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Radiation exposure during intramedullary nailing

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ABSTRACT

Surgeons should aim to keep radiation exposure "As Low As Reasonably Achievable (ALARA)" during intramedullary nailing and other minimally invasive surgical procedures. This requires understanding the principles of ionizing radiation and methods for minimizing exposure risk. The main source of radiation exposure to surgical personnel during fluoroscopy is from scattered radiation. Since radiation scatter is mainly directed towards the fluoroscopy source, the best configuration during surgery to reduce radiation dose to the surgeon is to position the fluoroscopic source below the operating room table and the image collector above the table. During cross table imaging, the surgeon should stand on the side with the image collector to minimize their exposure to radiation scatter. To reduce scattered radiation the patient must be placed as close to the image collector and as far away from the x-ray tube as possible. Standing farther away from the patient can exponentially reduce radiation exposure. The hands usually have the greatest dose exposure to radiation during surgical procedures, but they are far less radiosensitive than the eyes or thyroid. To minimize exposure to the hands, a surgeon should use the hands-off technique taking fluoroscopic images only when his or her hands are farthest from the radiographic field. Lead gowns, lead thyroid shields, and lead glasses, further reduces an individual's exposure to radiation.

Introduction

Intraoperative fluoroscopy is being increasingly used during orthopedic trauma surgery due to the expansion of minimally invasive techniques and expanding indications for intramedullary nailing. As such, it is important for Orthopedic surgeons to understand the principles of ionizing radiation and methods for minimizing exposure risk to themselves, their patients, and the operating room team. The goal should be to follow the ALARA principle, which means radiation exposure that is "As Low As Reasonably Achievable."

Radiation is defined as energy from a source that travels through space and may be able to penetrate various materials. Radiation may be nonionizing, such as light, radio, and microwaves. Ionizing radiation refers to radiation produced by unstable atoms, or by a high-voltage device such as an x-ray machine.

Units of measurement

The energy produced by x-rays is measured in Roentgen equivalents in men (Rems). Energy deposited in a material is measured in Gray (Gy) and reflects the physical effects of the radiation. Energy deposited in biologic material is expressed as a dose equivalent called Sievert (Sv) and reflects the biological effect of the radiation.

Radiation exposure

Everyone is exposed to a baseline level of radiation. In the United States the level of exposure from cosmic radiation is 0.27 mSv/year. Medical exposure through receiving a chest x-ray equals 0.1 mSv, while a head CT results in 1.5 mSv, and 9.9 mSv with a whole body CT scan. The dose of radiation required to produce radiation sickness is between 500 and 1000 mSv, which is equal to the amount that the citizens of Hiroshima were exposed to in 1945.

Adverse effects of radiation on the body can be due to either somatic effects or stochastic effects. Somatic effects are directly related to the radiation dose. Early somatic effects include radiation sickness, while late somatic effects include leukemia, thyroid cancer, and radiation induced cataracts. Levels of radiation below the calculated threshold levels for these injuries do not result in an increased risk of illness. In contrast stochastic effects occur by chance. There is no safe threshold for stochastic effects, and damage is cumulative with multiple exposures to radiation. Stochastic effects typically exhibit a latent period prior to effects

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development that can exceed 25 years. Late stochastic effects include thyroid cancer and leukemia.

Maximum allowable thresholds

The International Commission on Radiological Protection (ICRP) sets maximum allowable thresholds for radiation exposure. In 2012 they recommended a new lower annual limits for radiation dose to the eye. Threshold levels for the eye are 20 mSv per year averaged over 5 years or a maximum of 50 mSv in any single year [1]. The lens of the eye is particularly sensitive to radiation and high levels of exposure can cause radiation induced cataracts. Threshold levels for the thyroid are 300 mSV and for the hand are 500 mSv. Papillary thyroid cancer is the predominant cancer type seen in patients who have had previous radiation to the head and neck.

The hands usually have the greatest dose exposure to radiation during surgical procedures, but they are far less radiosensitive than the eyes or thyroid. The hands-off technique, which requires the surgeon to take fluoroscopic images when his or her hands are farthest from the radiographic field, is suggested for minimizing exposure to the hands.

Radiation exposure during intramedullary nailing

Radiation exposure during 8 closed interlocking intramedullary femoral nailings was monitored using high sensitive thermoluminescent dosimeters [2]. The average radiation dose received by the eye was 19.0 μSv, by thyroid gland was 35.4 μSv and by the hands was 41.7 μSv. The values reported in this study are μSv (10^{-6}) whereas threshold values are in mSv (10^{-3}), therefore they are far below the recommended threshold levels for even a very busy surgeon.

Radiation dose to primary surgeon's and the first assistant's hands was monitored during 41 intramedullary nailing of femoral and tibial fractures using ring dosimeters worn on their dominant index fingers [3]. The average radiation dose to the primary surgeon's dominant hand was 1.27 mSv, and that for the first assistant was 1.29 mSv. The authors calculated that the annual threshold level for the hand of 500 mSV would be exceeded only if a surgeon performed more than 407 intramedullary nailing procedures per year.

The researchers also performed in-vitro measurements during operative procedures of the lower leg simulating different intra-operative situations to assess the surface doses to the primary surgeon's thyroid gland with and without wearing a lead shield. The average radiation dose without a thyroid shield was approximately 70 times higher than with thyroid lead protection. Using an average fluoroscopy time of 4.6 min for intramedullary nailing, the authors extrapolated that if 1000 intramedullary nailings were performed without wearing a thyroid shield the surgeon would only reach 13% of the annual thyroid threshold level, and if wearing a thyroid shield they would only reach 0.2% of the annual threshold value.

A study comparing 12 senior surgeons with a group of 10 junior surgeons performing 23 long bone IM nailing procedures found that the junior group used statistically more fluoroscopic time and had significantly greater radiation exposure to their hands [4].

A study of 107 consecutive orthopaedic trauma operations found that the assistant, who commonly was performing the reduction, was approximately 10 cm from the fluoroscopy beam while the surgeon was always more than 90 cm from the beam [5]. As a result, the primary surgeon's dosimeter readings outside their lead gown averaged 3.3 mREM monthly, while the assistant closer to the beam averaged 20.22 mREM monthly. Dosimeter readings beneath their lead gown for the primary surgeon was zero, while the assistant still received a monthly average of 6 mREM.

The amount of radiation required to perform free-hand placement of interlocking screws has also been studied and compared to radiation free techniques. In a study of free-hand placement of 41 interlocking screws investigators found it took an average of 10 s of fluoroscopy producing 9.2 mrads of radiation during set-up to achieve "perfect circles" and an average of 18 s of fluoroscopy producing 32.9 mrads of radiation to insert each interlocking screw [6]. In another study, the average fluoroscopy time for placing two distal locking screws during 43 antegrade femoral nailing procedures was 10 s with an average radiation dose was 690.27 μGy (range, 200–2310 μGy) [7].

Protecting yourself and your team from radiation exposure

The main source of radiation exposure to surgical personnel during fluoroscopy is from scattered radiation. For every 1000 photons delivered by the fluoroscopy machine, only about 20 actually reach the image detector. Between 100 and 200 photons bounce off the patient as scattered radiation. Radiation scatter is mainly directed towards the fluoroscopy source. The remaining photons are absorbed by the patient (radiation dose to the patient) (Fig. 1).

Methods to reduce radiation exposure during intra-operative fluoroscopy can be categorized into 1) fluoroscopy tube position, 2) position and distance from fluoroscopy tube, and 3) use of various protection equipment.

Since radiation scatter is mainly directed towards the fluoroscopy source, the best configuration during surgery to reduce radiation dose to the surgeon is to position the fluoroscopic source below the operating room table and the image collector above the table (Fig. 2). Since scatter radiation follows Newton's inverse-square law, that is the radiation intensity is inversely proportional

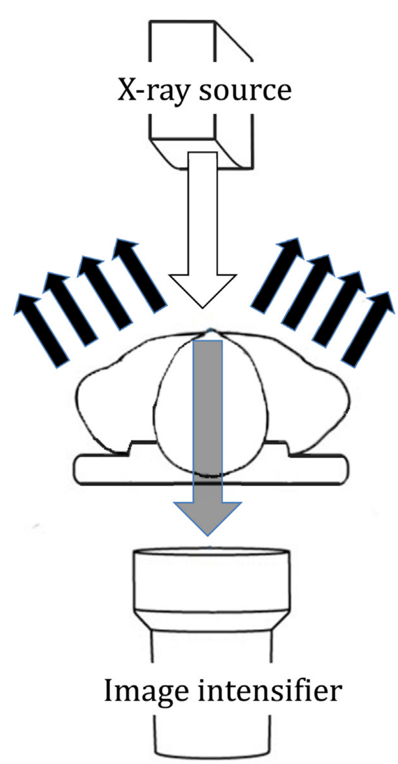

Fig. 1. Radiation not absorbed by the patient is scattered (solid arrows) and is mainly directed towards the x-ray source.

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