

Chapter 5

Radiation Management: Patient and Physician

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1 Introduction

Ionizing radiation is a powerful tool that interventionalists use daily to diagnose and treat a variety of diseases. Since ionizing radiation potentially has deleterious effects for patients and those working in an angiographic suite several organizations advise on regulations for radiation protection. These rules are usually adopted by state and federal regulatory bodies. The International Commission of Radiological Units and Measurements (ICRU) and the National Committee on Radiological Protection and Measurements (NCRP) are the two most accepted agencies in the United States.

In addition to following dose limitations for occupational and nonoccupational exposure delineated by the ICRP and NCRP, patient dose should be limited by the *as low as reasonably achievable* (ALARA) principle. The interventionalist needs to make every reasonable effort to limit ionizing radiation exposure to the patient ensuring the benefits of the procedure outweigh the risks.

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2 Radiation

- A. Radiation is defined simply as the transfer of energy through space or matter. In vascular interventional, X-rays are the principal form of ionizing radiation utilized for diagnostic and therapeutic procedures. X-rays are created in a vacuum tight X-ray tube where electrons are accelerated with high velocity from a cathode to collide with an anode made of tungsten. The maximum energy of an X-ray photon is determined by the maximum energy of the electron. For example, a 30 kV electron can only make X-rays with a maximum energy of 30 keV.
- B. Two main types of radiation are created during this process:
1. *Bremsstrahlung*: Continuous spectrum of X-ray photons is produced when incident electrons are slowed down while interacting with the electric fields of atoms. The difference in kinetic energy is emitted as an X-ray.
 2. *Characteristic radiation*: A discrete level of energy is emitted as an X-ray from ionization of the anode from the incident electrons. The energy is characteristic of the anode (usually tungsten).
- C. Of the X-rays created, the nondiagnostic low energy X-rays are filtered away (usually with aluminum), decreasing the patient dose, leaving mostly diagnostic X-rays which contribute to the making of an image.

3 Interaction of Radiation with Tissue

- A. X-rays have potential for transmission and absorption, which contribute to making an image, or scatter, which degrades the image. Scattered photons degrade an image. The two main interactions with tissues are:
1. *Photoelectric effect*: The X-ray photon is absorbed by the inner electron shell (K-shell) resulting in ionization. The energy difference is emitted as an Auger electron or radiation as an outer shell electron fills this vacancy. The probability of photoelectric effect absorption increases significantly with atomic number

and is highest as the X-ray photon energy just exceeds the K-shell binding energy (K-edge).

This principle is important in endovascular imaging as iodinated contrast is used to visualize otherwise less radiodense blood vessel at energies just above the K-edge of iodine, 33 keV.

2. *Compton scatter*: The X-ray photon interacts with a loosely bound outer shell electron causing the X-ray to be deflected with less energy. The energy difference is transferred to the ejected electron.

4 Radiation Effects

- A. X-rays transfer energy to tissue mainly as heat but a smaller fraction is deposited through ionization. Ionization has potential to cause biological damage and most concerning are changes to DNA or RNA. This can occur by direct or indirect ionization.

Direct ionization: The interaction between photon and DNA/RNA molecule resulting in ionization and subsequent damage.

Indirect ionization: Formation of free radicals through interactions of photons and water which in turn are very chemically reactive and damage DNA or RNA. Indirect ionization is thought to be the main process that produces biological damage as the human body is mostly water.

- B. If damage is done to a single DNA strand then repair can occur through the complementary strand. If there is more severe damage and both strands are involved a base deletion, substitution, complete strand break, or chromosomal aberrations, such as translocations may occur as a consequence.
- C. Radiosensitivity is the relative sensitivity of cells to ionizing radiation and determined by variety of factors:

Fractionization: If radiation is fractioned over a period of time cells have more time for repair therefore a single high dose has more potential for doing more biological damage.

Oxygen: Free oxygen increases damage by inhibiting recombination of free radicals to form water as well as inhibiting repair of damage.

Cell type: Rapidly dividing cells such as spermatogonia, myeloid cells, endothelial cells, and basal cells of epidermis are more affected by radiation than the slower dividing muscle, bone, or neural cells.

Cell phase: In general, cells are most sensitive during mitosis (M-phase) and RNA synthesis (G2). They are less sensitive during the G1 phase and least sensitive during DNA synthesis (S-phase).

- D. The biologic effects of radiation damage can be classified into two categories:

Stochastic effects: Stochastic effects relies on probability; the longer exposed or the higher the X-ray energy the higher probability of damage. This does not have a threshold value and can occur at the low levels of radiography. The prototype example of a radiation-induced stochastic effect is cancer as one harmful event may theoretically induce carcinogenesis at low levels.

Deterministic effects: This effect worsens with dose but does not occur if below a certain threshold. Deterministic effects generally require a much higher dose to make an effect. Examples include sterility, cataracts, and skin erythema. This effect can occur during radiation accidents, radiation therapy, or lengthy fluoroscopic interventional procedures.

- E. Biological effects that can occur within the first few days after prolonged endovascular procedure include mild to severe erythema to the skin, temporary sterility, and enteritis depending on the radiation exposure and region of anatomy where the radiation is focused. Effects such as intractable skin ulcers, dry cracked skin and nails, cataracts, and cancer usually take years to develop.

5 Radiation Monitoring Techniques

Personal dosimetry is usually monitored with film badges which are small sealed film packets that absorb X-ray photons. Film badges are worn at the collar level in front of a lead apron. A second badge may also be worn behind a lead apron, especially if a worker is pregnant. Every month the badge exposures are calculated to determine if radiation exposure is at a safe level.

Drawbacks to personal dosimetry include leaving film badges in a radiation field when not working, lost or damaged badges, personnel not wearing or not positioning the badges correctly. All of these problems may increase or decrease the calculation of radiation exposure.

6 Angiography Suites

Angiography suites are specially designed to meet the needs of an interventional radiologist. The angiography system commonly consists of a table as well as a fluoroscopy system or C-arm (an X-ray tube and image intensifier located opposite each other). The table glides from side to side and head to toe to follow an advancing catheter. The C-arm is able to pan around the patient and rotate to obtain oblique projections.

Uniplanar imaging: One fluoroscopic system is used to obtain a two-dimensional image.

Biplanar imaging: Biplane fluoroscopic systems consisting of two X-ray tubes and two image intensifier systems record two angles simultaneously, usually an AP and lateral view. Not only can complex vascular anatomy be imaged but injection of contrast media is reduced as two planes are imaged during injection.

7 Fluoroscopy Adjuncts and Radiation Reduction Methods

Digital subtraction angiography: This is a form of temporal subtraction used to remove the background in angiography. An initial succession of images is taken of the anatomical region of interest then more images are taken of the exact region after iodinated contrast material has been injected into the blood vessels. The images are then digitally subtracted leaving an image of contrast-filled blood vessels.

Image intensifiers: An image intensifier is a vacuum tube that converts X-rays into an image while amplifying the signal in the process. An input layer converts X-rays to electrons. The electrons are then focused and concentrated on an output phosphor. The output phosphor finally converts the electrons into visible light for an image.

Through an amplification of electrons a similar diagnostic image results in a smaller dose to the patient.

Last frame hold: This function allows an angiographer to examine the last image without continually giving radiation. The last frame hold image can be captured but it is of less diagnostic quality than a formal digital photo-spot.

Road mapping: Road mapping employs last frame hold in which an angiographic image obtained is displayed next to a live fluoroscopy monitor in which an angiographer is advancing a catheter. More commonly, the image can be used as a “road map” where it is overlaid onto the live fluoroscopy monitor. This is thought to ultimately help negotiate complex vascular anatomy reducing the overall fluoroscopy time.

Frame averaging: Fluoroscopy images are obtained with relatively lower radiation than typical radiography and produce higher noise. With frame averaging fluoroscopy images are averaged in a series with a resultant reduction in noise. The major drawback is reduced temporal function causing an image lag.

Pulsed fluoroscopy: Instead of continuous fluoroscopy, short X-ray pulses are produced to make an image. Exposure times are shortened and blurring is reduced from motion. This tool can be used with highly pulsatile vessels in which motion is high. Low frame rates can be used to further reduce exposure when high temporal resolution is not needed (such as advancing a catheter through a long vessel).

Collimation: Restriction of the field size keeps the angiographer from irradiating tissue that does not need to be imaged. Magnification modes do decrease the field of view but increase the radiation dose significantly.

Automatic brightness control: This function changes the exposure rate as the attenuation of the tissue changes. A thick area such as the mediastinum would require higher settings compared to imaging over the lung which is done automatically with the automatic brightness control.

Selectable automatic brightness control: Some fluoroscopy systems allow the operator reduce the mA and kV if quality is not essential. This will result in higher noise

8 Radiation Protection

There are three main principles of radiation protection: time, distance, and shielding. In addition, personnel whose presence is necessary should only be allowed in the interventional suite. If there is a pediatric patient, restraining devices (physical or chemical) may be used and aid in reducing the radiation exposure.

- A. Time: Simply reducing fluoroscopy time reduces dose to patient as well as to the staff in the room. More experienced physicians are typically able to use less fluoro time for a given procedure. At times work can be performed without continuous fluoroscopy using occasional spot fluoro to verify position.
- B. Distance: Increasing the distance from the source reduces X-ray exposure. The principle is governed by the inverse square law, $x_2 = x_1(d_1/d_2)^2$. This usually applies mostly to accessory staff in the room in avoiding scattered radiation. Dose to the patient can be reduced by increasing the source to object (the patient) distance. The image intensifier is typically close to the patient to reduce geometric blur.
- C. Shielding:

Equipment shielding: Special structural shielding reduces leakage radiation from the X-ray tube. Also, specific organ shielding can be used such as gonadal shielding to protect radiosensitive areas from primary radiation.

Lead aprons: A lead apron is to be worn by everyone working in a room with fluoroscopy running. The weight may limit mobility but the lead is in the form of rubber and provides some flexibility. Awareness of the apron design is important especially if the back is open as the wearer cannot turn his or her back during fluoroscopy. Wrap around designs are also available are useful when the workers back may be exposed. Skirt and vest combinations distribute weight better on hips while decreasing weight on the shoulders. 0.5 mm lead equivalent thickness is typically used and decreases the transmission to 3.2 % at 100 kV.

Thyroid shields: Are typically used to reduce radiation to the thyroid, a relatively more radiosensitive organ. Other adjuncts like lead glasses and protective gloves are used less often.

Portable radiation protection barriers: These barriers generally offer more protection than lead aprons and are placed between the X-ray source and personnel needed in room.

Flat panel detectors: X-ray photons are made into a proportional charge by indirect conversion, from a scintillator, or direct conversion to create an image. The technology allows for an improved dynamic range and reduction in artifact. Also, since there is a higher detective quantum efficiency when compared to traditional detectors, the radiation dose is reduced, especially during high dose procedures.

9 Outcomes

Endovascular and other fluoroscopic procedures have become mainstream and are growing in complexity requiring more fluoroscopic time. These two factors have led to more events of radiation-induced damage to the patient and physician. Radiation damage to the skin requiring reparative plastic surgery has been well documented during endovascular procedures. Cataracts have also been reported among those working with ionizing radiation. More importantly, interventionalists may be unaware that these problems may occur with modern equipment and referring physicians may not associate their patient's injury with a recent fluoroscopic procedure.

Ionizing radiation is an essential tool used in the diagnosis and endovascular treatment of a multitude of diseases but is not without risk. Proper education in fluoroscopy, adjuncts to reduce time, and effects of ionizing radiation can reduce radiation exposure to the patient and angiography staff thus reducing injury.

10 Reality

In general, interventional radiologists have a liberal attitude concerning radiation safety. I have seen too many physicians and hospital workers walk into endovascular suites unprotected stating, "I will be here for only a second" or "I have already had my children." We must

learn from our predecessors as some early interventionalists have experienced the effects of prolonged exposure including early arthritis of the hands and cataracts. While modern equipment significantly reduces our risks I urge all workers in radiation to strictly adhere to ALARA to reduce radiation risks.

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