



Radiation Safety for the Interventional Cardiologist—A Practical Approach to Protecting Ourselves From the Dangers of Ionizing Radiation

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Expert Analysis

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Radiation safety is the concern of all health care providers who perform procedures associated with radiation imaging, whether for diagnostic purposes or therapeutic procedures. Appropriately, there has been increasing public and societal interest in limiting patient radiation. Likewise, laboratory personnel are at risk for radiation compounded by long procedures and multiyear careers using radiation procedures.

Over the years, there have been various equipment modifications. The initial focus was to improve image quality by increasing radiation intensity. However, there is now a greater focus on limiting patient exposure in the setting of often prolonged procedures, such as complex multivessel and chronic total occlusion (CTO) revascularization procedures. X-ray systems are able to provide excellent image quality with lower X-ray exposure.

However, despite these improvements, radiation remains a risk for procedure personnel. Unfortunately, the focus on the complexity and intensity of the procedure itself often overshadows attention to personal optimal "self-radiation" protection. The following article not only describes these risks but also, importantly, enumerates the specific operator and personnel approaches to minimize radiation risk. A review of these preventive strategies is important to re-emphasize the personnel opportunities and responsibilities for radiation protection. Finally, the authors describe some of the

evolving opportunities to more dramatically reduce radiation exposure. This article is an excellent refocus on an important issue for the interventional community.

Ionizing radiation in the form of X-rays is used extensively in the modern cardiac catheterization laboratory. Unlike patients who receive a dose of ionizing radiation during their procedure, interventional cardiologists and cardiac catheterization laboratory personnel are repeatedly exposed to ionizing radiation in the course of their duties. This issue has been magnified with increased exposure in the long duration of structural or complex adult congenital heart disease intervention and CTO cases. Personnel not previously exposed to ionizing radiation such as echocardiographers, ultrasound technologists, cardiac surgeons, and anesthesiologists are frequently close to the X-ray field. Therefore, minimizing radiation exposure is of utmost importance.

Understanding the Hazards

Significant radiation exposure has the potential to impact the health and well-being of interventional cardiologists in the following ways:

- **Brain Tumors:** A case report of brain tumors in 2 Canadian interventional cardiologists¹ first raised this concern. There were three additional cases identified in a study from Sweden in physicians who had worked with fluoroscopy.² The left-sided predisposition of these tumors raised further alarm when four additional cases were reported from France and Israel.³ Active case findings from this group highlighted this concern further when they identified that 22 of 26 cases (85%) had a left-sided distribution of brain tumors, which is a phenomenon that is not noted in the general population.⁴ In a study of 11 cardiologists performing invasive (diagnostic and interventional) procedures, radiation exposure to the outside left side and outside center of the head was significantly greater than the outside right side of the head (106.1 +/- 33.6 and 83.1 +/- 18.9 vs. 50.2 +/- 16.2 mrad, $p < 0.001$). This was significantly attenuated by the usage of a radiation protection cap (42.3 +/- 3.5 and 42.0 +/- 3.0 vs. 41.8 +/- 2.9 mrad) and only slightly higher than ambient control (38.3 +/- 1.2 mrad, $p = 0.046$).⁵
- **Cataracts:** Higher incidence of cataracts (specifically posterior subcapsular) has been reported in interventional cardiologists in a large French multicenter observational study.⁶ Similar results were also noted in a separate study of

both interventional cardiologists and CCL nurses and technicians. Fortunately, this risk appeared to be mitigated in those who wore lead-lined glasses.⁷

- **Thyroid Disease:** Structural and functional changes as a result of radiation exposure have been reported in the thyroid gland. The degree of exposure has been correlated with a linear increase in the development of both benign and malignant thyroid neoplasms.^{8,9}
- **Cardiovascular Effects:** Exposure to radiation has been associated with both macrovascular and microvascular abnormalities. The occupational significance of this is not well-identified presently.¹⁰
- **Reproductive System Effects:** Although exposure to ionizing radiation reduces both sperm count and quality, the occupational effects of this have not been determined.¹¹ A study of 56,436 female radiology technicians in the United States revealed 1,050 cases of breast cancer and concluded that daily low-dose radiation exposure over several years may increase the risk of developing breast cancer.¹² It is concerning that in the small series reported by the "Women in Innovation" group for safety, two cardiologists and one nurse with breast cancer had left-sided tumors.¹³ Radiation safety for the pregnant interventional cardiologist and/or cardiac catheterization laboratory nurse/technician is a pressing issue. US federal law prohibits discrimination against the pregnant worker, but pregnancy should be declared to the employer as early as feasible so that adequate fetal protection can be undertaken. Protective garments must provide at least 0.5 mm lead-equivalent protection throughout the entire pregnancy, and an additional monthly fetal dose-monitoring badge should be issued and worn at waist level under the protective garment.¹⁴

Understanding Adverse Effects of Radiation Exposure

The adverse risks of radiation exposure may be described in terms of **stochastic** and **deterministic** effects.

The **stochastic** effect is the non-threshold biologic effect of radiation that occurs by chance to a population of persons whose probability is proportional to the dose and whose severity is independent of the dose. Developing malignancy due to radiation exposure is a stochastic risk.

The **deterministic** effect is a dose-dependent direct health effect of radiation for which a threshold is believed to exist. Developing a skin burn as a result of a prolonged case is a deterministic effect.

Dose exposure is usually described in terms of the following parameters:

- 1. **Fluoroscopic Time (min):** This is the time during a procedure that fluoroscopy is used but does not include cine acquisition imaging. Therefore, considered alone, it tends to underestimate the total radiation dose received.
- 2. **Cumulative Air Kerma (Gy):** The cumulative air kerma is a measure of X-ray energy delivered to air at the interventional reference point (15 cm from the isocenter in the direction of the focal spot). This measurement has been closely associated with deterministic skin effects.
- 3. **Dose-Area Product (Gy.cm²):** This is the cumulative sum of the instantaneous air kerma and the X-ray field area. This monitors the patient dose burden and is a good indicator of stochastic effects.

The annual occupational dose limits for catheterization laboratory personnel are as follows:

Area	Maximum Dose/Year
Whole body	50 mSv
Eye lens	150 mSV
Skin or extremities	500 mSv
Fetus	0.5 mSv/month or 5 mSv/pregnancy

Tissue Reactions

Radiation-induced hair loss and injuries of the skin and subcutaneous tissues are collectively termed "tissue reactions" and are rare complications of prolonged fluoroscopic procedures. Tissue reactions may be graded; this is influenced by

biological variability. In general, Grade 1 reactions are visible but seldom clinically important, but Grade 2 reactions may be clinically important. Grades 3 and 4 tissue reactions are usually considered to be clinically important.^{15,16}

Notification levels are intended to make the operator aware, during the procedure, of the cumulative radiation used. This happens at 3 Gy. The substantial radiation dose level is a trigger level for certain processes and follow-up measures and happens at 5 Gy. It is not an indicator of a tissue reaction or a predictor of the risk of a stochastic effect but is intended to alert providers to the possibility of a tissue reaction. The following process should be followed when a substantial radiation dose level is reached:

1. At the end of the procedure, the primary operator documents the clinical necessity for exceeding any substantial radiation dose level in the medical record.
2. Patients are promptly informed when substantial amounts of radiation were used for their procedures and the necessity for this.
3. Patients receive follow-up to determine whether tissue reactions occurred.
4. If a tissue reaction is identified, the patient should be referred to an appropriate provider for management. In general, biopsies of these areas must be avoided.
5. These results are reported to and reviewed by the interventional service quality assurance and peer review committees.

Minimizing X-ray Exposure

This is enshrined in the "as low as reasonably achievable" (ALARA) principle. The level of protection should be the best under the prevailing circumstances, maximizing the margin of benefit over harm. Imaging requirements depend on the specific patient and the specific procedure. Although better-than-adequate image quality subjects the patient to additional radiation dose without additional clinical benefit, reducing patient radiation dose to the point at which images are inadequate is counterproductive and results in radiation dose to the patient without any clinical benefit.¹⁷ Using an anthropomorphic phantom, significant differences were identified between different manufacturers in terms of radiation doses in comparable views.¹⁸

Commonly employed strategies to minimize radiation exposure are summarized below and also in Figures 1 and 2.¹⁹

Figure 1

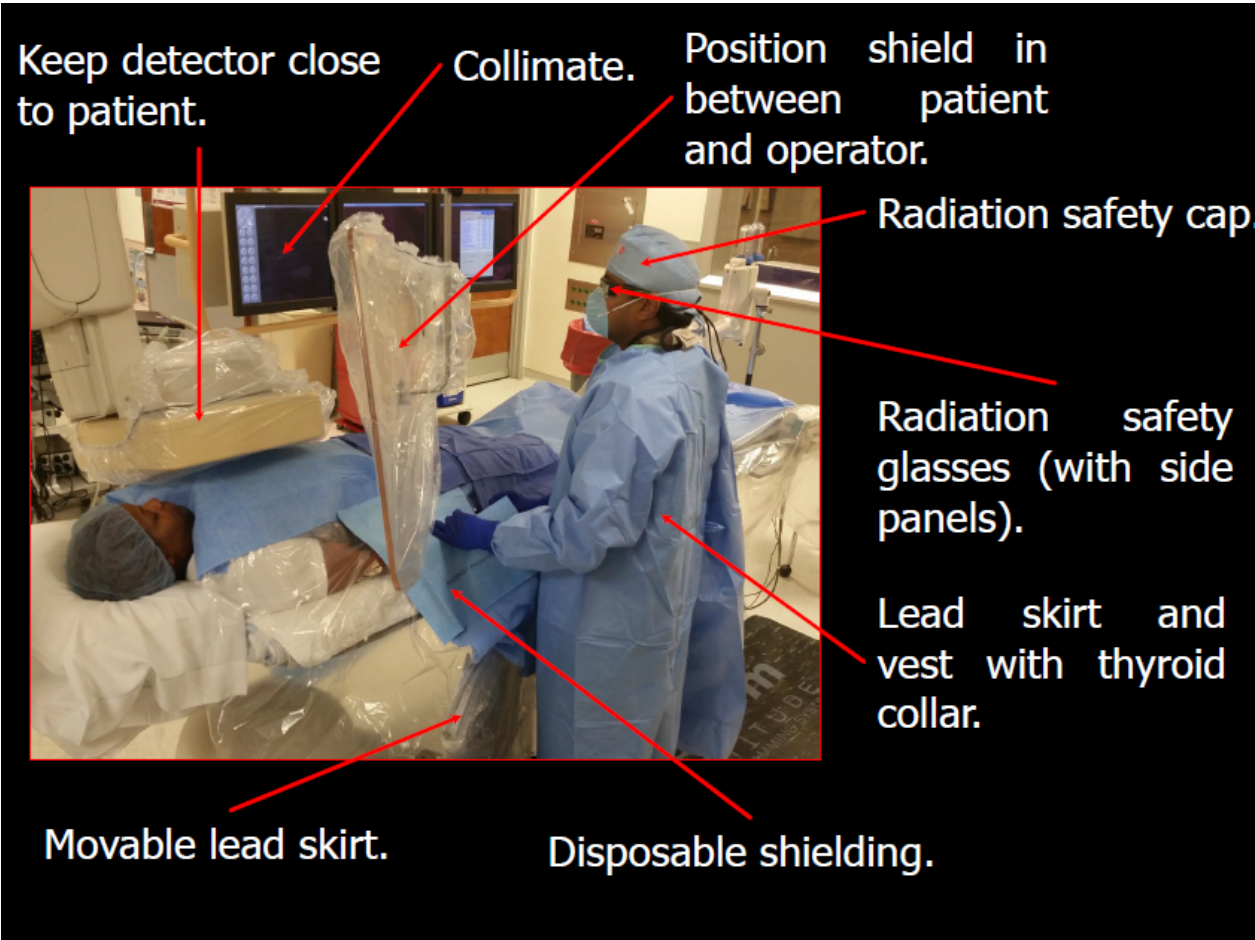
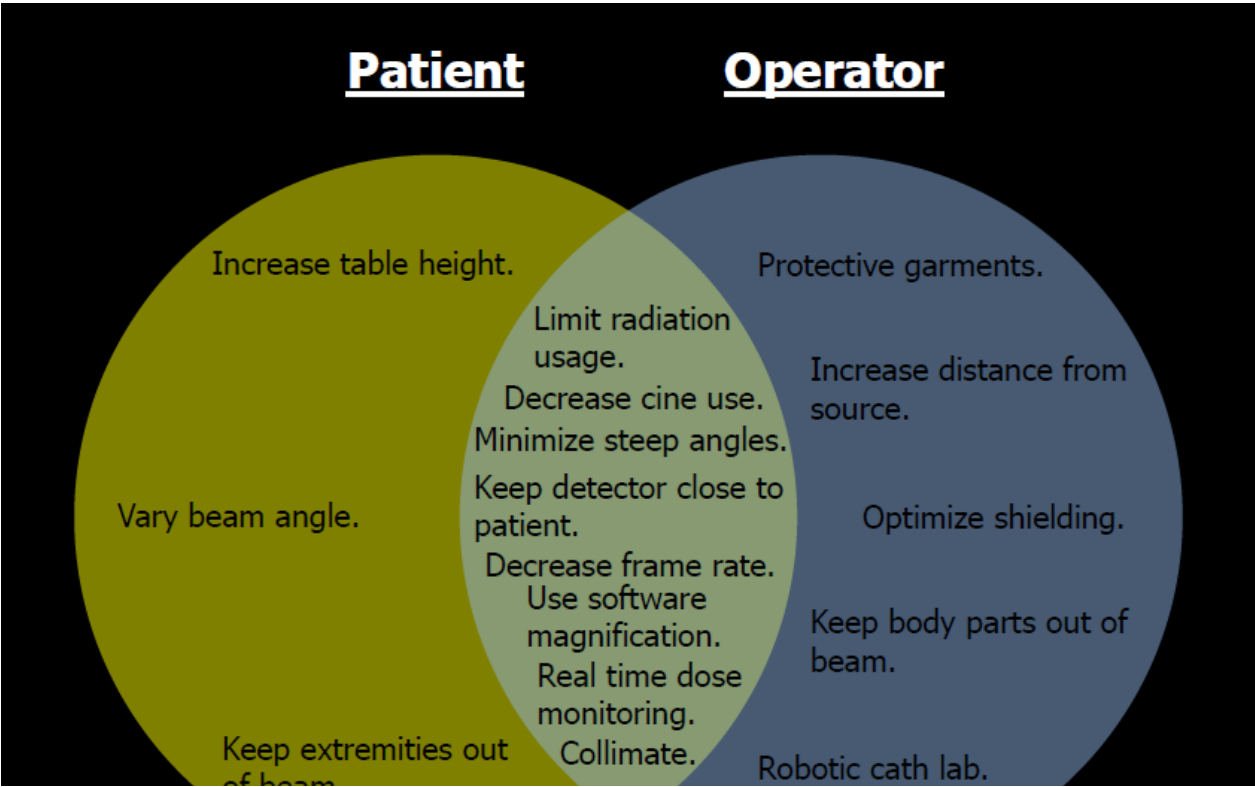


Figure 2





Precautions to Minimize Exposure to Patient and Operator

- Utilize radiation only when imaging is necessary to support clinical care. Avoid allowing the "heavy foot," to step on the fluoroscopy pedal while not looking at the image.
- Minimize use of cine. "Fluoro-save" has a <10% radiation exposure of cineangiography.
- Minimize use of steep angles of X-ray beam. The left anterior oblique (LAO) cranial angulation has the highest degree of scatter exposure to the operator.
- Minimize use of magnification modes. Most modern systems have software magnification algorithms that allow for magnification without additional radiation. In modern machines, there is a "Live Zoom" feature without significant degradation of the image. For example, in lieu of magnification, an 8-inch field of view with a zoom factor of 1.2 results in a 6.7-inch field of view without added radiation.
- Minimize frame rate of fluoroscopy and cine. Ensure that CTOs and other long cases are performed on the 7.5 frames/sec fluoroscopy setting. A reduction of the fluoroscopic pulse rate from 15 frames/sec to 7.5 frames/sec with a fluoroscopic mode to low dose reduces the radiation exposure by 67%.
- Keep the image detector close to the patient (low subject-image distance).
- Utilize collimation to the fullest extent possible. In a room with a peripheral-compatible large flat panel detector, ensure that this is collimated to the field of view adequate for coronary procedures.
- Monitor radiation dose in real time to assess the patient's risk/benefit ratio during the procedure.

Precautions to Specifically Minimize Exposure to Operator

- Use and maintain appropriate protective lead garments. We recommend a full protective suit with thyroid collar and additional head protection. However, 49% of active interventional operators report at least one orthopedic injury.²⁰ Consideration should be given to ceiling suspension or floor-mounted personal radiation shielding for enhancing radiation protection and preventing orthopedic issues. For women, we also suggest additional protection to the

breast with sleeves, which ensure full coverage of this area, in addition to dedicated breast shields. In view of the concern about brain tumors, protective hats are recommended, especially for the primary operator.

- Maximize distance of operator from X-ray source and patient.
- Keep above-table (hanging) and below-table shields in optimal position at all times. A larger ceiling-mounted shield with attached lamellae, used in combination with a drape, decreased exposure to the operator by half.²¹
- Use additional disposable shielding material for protection from scatter radiation.
- Keep all body parts out of the field of view at all times. When it is unavoidable that a body part would be exposed to radiation, consider usage of radiation attenuating gloves (for example, for an echocardiographer imaging during cardiac biopsies) or attenuating cream (for example, for an electrophysiologist attempting to perform device implantation).
- A robotic percutaneous coronary intervention (PCI) system may be considered as a viable alternative for both radiation protection and occupational hazard mitigation because lead shielding need not be worn when seated in the interventional cockpit during PCI procedures.

Precautions to Specifically Minimize Exposure to Patient

- Keep table height as high as comfortably possible for the operator.
- Every 30 minutes, vary the imaging beam angle to minimize exposure to any specific skin area
- Minimizing steep LAO and anteroposterior cranial angles
- Keep the patient's extremities out of the beam.

Conclusion

A radiation safety program is an essential part of the quality administration for the catheterization laboratory. This should be a collaborative effort involving physicians, staff, medical or health physicists, quality assurance personnel, and hospital administration. Interventional cardiologists are an essential part of this process and need to ensure the best possible outcomes for ourselves and for our patients.

As a profession, interventional cardiologists need to be conscious of their own radiation safety. Improved wall hanging or floor-mounted personal shielding and robotic cardiac catheterization laboratories need to become a standard of care and

not a luxury. The high prevalence of orthopedic issues among catheterization laboratory professionals and subsequent disability should prompt governmental oversight agencies like the Occupational Safety and Health Administration to mandate these types of procedures and equipment. We need to continue pursuing research and development of customized radiation safety equipment for peripheral interventions and structural procedures.

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Surgeons, Thyroid Diseases, Thyroid Neoplasms, United States Occupational Safety and Health Administration, X-Rays

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