The AAPM/RSNA Physics Tutorial for Residents

Fluoroscopy: Patient Radiation Exposure Issues[1]

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Fluoroscopic procedures (particularly prolonged interventional procedures) may involve high patient radiation doses. The radiation dose depends on the type of examination, the patient size, the equipment, the technique, and many other factors. The performance of the fluoroscopy system with respect to radiation dose is best characterized by the receptor entrance exposure and skin entrance exposure rates, which should be assessed at regular intervals. Management of patient exposure involves not only measurement of these rates but also clinical monitoring of patient doses. Direct monitoring of patient skin doses during procedures is highly desirable, but current methods still have serious limitations. Skin doses may be reduced by using intermittent exposures, grid removal, last image hold, dose spreading, beam filtration, pulsed fluoroscopy, and other dose reduction techniques. Proper training of fluoroscopic operators, understanding the factors that influence radiation dose, and use of various dose reduction techniques may allow effective management of patient dose.

Abbreviations: DAP = dose-area product, FDA = Food and Drug Administration

Index terms: Dosimetry • Education • Fluoroscopy • Physics • Radiations, exposure to patients and personnel • Radiations, injurious effects • Radiations, measurement

RadioGraphics 2001; 21:1033–1045

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Introduction

Since the early 20th century, fluoroscopy has been integral to the practice of diagnostic radiology. For the most part, fluoroscopic procedures were primarily diagnostic and involved relatively small risks to patients and personnel. However, over the past 10–15 years, fluoroscopic procedure mixes have included an increasing fraction that are primarily therapeutic. Because these procedures are often technically difficult, they can involve total exposure times exceeding an hour or more. The number of prolonged fluoroscopic procedures performed in the United States has increased dramatically over the past 10 years. This phenomenon is partially driven by the preference of managed care to use methods that are less invasive and less costly than surgery. For example, an estimated 300,000 coronary angioplasty procedures were performed in the United States in 1994 (1). It is likely that the current number of procedures has increased by a factor of two or more. A wide range of other fluoroscopically guided procedures, such as neuroembolization, placement of transjugular intrahepatic portosystemic shunts, and pain management, have also shown considerable growth. The nature of these prolonged fluoroscopic procedures has led to an increase in reports of high skin doses causing significant tissue injury.

In response to the problem, the Center for Devices and Radiological Health of the Food and Drug Administration (FDA) issued an advisory in 1994 (2) warning health care facilities of the potential for radiation-induced burns to patients from prolonged fluoroscopic procedures. According to the advisory, a number of interventional procedures (Table 1) have the potential to cause skin injury even when the fluoroscopic time is 1 hour or less at normal dose rates. An insidious aspect of the problem is that onset of injury is delayed and the extent of damage may not be evident until weeks after the procedure. Approximately 50 injuries were reported to the FDA in 1994 alone (1), and since then the FDA has documented many more cases of radiation-induced burns (3). A number of case histories of injuries to both patients (4–7) and physicians (8) have subsequently appeared in the literature; some of the radiation-induced wounds have required skin grafts, resulting in permanent disfigurement. The actual extent of the problem is essentially unknown, since there are currently neither requirements for reporting nor a central repository for this information.

Table 1
Procedures Typically Involving Extended Fluoroscopic Exposure Time

Radio-frequency cardiac catheter ablation
Percutaneous transluminal angioplasty (coronary and other vessels)
Vascular embolization
Stent and filter placement
Thrombolytic and fibrinolytic procedures
Percutaneous transhepatic cholangiography
Endoscopic retrograde cholangiopancreatography
Transjugular intrahepatic portosystemic shunt placement
Percutaneous nephrostomy
Biliary drainage or urinary or biliary stone removal

Source.—Reference 2.

This article examines a number of technical factors and conditions that may lead to such skin injuries. Specific topics discussed include biologic effects of radiation, receptor entrance exposure rates, and skin entrance exposure rates. The article also examines current available patient dose monitoring methods and radiation exposures during various fluoroscopic procedures. The latter part of the article discusses various dose reduction techniques and emphasizes the importance of training for operators of fluoroscopy systems.

Biologic Effects of Radiation

Biologic effects of radiation can be broadly grouped as stochastic or nonstochastic effects. A stochastic effect is one in which the probability of the effect, rather than its severity, increases with dose. Radiation-induced cancer and genetic effects are stochastic. For example, the probability of radiation-induced leukemia is substantially greater after exposure to 1 Gy (100 rad) than after exposure to 1 cGy (1 rad), but there will be no difference in the severity of the disease if it occurs.

Table 2
Skin Effects after Single Radiation Exposure

Effect	Single-Dose Threshold (mGy)	Onset	Peak
Early transient erythema	2,000	Hours	~24 h
Temporary epilation	3,000	~3 wk	· · ·
Main erythema	6,000	~10 d	~2 wk
Permanent epilation	7,000	~3 wk	· · ·
Dermal necrosis	18,000	>10 wk	· · ·
Secondary ulceration	20,000	>6 wk	· · ·

Source.—Reference 9.

Stochastic effects are believed to lack a threshold dose because injury to few cells or even a single cell could theoretically result in production of the effect.

On the other hand, there are other effects for which the probability of causing certain types of harm will be zero at small radiation doses. Above some threshold level, damage will become apparent, with severity increasing as dose rises above the threshold. Such effects are called nonstochastic or deterministic effects. Cataracts, erythema, epilation, and even death are examples of the deterministic effects that can result from high radiation exposures.

Except in the early days of radiology, when precautions were few, the emphasis in radiation safety has been on stochastic effects. The recent popularity of prolonged interventional procedures has added concern about deterministic effects. Since, at diagnostic x-ray energies (eg, those for fluoroscopy, radiography, computed tomography, and angiography), doses are highest at the beam entrance point, the most commonly observed harm has been skin tissue damage and hair loss. Table 2 summarizes some of the skin reactions and their dose thresholds (9).

Modern fluoroscopy systems based on image intensifiers are extremely flexible devices and permit operation in a wide range of modes for dynamic and static imaging. Accompanying this flexibility is the fact that different imaging modes have different dose characteristics, which can make dosimetry a difficult task. Fluoroscopes typically have the capability of operation in a number of dynamic imaging modes: normal fluoroscopy, high-dose fluoroscopy, and conventional and digital cine fluoroscopy. In addition, these systems may record analog or digital static images (eg, conventional photospot images, digital photospot images). The operator should have knowledge of the relative dose characteristics of the different imaging modes, and it is important that these modes be properly configured and maintained during the life of the system.

Although other factors are important, the performance of a fluoroscopy system with respect to radiation dose is best characterized by the receptor entrance exposure rates and skin entrance exposure rates. In addition, exposure rates are dependent on the patient thickness and operational factors; hence, it is becoming increasingly apparent that some sort of dynamic patient dose monitoring is desirable during extended fluoroscopic procedures.

Receptor Entrance Exposure Rates

The receptor entrance exposure rate is arguably the most important dose performance parameter. Receptor entrance exposure measures the effective "speed" of the imaging system, that is, the amount of radiation used in image formation. The receptor entrance exposure is critical because skin dose is dependent on and increases with increasing receptor entrance exposure and because the level of image noise, and thus the perceptibility of low-contrast detail, is also dependent on it. Despite the critical importance of this parameter, there are no regulations limiting receptor entrance exposure rates, although x-ray system manufacturers generally set receptor entrance exposure values to comparable levels for similar imaging modes (10).

Receptor entrance exposure is normally specified as the entrance exposure at the surface of the image receptor (with the grid removed) required to produce a single image for a given x-ray spectrum. In the measurement geometry, the ionization chamber is placed 20–30 cm from the image intensifier surface (with a fixed source-to–image

Table 3
Suggested Receptor Entrance Exposures for Various Fluoroscopic Imaging Modes

Operational Mode	REE* Range (nC/kg)	REE Range (μR)
Normal fluoroscopy†	0.39–0.65	1.5–2.5
High-dose fluoroscopy†	0.77–1.55	3–6
Cine film fluoroscopy‡	2.58–3.87	10–15
Digital angiography‡	12.9–25.8	50–100
Digital subtraction angiography‡	129–258	500–1,000
Screen-film imaging (400 speed)‡	77.4	300

Note.—Values are for an image intensifier with a 23–25-cm field of view without a grid at 80 kVp.
*REE = receptor entrance exposure.
†Per video frame.
‡Per image.

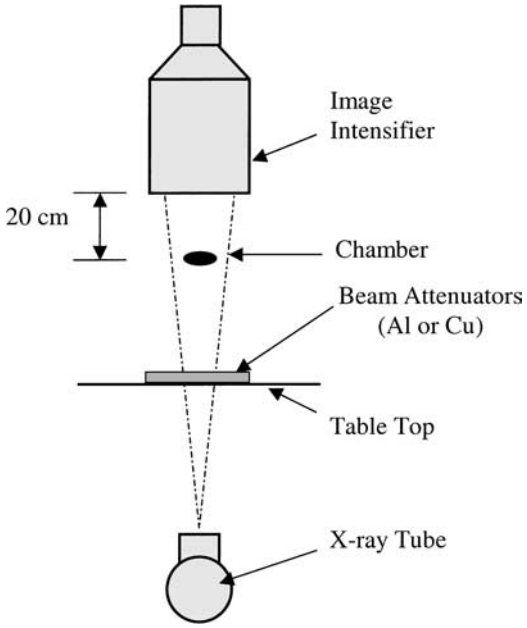

Figure 1. Setup for measuring receptor entrance exposure rates. Constant beam attenuators (aluminum or copper) are placed on the table top or the surface of the collimator (11,12). Measurements are performed by placing the ionization chamber 20 cm from the surface of the image receptor with the grid removed.

intensifier distance of 100 cm) to reduce the backscatter contribution (11) (Fig 1). The exposure rates are corrected to the entrance surface of the image intensifier by using the inverse square law. Receptor entrance exposure rates are measured with the grid removed (12); however, it is often impractical to remove the grid from some systems, in which case the manufacturer-specified grid transmission factor can be used to correct for the presence of the grid (11).

Video fluoroscopy and other dynamic recording modes acquire a series of static images, usually at 25–30 images per second. Expression of receptor entrance exposure on a per-image basis permits comparison of both dynamic and static imaging techniques. Table 3 lists typical receptor entrance exposure values (10,12,13) for an image intensifier with a 23–25-cm field of view at a peak kilovoltage of 80 for different fluoroscopic imaging modes. These values will not be the same for a larger image intensifier (eg, 30- or 40-cm field of view) operated in the 23-cm field of view mode. To give perspective to these values, standard suggested values for different fluoroscopic modes are compared with the equivalent number of radiographs and digital photospot images (13) that can result due to the required receptor entrance exposure rates (Table 4) under the same exposure geometry and kilovolt peak.

Skin Entrance Exposure Rates

The likelihood of deterministic radiation skin injury to a patient is predictable from the skin dose. One can estimate the skin dose to a "typical" adult patient from measurements under simulated conditions (14). This measurement, the skin entrance exposure, quantifies the dose at the beam entrance surface to a patient-simulating medium (17 cm of acrylic with 5 mm of aluminum) on a fluoroscopy system. Typically, skin entrance exposure is measured only to determine its maximum value, which is regulated by various agencies but only in fluoroscopic mode. The skin entrance exposure limitations set by regulatory bodies are 2.58 mC/kg per minute (10 R/min) for normal fluoroscopy and 5.16 mC/kg per minute (20 R/min) for high-dose fluoroscopy. Currently, there are no maximum limitations on other fluoroscopic imaging modes, such as cine and digital subtraction angiography.

The maximum skin entrance exposure value is important, but to obtain a realistic estimate of the level that a patient would receive, a measurement of the average skin entrance exposure is required. Skin entrance exposure values can vary widely with x-ray tube voltage (kilovolt peak) and patient thickness, presence or absence of a grid, source-to-image distance, and so on. As shown in Table 5, an hour of exposure with typical skin entrance exposure rates during normal fluoroscopy and high-dose fluoroscopy can yield a patient entrance exposure of 0.6–3 Gy and 6–12 Gy, respectively. When these values are compared with threshold levels associated with skin injuries

Table 4
Radiographic Equivalencies of Receptor Entrance Exposures for Various Fluoroscopic Imaging Modes

Operational Mode	REE* per Image (nC/kg)	Equivalent No. of Radiographs	
		Film†	Digital Photospot‡
Normal fluoroscopy§ for 1 min	0.52 (2)‖	12	36
High-dose fluoroscopy§ for 1 min	1.55 (6)‖	36	108
Cine fluoroscopy§ run for 1 min	3.87 (15)‖	90	270
Digital subtraction angiography#	258 (1,000)‖	333	1,000

*REE = receptor entrance exposure.
†Film images (400-speed) with an REE of 77.4 nC/kg (300 μR) per image.
‡Digital photospot images with an REE of 25.8 nC/kg (100 μR) per frame.
§Frame rate of 30 frames per second.
‖Numbers in parentheses are values in conventional units (microroentgens).
#Ten runs at 10 images per run.

Table 5
Typical Skin Entrance Exposure Rates

Operational Mode	SEE* Rate (mGy/min)	SEE after 1 hour (Gy)
Normal fluoroscopy	10–50 (1–5)†	0.6–3
High-dose fluoroscopy	100–200 (10–20)†	6–12

Note.—For diagnostic energies, 2.58×10^{-5} C/kg ≅ 1 mGy ≅ 1 mSv.
*SEE = skin entrance exposure.
†Numbers in parentheses are values in conventional units (rads per minute).

(Table 2), it is clear that the potential exists for skin injuries during prolonged fluoroscopic procedures.

The proper management of patient exposure during fluoroscopic procedures involves not only measurement of skin entrance exposure and receptor entrance exposure rates but also clinical monitoring of doses. Ongoing monitoring allows management of image quality, of radiation risk to patients and operators, and of changes in the operational performance of the equipment over time.

Patient Dose Monitoring Methods

Average skin entrance exposure measurements can provide an estimate of the skin entrance exposure to a typical patient, and one can use receptor entrance exposure measurements to scale doses from the different imaging modes. For example, one can multiply recorded fluoroscopy time with typical skin entrance exposure values to obtain a rough estimate of skin dose. The estimate can be improved to some extent by recording the average kilovolt peak and tube current (milliamperage) for the patient and appropriate scaling of the skin entrance exposure. This technique has been commonly reported in research surveys (15–18) but in practice is subject to considerable error. Even if parameters are correctly recorded, variations in patient size, imaging modes, and other factors make these estimates less reliable. This method provides a rough estimation of patient dose for very simple procedures but can be misleading if multiple views are involved, as is the case in any standard fluoroscopic examination. In such cases, this method can produce either an underestimate or overestimate of the patient skin dose. Real interventional procedures are often complex and may involve dynamic changes in field size, geometry, position, kilovolt peak, imaging mode, and so on; moreover, few patients are really "average" in size. In reality, the clinician has no idea of skin dose and cannot tell when doses are reaching harmful levels.

There are currently a number of methods available by which one can estimate or measure patient skin dose; they may be classified as direct or indirect methods. Direct methods involve measurement of skin dose during the procedure by using one of several types of small dosimeters taped to the patient's skin. Indirect methods involve calculation of skin dose from measurements in the beam or from operational factors that affect dose.

Direct Methods

The direct method of skin dose estimation involves use of small detectors placed on the patient's skin at the beam entrance location. Several types of detectors have been used, including thermoluminescent dosimeters (TLDs), photographic

films (16–19), and, more recently, diodes or metal-oxide semiconductor field-effect transistor (MOSFET) detectors. Use of a TLD is potentially the most accurate way of determining actual skin dose, but results can be very inaccurate because it is often impossible to know exactly where on the skin the peak dose will occur in a given procedure. Use of an array of dosimeters can reduce uncertainty, but this strategy is not always practical. With single dosimeters, considerable care is required to correctly place the dosimeter and to ensure that it is not moved from the field during the procedure. The method requires that the entrance field be known a priori, and, since the x-ray source is usually located beneath the patient table, it requires the patient to lie directly on the detector during the procedure.

Photographic films have several advantages such as low cost, an easy-to-locate high-dose region, and dose measurement by using densitometers. However, there are only a few films available in large sizes that have the sensitivity to measure several ranges of doses. MOSFET detectors have the advantage of providing a dynamic reading of the skin dose as it accumulates during the procedure, but some physicians find them to be objectionable due to the visibility of the detector elements and connecting leads in the image field. Although TLDs are essentially invisible, they are read out after the procedure and cannot provide a dynamic display of dose during the procedure.

Indirect Methods

The most convenient and widely used method for indirect monitoring is the dose-area product (DAP) meter. The DAP meter uses a transmission type air-ionization chamber mounted on the face of the x-ray tube collimator, which integrates exposure over the entire image field. The DAP measurement is a function of the x-ray field size and the x-ray exposure at the collimator; thus, the measurement is expressed as either the dose-area product or the air-kerma-area product (20–24). The measured DAP is independent of distance from the focal spot. The distance factor cancels because the exposure rate varies inversely and the x-ray field area varies inversely as the square of the distance from the focal spot to the point of measurement. A given DAP reading can result from a high dose over a small field or a low dose over a large field. The stochastic risk can be roughly assumed to be equivalent under these two conditions; thus, DAP meters have been used to estimate total stochastic risk for latent effects (14,15). Unfortunately, a high dose over a small field is not equivalent to a low dose over a large field in terms of skin damage; hence, the DAP reading requires some interpretation.

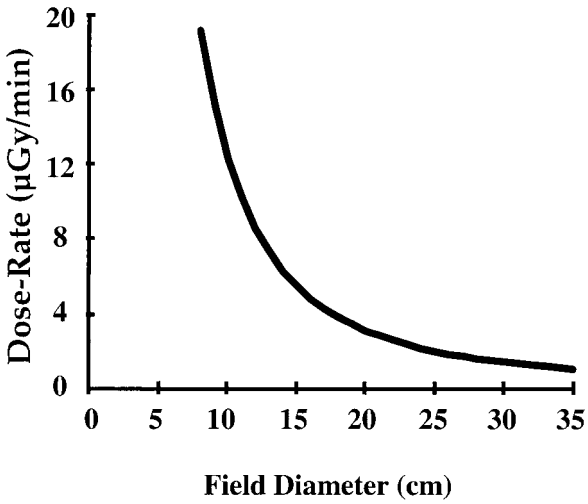

Figure 2. Computed dose rate for a constant DAP reading as a function of field diameter.

Skin entrance dose can be computed from DAP readings only at a specific dose rate and field size. For example, if a 1-minute fluoroscopic procedure produces a DAP reading of 2,000 $\mu Gy \cdot cm^2$, this result could be obtained with a 20 × 20-cm field at 5 μGy/min or a 10 × 10-cm field at 20 μGy/min, a factor of four difference in skin dose. When magnification mode is selected, the input field size is reduced, which results in decreased brightness. The automatic brightness stabilizers on many systems then respond by increasing the x-ray dose to maintain constant image brightness. This process can produce a static DAP reading (Fig 2), even though the skin dose rate scales by a factor of two or more. In situations where dose rate and field size are changing dynamically, accurate estimation of skin dose from DAP readings may be problematic.

Despite these limitations, many modern fluoroscopy systems installed for interventional applications incorporate a DAP meter. Conceivably, DAP meters could be installed in fluoroscopy systems with field size software corrections to aid in estimation of skin doses during different imaging modes, although such a system is not yet available. At present, DAP meters are widely used in Europe; however, in my experience, DAP meters are often ignored by U.S. clinicians due to difficulty in converting readings to an estimate of entrance skin dose.

There is at least one system available that will dynamically record and display an estimate of total skin entrance exposure. This product is based on the fact that skin dose can be predicted from operational factors. This device, currently marketed under the name PEMNET (Clinical Microsystems, Arlington, Va), measures peak

Table 6
Radiation Exposures during Diagnostic Procedures

Procedure	Mean Fluoroscopic Exposure Time (min)	Mean Entrance Skin Dose (mGy)*
Barium enema study (18)	3.3 (<1–5)	44 (23–59)
Barium swallow study (18)	3.8 (2.5–6.1)	66 (41–150)
Renal angiography (20,21)	5.1 (2.9–7.6)	100 (80–220)
Cerebral angiography (20,21)	12.1 (2.9–36)	220 (60–590)
Hepatic angiography (20,21)	12.1 (3.6–42)	340 (100–580)
Percutaneous transhepatic cholangiography (20,21)	14.6 (2.9–44)	210 (30–520)

Note.—Numbers in parentheses are ranges.
*10 mGy = 1 rad.

Table 7
Radiation Exposures during Interventional Procedures

Procedure	Mean Fluoroscopic Exposure Time (min)	Mean Entrance Skin Dose (mGy)*
Nephrostomy (20,21)	7.0 (1.3–21)	110 (<1–410)
Insertion or removal of biliary stent (20,21)	7.1 (0.6–26)	110 (10–370)
Endoscopic retrograde cholangiopancreatography (17)	13.6 (2–63)	80 (2–730)
Cerebral embolization (20,21)	34.1 (15–56)	340 (190–660)

Note.—Numbers in parentheses are ranges.
*10 mGy = 1 rad.

kilovoltage, tube current (milliamperage), and exposure time signals from the x-ray generator to dynamically compute and display an estimate of the skin entrance dose based on calibration of radiation output as a function of these parameters (25,26). Some versions have the capability to compensate for attenuation by the table and adjust for oblique angles (26) while providing skin entrance exposure at known distances. However, these systems share a limitation with DAP meters in that dose estimates do not take into account overlapping beams from several sources. The source-to–skin entrance distance is a major uncertainty in the estimate, but some versions incorporate a proximity detector to measure this parameter during the procedure. The complexity of installation required for calibration has hindered widespread use of the system, although it has considerable potential.

Recent reviews by Geise and O'Dea (16) and Strauss (10) have examined the features of currently available skin dosimetry methods and have concluded that currently there is no perfect dose monitoring system for complex interventional procedures.

Patient Doses for Typical Fluoroscopic Procedures

Patient doses depend on a number of factors such as machine factors; age, size, and body composition of the patient; and user setup, such as collimation, source-to-skin distance, and so on. The dose rate to the patient is greatest at the skin where the x-ray beam enters the patient. The typical fluoroscopic entrance exposure rate for a medium-sized adult is approximately 30 mGy/min (3 rad/min) (since 10 mGy = 1 rad) but is typically higher in image-recording modes. A number of studies have reported patient doses during diagnostic and interventional procedures (17–24,27–29). Table 6 lists entrance skin doses for a number of diagnostic procedures, in which the fluoroscopic time typically ranges from ~3 to 15 minutes (18,20,21) with entrance skin dose ranging from 44 to 340 mGy (4.4–34 rad). Doses for the more complex interventional procedures are listed in Table 7. Diagnostic procedures

Table 8
Radiation Exposures during Coronary Angiography and PTCA (27)

Parameter	Coronary Angiography (Diagnostic)	PTCA (Interventional)
Fluoroscopic time (min)	4.5 (2.9, 8.2)	21.9 (14.4, 33.2)
Cine time (min)	0.7 (0.5, 0.9)	1.4 (1.1, 2.0)
Fluoroscopic exposure (mGy)	290 (170, 510)	1,880 (1,150, 2,900)
Cine exposure (mGy)	950 (600, 1,340)	1,740 (1,130, 2,530)
Total exposure (mGy)	1,350 (900, 1,910)	3,760 (2,400, 5,560)

Note.—Results are presented as medians and interquartile intervals (within parentheses). PTCA = percutaneous transluminal coronary angioplasty.

Table 9
Radiation Exposures during Radio-Frequency Catheter Ablation (15)

Parameter	Female Patients	Male Patients
Fluoroscopic time (min)	42 ± 36	59 ± 54
Estimated dose rate (mGy/min)	31 ± 19	35 ± 18
Estimated entrance skin dose (mGy)	1,200 ± 1,200	1,800 ± 1,800

performed under fluoroscopic control have significantly shorter fluoroscopic times and lower entrance skin doses compared with those of interventional procedures. Mean fluoroscopic times for interventional procedures are significantly longer (17,20,21).

This point is well demonstrated by Cusma et al (27), who performed real-time measurement of radiation exposure to patients undergoing diagnostic and interventional procedures using the PEMNET system. These authors found significant differences in average fluoroscopic exposure times between diagnostic and interventional procedures: 4.7 minutes versus 21.0 minutes. Correspondingly, the median exposures for diagnostic and interventional procedures were 1,350 mGy (135 rad) and 3,760 mGy (376 rad), respectively (Table 8). During coronary angiography, multiple views are used compared with fewer views during percutaneous transluminal coronary angioplasty procedures; hence, the dose appears higher than those reported previously (28,29). Also, the results are higher due to real-time exposure measurements and adjustments made for different angulations and projections.

O'Dea et al (26) presented skin dose data obtained with the PEMNET system from more than 500 interventional neurologic radiology procedures. They examined the data for the probability of specific types of procedures causing skin doses greater than levels recommended for monitoring (>1 Gy) or implicated in radiation-induced skin damage (>2 Gy) (2). Six percent of embolization procedures and 1% of cerebral angiographic studies were estimated to have potential for main erythema (entrance skin dose >6 Gy). Rosenthal et al (15) estimated radiation exposure during radiofrequency catheter ablation procedures using recorded fluoroscopic time and radiation output measurements. This study involved more than 750 patients from nine centers. Recorded fluoroscopic times averaged 53 minutes with a very large variation (standard deviation = ±50 minutes). Estimated skin doses were 1,300 mGy ± 1,300 (130 rad ± 130) (Table 9) and indicated that the dose threshold for radiation skin injury (~2 Gy) was exceeded in 22% of procedures.

Dose Reduction Techniques

There are a variety of ways to limit skin doses during protracted interventional procedures; some are methodological and some involve taking advantage of technical features present in modern equipment.

Intermittent Fluoroscopy

Most radiologists are trained to control the fluoroscope intermittently, that is, keeping the x rays on only a few seconds at a time, long enough to view the current catheter position. Judicious use of the method can reduce total fluoroscopic times considerably. This simple technique is particularly effective when combined with last image hold features.

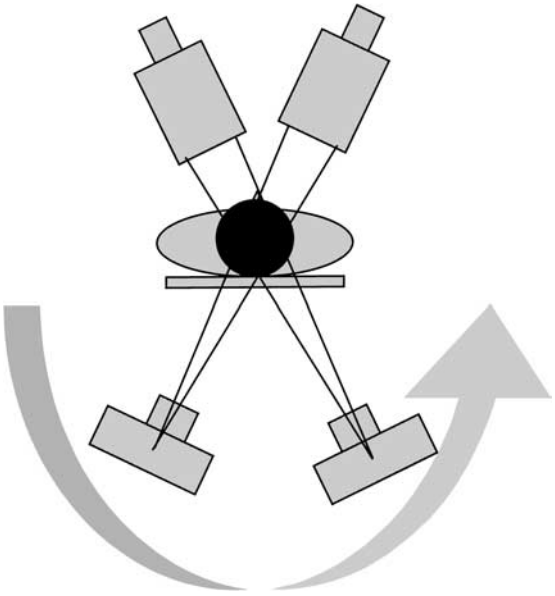

Figure 3. Effect of dose spreading by varying the beam incidence angle. The maximum dose thus tends to be spread over a broader area of the patient's skin.

Removal of Grid

The presence of grids in x-ray systems primarily increases the contrast and hence the image quality; however, they increase the dose to the patient and staff by a factor of two or more. Studies have shown that, especially in pediatric cases, removal of the grid has resulted in dose reduction of up to one-third to one-half with little or no degradations in contrast and image quality (30,31). Grids should be used with discretion when fluoroscopic examinations are performed on children, and the systems for such examinations should have the capability for easy removal and reintroduction of the grid.

Last Image Hold and Electronic Collimation

A useful feature on many modern fluoroscopy systems is last image hold, whereby the last image is digitally "frozen" on the monitor after x-ray exposure is terminated. Last image hold is a dose-saving feature (32), since it allows physicians to contemplate the last image and plan the next move without additional radiation exposure in an interventional procedure. In addition, some modern systems have electronic collimation, which overlays a collimator blade on the last image hold so that one can adjust field dimensions without exposing the patient.

Dose Spreading

In most interventional fluoroscopic procedures, the bulk of the fluoroscopic time is spent at a particular anatomic region during the procedure. For example, in radio-frequency ablation procedures, the fluoroscope is used to guide the catheter from the femoral artery to the heart but thereafter remains over the heart region. Some reduction of maximum skin dose can be achieved by periodically rotating the fluoroscope about a center within the anatomy of interest. This method tends to spread the maximum dose over a broader area of the patient's skin so that no single region receives the entire dose (Fig 3).

Adjustment of Beam Quality

Beam energy primarily depends on the peak kilovoltage selected and the amount of filtration in the beam. Selection of higher kilovolt peaks increases the average beam energy of the x rays (beam hardening) and therefore the fraction of the entrance beam that passes through to the image receptor. For a fixed receptor entrance exposure, the skin entrance dose varies inversely with the kilovolt peak, more precisely as $(kVp)^3$. The worst case is with a thick patient and a low kilovolt peak. The drawback of using a high-energy beam is some loss of image contrast. It has been shown that the loss in image contrast resulting from increasing the kilovolt peak from 60 to 70 is not significant, whereas the corresponding decrease in skin entrance dose is substantial (eg, about 30%). Maintaining the highest peak kilovoltage that will provide acceptable image contrast leads to lower skin dose.

Substantial reductions in skin dose are also achieved by inserting appropriate metal filters (aluminum, copper, or other materials) into the beam at the collimator. Filtration reduces skin dose by preferentially removing lower-energy photons, which would not penetrate the patient to contribute to the image. Nicholson et al (33) have shown that the addition of 0.1–0.3 mm of copper reduced the skin dose by 30%–50%. In general, if optional filters have been designed into the fluoroscopy system (eg, Carefilters [Siemens Medical Systems, Iselin, NJ] and Spectrabeam [Philips Medical Systems, Shelton, Conn]), they should be used for all lengthy or repeated examinations provided the image quality is diagnostically acceptable.

Image Magnification

The ability to create magnified images can be clinically very useful but in almost all cases results in a higher patient dose. There are two basic ways to magnify the image in fluoroscopy: geometric and electronic. Geometric magnification takes

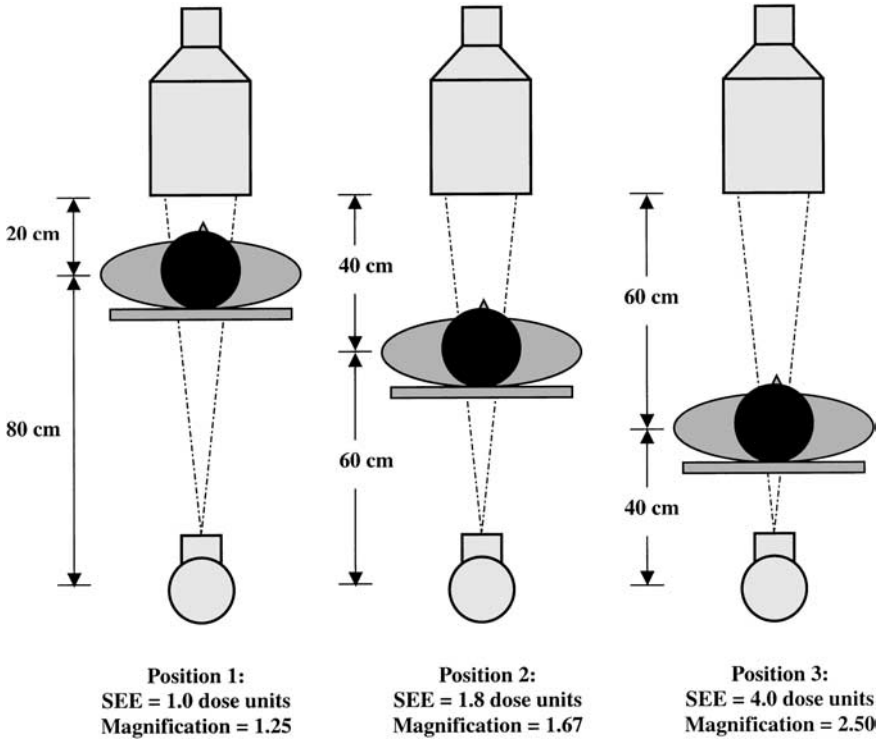

Figure 4. Effect of geometric magnification on entrance skin dose. With fixed source-to–image receptor distance, both magnification and skin entrance exposure (*SEE*) increase as the patient is moved closer to the x-ray source.

advantage of the diverging x-ray beam to project a smaller region in the patient to a larger area on the image intensifier. When source-to–image receptor distance is fixed, both image magnification and skin dose increase as the patient is moved closer to the x-ray source (Fig 4). Many interventional system fluoroscopes do not fix the source-to–image receptor distance, and the positions of the tube and the receptor can both be changed independently. Thus, moving the source closer to the patient or the receptor further away can magnify the image. Also, there is increased penumbra (focal spot blur) with higher magnification, and unless a very small focal spot is used (eg, 0.3 mm), the spatial resolution is degraded. It is generally best to minimize geometric magnification in prolonged procedures by keeping the image receptor close to the patient and the source away.

Most modern fluoroscopes can also magnify the image electronically within the image intensifier. Systems typically have at least three and sometimes as many as five electronic magnification modes, each with a unique dose level. Usually, dose increases with greater electronic magnification. One rule of thumb is that the radiation dose to the patient increases by the square of the ratio of the image intensifier diameters (Fig 5). For example, if the entrance skin exposure is 100 units for a 23-cm field of view, the radiation entrance dose increases to 235 units when the field

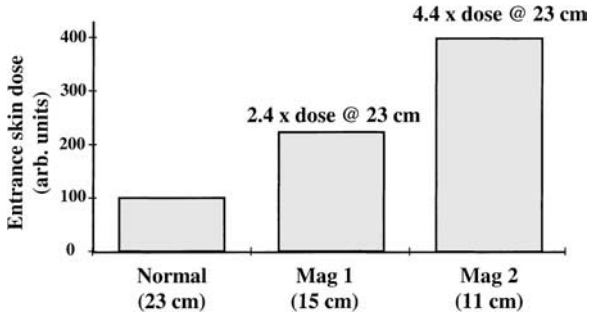

Figure 5. Effect of electronic magnification on entrance skin dose. The radiation dose increases by the square of the ratio of the image intensifier diameters. *arb* = arbitrary, *Mag* = magnification.

of view is reduced to 15 cm $(23/15)^2$ and to 440 units for a field of view of 11 cm $(23/11)^2$.

Dose Level Settings

Within each magnification mode, most fluoroscope manufacturers also provide more than one dose level. A typical configuration by one manufacturer is to provide three settings—low, medium, and high—with the dose being half or twice the medium level at the low and high settings, respectively. Generally, one should use the medium dose setting for most work. The low dose setting tends to produce a very noisy image, and the high dose setting should be used rarely when viewing very low contrast information since the image noise is diminished. Some systems are also equipped with a "high-dose fluoroscopy" mode, which for regulatory reasons produces a continu-

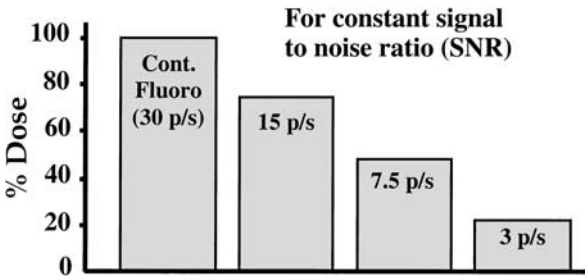

Figure 6. Effect of pulsed fluoroscopy on entrance skin dose. For example, by switching from continuous fluoroscopy (*Cont Fluoro*) mode to 15 pulses per second, dose savings of nearly 22% are achieved (34).

ous warning tone when engaged. This capability is equivalent to the high dose setting but also permits the maximum skin dose (5.16 mC/kg per minute) to reach twice that of normal fluoroscopy levels (2.58 mC/kg per minute). This type of mode should be used carefully and should be necessary only with very thick patients or body regions.

Pulsed Fluoroscopy

Some modern fluoroscopes have the capability of pulsed fluoroscopy, whereby the x-ray beam is emitted as a series of short pulses rather than continuously. At reduced frame rates, pulsed fluoroscopy can provide substantial dose savings. Images may be acquired at 15 frames per second rather than the usual 30 frames per second. Each image is displayed multiple times in sequence to provide a 30 frames per second display. Pulsed fluoroscopy can also be performed at even lower frame rates (eg, 7.5 or 3 frames per second) at the expense of a "choppy" display when imaging rapidly moving regions like the heart.

Because simply reducing the number of pulses would result in an increase in image noise, manufacturers may increase the milliamperage setting to achieve a similar visual appearance. For example, one would expect a 50% dose reduction when going from 30 to 15 frames per second, but, because of increased milliamperage, the actual dose savings are 25%–28% (Fig 6). With equivalent perceptibility levels, Aufrichtig et al (34) showed average dose savings of 22%, 38%, and 49% at 15, 10, and 7.5 frames per second, respectively. When operating at lower frame rates and higher magnification (decreased field of view), some systems open the television camera aperture instead of increasing the exposure to maintain similar image brightness. Pulsed fluoroscopy has a great advantage as long as the radiation exposure is lower at lower frame rates. If the tube current is set too high to achieve better-quality images, the entire advantage of pulsed operation is defeated and there may be no actual dose savings.

Training of Fluoroscopic Operators

With the dramatic increase in fluoroscopy use in medicine and advances in technology, it becomes critical for fluoroscopy users to have specialized training in proper use of radiation. It is necessary to develop procedures for managing safe use of radiation to ensure that both patients and personnel are not exposed to excessive radiation levels (3,35). The need for adequate training was emphasized in the 1994 FDA health advisory (2). Specifically, the advisory suggested that fluoroscopic operators should understand system operation, including the implications for radiation exposure of each operational mode.

To date, there are no uniform national standards regarding who may operate fluoroscopy systems or what minimum training they should have (3,36). All resident physicians undergo a credentialing process that involves verification and assessment of their qualifications to ensure that they are appropriately trained to perform clinical procedures with technical proficiency and henceforth grant clinical privileges (3,36). However, none of the credentialing processes mandate that resident physicians, especially those who work with radiation, learn about radiation management in fluoroscopic procedures (36). Except for radiologists and nuclear medicine specialists, most physicians receive minimal to no training in the safe use of ionizing radiation during their residency program. In addition, except for a few boards such as the American Board of Radiology, American Board of Nuclear Medicine, and Royal College of Physicians and Surgeons of Canada (diagnostic radiology), no other medical specialty board includes radiation in the curriculum (36). However, there have been positive developments, as seen in the position statements taken by some prominent organizations such as the American College of Cardiology (37) and American Heart Association (38), strongly advocating education of fluoroscopy users. For example, the American College of Cardiology consensus document, "Radiation Safety in the Practice of Cardiology" (37), clearly stresses the importance of radiation safety and education for everyone using fluoroscopy.

Some state regulations include mandatory education and training in the safe use of x rays. Even if this is not required by law, it is to the advantage of a facility to establish minimum requirements for the safe use of fluoroscopic equipment for all physicians performing fluoroscopy, particularly those performing prolonged interventional procedures. Any training or credentialing process

should include education on radiation safety issues, proper use of fluoroscopic equipment, and control settings (35). In addition, biologic effects of radiation with emphasis on deterministic effects should be discussed along with detailed discussions on dose-reducing techniques. The training or credentialing process can be achieved by means of World Wide Web–based short courses, workshops, or tutorials with tests (39,40); by adding study materials to respective board curricula; or by developing institution-based courses. There are a number of sources, such as medical physics textbooks, AAPM reports (35), and medical literature in radiographic physics series, that can help a facility establish a program to train or credential their physicians using fluoroscopy to obtain minimal competency in terms of the safe use of radiation. Enlisting a qualified medical physicist to assist in training fluoroscopy users, as recommended in the FDA advisory (2), can be of great advantage to the facility.

Conclusions

With the increased proliferation of fluoroscopy in modern medicine, it is important to effectively manage radiation exposure by properly setting the fluoroscopy system. A number of factors influence patient radiation dose during fluoroscopic procedures. By understanding the factors that affect patient doses, clinicians can help keep doses as low as possible without compromising image quality or the efficacy of interventional procedures. Direct monitoring of patient skin doses during procedures is highly desirable, but current methods still have serious limitations. Effective management of radiation exposures by proper use of equipment, adequate training of fluoroscopic operators, and frequent quality control can contribute to an overall reduction in patient and personnel exposures.

Acknowledgments: The author thanks Thomas J. Beck, ScD, for useful discussions during the preparation of the manuscript and the presentation at the 1999 RSNA/AAPM Physics Tutorial for Residents.

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