3D images, as well as multi-plane, 2D and fluoroscopic imaging. It is no longer necessary to wear lead aprons while operating under O-arm guidance. Only one set of images is required to be acquired by the O-arm (which takes approximately 13 s), during which the staff vacate the room or stand behind a lead shield.³¹

G-arm imaging system consists of G-shaped arm used to connect two X-ray generators and two X-ray detectors, image intensifiers or digital flat panel detectors, to one another. It allows simultaneous views in two perpendicular planes. Benefits are shorter procedures, higher accuracy and lower radiation exposure.³²

Educational efforts of patients, families, radiologists and radiology technicians have initiated by joint efforts between the American college of Radiology and the US Food and Drug administration, called Image Wisely (in adults) and Image Gently (in children), in an attempt to eliminate unnecessary radiation exposure.^{25–27}

10. Radiation protection to patient

Radiation protection of patient²⁸ is also equally important. It is recommended to protect the thyroid, breast and gonads in children and young adults. Lead apron should be placed to protect the gonads from primary beam radiation exposure; lead collar should be provided to cover patient's neck and thorax to shield thyroid and breast.

It is important to decide the placement of shield on front of patient, beneath or all around based on the direction of the tube during the procedure. It is a common to think that in all cases the lead shield should be placed over the top of their gonads which do not provide the protection, rather become source of scatter radiation and increase the radiation exposure if tube is placed through inferior direction. It is important to consider shielding the patient before preparation and draping.

When using fluoroscopy, the patient should be positioned as close as possible to the image intensifier side of the fluoroscopic equipment and as far away as possible from the tube side, to reduce scatter radiation.¹⁶

10.1. Pregnant patients

It is the responsibility of the Medical personnel to screen the female of childbearing age for potential pregnancy. Radiation dose of less than 1 rad/rem to the fetus is considered to have negligible effect. National commission for radiation Protection (NCRP) report on Medical Exposure of Pregnant and Potentially Pregnant Women states that a risk of 5 rad is negligible when compared to other risks associated with pregnancy.

There are at least three considerations to decide “should” the pregnancy be terminated because of exposure: the exact gestational Age at exposure, estimated fetal dose and patients wish.

Most vulnerable time of fetus irradiation is the first trimester. The risk of malformations increases greatly above 15 rad of fetal dose. A woman who receives 25 rad within 4 weeks of conception should consider abortion, whereas 5 rad in the third trimester would rarely be a reason for termination of pregnancy. First two weeks of gestation when the female may not be aware whether she is pregnant are crucial, hence the best time to image females is in the 10 day period, following the onset of menstruation. Atomic energy review board (AERB) recommended that in established pregnancy the radiation dose to surface of pregnant woman's abdomen should not exceed 2 mSv.

11. Children

The radiation risk is higher for children than for adults, as children's tissues have a higher cell division rate, and cells can be damaged during this process. Children also have a higher water content and therefore absorb more radiation.

Pediatric doses of radiation should always comply with the ALARA (as low as reasonably achievable) principle. Radiation-induced damage can be reduced by the selection of an appropriate procedure, the technical specifications of the X-ray machine, like low tube voltage and collimation, use of the shortest possible scan times despite short target times, and the use of modern storage-plate systems. X-ray examinations of adults must be performed with a tube filter of at least 2 mm aluminum. For children and adolescents, an additional tube filter of 1 mm aluminum (Al) and 0.1–0.2 mm copper (Cu) must be used. The child being examined can also help ensure that no additional images are needed by lying still, which sometimes requires fixation devices.³³

Unlike adults, in infants and small children thoracic images are captured using an anterior-posterior (AP) projection, because more hematopoietic bone marrow (vertebrae, ribs, shoulder blades) is located in the dorsal part of the body.

Although many CTs could be replaced by MRI, the fact that MRI is more time-consuming and expensive, machines are less available, and uncooperative patients need to be sedated restricts its use.

However, one simple and important method of providing radiation protection is the correct use and positioning of layers of lead rubber to protect areas such as the gonads or eyes.

Finally, it is our duty to stop ordering repeat radiographic tests simply because the studies are not available for review or in our own picture archiving and communication system (PACS). A PACS consists of four major components: the imaging modalities such as X-ray plain film, Computed tomography and Magnetic resonance imaging, a secured network for the transmission of patient information, workstations for interpreting and reviewing images, and

archives for the storage and retrieval of images and reports.³⁰ We should do everything possible to have the patient bring all previous studies and attempt to integrate them into our system by giving unique ID, before ordering another test. As treating physicians, we are responsible for doing all we can to eliminate unnecessary tests.

11.1. Summary

Radiation protection is an integral component of hospital setup. The principles of radiation protection are to provide protection from undue exposure of radiation to medical personnel and patient. Radiation protection program should include justification of the procedure involving the radiation exposure, use of minimum radiation exposure just adequate for diagnostic and interventional procedures. Regular surveillance of radiation exposure, protection and educational activities should be the part of responsibilities of RSO and other administrative authorities of the hospital.

Orthopaedic surgeons are relying more heavily on X-rays, CT scans, and fluoroscopy during advanced procedures. For this reason, we must be well versed in the safety concerns of all forms of ionizing radiation. Many measures exist to protect the patient, surgeon, and medical personnel from the harmful effects of radiation. Each situation involving X-ray radiation should be carefully evaluated to limit adverse effects, and ICRP guidelines should be followed to prevent potential harm to healthcare providers and patients.

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