Procedure- and Patient-Specific Factors Affecting Radiation Exposure

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INTRODUCTION

Image-guided procedures can be both diagnostic and therapeutic. Despite their utility, the effective radiation dose to patients can be quite high. Based on estimates available from the literature and reports to the FDA, the frequency of major radiation injury is likely between 1:10,000 and 1:100,000 fluoroscopy procedures [1].

Radiation dose to the patient is influenced by many factors, such as the nature and complexity of the procedure, patient, prior radiation exposure, operator, and fluoroscopic equipment. In this section, we focus on how the procedure and patient may affect radiation dose.

PROCEDURE-SPECIFIC FACTORS AFFECTING RADIATION DOSE LEVEL

Reference Levels

Compiling reference levels for radiation exposure during fluoroscopy in interventional radiology (IR) is difficult. There can be substantial variation in similar procedures because of patient, operator and equipment-related factors. The largest registry of dose data in the United States is the Radiation Doses in Interventional Radiology Procedures (RAD-IR) study [2,3]. This study contains data on 2,142 procedures, and reference levels were proposed for certain IR procedures (table 1). These reference levels should serve as a general guide. Dogmatic adherence to reference levels fails to take important factors into account.

The goal of all IR procedures is patient care. A low radiation dose may degrade image quality and potentially sacrifice diagnostic and therapeutic capability. At the other extreme, high-dose cases expose patients to the risk of radiation injury. It is important to note, however, that in some circumstances, a planned intervention to achieve a life-preserving outcome may exceed the threshold for deterministic radiation injuries. Prior to cases in which a substantial radiation dose is expected, a discussion of radiation injury should be part of the informed consent process.

Nature and Complexity of Procedure

One of the difficulties in applying reference levels to IR is that the procedures are unique, potentially complex and complications may arise during the course of the procedure. Furthermore, IR procedures are increasingly performed for therapy and, as a result, continue until treatment is completed.

At our institution, it is not uncommon for radiation dose from hepatic tumor embolization to exceed the proposed 1.9 Gy reference level published by the RAD-IR study. Procedure complexity is increased by 1) the size and number of tumors, 2) quantity, caliber and tortuosity of supplying arteries, 3) and associated problems with vascular access.

To mitigate the use of radiation exposure in complex cases, operators should thoroughly review all pre-procedure imaging. Review of cross-sectional imaging can assist in treatment planning, device selection, and, in the case of peripheral arterial disease, may minimize or exclude the necessity of angiography altogether.

In addition, the adjunctive use of ultrasound during fluoroscopic procedures should be used whenever possible. When we compared our institutional database of patient radiation dose to those reported by the RAD-IR study, we noted that cumulative air kerma for nephrostomy and biliary access was lower at our institution, a finding we attributed to our routine use of ultrasound guidance [4].

Optimizing Fluoroscopic Study

Spatial Resolution

There may be moments during a fluoroscopic procedure when high spatial resolution is necessary. Spatial resolution can be improved by using the magnification mode of the image intensifier on most modern flat panel detectors. Magnification almost always results in higher patient radiation dose.

Electronic, geometric and digital techniques are available to magnify the image in fluoroscopy. Electronic magnification occurs within the image intensifier, with most units having three to five magnification modes. Generally, increasing magnification levels results in a decrease to the brightness gain of the image intensifier.

The automatic brightness control algorithms used in analog image intensifiers will compensate by increasing the radiation dose rate by the square of the magnification factor. Thus, if magnification increases by a factor of four, the radiation dose rate increases by a factor of 16. In flat panel systems, the increased dose rate with magnification is typically less [5].

In geometric image magnification, the image receptor is moved further from the patient (increasing scatter radiation) or the patient is moved closer to the source (increasing patient dose). Another factor to consider is that unless a very small focal spot is used (e.g., 0.3 mm), geometric magnification results in a larger penumbra, which can degrade spatial resolution.

Finally, in lieu of geometric and electronic magnification, digital magnification can be used on fluoroscopic images without any additional radiation dose to the patient. This magnification technique, however, can only be applied after image acquisition, and, therefore, is best used as a problem-solving tool.

Similar to other digital media, digital magnification crops a portion of the image and enlarges it to size. When this is performed, image quality (i.e., resolution) decreases, but may still be acceptable depending on the indication for the exam.

Contrast Resolution

Most studies performed in IR utilize some form of contrast (e.g., iodine, carbon dioxide or room air). High-contrast images are optimized by enhancing the sharpness of the edges. This enhancement, however, also increases quantum mottle. The degree of edge enhancement is often set by the manufacturer of the fluoroscopy equipment or medical physicist. In practice, low-contrast images are rarely needed for diagnostic purposes in IR (e.g., vascular access or placement of pleural and intraperitoneal drainage catheters). In these cases, fluoroscopy is used to ensure adequate device position, and fine anatomical detail is unnecessary.

Temporal Resolution

Temporal resolution is the ability to detect that an object has moved over time. IR procedures require varying degrees of temporal resolution. Rapidly dynamic systems, such as the thoracic aorta, will need a higher imaging frequency than more static systems, such as the biliary tree.

During pulsed fluoroscopy, temporal resolution increases with pulse rate assuming constant pulse width. Typical pulse rates on most modern fluoroscopy units range from 3.75 to 30 pulses per second. Pulsed fluoroscopy at the lowest pulse rate should be used to decrease patient dose. In our practice, pulse rates of 7.5 to 15 are generally used for dynamic systems while lower pulse rates are used for relatively static systems.

Compared to continuous fluoroscopy, dose savings to the patient have been calculated to be 49 percent for pulsed fluoroscopy operated at 7.5 frames per second and 80 percent for pulsed fluoroscopy operated at 3.75 frames per second [6].

Table 1: Proposed patient reference levels, not corrected for body habitus, for certain interventional radiologic procedures [7]

Procedure	Reference Dose (Gy)	KAP (Gy cm^2)	Fluoroscopy Time (min)	No. of Images
Transjugular intrahepatic portosystemic shunt creation	3.00	525	60	300
Biliary drainage	1.40	100	30	20
Nephrostomy				
For obstruction	0.40	40	15	12
For stone access	0.70	60	25	14
Pulmonary angiography	0.50	110	10	215
Inferior vena cava filter placement	0.25	60	4	40
Renal or visceral angioplasty				
Without stent	2.00	200	20	210
With stent	2.30	250	30	200
Iliac angioplasty				
Without stent	1.25	250	20	300
With stent	1.90	300	25	350
Bronchial artery embolization	2.00	240	50	450
Hepatic chemoembolization	1.90	400	25	300
Uterine fibroid embolization	3.60	450	36	450
Other tumor embolization	2.60	390	35	325
Gastrointestinal hemorrhage localization and treatment	3.80	520	35	425
Embolization in the head				
For AVM	6.00	550	135	1500
For aneurysm	4.75	360	90	1350
For tumor	6.20	550	200	1700
Vertebroplasty	2.00	120	21	120
Pelvic artery embolization for trauma or tumor	2.50	550	35	550
Embolization in the spine for AVM or tumor	8.00	950	130	1500

Reprinted from Radiology;253(3), Miller DL, Kwon D, Bonavia GH, Reference level for patient doses in interventional radiology: proposed initial values for U.S. practice — Table 3, p760, 2009, with permission from RSNA.

PATIENT-SPECIFIC FACTORS AFFECTING RADIATION DOSE LEVEL

Patient Size

Fluoroscopy is restricted to patients who do not exceed the table weight limit, which varies by manufacturer but is generally 350 pounds. The maximum clearance between the table and image intensifier is approximately 45 cm. For larger patients, radiation dose is severely influenced by the patient's body habitus.

Recall that half value layer is the amount of tissue that will reduce the quantity of X-rays to half the original number. At 60 kV, an increase in patient thickness by 3.5 cm doubles the number of X-rays required to penetrate the patient. It is important to ensure that the protocol selected prior to the procedure, which sets variables such as automatic brightness control and tube current, is appropriate for both the patient and procedure.

Pediatric Patients

The website imagegently.org provides an extensive discussion of fluoroscopy and radiation reduction techniques particular to the pediatric population.

Patient Position

Patient positioning during fluoroscopy is important to visualize anatomy, enhance image quality and optimize patient radiation dose. Radiation exposure is influenced by path through the body. Thus, orientations which yield high dose rates (i.e., tube angulation) should be used only when absolutely necessary.

The post-operative patient is a unique challenge for interventional radiologists. Prone position for a patient following laparotomy may not be feasible. In these cases, patient safety and comfort must be weighed against technical success of the procedure and radiation dose. If a decubitus position is necessary, the same methods to minimize radiation dose apply with the added caveat that the source should be furthest away from the operator.

Patient Cooperation

Patient cooperation is necessary when performing fluoroscopy. Patients are not only expected to remain motionless during the procedure, but also they may be asked to suspend respiration for periods up to 10-20 seconds.

Any patient movement creates motion artifact. To combat this, operators may repeat the imaging or increase the fluoroscopic frame rate, which both increase radiation dose. The patient's ability to cooperate during the exam should be evaluated during the pre-procedure consent with anesthesia consultation, if necessary.

Pregnancy

On occasion, fluoroscopically-guided procedures may be required during pregnancy. A consensus statement was produced by the Society of Interventional Radiology and the Cardiovascular and Interventional Society of Europe regarding radiation management for interventions using fluoroscopic or CT-guidance during pregnancy [8].

As with all medical procedures, the benefits of the fluoroscopically-guided procedure must exceed the potential radiation risks to the patient and fetus. The magnitude of the risk to the fetus is dependent on the fetus' gestational age and the absorbed dose.

Radiation risks are most pronounced during pre-implantation, organogenesis and during the first trimester. Table 2 lists specific radiation effects to the fetus and their corresponding threshold doses. The techniques to reduce radiation dose to the fetus are generally the same radiation reduction techniques used elsewhere. Additional considerations are to consider arm/neck access, decrease tube current (mA)/increase tube voltage (kVp) and use intravascular ultrasound.

Biologic Variation

Some patients are at risk for exaggerated radiation response because of an underlying condition. Prior exposure to high doses of radiation is perhaps the single greatest predictor of radiation injury. Repair of DNA injuries is usually complete by 24 hours, but repair and repopulation of damaged cells may take several months.

During the pre-procedure evaluation, patients should be screened for prior high-dose radiation, location and skin changes. Patients with active skin injury from prior radiation do occasionally require additional fluoroscopy. In this scenario, Balter et al. described the use of solder wire to delineate the area so that fluoroscopy could be avoided [9].

In practice, radiopaque wires, catheters or dilators could also be used. Also, patients with diabetes mellitus, connective tissue disease and homozygosity for ataxia telangiectasia should be informed of an elevated risk of radiation injury [10].

Summary

Radiation injury during fluoroscopic procedures is influenced by many factors, including the procedure and patient. Adequate pre-planning and attention to techniques to minimize radiation dose during the case are integral components of mitigating the risk of radiation injury.

Table 2: Deterministic Radiation Effects at Different Stages of Gestation [8]

Stage of Gestation (wk)	Possible Radiation Effect	Dose Characteristic	Estimated Threshold Dose (mGy)
3–4	Most sensitive period for the induction of embryonic death	Minimum lethal dose (from animal studies)	100–200
4–8	Embryo is also predisposed to the induction of major malformations and growth retardation	Minimum lethal dose (from animal studies)	250 (at 18 d), >500 (at >50 d)
		Minimum dose for growth retardation	200–500
8–15	Most sensitive period for irreversible whole-body growth retardation, microcephaly, and severe mental disability	Minimum dose for growth retardation	250–500
		Threshold for severe mental disability	60–500
		Decrease in IQ can occur at lower doses	~100
		Microcephaly	≥20,000
16-Term	Higher exposures can produce growth retardation and decreased brain size and intellect, although the effects are not as severe as occurs from similar exposures during midgestation	Minimum lethal dose (from animal studies)	>1,500
		Minimum dose for severe mental disability	>1,500
		Decrease in IQ can occur at lower doses	>100

Note.—IQ = intelligence quotient.

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