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HANDBOOK OF FLUOROSCOPY SAFETY

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HANDBOOK OF FLUOROSCOPY SAFETY FOR PHYSICIANS

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Introduction

Fluoroscopically-guided procedures are an integral part of healthcare throughout the United States. Fluoroscopes are used by many services in medical facilities in areas, such as, but not limited to, interventional radiology, cardiology, radiation oncology, orthopedic surgery, vascular surgery, gastroenterology, anesthesiology, podiatry, and urology. Fluoroscopically-guided procedures have become increasingly common, a reflection of their diagnostic and therapeutic power. In general, fluoroscopy improves safety, for example by shortening anesthesia time and hospital length of stay. However, when used improperly, fluoroscopes can cause skin burns, non-healing ulcers, and cataracts. Radiation is also known to increase the risk of cancer. The amount of radiation delivered to the patient, and to the fluoroscope operator, depends heavily on technique and fluoroscope settings. This handbook is designed to help operators minimize the amount of radiation in a fluoroscopy procedure, thereby reducing the risk of tissue injury and cancer.

Rationale for Safety Training

Fluoroscopic procedures of high complexity and duration have become increasingly common, resulting in higher radiation doses to patients and staff. These complex interventional procedures are being performed by a spectrum of physicians who may not have received formal fluoroscopic safety training in their residency or fellowship programs. Physicians may not be aware of the options available on a fluoroscope or how selection of these options affects the radiation dose. As of January 1st, 2019, the Joint Commission requires annual training for fluoroscopy operators.

Radiation-Induced Injuries

An increasing number of reported injuries to patients resulting from fluoroscopic procedures prompted Wagner, Eifel, and Geise to publish an article in 1994 entitled "Potential Effects Following High X-Ray Dose Interventional Procedures." The U.S. Food and Drug Administration (FDA) issued a Public Health Advisory in September 1994 that referenced this article and detailed the types of procedures and doses most often associated with injuries. The procedures listed were complicated interventions, including percutaneous transluminal angioplasties, vascular embolizations, radiofrequency cardiac catheter ablations, transjugular intrahepatic portosystemic shunt creations, and complex urinary and biliary procedures. This advisory urged physicians to be aware of the risks and to take steps to minimize the risk of injury.

Physicians performing these procedures should be aware of the potential for serious, radiation-induced skin injury caused by long periods of fluoroscopy during these procedures. It is important to note that the onset of these injuries is usually delayed, so that the physician cannot discern the damage by observing the patient immediately after the treatment. The FDA has continued to issue advisories and guidance on fluoroscopy safety.

The Need for Training

In the same 1994 Public Health Advisory, FDA recommended that facilities establish protocols and standards for each type of fluoroscopic procedure they use. FDA made these specific recommendations for physicians:

- Identify threshold doses for various injuries.
- Document information in patient charts which would permit the estimation of absorbed dose to the skin.
- Advise patients to report signs or symptoms of injury to their attending physicians.

Also, in response to the increase in reports of injuries, many professional societies, accreditation organizations, advisory bodies, federal agencies, and state legislatures called for improved training for physicians who perform or direct others in fluoroscopic procedures. Today, formal training is required by an increasing number of hospitals including those accredited by the Joint Commission.

Hospital Fluoroscopy Policy

IU Health Policy 8.4.05, "Documentation and Management of Elevated Radiation Exposure from Fluoroscopic Procedures" is available on the Team Portal website. Be sure to review this policy thoroughly when working at Indianapolis IU Health locations. When working at other locations such as Eskenazi Health or the Richard L. Roudebush Veterans Affairs Medical Center, review their respective policies as well. A summary of required actions based on air kerma is provided below.

REQUIRED ACTIONS BASED ON DISPLAYED AIR KERMA VALUE

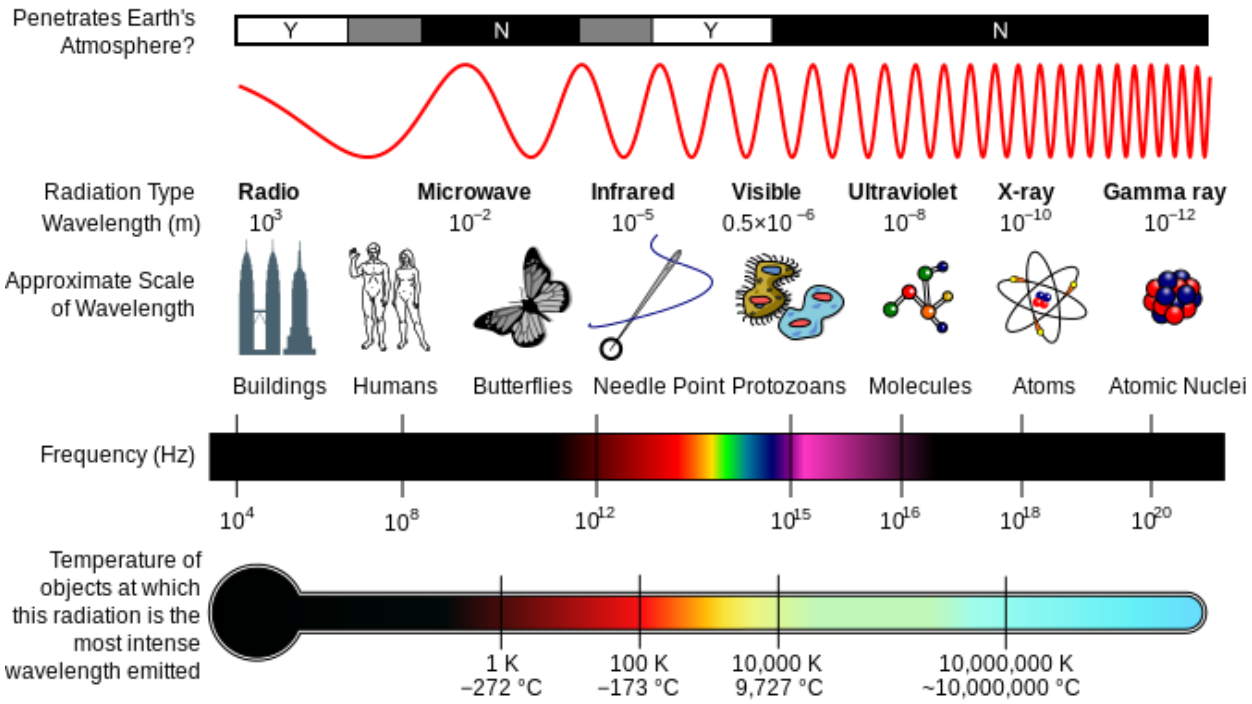
Action Levels →	3.0-5.9 Gy	6.0-14.9 Gy	≥15 Gy
Notify Fluoroscopist that Air Kerma value has been reached. Physician documents decision to continue procedure.	X	X	X
Complete & Send "Radiation Exposure Form for Skin Dose Calculation and Reporting" to RSO; document total air kerma in the patient's chart.	X	X	X
Inform Patient of Potential Skin Effects using Radiation Exposure Information form.	X	X	X
Complete an incident report on Pulse.	X	X	X
Schedule Follow-Up with Patient, via phone call or in-person appointment as necessary.		X	X
Immediately Contact RSO by Telephone.			X

Chapter 1 - Radiation and Dose

This section will cover the quantities and units used to describe radiation exposure. As a fluoroscope operator, you need to know these units in order to document dose and estimate the risk of injury. When you complete this chapter, you should be able to define terms used to describe radiation doses.

What Are X-Rays?

X-rays are a type of electromagnetic radiation. They are used in fluoroscopy because they are absorbed in varying degrees by different type of tissues, contrast agents and devices. X-radiation, like all electromagnetic radiation including visible light, consists of small packets of energy called "photons." The differences in absorption and scatter of photons by various tissues of the body provide information about the anatomy and composition of internal organs.



X-rays are a form of ionizing radiation, meaning that x-ray photons are energetic enough to directly detach electrons from atoms, resulting in free radicals. This indirect action is most commonly how ionizing radiation can cause chromosomal damage and cell death.

The characteristic of fluoroscopy that differentiates it from other x-ray imaging methods is that it depicts anatomy in real-time. Fluoroscopy is used to view and record the motion of organs, passage of contrast material, and manipulation of devices.

Radiation Quantities and Units

Whenever a fluoroscope is used for a procedure, the patient absorbs energy from x-radiation. The measure of dose we are commonly interested in is the dose delivered to the skin.

Absorbed Dose

The absorbed dose is the amount of radiation energy absorbed by tissue per mass of tissue. The organ that receives the highest dose is the skin where the x-ray beam enters the body. The absorbed dose to a patient is expressed in units of gray (Gy). A Gy is defined as the amount of radiation energy equal to one joule absorbed per kilogram of tissue. The Gy replaces the traditional unit of rad whereby 1 Gy equals 100 rad. Fluoroscopes may display estimated absorbed dose in units of milligray (mGy).

Peak Skin Dose

The peak skin dose is the absorbed dose at the skin location that has received the highest dose. This quantity is used to predict if a skin injury may occur as a result of a fluoroscopic procedure.

Entrance and Exit Skin Dose

Radiation energy is absorbed as it passes through the body. As a result, the dose to the skin where the beam enters the patient is much higher than the dose where the beam exits the patient. As a rule, for every four centimeters of travel through soft tissues, the dose to tissues from the x-ray beam is reduced by about one-half. For example, when an x-ray beam passes through a 25 centimeter (cm) thick abdomen, the entrance skin dose is about 100 times greater than the exit dose[1]. As a result, radiation injuries to the skin from fluoroscopy are always located on the X-ray tube side of the patient.

Measured versus Estimated Skin Dose

Skin dose can be measured by placing dosimeters on the patient's skin. In practice this is inconvenient and seldom done. More often one estimates the dose from the amount of radiation emitted from the fluoroscope. By knowing the duration and intensity of the beam, and by assuming the location of the patient's skin, one can arrive at an approximation. Methods used to estimate dose will be covered later in this handbook.

[1] Wagner, Louis K & Archer, Benjamin R & Partners in Radiation Management (1996). Minimizing risks from fluoroscopic x rays : bioeffects, instrumentation, and examination ; a credentialing program for Anesthesiologists, Cardiologists, Gastroenterologists, Interventionalists, Orthopedists, Physiatrists, Pulmonologists, Radiologic Technologists, Radiologists, Surgeons, and Urologists (3rd edition). Partners in Radiation Management, The Woodlands, TX.

Effective Dose

Effective dose is a quantity devised to account for the fact that exposures to people are not usually uniform throughout the body. Two procedures may involve the same dose in Gy, but one procedure could be directed at tissues that are more susceptible to cancer than does another procedure, resulting in a greater cancer risk. Effective dose attempts to convert the localized absorbed doses to a whole body risk factor, enabling comparison of risks among exposed individuals even if doses were delivered to different sets of organs[2]. Effective dose is expressed in Sv. The Sv replaces the traditional unit of rem, whereby 1 Sv equals 100 rem, and 1 mSv (millisievert) equals 0.1 rem.

Effective doses may be used to compare potential detriments for various modalities of imaging procedures. The largest effective doses in medical x-ray imaging are from computed tomography (CT) and fluoroscopically-guided interventional procedures.

When expressing risk of cancer, we are most interested in effective dose. When predicting a skin injury, we are most interested in absorbed dose.

Effective Doses from Medical Imaging Procedures

The table below compares effective doses for procedures using imaging[3]. Even though the exams listed pertain to certain body parts or organs, effective dose is a weighted average of the doses to various organs and is a measure of the estimated risk. Exams that use fluoroscopy are marked with an asterisk. This table shows that the cancer risk of a common fluoroscopic procedure is tens, hundreds, or even thousands of times greater than that of a simple radiograph.

EXAM	EFFECTIVE DOSE (mSv)
DXA	0.001
Dental (lateral) Intraoral X-Ray	0.005
PA Chest X-Ray	0.02

[2] Hirshfeld JW Jr, Balter S, Brinker JA, Kern MJ, Klein LW, Lindsay BD, Tommaso CL, Tracy CM, Wagner LK, Creager MA, Elnicki M, Lorell BH, Rodgers GP, Weitz HH; American College of Cardiology Foundation; American Heart Association/; HRS; SCAI; American College of Physicians Task Force on Clinical Competence and Training. ACCF/AHA/HRS/SCAI clinical competence statement on physician knowledge to optimize patient safety and image quality in fluoroscopically guided invasive cardiovascular procedures: a report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training. *Circulation*. 2005 Feb 1;111(4):511-32. doi: 10.1161/01.CIR.0000157946.29224.5D

[3] Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology*. 2008 Jul;248(1):254-63. doi: 10.1148/radiol.2481071451.

EXAM	EFFECTIVE DOSE (mSv)
Mammogram (four view)	0.4
Abdomen X-Ray image	0.7
*Barium Swallow (including fluoroscopy)	6
*Barium Enema (including fluoroscopy)	8
CT Head, each series	2
CT Abdomen, each series	8
PET/CT (F-18 FDG)	14
*Endoscopic Retrograde Cholangiopancreatography	4
*Coronary Angiography	2-16
*Coronary Angioplasty or Radiofrequency Ablation	7-57
*Transjugular Intrahepatic Portosystemic Shunt placement	20-180

Knowledge Check #1

See Knowledge Check answers beginning on page 74.

1. In performing fluoroscopy on a patient with a 25 cm thick abdomen, which of the following statements regarding the entrance and exit skin doses are true? Select all correct statements from the four that follow:
   a. The entrance dose is the dose at the beginning of the procedure and the exit dose is the dose at the end.
   b. The entrance dose is about 100 times greater than the exit dose.
   c. For every 4 cm of travel through soft tissues, the dose to tissue from the X-ray beam is reduced by about one-half.
   d. The entrance dose can be less than the exit dose.

2. Which of the four terms below is used for the dose at the skin location that has received the highest dose? Select the correct answer from the four options that follow:
    a. Absorbed dose
    b. Peak skin dose
    c. Entrance dose
    d. Effective dose

3. Which statements are true of ionizing radiation? Select all that apply from the following four statements:
    a. Ionizing radiation is only measured in rems.
    b. Ionizing radiation is energetic enough to detach electrons from atoms.
    c. Ionizing radiation passes through the body without any risk to tissue.
    d. X-rays are a form of ionizing radiation.

4. True or false? The two International System of Units (SI) units used for patient exposures are the gray and the Sievert.
    a. True
    b. False

Chapter 1 Summary

This chapter covered measures used to estimate x-radiation doses to patients and personnel. You will use these units and measures to document radiation dose. By now, you should be able to define the quantities and units used to describe x-radiation dose.

Chapter 2 - Biological Effects of Radiation

A range of biological effects may occur when a fluoroscopic procedure imparts a high radiation dose to the patient. Skin injuries are not evident immediately. They may take weeks to become apparent and may continue to progress for months or even years. Radiation induced cancers take even longer to develop, and can be 20 years or more after the exposure.

By the end of this chapter, you should be able to determine the type and severity of potential skin injuries to patients based on radiation doses from fluoroscopic procedures.

Stochastic and Deterministic Effects

The biological effects of radiation are classified as either stochastic or deterministic. A stochastic effect is an effect whose likelihood increases with dose, but whose severity is independent of dose. A deterministic effect is an effect whose severity increases with dose, once a dose threshold has been exceeded. Examples include these:

- Stochastic means involving a chance or a probability. Cancer is a stochastic effect because, in this case, cancer is measured as being either present or not present. The *risk* of cancer increases with dose; the severity does not. The risk of cancer from multiple procedures is thought to be additive. Another example of a stochastic effect is heritable changes in reproductive cells, though this has not been observed in humans. In both examples, risk is based on the fact that ionizing radiation can induce a change in the genetic material of a single cell.
- Deterministic means determined by prior events. A skin burn is a deterministic effect because the severity of the injury is determined by the dose. Severity can range from erythema at moderate doses to tissue necrosis at high doses. Deterministic effects develop above a dose threshold. Below the dose threshold, skin injuries are not apparent.

Cataracts

Clinicians who perform interventional procedures can sustain damage to the eyes if protective measures are not in place. Many have opacities in their posterior lenses, thought to be an early stage of cataract. A study of interventional cardiologists revealed lesions in 50 percent of practitioners examined[4]. It is not known whether these microlesions will develop into symptomatic cataracts. In 2016, the National Council on Radiation Protection and Measurements (NCRP) released Commentary No. 26, "Guidance on Radiation Dose Limits for the Lens of the Eye," and recommended that the annual dose limit to the eye be reduced. It is prudent for personnel performing fluoroscopic procedures to use eye protection, such as ceiling-mounted transparent radiation shields and radiation protective glasses.

[4] Vano E, Kleiman NJ, Duran A, Rehani MM, Echeverri D, Cabrera M. Radiation cataract risk in interventional cardiology personnel. *Radiat Res*. 2010 Oct;174(4):490-5. doi: 10.1667/RR2207.1.



Actions should also be taken to protect the eyes of patients. For procedures in which the patient's eyes are in or near the x-ray beam, efforts should be made to have the beam oriented so that it enters the patient on the side opposite the eyes. If the eyes must be in or near where the beam enters the patient, they should be protected by shielding or beam collimation when practical.

Skin Effects

The table[5] that follows provides typical dose thresholds for skin effects. Exposures of less than 2 gray (Gy) generally result in no observable skin effects. For skin doses exceeding about 2 Gy, erythema may occur within a few hours and last up to about 48 hours. For doses exceeding about 5 Gy, a second episode of erythema occurs, beginning about ten days or sooner in the case of higher doses, peaking at about 14 days, and lasting for a period that increases with the dose. The appearance of erythema and other effects such as dry and wet desquamation can help in estimating the dose to the skin and can reveal the areas that received the larger doses.

SKIN DOSE (GY)	PROMPT EFFECT LESS THAN 2 WEEKS	EARLY EFFECT 2-8 WEEKS	MIDTERM EFFECT 6-52 WEEKS	LATE EFECT MORE THN 40 WEEKS
0-2	None observed	None observed	None observed	None observed
2-5	Transient erythema	Epilation	Recovery from hair loss	None observed

[5] Balter S, Hopewell JW, Miller DL, Wagner LK, Zelefsky MJ. Fluoroscopically guided interventional procedures: a review of radiation effects on patients' skin and hair. *Radiology*. 2010 Feb; 254(2):326-41. doi: 10.1148/radiol.2542082312.

SKIN DOSE (GY)	PROMPT EFFECT LESS THAN 2 WEEKS	EARLY EFFECT 2-8 WEEKS	MIDTERM EFFECT 6-52 WEEKS	LATE EFECT MORE THN 40 WEEKS
5-10	Transient erythema	Erythema, epilation	Recovery; at higher doses, prolonged erythema, permanent partial epilation	Recovery; at higher doses, dermal atrophy or induration
10-15	Transient erythema	Erythema, epilation, possible dry or moist desquamation; recovery from desquamation	Prolonged erythema; permanent epilation	Telangiectasia; dermal atrophy or induration; skin likely to be weak
Greater than 15	Transient erythema; after very high doses, edema and acute ulceration; long term surgical intervention likely to be required	Erythema, epilation, moist desquamation	Dermal atrophy; secondary ulceration due to failure of moist desquamation to heal; surgical intervention likely to be required; at higher doses, dermal necrosis; surgical intervention likely to be required.	Telangiectasia; dermal atrophy or induration; possible late skin breakdown; wound might be persistent and progress into a deeper lesion; surgical intervention likely to be required

Dose Fractionation and Risk

Radiation oncologists have long known that delivering x-rays in multiple fractions separated by time increases the dose threshold and lessens the severity of skin injury. There are thought to be at least two mechanisms for this:

1. A low dose rate or fractionation permits cellular repair of deoxyribonucleic acid (DNA) lesions before additional damage occurs to the DNA. DNA repair processes are believed to be complete within 24 hours after irradiation.
2. For tissues, such as the skin, in which mature cells are continuously replaced by a population of stem cells, a very low dose rate or long periods of time between fractions permits repopulation of the stem cells. Repopulation of skin cells occurs over weeks.

Because of the repair that takes place between procedures, deterministic injuries are not fully additive between multiple procedures, especially if these procedures are separated by days or weeks. For example, a skin injury from a cardiac catheterization one year after a prior catheterization is much less likely than after the same procedure repeated after one day. When discussing additive skin dose, IU Health, Roudebush VAMC, and Eskenazi Health consider doses over a period of six months.

Factors Decreasing the Threshold for Skin Injury

In addition to peak skin dose, the rate at which the dose is delivered, and fractionation, other factors must be considered if present. The patient may be at greater risk for skin injury from x-radiation under these following conditions:

- Previous fluoroscopic or radiation therapy procedures to the same area of skin, especially if the procedures occur within days of each other
- The presence of preexisting health condition such as diabetes mellitus, some autoimmune disorders, deoxyribonucleic acid (DNA) repair disorders, and connective tissue disorders
- Certain medications, mostly those used for chemotherapy
- Obesity, which necessitates a greater dose of x-radiation to penetrate the body

Dose, Effect, and Follow-Up

The dose ranges here are expressed in gray (Gy). Each dose range gives examples of potential skin injuries that may result, with timelines and guidelines for patient advice. We'll discuss skin effects and follow-up more in this chapter.

2-5 Gy range

Skin effects from doses in the range of 2-5 Gy may result in mild transient erythema appearing within 24 hours and typically fading by 48 hours after the procedure. There also may be temporary epilation, beginning in about three weeks, with regrowth at about eight to twelve weeks.

Recommended follow-up: Advise the patient that erythema may be observed, but should fade with time. Advise the patient to call you if skin changes cause physical discomfort, or if erythema does not fade. Ensure that the patient knows that a skin biopsy is not recommended for this type of skin effect.

5-10 Gy range

In addition to the transient early erythema described for the 2-5 Gy range, there is a second wave of erythema beginning at about ten days after the procedure. The patient may experience itching, partial or permanent epilation, and prolonged erythema.

Required follow-up 6 Gy and above: Tell the patient where skin effects would most likely occur. Arrange for documented follow-up phone call or examination between 4 to 8 weeks post-procedure. If you find skin changes, you must make provisions for long-term monitoring. Skin reactions are often treated conservatively. You might advise the patient to be examined by a dermatologist. Inform the treating physician that injury may be due to radiation and communicate expected location of radiation-related skin effects. Ensure that the patient and treating physician knows that a skin biopsy is not recommended for this type of skin effect.

10-15 Gy range

Appearance may be similar to a 5-10 Gy range, with dry or moist desquamation possibly occurring within the 4-8 week period and permanent epilation, skin telangiectasia and atrophy.

Required follow-up: Medical follow-up is appropriate. Advise the dermatologist or other treating physician that skin effects may be prolonged and that prophylactic treatment for infection and monitoring of wound progression may be required. Pain could become a concern. Skin biopsy may result in skin breakdown and should be avoided.

Greater than 15 Gy range

The patient will demonstrate dry or moist desquamation approximately 4 to 8 weeks after the procedure. These initial signs may partially resolve, but the injury may later progress due to vascular damage. The most clinically significant long-term effect for an absorbed dose of 15 Gy or more is ischemia with persistent ulceration and infection. Note that erythema that is evident immediately after the procedure while the patient is still in the fluoroscopy suite is a worrisome sign associated with very high exposures.

Required follow-up: Medical follow-up is essential, the nature and frequency of which depends on the estimated radiation dose. Advise the treating physician that the wound could progress to ulceration or necrosis, with full development of the injury possibly occurring more than a year after the fluoroscopic procedure. Such injuries will often require a full-thickness grafting. It is important to ensure that the patient and treating physician know that a skin biopsy is not recommended for this type of skin effect.

Note: The Joint Commission considers any prolonged fluoroscopy with a cumulative dose greater than 15 Gy to a single field to be a reviewable sentinel event. Length of time is not specified. IU Health and Eskenazi consider 15 Gy to a single field over a period of 6 months to be a sentinel event and is required to be reviewed.

A Common Follow-up Scenario

A common scenario is a skin dose in the 3 to 5 Gy range. This dose is often encountered following prolonged interventional cardiac, neuroradiological, and body procedures. It is important to review guidance for this common scenario.

If you will be performing a procedure that might exceed 3 Gy, you should include the risk of erythema and epilation in the informed consent conversation and document this conversation in the medical record.

After the procedure, if the estimated peak skin dose is in the 3 to 5 Gy range, and assuming the patient is otherwise healthy and can follow instructions, you should tell him or her that erythema might develop and what it will look like. Have the patient check his or her skin in the weeks after the procedure, if possible. The erythema should resolve completely.

If the erythema doesn't fade away, with substantial resolution in four weeks, or if the skin becomes painful or exhibits dry or moist desquamation, instruct the patient to call you. The patient should be examined. This exam should be repeated as frequently as every two weeks until it shows clear evidence of resolution.

If the patient is at high risk or unable to perform a self-examination, it is a good idea to arrange for him or her to return for a skin exam four to eight weeks after the procedure. If the skin is clear at that time, no further follow-up is necessary. Note that this follow-up appointment is required above 6 Gy.

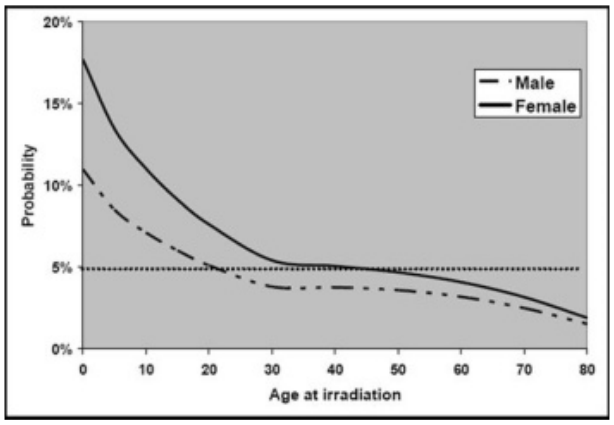
If moist desquamation occurs, the dose was not in the 3-5 Gy range, but likely well above 10 Gy. Although the injury may at first appear to resolve, follow the patient for up to two years.



Carcinogenesis

Cancer as a stochastic effect was mentioned earlier in this chapter. Based on epidemiological studies of atomic bomb survivors and other populations, the National Research Council estimated that each 10 millisievert (mSv) of effective dose to a working-age adult increased the chance of developing a fatal cancer by a factor of 1 in 2,000[6].

The graph below shows the calculated lifetime attributable risk for cancer mortality as a function of gender and age at exposure after a uniform 1 Gy irradiation of the entire body. Note that children and young adults are particularly susceptible to radiation-induced cancer. The difference between female and male death rates is largely explained by induced breast cancer.



[6] National Research Council. 2006. *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. Washington, DC: The National Academies Press. https://doi.org/10.17226/11340.

Excess incidence of breast cancer has been observed in patients who underwent fluoroscopically guided treatments for pulmonary tuberculosis. It is observed in middle-aged women who were given radiation therapy when they were children, particularly for Hodgkin's lymphoma.

Recent computed tomography (CT) literature is consistent with the assertion that that cancer can develop following exposures in the range of diagnostic imaging procedures. A recent study found a three-fold increase in the relative risk of leukemia for people who received a cumulative dose of at least 30 mGy when they were children[7].

Based on these early findings, some have estimated that, as a result of medical diagnostic exposure in the U.S., thousands of patients may acquire radiation-induced cancer in the decades to come. However - even if true - this would represent a tiny percent increase in the total number of cancers.

Latent Period

There is a latent period between the time of radiation exposure and the induction or detection of cancer. The latent period for leukemia may average five years. The latent period for solid tumors may be 20 years or more. The propensity for young patients to develop radiation-induced cancer in comparison with the elderly is, in part, because children have more years of life remaining in which to develop cancer, whereas elderly patients are likely to die of other causes before incurring a radiation-induced cancer.

As a result, you must be especially cautious when exposing children and young adults to radiation.

Sensitivity of Specific Organs and Tissues

When calculating effective dose, individual organs and tissues are assigned weighting factors. The weighting factors consider the risk of cancer and the detriment when cancer occurs.

The information that follows shows tissue type and its relative weighting factor, specified by the International Commission on Radiological Protection (ICRP).

According to the table, radiation to bone marrow is more likely to result in a cancer death than is radiation to skin. If the entire body is radiated uniformly by 1 Gy, then the sum of the weighted doses to the tissue types is also 1 Gy, in which case the absorbed dose in Gy equals the effective dose in sievert (1 Gy = 1 Sv). Note that this equality only applies to full body radiation. The calculation of effective dose for an actual clinical procedure can be quite challenging.

[7] Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet*. 2012;380(9840):499-505. doi:10.1016/S0140-6736(12)60815-0.

Weighing Factors[8]

TISSUE TYPE	WEIGHING FACTOR
Bone Marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Breast	0.12
Other Tissues	0.12
Gonads	0.08
Bladder	0.04
Esophagus	0.04
Liver	0.04
Thyroid	0.04
Bone Cortex	0.01
Brain	0.01
Salivary Gland	0.01
Skin	0.01
Total	**1.00**

Heritable Effects and Fetal Teratogenesis

Heritable Effects

Heritable effects are radiation-induced mutations of sperm or ova that can be passed on to future generations. While radiation induced heritable effects have been demonstrated in insects and mice, they have not been seen in humans. Still, it is prudent to use appropriate shielding and collimation to mitigate exposure to the testes and ovaries of patients who are or will be capable of reproduction.

[8] ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4).

Fetal Teratogenesis

A dose of x-radiation to a developing embryo or fetus can lead to malformations and developmental defects in the child. The risk increases with dose (it is not seen below 50-100 mGy) and is dependent on the stage of pregnancy.

The table below is based on information from the American College of Radiology[9] and describes the potential teratogenetic effects based on radiation doses. The dose of most fluoroscopic procedures is well below the threshold for effect. Nevertheless, it is prudent to keep radiation to a fetus at a minimum.

DOSE TO FETUS (mGy)	EFFECT
Less than 100	No increased incidence of malformation or death
100-200	Very low risk of malformation
200-500	Teratogenic effects vary with phase of pregnancy. If exposed between 8 and 15 weeks there may be a measured reduction of IQ.
Greater than 500	Significant risk of growth retardation, malformation, and central nervous system (CNS) damage, especially if during the 3rd to 16th week of pregnancy.

Skin Injury Scenario

A radiation exposure scenario is described in the next few pages. The information in this scenario is loosely based on a 2010 case study from FDA that occurred in the early 1990s. The purpose of this scenario is to provide an opportunity for you to apply your experience and the information in this chapter to answer questions based on the story. The patient and the unfolding of events in this scenario are fictitious.

The patient is a 40-year old male, Timothy Smith, who underwent four complex procedures in one day: coronary angiography, coronary angioplasty, a second angiography procedure due to complications, and a coronary artery by-pass graft. The readout on the fluoroscope indicated a total of 30 Gy of radiation over several skin sites during the course of the first three procedures. As his physician, you visit Mr. Smith just before his release from the facility. In addition to follow-up instructions for his heart surgery, you advise Mr. Smith that there may be skin effects over the next 6 to 12 months as a complication of radiation exposure. You ask him to return for a follow-up examination in four weeks.

[9] American College of Radiology. ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation. Revised 2018.

Instructions: Select an answer and check after the question for the correct answer.

1. What is the most likely early skin sign that might be seen at the 4-week examination?
    a. dry or moist desquamation
    b. epilation
    c. skin cancer
    d. infection
    e. ulceration
    f. erythema

Skin Injury Scenario

Correct answer:

The correct answer is (F). Although each of these effects might occur later in this patient's clinical course, the most likely early sign is erythema.

Skin Injury Scenario: Four Weeks After Procedures

Mr. Smith missed his follow-up appointment but phoned you to report that a square-shaped patch on his back turned red and then peeled. Mr. Smith mentioned that his skin was somewhat tender at that site. You convince him to come in for an appointment two weeks later so that you can inspect the affected skin. Mr. Smith agrees to come in. He mentions that his wife suggested that he might need a skin biopsy.

Instructions: Select an answer and review the correct answer, which is located after the question:

1. Should you arrange for a skin biopsy for Mr. Smith?
    a. Yes
    b. No

Skin Injury Scenario: Four Weeks After Procedures

Correct answer:

No. If an acute lesion is known to be caused by radiation, a biopsy is not indicated as it could result in further injury to the affected skin.

Skin Injury Scenario: Six Weeks

Mr. Smith is anxious for you to inspect his back when he arrives for his appointment six weeks after the procedures. His skin effects, shown in the photograph below, appear similar to a second degree burn. He reports feeling a lot of pain. You determine he has moist desquamation. You discuss the treatment options with Mr. Smith.



Instructions: Select an answer and check the correct answer after the question

1. Mr. Smith wants to know when his skin will recover. Which answer would be most appropriate, based on the information given earlier in this chapter?

a. Tell Mr. Smith that it is not yet known whether the skin injury will get worse. You recommend examinations continue for a year or more to determine the final extent of injury. You ask him to call you if symptoms get worse and to come back in another ten weeks.
b. Tell Mr. Smith that radiation injuries peak at six to eight weeks and that he can expect a full recovery.

Skin Injury Scenario: Six Weeks

Correct answer:

"A" is the best answer. The presence of moist desquamation confirms a high radiation dose, likely exceeding 10 Gy. Injuries from doses at this level may evolve for many months.

Skin Injury Scenario: Sixteen Weeks

Mr. Smith is cheerful when he arrives for his next appointment. You examine his affected skin, which appears similar to the photograph below. He feels that he is almost healed, but his wife insists that there is a small sore in the middle of the affected skin.

When you examine his skin, you confirm the presence of a small ulcer. When you tell Mr. Smith that he will require further examinations, he states that he would rather be followed by his primary care provider (PCP) whose clinic is closer to his home.

You refer Mr. Smith to his PCP and provide him with a copy of all pertinent medical records.



Skin Injury Scenario: Some Months Later

You are a PCP who has received a referral from a cardiologist for a patient who received a high radiation dose to the back. The patient, Mr. Smith, is followed by you periodically. Twenty months after his procedures, you determine he has developed a persistent skin ulceration much like the injury shown in this image below.



Instructions: Select an answer and check the correct answer after the question.

1. What would be the most appropriate course of treatment?
   a. Continue to follow with simple wound care until the wound heals.
   b. Biopsy the lesion because a malignancy is likely.
   c. Refer the patient for resection of necrotic tissues with full thickness skin graft.

Skin Injury Scenario: Some Months Later

Correct answer:

The correct treatment is (C), a skin graft. This wound will not heal on its own.

Skin Grafting

Mr. Smith undergoes a skin grafting surgery with good results, shown in the image below.

No two patients, procedures, or skin effects are exactly the same. However, this scenario demonstrates that often the most severe skin effects manifest in various forms for months after radiation exposure during a fluoroscopic procedure.



Knowledge Check #2

See Knowledge Check answers beginning on page 74.

1. Which statement is true regarding skin effects of radiation exposure? Select the correct statement from the four that follow.
   a. Transient erythema can occur at a dose of 2 Gy, epilation at 3 Gy, and ischemic dermal necrosis at doses over 15 Gy.
   b. Inspecting the skin before the patient leaves the fluoroscopy suite is the best way to rule out skin effects.
   c. If after a skin dose of 10 Gy the patient experiences no skin irritation at 10 days, the skin is not at risk.
   d. Skin ulceration is an early complication, while erythema is seen later.

2. Which of the following groups of tissues is most susceptible to radiation-induced cancer? Select the correct answer from the two options that follow.
   a. Bone marrow, breast, lung
   b. Skin, brain, salivary gland

3. You are told that it is the policy of your hospital to inform the patient if he or she has received more than 3 Gy of radiation during a fluoroscopic procedure. If a patient

receives 4 Gy, what should you tell the patient during that conversation? Select all that apply from the following four choices.

a. You should tell the patient that he or she will possibly require a skin graft.
b. You should tell the patient to check his or her skin for redness that might develop up to 14 days after the procedure.
c. Tell the patient that he or she should call you if redness develops or the skin becomes uncomfortable.
d. You should tell the patient that they must come back to see you in one week for a skin examination.

4. Which of the following four statements is true regarding the cumulative effects of repeated fluoroscopy? Select all the right answers from the four choices that follow:
    a. The risk of stochastic effects such as cancer accumulate over multiple fluoroscopic procedures.
    b. Deterministic and stochastic effects are dependent only on the radiation dose of the most recent procedure
    c. If a patient didn't have a deterministic effect due to a fluoroscopic procedure, it is unlikely that he or she will have one from a second procedure.
    d. A procedure repeated on the same day is more likely to cause a skin injury than a procedure repeated after several weeks.

Chapter 2 Summary

This chapter covered stochastic and deterministic biological effects of radiation. Now that you are aware of the relationship between radiation dose and the severity of skin and other injuries, you can weigh this information against the benefits of a planned procedure. The exposure displayed by the fluoroscope can help you identify which patients require surveillance for a possible skin injury.

Chapter 3 - Basic Fluoroscopic Technology

Fluoroscopes are built with a variety of safety features. A basic understanding of these features will help you mitigate radiation risk.

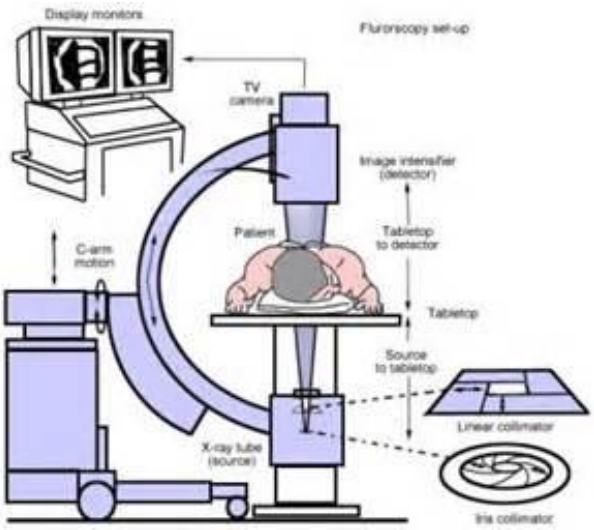
When you have completed this chapter, you should be able to describe the basic technology and components used in fluoroscopic equipment.

Components of an X-ray Machine

There are many different kinds of fluoroscopes—some small and mobile with few controls, others large and stationary with numerous controls. While these instruments may vary in layout, they have common functionality regardless of the manufacturer and model.

You will have an opportunity to familiarize yourself with components on the next page. After that, we will look at each component in some detail.

Among the fluoroscopic components that you should understand are the following: x-ray tube, collimator, separator cone/spacer, table, anti-scatter grid, image receptor, and one or more display monitors.



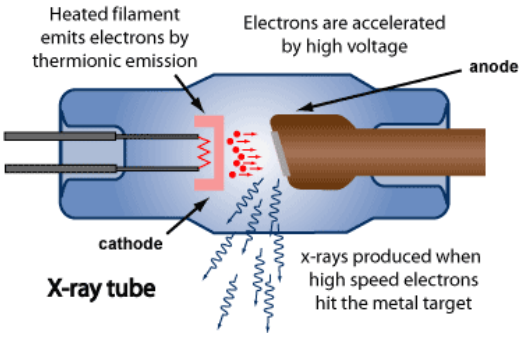
X-ray Tube

The x-ray tube is a glass vacuum chamber that contains a negatively-charged cathode filament, which is a source of electrons, and a positively-charged tungsten anode, which serves as a target for the electrons.

X-ray production begins when the cathode is heated, with a low-voltage electric current regulated by a setting on the fluoroscope, to release electrons. As shown in the diagram on this page, the electrons released from the cathode travel through a high-voltage field which accelerates them to large kinetic energies before they collide with the tungsten target, where they decelerate and give off x-rays. The tube current, in milliamperes (mA), describes the number of electrons per unit time flowing from the cathode to the anode. X-ray generation is inefficient from the standpoint of energy transformation. Less than 1 percent of the electrical

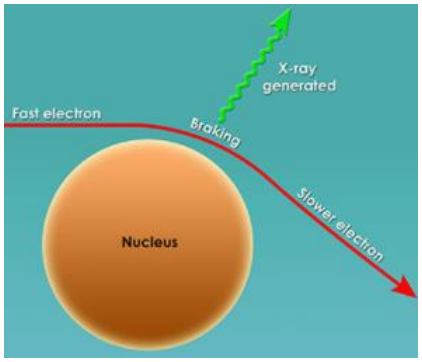
energy applied to the tube is converted to x-rays; the remainder is deposited in the tube as heat.



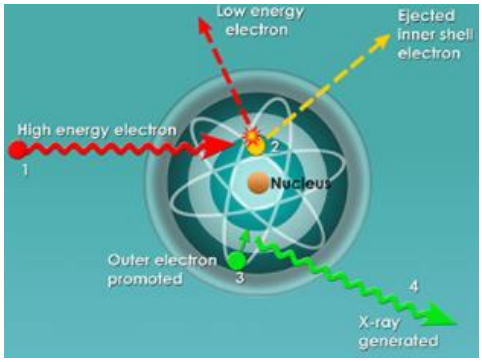


Radiation Production

The electrons interact with the anode atoms in one of two ways. Bremsstrahlung, or braking radiation, occurs when an electron's path is altered in the direction of the positive nucleus. This acceleration causes a loss in the energy of the electron. That energy is emitted in the form of an x-ray of various energies, meaning that the x-ray energies emitted from the source tube are actually a spectrum. Bremsstrahlung accounts for approximately 80% of the useful x-ray beam.



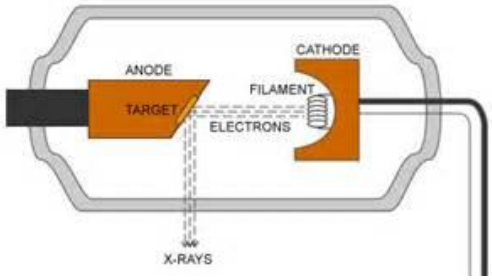
Electrons can also interact with the anode atom's electron shell. In this case, an electron is ejected from an inner orbital of the anode atom. In response to the empty space below, a higher-energy electron drops into a lower energy state. The difference in energy is released in the form of a photon of discrete energy, called a characteristic x-ray. This is far less common than bremsstrahlung radiation, comprising only 20% of the x-ray beam.



Anode Focal Spot

The stream of electrons is focused onto a small "focal spot" on the anode, where the x-rays are produced. For optimal imaging, we would like the x-ray beam to emanate from an infinitesimally small point, but electrons striking a tiny point would melt the anode. The focal spot must be wide enough to allow dissipation of heat. At least two focal spot sizes are available on most x-ray tubes: a large one, generally about 1 millimeter (mm) in diameter, and a small one of about 0.5 mm. The small size provides better image definition, but the x-ray output is limited and not sufficient for all tasks. A typical application for a small focal spot is the wrist, while a large focal spot might be used for the lumbar spine. In practice, most fluoroscopes automatically choose the focal spot size for you.

If the anode heats to a level that might result in damage, the machine will turn off. An overheated tube is a measure of high x-ray output and a warning that you are using high dose rate imaging modes or long beam-on times without interruption.



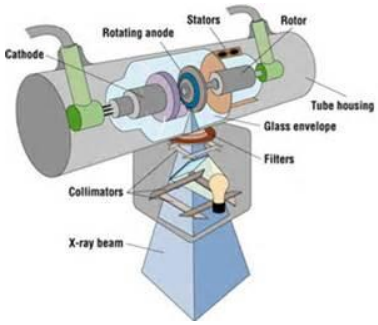
Beam On-Off Switch

The switch used to engage fluoroscopy requires continuous pressure and automatically disengages when released. This safety feature applies to hand and foot controls. The intent of the switch design is to ensure that x-rays are produced only as you need them, so the fluoroscope cannot be left on by mistake.



Collimator

The collimator is an adjustable lead shutter attached to the beam port of the x-ray source that can be closed down to limit the area of the body that is irradiated. By collimating the beam to the diagnostically appropriate field of view, you will minimize radiation to the patient, as well as to yourself. Image contrast and signal to noise ratio may also be improved because less of the patient will be giving rise to scattered photons. (Scattered and transmitted radiation will be discussed in more detail later in the chapter.) The operator should continually adjust the collimator setting during the course of the procedure.





Separator/Spacer

The spacer is a safety device that keeps the patient from getting too close to the x-ray source. Placing the source too close to the patient is a leading cause of skin injury. On some machines, particularly mobile machines, the spacer can be removed because it can inhibit placement of the x-ray unit under a bed-bound patient or operating room table. The practice of removing a spacer is not without risk. If a spacer is removed, the operator may forget to replace it.

The U.S. Food and Drug Administration (FDA) requires fluoroscopic x-ray machines to maintain a minimum distance between the patient's skin and the x-ray tube. For modern fluoroscopes that are fixed in a room, the minimum distance is 38 centimeters (cm); for mobile units the minimum distance is 30 cm[10].

[10] 21 CFR 1020

Patient Table

Hospital beds and gurneys are not optimal for fluoroscopy because they may contain metal or other dense materials that impede the beam. A fluoroscopy table is made of materials that are transparent to x-rays. Most tables are height adjustable. On high-end fluoroscopy units, the table is motorized and can be programmed to move the patient with, for example, the passage of intravascular contrast material down the leg.





Image Receptor/Detector

An image receptor converts low intensity x-rays to a signal that may be viewed as an image on a video monitor or that may be stored. There are two types of image receptors: image intensifier tubes and flat panel detectors.

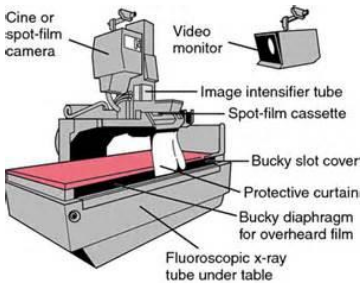
Image intensifier tube

By this technology, x-rays strike a cesium iodide phosphor that converts the radiation into visible light. The number of photons is amplified by a phototube. The light is detected by a CCD video camera and displayed on a monitor. Image intensifiers tend to be bulky in comparison with flat panel detectors.

Flat panel detector

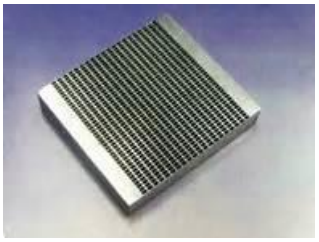
A flat panel detector transmits images directly to the display monitor without an intervening video camera. A flat panel detector has the potential to reduce the radiation dose to the patient because it has greater sensitivity to x-rays than does an image intensifier.





Anti-Scatter Grid

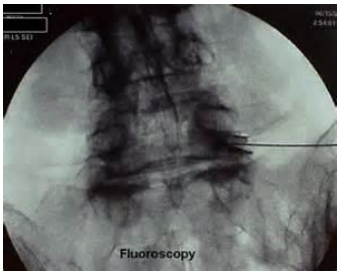
An anti-scatter grid intercepts the x-rays scattered by the patient that can cause clouding of the image, while allowing transmitted x-rays to pass through. Without a grid, much of the radiation reaching the detector is scattered x-rays. A grid consists of numerous tiny thin plates of lead that are aligned toward the source. Grids are placed just before the image receptor. Only photons that are moving in a straight line from the source, i.e., not scattered, can pass between the lead plates and strike the detector. Unfortunately, the grid also removes a significant fraction of the potentially useful x-rays that have passed through the patient without scattering.

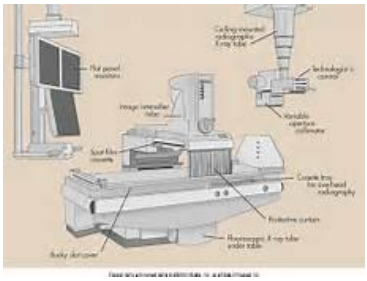




Display Monitor

A display monitor can take the form of a cathode ray tube or flat panel display; newer systems have flat panel displays. The monitor displays images, settings in use, and measurements of x-ray dose. Multiple monitors are often used to display information such as the live view, a static image, and physiologic vital signs. An image displayed on the monitor can be better seen when the room lights are dimmed.





X-ray Interactions with Tissue

In order to understand image generation, one must know how x-rays interact with tissues. X-rays entering the patient can do one of three things:

1. *No interaction*: The x-ray passes through the tissue along a straight line into the image receptor. These are the x-rays that create the anatomic image.

2. *Total absorption*: X-ray energy of a photon is completely absorbed by the tissue so it does not strike the image receptor. The differing degree to which tissues absorb x-rays generates light and dark features on the image.
3. *Partial absorption and scatter*: Some of the energy of the photon is absorbed and the photon, now of lower energy, is deflected to travel in a new direction. This is called Compton scattering. Scattered radiation disperses in all directions. The scattered photons may irradiate the operator or others in the room. They may be absorbed by a subsequent interaction with patient tissues. They may fall on the image receptor, resulting in degradation of the image by a background haze that does not contribute useful anatomic information.

Factors that Affect Radiation Interaction

Radiation interaction with tissues is affected by these factors:

- *Density and atomic number*: The absorption of photons and consequent attenuation of the x-ray beam increases with the density and atomic number of the material encountered. Air is the least dense material, followed by fat, soft tissue organs and muscle, bone, pharmacologic contrast material, and metal. Radiation passing through dense and high atomic number materials such as bone, metal, and contrast material is largely absorbed, resulting in few x-rays at the image intensifier.
- *Tissue thickness*: Thicker parts of the body remove more x-rays from the beam than do thinner parts. Thicker body parts also produce more scatter.
- *X-ray energy:* Increasing the x-ray tube voltage results in energetic radiation with greater penetration that is less likely to be absorbed in the patient's body. But the image contrast between different tissues is reduced and contrast material becomes less visible. For example, a low energy x-ray beam is mostly absorbed by bone so the contrast between bone and soft tissues is strong, while high energy x-rays pass through bone more easily, so that the contrast between bone and soft tissues is diminished.

mA and kv Defined

Fluoroscopes have controls for milliamperes (mA) and kilovolts (kV). The mA control sets the tube current which in turn controls the number of electrons produced at the cathode. As mA is increased, so too is the number of electrons that generate an x-ray beam. This in turn increases the number of x-ray photons being detected and thereby the signal to noise of the image. mA must be increased when viewing dense or thick tissues. Generally, a grainy image results from a mA setting that is too low.

Note that image noise decreases as mA is increased, but eventually one reaches an adequate dose rate beyond which additional mA does not result in further improvements to the image, but just increases radiation to the patient.

As explained earlier, when electrons are released from the cathode they travel across a high-voltage (kV) field toward the anode target. The amount of kV between the cathode and anode

determines the energy with which electrons strike the anode material, and therefore the energies of the photons generated. When imaging large body parts it is often necessary to increase kV to improve penetration of the beam. But when kV is increased the image contrast is reduced. Fluoroscopy employs tube potentials in the range of 70 to 120 kV. This is because x-rays at these energies provide the best compromise of tissue penetration and contrast.

Automatic Exposure Rate Control

Automatic exposure control (AEC), automatic exposure rate control (AERC), and automatic brightness control (ABC) are alternative names for the automatic variation of mA and kV as needed for the body part being imaged. Nearly all fluoroscopy is performed using this feature. When the fluoroscope is set to ABC mode, the output from the image receptor is continually monitored and the x-ray settings adjusted automatically to produce consistent image brightness and quality.

If the tissue is dense or thick, mA and kV are increased to generate more photons and higher energy photons that penetrate better. The adjustments are made by the machine and are not directly controlled by the operator. However, many machines offer more than one ABC setting, with different selections of kV and mA. Some setting selections provide better image contrast at the cost of more exposure to the patient, whereas others provide less image contrast, but reduce patient dose.

When optimizing the appearance of an image, one may need to use the collimator to help the fluoroscope find the intended setting. For example, if one is studying the knee with a wide-open collimator, numerous photons will pass around the knee and strike the receptor. mA will drop and the knee will become too dark. By narrowing the collimation to include soft tissues only, air can be eliminated from the view and the correct exposure settings and brightness selected.

Continuous vs. Pulsed Modes

Modern fluoroscopes are equipped with two modes of operation whereby the electrical current to the x-ray tube is applied continuously, or pulsed on and off. When using pulsed fluoroscopy, the beam is off between pulses but the image is displayed continuously and updated with each pulse. Because the beam is mostly off, pulsed fluoroscopy is a means to reduce radiation to the patient. The pulse rate can be selected. Common rates are 3.75, 7.5, 15, and 30 pulses per second.

Selection of the best pulse rate depends on how quickly objects are moving. If motion is slow, 3 images per second may be adequate, and considerable radiation dose saving is gained. If one is following the delicate motion of intravascular catheters, or passage of contrast through coronary arteries, the pulse rate must be higher, in order to avoid choppy motion on the display screen. For coronary procedures in adults, a pulse rate of 15 per second is commonly used, but greater pulse rates such as 30 per second may be needed for difficult manipulations during a

procedure. In the cardiac electrophysiology laboratory, a pulse rate of 7.5 frames per second is commonly used.

Very high pulse rates (e.g., 30 pulses per second) may result in little or no dose savings. In fact, for very high pulse rates, the dose rate may be slightly greater than that from continuous fluoroscopy.

Last Image Hold

The last image hold feature on fluoroscopes refers to the fact that the last image is displayed on the monitor when the beam is turned off rather than letting the screen go blank. Last image hold allows the operator to study the last image (or multiple prior images) without irradiating the patient. For this reason, FDA requires manufacturers to provide all new fluoroscopes with last image hold capability.

Variability in Machine Controls

The controls of a fluoroscope that permit optimization of the radiation dose to the patient may be labeled or positioned differently on the control panels of instruments made by individual manufacturers. As an operator, it is your responsibility to seek out the necessary training so you understand how your specific machine operates. When using a new machine, you should ask for hands-on orientation by an experienced operator.

Configuration of Fluoroscopes

Fluoroscopes are manufactured in many configurations to suit specific clinical applications. Some are mobile and others are fixed in place. In some, the x-ray source and the image receptor are aligned so that one is always above the other. Others, called “C-arm fluoroscopes”, permit great flexibility in the orientation of the x-ray beam.

Types of mobile C-arm system:

- General purpose fixed C-arm system with a large area image receptor
- Cardiology or neuroradiology C-arm system with a small area image receptor
- Biplane angiography system for simultaneously imaging in two planes
- GI/GU system with x-ray source below the patient table
- Urology system with the x-ray source above the patient table
- Mini C-arm system for imaging the extremities

Mobile C-Arm System

Features:

A typical mobile C-arm system has a fixed 100 cm source-to-image receptor distance. These systems are used in operating rooms and procedure rooms for many procedures, including

orthopedic, vascular surgery, and pain management procedures. The C-arm configuration permits great flexibility in projection angle. A mobile C-arm system has a removable separator that can be mounted on the x-ray source housing to keep the x-ray source from being dangerously close to the patient; the separator should be attached when feasible. Too often, these separator devices are not kept with the C-arm systems.



General purpose fixed C-arm system with a large area image receptor

Features:

These systems can be used for a wide variety of diagnostic and interventional procedures. The large area image receptor permits a bolus of intravascular contrast material to be followed over a considerable length of the patient. For most fixed C-arm systems, the x-ray source is at a fixed distance, typically 75 to 80 cm, from the axis of rotation (isocenter), but the image receptor can be moved toward or away from the x-ray source, varying the source-to-image receptor distance from about 90 or 95 cm to 120 cm. When the x-ray tube is below the patient, keeping the patient table as high above the floor as possible maximizes the x-ray source to patient distance.



Cardiology or neuroradiology C-arm system with a small area image receptor

Features:

Dedicated cardiology and neuroradiology systems commonly have small area image receptors. These smaller image receptors permit great flexibility in the projection angle, permitting considerable cephalad and caudad angulation, in addition to lateral angulation.



<u>Biplane angiography system for simultaneously imaging in two planes</u>

Features:

A biplane fluoroscopy system has two separate imaging systems, each with an x-ray tube and an image receptor. A biplane system permits simultaneous imaging of injected contrast material in two projections, thereby reducing the amount of contrast material that is injected into a patient.



<u>GI/GU system with x-ray source below the patient table</u>

Features:

Nearly every radiology department has a GI/GU fluoroscopy machine with the x-ray source below the patient table and the image receptor above the patient. These are commonly used for upper and lower GI studies with barium contrast material. On some machines, the recorded images are directly captured in digital format. On other machines, the images are captured on computed radiography imaging plates that must be read by a CR reader. The lead curtain hanging from the image receptor in front of the operator protects the operator from scattered x-rays. However, the operator should still wear a radiation protective apron.



Urology system with the x-ray source above the patient table

Features:

In many urology systems, the x-ray tube is mounted above the patient table and the image receptor is mounted below the patient. The operator and staff should recognize that this configuration causes the most intense scattered radiation to be above the patient and take appropriate precautions.



Mini C-arm system for imaging the extremities

Features:

A mini C-arm fluoroscopy system is intended for imaging of the extremities. A mini C-arm system typically has a very short source-to-image receptor distance of about 45 cm, a small area image receptor (such as a 6-inch diameter image intensifier tube), a low output x-ray tube, a limited range of x-ray tube voltages (kVp), and may lack an anti-scatter grid. A mini C-arm is commonly used with the x-ray tube directly above the image receptor.



Mini C-arms

Mini C-arms are small fluoroscopes whose source to detector distance are about one-half that of a full size c-arm. Their small size makes them convenient for manipulations and operative procedures of the extremities, such as wrist surgery. Mini c-arms impart much lower radiation dose to the operator than do full size units.

However, radiation to the patient is fully one-half the radiation of a full size unit. Some publications have reported patient doses that are greater than that of standard c-arms, particularly if one rests the body part on or near the x-ray source. Unlike standard c-arms, it is recommended that the x-ray source be placed above the patient so the extremity can rest on the detector and avoid approaching the source.

One might assume that the short source to detector distance results in dose savings to the patient, but this potential benefit is counterbalanced by a short source to patient distance. The reason mini c-arms are usually associated with low radiation dose is that extremity imaging does not require as many mA as does imaging of the chest or abdomen.

We recommend that surgeons who operate mini c-arms be safety trained because improper use of this equipment, or imaging of thicker parts such as obese knees, can result in relatively high dose.

Knowledge Check #3

See Knowledge Check answers beginning on page 74.

1. What factors should you consider when adjusting the pulse-rate in variable pulse-rate fluoroscopy? Select the correct answers from the four choices that follow.
    a. Patient dose
    b. The speed at which structures in the image are moving
    c. Beam collimation
    d. Tissue contrast

2. What is the purpose of the collimator? Select all that apply from the four choices that follow.
    a. To limit the area of the body that is irradiated
    b. To minimize the amount of scattered radiation striking the operator
    c. To reduce the amount of scatter reaching the image receptor
    d. To magnify the image

3. Which mode varies the mA and kV as needed for the density and thickness of the body part being imaged? Select the correct answer from the four choices that follow.
    a. Automatic brightness control
    b. Pulsed fluoroscopy
    c. Continuous fluoroscopy
    d. Small focal spot

4. Which of the following statements about the 0.5 mm focal spot versus 1 mm focal spot on the anode is true? Select all that apply from the four statements that follow.
    a. A focal spot of about 0.5mm provides better image definition, but the x-ray output is limited.
    b. A focal spot of about 1mm in size provides better definition and permits a greater x-ray output.
    c. A focal spot of about 1mm in size provides less definition and permits a greater x-ray output.
    d. A focal spot of about 0.5 mm tends to degrade the image while increasing x-ray output.

5. Match each component to the correct function.

a. Separator/Spacer	1. Converts low intensity x-rays to high-brightness visible light
b. X-Ray Tube	2. Intercepts scattered x-radiation to improve image quality
c. Collimator	3. Sends electrons across a high-voltage field to collide with a tungsten target on the anode
d. Anti-scatter Grid	4. Limits the area of the body to be irradiated
e. Image Receptor	5. Ensures a minimum distance between the x-ray source and the patient

Chapter 3 Summary

Fluoroscopes vary in form and layout of operating controls, but the basic components and how they function are similar. Like consumer cameras, fluoroscopes can select most settings for you, but they may allow you to override and operate the machine manually.

In this chapter, you were provided with descriptions of a fluoroscope and its components, including their purpose and functionality.

In the next chapter, you'll use what you have learned here to discover how various factors can affect the quality of the image.

Chapter 4 - Image Quality

In the previous chapter, you gained familiarity with the major components of a fluoroscope and were introduced to the concepts of image noise and contrast. In this chapter, we will revisit the issue of image quality in greater detail.

By the end of this chapter, you will be able to distinguish how image quality is affected by milliamperes (mA) and kilovolts (kV), patient size, scatter, and fluoroscope components and settings.

Spatial Resolution, Contrast, and Noise

The quality of an image can be described by three parameters: spatial resolution, contrast, and noise. Each parameter has implications for patient dose.

- ***Spatial Resolution***
- ***Contrast***
- ***Noise***

Spatial Resolution

Spatial resolution describes the ability to portray small features and may be considered the "sharpness" of the image. Image spatial resolution is governed by:

- X-ray tube focal spot size (small focal spot results in sharper image)
- Design of the image receptor
    - Flat panel detectors (major factor is size of the detector elements)
    - Image Intensifiers (resolution is limited by the design of the video camera and other factors)
- Magnification mode selected (magnified image has higher resolution)
- Geometric magnification (increases with greater distance from patient to receptor in comparison with source to receptor)
- Motion blur
- Number of pixels in the acquired or stored image
- Design of the display monitor, particularly the number of pixels

The number of pixels in the stored image is typically 512 x 512 or 1024 x 1024. 1024 matrix images are available in high-end equipment such as cardiac catheterization labs.

Contrast

Contrast is the relative difference between light and dark areas of an image and the ability to differentiate gray-scale gradations ranging from white to black. Factors that influence contrast include:

- Kilovoltage (higher voltage reduces contrast)
- X-ray scatter in the patient (scatter increases image haze, reducing contrast)
- Body part thickness and x-ray field size selected (a thicker body part and larger x-ray field size cause more scatter to reach the image receptor)
- Anti-scatter grid
- Design of the image receptor
- Calibration of the video display system
- Design of the display monitor
- Ambient light in the viewing room, which detracts from the perception of contrast

Noise

In this context, noise is random variation in the intensity of individual image pixels that do not provide information about the patient's anatomy or material in the patient. It is sometimes referred to as "graininess" or "snow." A major source of noise, commonly the most important, is variation in the number of x-ray photons detected by individual areas on the image receptor. This phenomenon is called "quantum mottle." These variations become apparent if there are insufficient x-ray photons reaching the detector elements of the image receptor. Another source may be electronic noise. Noise is especially apparent when you are subtracting two similar images, as you would do in digital subtraction angiography (DSA). Factors that can influence image noise include:

- mA and kV (Thicker patients and oblique and lateral views require greater radiation doses or more energetic beams to maintain the image quality.)
- Resolution (Small detector areas require more photons per area to maintain the same level of noise. When a magnification mode is selected, the mA and possibly the kV must be increased to achieve the same level of apparent image noise.)
- Duration of the acquisition (Pulsed fluoroscopy with longer pulses results in more signal at the expense of motion blurring.)
- Scattered radiation reaching the image receptor (the amount increases with the thickness of the body part and the x-ray field size)

If noise is high, it may indirectly degrade the apparent resolution and contrast as well. If you need to reduce noise, then you must increase the intensity of the x-ray beam, thereby exposing the patient to a higher dose of radiation.

Important Note:

To a large degree, the safe practice of fluoroscopy consists of deciding when improved image quality is necessary for the procedure, or can be avoided to reduce radiation dose.

Effects of mA and kV

When the automatic exposure rate control is on, a fluoroscope automatically attempts to select the best combination of kV and mA. On some machines you must set the controls to thin, average, or large body size. If you image a large patient with a large patient setting, the machine will automatically increase kV with mA. For machines that allow the operator to set their own manual technique selections, it is valuable to know what kV settings are typically used.

The best kV for image contrast is about 70 kV. This is a good selection for smaller body parts such as hands, but this voltage does not produce an x-ray beam that penetrates the adult chest and abdomen well. A large mA is required for imaging of the trunk at this voltage.

In order to reduce patient dose to the trunk of heavy adult patients, and prevent excessive heat load to the anode, a voltage of 110 or even 120 kV may be necessary. A high voltage produces an image that appears "flat" in contrast, but this is acceptable for many applications.

Another option is to keep the kV low but limit the mA, accepting a grainy image in order to maintain contrast. For example, when placing a feeding tube in an adult patient, one may prefer to keep the image contrast high by setting the voltage low so the feeding tube is highly visible. Image graininess would not be important in this application.

Effect of Patient Size

As we have seen, imaging of thick body parts exposes the patient to a higher radiation dose than does imaging of thin parts. What happens if we image a patient from their side? Since patients are generally wider in the right-to-left direction than they are front-to-back, the dose increases when the beam is directed laterally or at a steep oblique.

A further problem for thick body parts is that they scatter radiation to a greater degree, and much of this scatter interacts a second time to be absorbed, further increasing tissue dose.

Radiation skin injuries are much more common in the obese. Choosing the best technique for bariatric patients can be especially challenging. By limiting the mA, one may control the dose rate. But if the image is too grainy, then the procedure may be more challenging and prolonged, negating the advantage of low dose technique.

Complex interventions on the morbidly obese should be performed with reluctance. For these patients especially, one should use the entirety of dose sparing techniques, such as low pulse rate, narrow collimation, and dose spreading (explained in the next chapter) to the maximum extent possible.

Radiation of Extraneous Tissues

On occasion, an arm has inadvertently been allowed to lie in the primary beam during lateral cardiac imaging. In such cases, the arm may be obscured by sterile drapes. The increased tissue

in the beam causes the machine to greatly increase the intensity of the x-ray beam. Because the arm is close to the x-ray source where the x-ray beam is dangerously intense, radiation injuries have resulted.

Make sure you move extraneous body parts out of the path of the direct beam. This will eliminate these structures from the image, decrease the amount of scatter, and protect those parts of the patient's body from excessive radiation. A particular challenge in this regard is the female breast during cardiac procedures, which in younger patients are particularly susceptible to cancer.



13.Anti-Scatter Grids

Grids reduce scatter to the image receptor, improving contrast and reducing noise. But they also increase dose to the patient by a factor of 2 or more because the machine will need to compensate for the loss of transmitted x-rays that are blocked by the grid veins. Therefore, grids should not be used when scatter is low, as in children or thin body parts.

If the x-ray tube is beneath the patient and you need more work space above the patient, you may need to move the detector further from the patient (and the source). Doing so will increase radiation dose because mA will be increased to compensate, but it will also decrease the number of scattered x-ray photons that reach the image receptor. In that case, the grid may no longer be required. If circumstances require a gap of more than 25 cm between the patient and the image receptor, removing the grid is usually a good strategy. The technique of increasing patient to receptor distance to reduce reception of scattered radiation is known as introducing an air gap.

Collimation

Collimation is an effective means of reducing scatter without compromising image quality. By limiting radiation to just the area that is being examined, one can lessen scatter significantly. For example, if the width of the beam is reduced by one-half, scatter may be reduced to as little as one-fourth.

When magnification modes are employed, the collimator automatically closes as the field of view is reduced. However, the operator can use the collimator to further limit the field when that is feasible.

While closing down the collimator does not significantly affect the skin dose at the center of the x-ray beam, this practice reduces the total area of the patient's skin that is at risk. In the event of a skin injury, the radiation injury will be smaller and will be more likely to heal than injury to a large field, since stem cells can migrate into a small skin field more easily. Another advantage of collimation is that, by reducing the field size, the overlap of x-ray fields on the patient's skin can be reduced or eliminated. By reducing the volume of the patient in the x-ray beam, it also likely reduces the risk to the patient of future cancer.

Effective collimation can greatly reduce the radiation doses from scattered radiation to nearby staff.

Virtual Collimation

On older fluoroscopes, you may have to collimate with the beam on in order to view the resulting image area. Newer systems provide a software preview of collimator adjustment in which the exposed field appears as a computer-simulated rectangle overlying the last image held. This is sometimes called virtual collimation. Use this feature to eliminate the unproductive radiation that otherwise would be required to finely adjust the collimator.

Magnification Mode

Most fluoroscopes offer several magnification modes. In a magnification mode, the image information from only part of the image receptor is used to form an image that is displayed using the entire active area of the display monitor. This produces a magnified view of structures in the patient.

As a rule, patient dose rises dramatically with magnification. As you increase the magnification using fluoroscope settings or by moving the image receptor farther from the patient, the number of x-ray photons per pixel will decrease. The ABC on the fluoroscope will automatically increase the radiation output accordingly to produce a viewable image. Avoid magnification whenever possible and use the lowest acceptable magnification in order to minimize radiation dose to the patient.

Detector Size Magnification

Magnification is expressed in terms of the field of view. A smaller field of view improves visualization of small structures at the expense of higher dose.

For example, you may be imaging a patient at a 25 centimeter (cm) field of view and 0.3 mGy per second dose rate. Based on your procedural needs, you might then reduce the field of view to 12 cm by selecting an electronic magnification mode. This increases the patient's dose rate from 0.3 to 1.3 mGy per second (mGy/s) in order to provide sufficient photons for the image receptor. Considering that 1.3 mGy/s is a very high dose rate, you will want to spend as short a time as possible in this mode.

Geometric Magnification

As a result of the diverging x-ray beam, the apparent size of the patient at the image receptor is the actual size multiplied by the ratio of the distance from the source to the receptor divided by the distance from the source to the patient. This is called geometric magnification. This form of magnification increases radiation dose to the patient. Geometric magnification can be achieved by moving the patient closer to the x-ray source in order to increase distance to the image receptor. Alternatively, on some fixed C-arm systems, the patient may be left at the same distance from the x-ray source, but the image receptor may be moved away from the patient. In this case, the ABC will automatically boost x-ray production.

In general, you should only use any method of magnification if it is necessary for the procedure, and not as a default. The balance you want to achieve is to use the least degree of magnification yet still achieve a diagnostic image.

High Dose Rate ("Boost") Mode

Normally the fluoroscope is automatically limited to an estimated skin dose of 0.1 Gy per minute. This is an FDA regulation. Boost mode allows you to override that safety feature. Boost mode increases the intensity of the radiation beam by a factor of two or more. Activation of boost mode requires that you push a control continuously. When active, you will hear a continuous audible signal. Boost mode is limited to an estimated skin dose of 0.2 Gy/min.

The purpose of boost mode is to increase the amount of radiation reaching the image receptor, thereby reducing image noise and increasing the conspicuity of structures or objects relevant to the clinical procedure.

During boost mode, the radiation dose can accumulate quickly. Don't forget that larger patients are already receiving a higher dose rate, so activating boost mode when working with a larger patient can place that patient at very high risk of injury. Boost mode should be used sparingly, and only when necessary.

Be sure to know which button activates normal fluoroscopy and which activates boost mode!

Fluorography

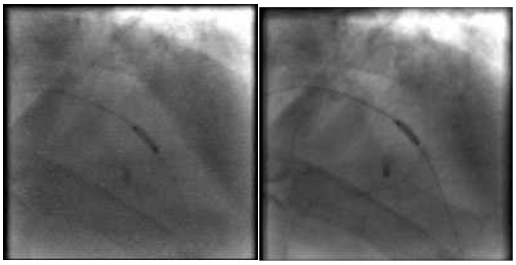
Fluorography is the digital recording of a still image or sequence of images by a fluoroscope, of quality nearly equal to conventional radiographs (plain films). This is done to record parts of the clinical procedure or to produce images for study and analysis after the procedure is completed.

A still image requires a much greater dose per frame than does fluoroscopy because noise is more apparent on a still image than it is when viewing continuous motion. Compared to fluoroscopy, the dose rate of fluorography is 10 to 60 times greater. Like pulsed fluoroscopy, fluorography can be acquired as a series of images, the difference being that each high-quality fluorographic image can be examined in detail.

Examples of fluorography are “spot films,” digital subtraction angiography (DSA), and cardiac CINE angiography. The operator who uses fluorography should be cognizant of the cumulative dose being delivered.

The dose rate of cinefluorography increases with frame rate. Fifteen frames per second is typically used for adult cardiovascular imaging. Dose to the patient is reduced by using as low a frame rate as acceptable and limiting the duration and number of cine runs.

A lower dose alternative to spot images or CINE fluorography is to save a fluoroscopic series. Newer fluoroscopes temporarily store the last dozens or hundreds of fluoroscopy frames. These can be stored for use if these relatively noisy images can be tolerated.



Knowledge Check #4

See Knowledge Check answers beginning on page 74.

1. What are the differences between fluoroscopy and fluorography? Select the correct answer from the four choices that follow.
    a. Fluorography is image recording whereas fluoroscopy displays real-time video images.
    b. The dose rate of fluorography is 10 to 60 times greater than fluoroscopy.
    c. Typical uses of fluorography are digital subtraction angiography and cardiac CINE.
    d. All of the above.

2. The diagnostic value of an image is defined by its resolution, contrast, and noise. Which of the three values is directly affected by the number of x-ray photons absorbed by the image receptor? Select the best answer from the three choices that follow.
    a. Resolution
    b. Contrast
    c. Noise

3. Match the following descriptions to the correct mode.

a. Automatic brightness control	1. Increases when the distance between the image receptor and patient is increased
b. Electronic magnification	2. Increases the maximum allowed intensity of the beam by a factor of 2 or more
c. Geometric magnification	3. Adjusts the radiation output to produce a viewable image
d. Boost mode	4. Increases the apparent resolution of the image by expanding a sub-section of the detector to fill the entire display

4. How will you increase image contrast? Select the correct answer from the four choices that follow.
    a. Increase kV
    b. Decrease kV
    c. Increase mA
    d. Decrease mA

5. Which method of image improvement is described as the practice of moving the image receptor farther from the x-ray source? Select the correct answer from the four choices that follow.
    a. Geometric magnification
    b. Electronic magnification
    c. Boost mode
    d. Automatic brightness control

Chapter 5 – Measuring Dose

In this chapter, you were provided with information that will help you achieve the best possible image. You learned how resolution, contrast, and noise are affected by patient size, scatter, mA and kV, and other fluoroscope settings that affect the quality of the image. Be mindful of the principle of ALARA – As Low as Reasonably Achievable. This principle will guide you into using no more than sufficient radiation to accomplish the procedure.

The next chapter allows you to use the information you've gathered so far, so you can better estimate the dose rate to the patient's skin.

Skin Dose Estimates

In this chapter, you will be presented with methods for estimating skin doses. Skin doses are measured for multiple reasons:

- Monitor the radiation dose in real-time. This helps the operator select parameter settings and to balance the choice between better image quality and lower patient radiation.
- Determine if a patient is at risk for skin injury, requiring clinical follow-up.
- Document the level of radiation exposure in the patient's medical record. This will assist clinicians who subsequently treat the patient.
- Record data for quality assurance and training. Dose metrics can be used to compare the dose management techniques of different operators and identify opportunities for improvement.

When you finish this chapter, you should understand the factors involved in estimating radiation skin dose to the patient during and after a fluoroscopic procedure.

Direct Measurement Technologies

Various types of dosimeters can be placed on the skin in the field of view to measure entrance dose directly. Some of these dosimeter types are read out at the end of the procedure, including thermoluminescent dosimeters (TLDs), optically stimulated luminescent dosimeters, or dosimetry film. Other dosimeters provide radiation measurements in real time, and can trigger audible or visual warnings when a particular dose threshold has been exceeded. Direct dosimeters measure dose at the locations of the dosimeters only and do not necessarily reflect *peak* skin dose, which is the dose at the point on the skin that receives the most radiation. Also, dosimeters may be visible on the final image.

If dosimetry is performed near a wound or percutaneous access, you can secure direct dose measurement devices to the patient's skin beneath an adhesive patch before scrubbing the area.



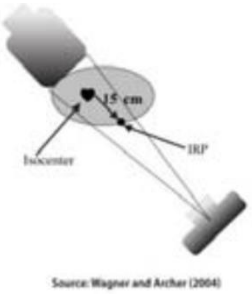
Estimated Dose Provided by the Fluoroscope

It was once common practice to measure the time the beam was on to provide a rough estimate of radiation dose. However this method did not take into account the intensity of the radiation, which varies with the attenuation of the body part being imaged, the settings (e.g., pulse rate and magnification mode) used, as well as dose from image recording, and so was quite inaccurate.

Modern fluoroscopes provide better measures of radiation output based on parameter settings. These measures are the air kerma (kerma is an acronym for kinetic energy released in matter), and the kerma area product (KAP), also known as the dose area product (DAP).

Air Kerma

Air kerma is the amount of energy absorbed by air at the assumed location of the skin. This location is called the reference point or the interventional reference point (IRP). As shown in the diagram on this page, the reference point for a C-arm fluoroscope is defined as 15 cm from the axis of rotation of the arm, called the isocenter, toward the x-ray tube. The fluoroscope calculates air kerma from the known amount of radiation in the center of the beam as it leaves the x-ray source, correcting for the distance from the x-ray source to the reference point. Alternate names for air kerma are “reference air kerma” or “air kerma at the reference point.” Kerma is expressed in units of Gy.



Source: Wagner and Archer (2004)

Kerma Area Product

While Air Kerma is a measure of absorbed dose, another measure is needed to gauge the integral dose delivered over the x-ray field of view. This second measure is called kerma area product (KAP) or dose area product (DAP).

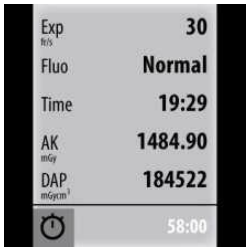
KAP is the sum of radiation over an area of the body. It is expressed in units of Gy*cm^2 (Gy times cm squared). This parameter is displayed on new fluoroscopes; however, it is less useful for estimating peak skin dose than is total air kerma.

KAP is a cumulative exposure metric that increases the longer the beam is on. KAP accumulates more quickly when the area of the beam is increased, or if the intensity of the beam is increased. Since these parameters should be as small as possible, the KAP can be used as a quality control measure of fluoroscopic technique.

We can consider total Air Kerma to be a predictor of deterministic effects, while Kerma Area Product is a predictor of stochastic effects.

Ambiguity in dose nomenclature

Fluoroscope vendors use different terms when expressing dose quantities. For example, air kerma may be referred to as AK. The expression "skin dose" could mean total air kerma or peak skin dose. You will need to ask for clarification from the manufacturer when a term seems ambiguous.



Dose Estimated from Air Kerma

As was previously stated, air kerma is the measure of the kinetic energy deposited into the air by the x-rays at a single reference point. This reference point is assumed to be the entrance skin location, but usually the skin location is closer or farther than this. For example, the air kerma may underestimate dose to an obese patient because the skin is closer to the source than expected.

Another source of error is back-scattered radiation. X-rays scattered back to the skin from deeper tissues may contribute an additional 40 percent to the skin radiation, so a multiplicative factor of 1.4 must be applied to improve the estimated peak skin dose.

A third source of error is that not all of the radiation is delivered to one point on the skin. If the beam is moved about the patient, or projected from different directions, then the incident radiation is distributed over several entrance skin locations. The fluoroscope is unaware of

these motions and attributes all radiation to one skin location, thereby greatly overestimating dose.

Because of the three sources of error listed above, it can be difficult to arrive at an estimation of peak skin dose.

Example: Dose Estimated from Air Kerma

Following cardiac angioplasty with stent placement, you note that the cumulative air kerma for the procedure was 7.5 Gy. Based on this number, you inform the patient that he or she may experience erythema or skin discomfort.

You are curious to know what the peak skin dose might have been. Your first step is to examine the dose report from the study, which logs the total air kerma for the procedure. Based on your memory of the procedure, you recall that the longest runs corresponded to a right posterior oblique (RPO) projection, and that the tube was pointed at this area of skin approximately 50% of the time. You apply this formula:

(Peak skin dose) = (7.5 Gy)*(0.5)*(1.4 back scatter correction)

In this example, the peak skin dose (PSD) is estimated at 5.25 Gy.

As you can see, this is only an approximation. The most relevant measure of dose is the extent of injury to the skin, which will only be known weeks or months after the procedure.

Air Kerma Estimated from KAP

Some older fluoroscopes may provide KAP but not air kerma. It is still possible to derive an estimation of skin dose, albeit with significant uncertainties. As stated previously, the KAP is the air kerma multiplied by the cross-sectional area of the beam. At the reference point where air kerma is measured, the cross-sectional area of the beam is usually 30 to 100 cm^2.

KAP = (total air kerma) * (beam cross-sectional area at reference point)

Therefore, if you divide the KAP (typically in units of $Gy*cm^2$) by an estimated cross-sectional area, usually assumed to be 100 cm^2, you would get an estimated value for air kerma. This is obviously a crude approximation if one is adjusting collimation during the course of the procedure.

Estimate Air Kerma from Beam-on Time

If neither air kerma nor KAP are available, you can roughly estimate skin dose based on the time the beam is on, typically shown in minutes. You can refer to data tables to convert beam-on time to skin dose. These data tables are generated during the mandatory yearly equipment inspection. The beam-on time is the least accurate form of estimation because it does not take

into account differences in technique, and should only be used if no other forms of dose determination are available.

Middle Dose/Continuous Fluoro Mode:

FOV	kV Controlled	mA	Tabletop Output (R/min)
16”	90	3.2	2.3
12”	89	3.2	2.2
8”	95	3.4	2.8
6”	102	3.6	3.5
4.3”	104	3.6	3.5
4.3”	104	3.6	3.6
3.3”	105	3.6	3.3

8” FOV, Continuous Fluoro:

FOV	kV Controlled	mA	Tabletop Output (R/min)
Low	89	3.2	2.2
Middle	95	3.4	2.8
Normal	95	3.4	2.8
High	103	3.6	3.8

Record Keeping

Records of each fluoroscopic procedure should be kept either manually or electronically, in accordance with best practices at your facility. This can be done by saving the dose page or dose report from your fluoroscope. If you cannot save the data, keep a manual record, such as a log or spreadsheet on a computer, or record it in a manner approved at your medical facility into the patient record. In addition, high doses should be specified in the report of the procedure so they are accessible to other treating physicians.

For quality assurance purposes, the following data should be recorded when possible:

- the date of the procedure

- the type of procedure
- fluoroscope operator
- the fluoroscopic unit used
- air kerma, KAP, total fluoro time, and PSD if known, with skin location of any high doses

A service may choose to record additional information. For example, a cardiac cath lab may wish to know the percent of air kerma due to cine image recording.

Thresholds for Documentation

Document dose in the procedure report if the thresholds shown in the table below are exceeded. This will allow providers who subsequently treat the patient or who perform subsequent fluoroscopic procedures to better plan their care.

Parameter	Threshold
Reference point air kerma	3,000 mGy
Kerma-area-product	300 Gy·cm^2; 30,000 µGy·m^2
Fluoroscopy time	30 min

When deciding whether dose thresholds have been exceeded, it is not necessary to perform a thorough and complex calculation of dose. A rough estimate, or even the raw Air Kerma reading from the fluoroscope, is sufficient.

Knowledge Check #5

See Knowledge Check answers beginning on page 74.

1. At the conclusion of a carotid placement, the fluoroscope console displays two dose numbers. The first is 167.85 Gy·cm^2. The second is 1382 mGy. What do these numbers most likely refer to? Select the correct answer from the four choices that follow.
    a. The first is the KAP; the second is the total air kerma delivered to a reference point.
    b. The first is the entrance skin dose in the area of the beam; the second is the exit skin dose.
    c. The first is the absorbed dose per unit area; the second is the equivalent dose.
    d. The first is the dose rate; the second is the cumulative dose.

2. The operator of a fluoroscope starts the procedure with the collimator open to get a wide view of the anatomy, but then collimates the beam down to a small area at the organ of interest. One reason for doing so is to reduce the total body dose of radiation received by the

patient. What measure of dose best reflects the total amount of radiation received by the whole body? Select the correct answer from the three choices that follow.

a. Air kerma
b. Kerma area product
c. Absorbed dose

3. Of the methods below, which is most accurate for measuring skin dose? Select the correct answer from the four choices

a. By noting the total beam on time and comparing it with published reference values
b. By multiplying the beam on time by the value in the phantom dose rate table corresponding to the same size patient and imaging mode
c. By noting the cumulative air kerma on the fluoroscopy console at the end of the procedure
d. By placing dosimeters directly on the patient's skin

Chapter 5 Summary

In this chapter, you were presented with several different methods for estimating radiation dose using information provided by a dosimeter or a fluoroscope.

Deriving a precise skin dose is complicated, but a precise value is rarely necessary. The basic goal should be simply to simply determine which patients received doses below the threshold for skin effect (2 to 3 Gy) and do not require further surveillance, and which received a dose above that level and should be followed. The ultimate measure of skin dose is the biological effect on skin.

While air kerma may be an approximation, the recording of approximate dose is of value to:

- Compose a rough lifetime dose history for the patient,
- Improve fluoroscopic technique for the clinician,
- Assist clinicians who may see the patient in the future if there are skin effects or who may later perform fluoroscopic or radiation oncology procedures on the same body part,
- Better understand deterministic and stochastic effects for society at large.

Chapter 6 - Minimize Dose to the Patient

In this chapter, we will describe additional considerations that should be made when reducing the possibility of a patient injury.

The practitioner has an obligation to the patient to follow these two principles:

- First, the procedure should only be done if it is indicated.
- Second, the procedure must be performed with as little radiation as is practicable.

At the end of this chapter, you should be able to apply strategies to minimize radiation dose to the patient during a fluoroscopic procedure.

Case Study

You are an interventional radiologist. Mrs. Navy has been referred to you for nephrostomy tube placement and ureteral stone retrieval. You are concerned that this procedure will result in a large exposure to the skin of the patient's lower chest. As always, you wish to employ dose sparing strategies. Over this and the next few pages, twelve strategies for minimizing dose to the patient are covered as they relate to Mrs. Navy's procedure.

Pre-Procedure

 # 1-Ensure the Procedure Is Indicated

The first step in minimizing dose takes place before the patient arrives at the imaging suite. You evaluate the proposed procedure before it is scheduled to determine whether it is indicated and safe. Would an alternative procedure be more appropriate? After reviewing prior imaging studies and lab values, you conclude that the requested procedure is the best choice.

 # 2-Standardize Your Protocol

The total amount of beam on time is reduced if the practitioner knows the steps of the procedure and what images will be required. If the procedure is new to you, write out the steps of the procedure before placing the patient on the table. In Mrs. Navy's case, you are familiar with the procedure.

 # 3-Screen for Pregnancy

If a patient is capable of pregnancy and if the procedure is one that is likely to impart a radiation dose to an embryo or fetus exceeding 0.1 gray (Gy), a serum pregnancy test should be performed even if the patient states she is not likely to be pregnant. A radiation dose of 0.1 Gy is only reached during prolonged studies involving direct imaging of the abdominal or pelvic region.

Mrs. Navy is of child-bearing age. Because the radiated field is near the uterus you are concerned of potential fetal radiation exposure. The procedure cannot be delayed until the pregnancy is completed. You elect to perform a serum pregnancy test. The result of the test is negative.

 # 4-Informed Consent

It is good practice to include the possibility of epilation or skin erythema in the informed consent when a lengthy fluoroscopic study may cause the patient to be exposed to greater than 3 Gy of radiation. Use this opportunity to inform the patient of potential skin effects that can develop as a result of his or her exposure. Informed consent should also be obtained if you perform a fluoroscopic procedure on a pregnant patient.

You tell Mrs. Navy that there is a possibility that she may experience some redness or discomfort on her back in the days and weeks following her procedure, and that she may need to return to see you for a skin examination.

During Procedure

 # 5-Position the patient

The safest position for the patient is as far as practical from the x-ray tube and as close as practical to the image receptor. If the patient is draped, ensure that arms cannot slide off the edge of the table and on to the source cowling or separator. Recall that dose increases dramatically as a body part approaches the tube.

For female patients, place the fluoroscope with the tube on the opposite side of breast tissue when possible (this is often not feasible). Breasts, particularly of younger females, are particularly susceptible to radiation-induced cancer.

Lateral approaches require higher doses than do antero-posterior approaches. During lateral exams, keep the patient's arms out of the path of the beam and away from the source.

You place Mrs. Navy on the table in a prone oblique orientation with her arms up. Once the nephrostomy tube has been placed you plan to convert to an antero-posterior projection rather than an oblique which will lower the dose rate significantly because the beam passes through a shorter tissue thickness in the antero-posterior projection.

In the Fluoroscopy Suite

Mary Navy is now positioned on the fluoroscope table and you are at the controls. Use the next steps, 7 through 11, to minimize dose for Mrs. Navy.

 # 6-Set fluoroscope parameters

The next step is to set the technique factors on the fluoroscope. Most fluoroscopes offer several modes optimized for particular classes of procedures. For a nephrostomy tube placement you select the following modes: General Mode, ABC on, low dose on, 23 cm field of view (no electronic magnification), and pulse rate 7.5 frames per second. During the procedure, you will vary the pulse rate and magnification as necessary.

 # 7-Collimation

During the course of the procedure, you adjust collimation frequently to radiate the smallest field necessary to perform the procedure. By keeping the field of view small, you can further apply the principle of dose spreading.

 # 8-Spread your dose

If prolonged exposures to one structure are required, you might close down the collimator as much as possible. Then by changing the degree of obliquity periodically you can spread the entrance skin exposure over several different skin sites. This is called "dose spreading." If a structure is imaged from two different projections, but the projections are not sufficiently different to prevent some of the skin to be exposed by both, then the area of overlap may become erythematous, while the center of each exposed field does not.

Because stone retrieval can be a prolonged procedure with imaging directed at one organ, dose spreading may be a valuable technique. But to effectively employ it, the collimators should be closed down to a small field of view.

Techniques to Minimize Dose to the Patient

 # 9-Tap Fluoroscopy/Last Image Hold

Tap fluoroscopy is a useful practice in which one periodically taps the foot switch momentarily rather than pressing on it continuously. Tap fluoroscopy updates the image on fluoroscopes using the last image hold feature. The image is inspected while the beam is off. This practice is an effective means of reducing the total beam-on time for certain types of procedures that have intervals where little changes on the image, or if one simply wants to check the location of an instrument.

During the procedure, you only turn the beam on when you are actively manipulating the catheter or other device.

 # 10-Be Cognizant of Dose

You assign someone to notify you when certain dose thresholds are exceeded. For example, the technologist could tell you when cumulative air kerma has reached 2000 mGy, and again at each

additional 500 mGy. You are required to have someone notify you at 3000 mGy, 6,000 mGy, and 15,000 mGy.

Record and Review Dose

Mrs. Navy's procedure was successful. There is one more step before you are finished: record and review her dose levels.

 # 11-Record and Review your Dose

By checking the dose at the end of the procedure, you can establish typical dose levels and compare them with other practitioners and with previous studies. One effective way to ensure that the dose is reviewed is by manually entering it in the report or in a quality assurance database.

The total air kerma at the end of the procedure is 3.2 Gy. In your experience, this is on the high end of dose for similar procedures. You conclude that Mrs. Navy might have some transient erythema of the skin but will not have a permanent skin injury. You tell Mrs. Navy that she may experience a temporary redness on her skin. If it doesn't resolve within 14 days, or becomes painful, she should call you. You enter the dose in the report of procedure and in a quality assurance spreadsheet.

<u>It All Adds Up</u>

The decisions to…

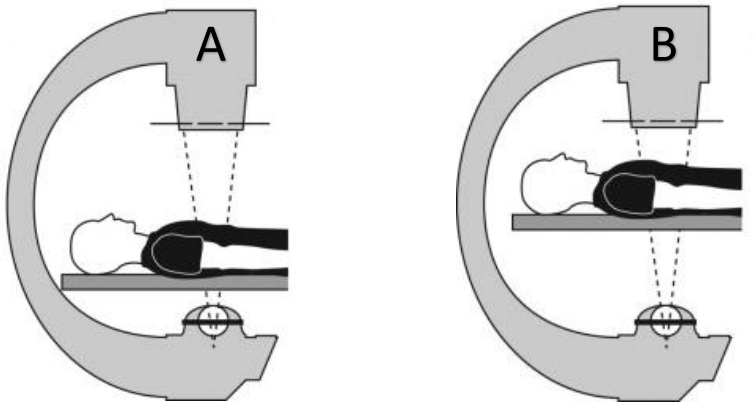
- maximize source to patient distance;
- minimize patient to receptor distance;
- avoid magnification and other high dose modes;
- select low pulse rates;
- avoid using a grid;
- avoid steep obliques;
- collimate the beam; and
- minimize beam on time

…are not small factors. Each of these choices often reduce dose rate by a factor of one-half or more, so that use of all of these techniques together can reduce the dose many fold.

<u>Knowledge Check #6</u>

See Knowledge Check answers beginning on page 74.

1. In the two images that follow, the tube is underneath the table. Select the image that demonstrates the optimal position for the patient.



2. Which approach requires a higher dose to obtain similar image quality?
    a. Lateral
    b. Antero-posterior

3. At which air kerma thresholds is the physician required to be notified that the air kerma has been reached?
    a. 1,000 mGy
    b. 3,000 mGy
    c. 6,000 mGy
    d. 15,000 mGy

Chapter 6 Summary

This chapter focused on methods used to minimize radiation dose to patients during fluoroscopic procedures. These methods involved reducing the time the beam was on, increasing the distance from the source to the patient, minimizing the irradiated area, and reducing the dose rate.

Now that you've finished this chapter, you should be able to apply methods to minimize radiation dose to the patient during a fluoroscopic procedure.

Chapter 7 - Minimize Dose to the Practitioner

Most methods that reduce dose to the patient also reduce dose to the operator and other people in the room. That is because the greatest source of radiation to the operator is scatter from the patient. Limiting the beam on time, collimating the beam, avoiding high dose modes, and using pulsed fluoroscopy at a low pulse rate all reduce dose to both patient and staff.

In addition, one should understand the importance of maintaining a distance from the beam entry site of the patient and using shielding to limit personal dose.

When you finish this chapter, you should be able to apply radiation protection practices to minimize exposure to the operator and other personnel.

Occupational Exposures

The U.S. Occupational Safety and Health Administration (OSHA) has established limits for radiation to the practitioner and other staff in the room, as specified in Title 29, Part 1910.1096, of the Code of Federal Regulations. These regulations state that the employer cannot cause an employee to be exposed beyond the following levels:

- 1.25 rem (12.5 mSv) in any quarter of the year to the whole body, head and trunk, or lenses of the eyes
- 3 rem (30 mSv) per quarter provided that the cumulative lifetime dose does not exceed 5 (N-18) rem, or 50 (N-18) mSv, where N is the age of the employee in years.
- 18.75 rem (187.5 mSv) in any quarter of the year to the hands and forearms or feet and ankles

In addition to the OSHA limits referenced above, state regulations also apply. Indiana Law 410 IAC 5-4-2 limits are as follows:

- 1.25 rem, (12.5 mSv) in any quarter of the year to the whole body, head and trunk, active blood-forming organs, lenses of the eyes, or gonads
- 18.75 rem (187.5 mSv) in any quarter of the year to the hands and forearms or feet and ankles
- 7.5 rem (75 mSv) in any quarter of the year to the skin of the whole body.

Where OSHA and state limits differ, the more conservative must be followed.

If the operator uses radioactive materials, he or she will need to adhere to Nuclear Regulatory Agency (NRC) occupational exposure limits instead of OSHA limits. In that case the sum of the exposures from x-rays and radioactive materials must not exceed NRC limits.

The radiation safety officer or radiation safety committee at your facility should review doses to employees. If exposures approach specified levels, a plan should be devised to improve safety practice or reduce the number of procedures.

Personnel Dosimetry

Each staff member in the room during a procedure must wear a dosimeter, often called a radiation badge, near the collar but outside of the lead apron to monitor dose to the face and eyes. In addition to the collar badge, employees will wear a second badge on the chest or abdomen under the protective apron. Do not confuse the collar dosimeter with the under-apron dosimeter! Each is labeled for correct placement. Inadvertently exchanging dosimeters will skew the readings of both for the monitoring interval.

Store your dosimeter away from x-ray equipment and other sources of radiation. A common error is to leave it on the lead apron in the fluoroscopy room. Some types of badges may give false readings if exposed to heat. Don't wear your badge if you become a patient – it is intended to monitor occupational exposure only.

Wear Your Dosimeter

Unfortunately, not all clinicians wear dosimeters. Only 33-77 percent of responding interventional cardiologists stated that they utilized radiation badges routinely in surveys conducted throughout 2008 by the International Atomic Energy Agency (IAEA) during various training courses in which cardiologists from over 56 countries participated. Physicians who refuse to wear badges may have been concerned that they were receiving excessive doses and were afraid they would be told to stop performing procedures. High volume interventionalists may come close to the OSHA dose limits but it is rare that a physician is asked to stop performing procedures for a quarter, particularly if they avail themselves of available shielding.



Finger Dosimeters

An operator whose hands may approach the radiation field can request a finger dosimeter to measure hand exposure. The finger dosimeter looks like a ring and can be worn under a sterile glove. Some dosimeter rings can be sterilized. The ring should be worn on the dominant hand with the sensitive badge area turned toward the beam. Be aware that the ring detects radiation at the base of the finger rather than at the fingertip where the dose may be higher. Wear the finger dosimeter for several months as a tool to troubleshoot technique and reduce radiation

exposure. In the table that follows, Wagner and Archer provide an example of actions and monitoring efforts needed based on ring dose measurements[11].

Monthly Ring Dose	Action	Continue Monitoring?
Less than 3 mSv (300 mrem)	Dose sufficiently low to discontinue monitoring	Discontinue for now; repeat in one year if desired
3 mSv-10mSv (300 mrem-1 rem)	Efforts to reduce dose are recommended	Yes
Greater than 10 mSv (1 rem)	Immediately adjust habits to reduce dose.	Yes



Basic Principles in Radiation Protection

The methods of personal radiation protection rely on the following three principles:

1. Time—minimize the time that the beam is on.
2. Distance—stand as far from where the beam enters the patient as reasonably possible.
3. Shielding—use protective x-ray barriers.

Time

The single most important exposure factor is the length of time the x-ray beam is on. Don't turn the beam on unless you must view a live image.

Modern fluoroscopes emit an audible signal after each five minutes of beam on time. This alarm must be manually turned off. By keeping track of the number of five-minute intervals, one knows whether the procedure is taking longer than usual.

Distance

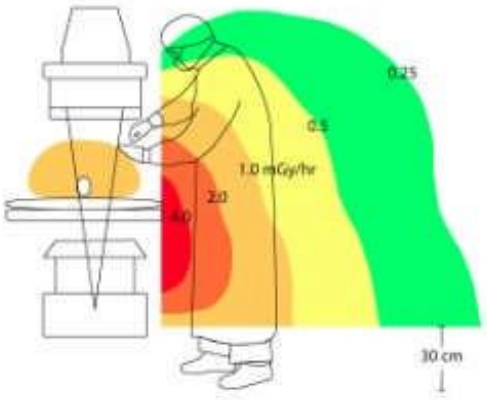
Scattered x-rays emanate from the radiated tissue of the patient, and especially from the entrance skin. You should keep as far away from the radiated field as the procedure allows. The

[11] Archer BR. Radiation management and credentialing of fluoroscopy users. *Pediatric Radiology*. 2006;36(Suppl 2):182-184. doi:10.1007/s00247-006-0209-z.

highest dose areas depend on where the x-ray tube is positioned: under the patient table, over the patient table, or laterally on one side of the patient table.

Under the table

The illustration below shows ranges of exposure from scattered radiation relative to the patient when the x-ray tube is located under the patient. The highest levels of radiation are found closest to the patient at about the level of the table as well as under the table, exposing the operator's legs. That is because much of the forward scattered radiation (in this case radiation traveling upwards) is shielded by the patient. Notice that radiation levels fall off quickly as one stands back from the table. Radiation to the face can be minimized if one stands upright rather than leaning into the field of view. Short operators will incur greater radiation to the face. This effect can be reduced by standing on a platform.



Over the Table

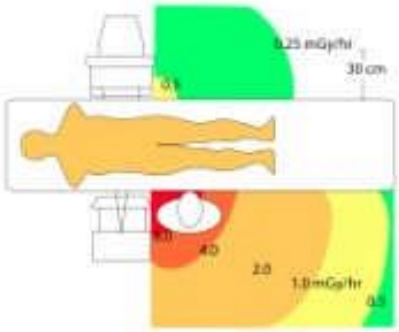
If the x-ray tube had been placed above the table, most scattered radiation from the entrance skin would be directed to the chest and face of a standing operator. This is usually a poor tube orientation. However, urology suites often place the x-ray tube above the patient because the urologist sits low, beneath the plane of the table, and wants to avoid radiation scattered downwards. Any other staff in the urology suite should remain several feet away when the beam is on. Note that newer generation urologic fluoroscopes may position the tube below the patient.



Lateral Projection

During a fluoroscopic procedure using a lateral projection, the dose of radiation scatter to you is highest when you are on the same side of the patient as the x-ray tube. The image below shows scattered radiation isodoses from a C-arm fluoroscopy system in a lateral projection. Since most radiation scatter is found on the side of the patient closest to the x-ray tube, plan to stand on the far side of the patient from the x-ray tube if it is practical to do so.

Orientation of the patient can also be a concern. If the x-ray tube is below a supine patient, while you are standing at the side of the patient, and if the patient is rolled 45 degrees toward you, the entrance skin remains on the far side of the patient. But if the patient is rolled 45 degrees away from you so the patient's back becomes visible, the entrance skin location on the patient's back scatters radiation toward you.



<u>The Irradiated Field</u>

Ensure that your hands are not exposed to the primary beam. Dose rates of a beam that exits above the patient from an x-ray tube located under the patient are in the range of 5 to 20 mGy per hour[12]. If the x-ray source had been above the patient, the beam dose rate above the patient would be 100 times greater to your hands. Your hands are directly exposed to the

[12] Miller DL, Balter S, Schueler BA, Wagner LK, Strauss KJ, Vañó E. Clinical radiation management for fluoroscopically guided interventional procedures. *Radiology*. 2010 Nov;257(2):321-32. doi: 10.1148/radiol.10091269.

primary beam if they appear on the display monitor. When your hands must be close to the beam, it is best to collimate the beam to be less than the full monitor width so you are certain of the limits of the beam.

When manipulating instruments in the radiated field, such as an aspiration needle, one should either turn the beam off and on as you adjust and check the position, or else hold the instrument with a clamp. If your hands must be in or near the beam when it is on, do so only briefly and only on the side of the patient opposite the x-ray tube. If you routinely do this, you should wear a finger radiation dosimeter on your hand that receives the largest dose.



Exercise

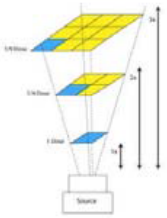
Read the problem below and select the best strategy to reduce radiation dose to the fluoroscope operator. The best strategy will lower dose for both the physician and the patient.

The Inverse Square Law

The level of scattered radiation drops with distance from the entry skin according to the inverse square law. This presents a simple strategy for lowering personal dose, namely, step back from the beam whenever possible.

The inverse square law means that radiation decreases by the inverse square of the relative increase in distance. For example, the dose rate to the operator standing 30 centimeters away from the entrance skin is 100 times greater than the dose rate to the observer standing three meters distant. Another way to think of this is that standing 3 meters away affords the same or greater level of protection as wearing a lead apron.

The nurse who sits next to the patient's head during procedures may incur high doses on her collar dosimeter. A typical dose rate next to the table during fluoroscopy is 10 mGy per hour. A better technique would be to stand. Even better, stand a few feet away from the table unless checking the patient's status. During digital subtraction angiography (DSA), or CINE runs, the nurse should step out of the room and observe the patient through the control window or stand behind a protective shield or barrier.



Shielding

Shielding comes in many forms, including lead in the walls and windows, lead drapes/skirts around the fluoroscopy table, transparent ceiling-suspended barriers, lead aprons, and even other people in the procedure room.

Aprons

Protective aprons of with 0.5 millimeters (mm) of lead or the equivalent are commonly worn by operators and others in the room.

Many interventionists complain of back and shoulder pain when wearing lead aprons for long hours. This results from the weight of the apron on the shoulders. One solution is an apron with a waistband that transfers some of the load to the pelvis. Another possibility is a two-piece apron consisting of a vest and skirt. One may purchase a lightweight apron made of composite materials that offers the same shielding as lead but is not as heavy. Another possibility is to wear a backpack frame to lift the apron off the shoulders.

When not in use, hang up aprons rather than throwing them down on a counter. Refraining from folding the lead prolongs the life of the lead material. Check aprons at least annually for cracks or holes.

Thyroid Shield

Thyroid shields that provide shielding equivalent to 0.5 millimeter (mm) of lead should be worn by males under 30 years old and females under 40 years old. These individuals are at increased risk for developing radiation induced thyroid cancer.



Eye Protection

Recent data on the radiosensitivity of eye lenses indicate that the threshold dose for radiation-induced cataracts is much lower than the 150 mSv annual limit established some years ago. If you routinely perform interventional procedures, it is strongly recommended that you use protective shielding for your eyes[13].

Eye shielding comes in two forms: ceiling-mounted shields and protective eyewear.

- The ceiling-mounted shield can be partially or fully transparent and can provide optimum shielding for your head, including your eyes, and your neck. Many mobile eye shields are contoured to fit against the patient or have an attenuating drape along the lower edge to position around the patient. This shielding arrangement also serves as a barrier for other staff in the room.
- Protective glasses or goggles should be worn by practitioners who perform a high volume of procedures and who require direct access to the patient near the imaging field. Most glasses for this purpose have lenses of 0.75 mm lead-equivalent thickness. This reduces eye dose to approximately 17.5% of the unshielded dose. By comparison, non-leaded conventional glass lenses afford about a 35-percent dose reduction. Plastic lenses are not protective. Designs differ, but should have side shields because scatter can enter from the side when you look at the monitor. Full face shields are also available.

Note: Ceiling-mounted shields will also shield the collar badge, but leaded glasses will not. In order to more accurately estimate eye dose, notify the Radiation Safety Officer that you wear leaded glasses and a correction can be applied.

Mobile Shields

In addition to ceiling-mounted radiation shields, floor-standing mobile shields may be used in the vicinity of the fluoroscope. Mobile shields are available in 1.0 to 1.5 mm lead-equivalent thickness to provide nearly complete protection from scatter in the shield's shadow. Mobile shields can be tall, whole-body, or lower body shields that protect from radiation scatter when the x-ray tube is below the patient.

Savvy technologists often stand behind the physician in order to gain additional shielding while also remaining close at hand.

Collimation to Reduce Staff Exposure

In addition to time, distance, and shielding, one should make use of collimation. Reducing the exposed field of view dramatically reduces scattered radiation to the operator and other staff.

[13] Miller DL, Balter S, Schueler BA, Wagner LK, Strauss KJ, Vañó E. Clinical radiation management for fluoroscopically guided interventional procedures. Radiology. 2010 Nov;257(2):321-32. doi: 10.1148/radiol.10091269.

As was stated previously, if you need to move your hands near the image field, first collimate to make the field as small as possible to ensure that your hands are not exposed to the primary beam.

Exposure to Persons Not Involved with the Procedure

Fluoroscopy exam rooms and operating rooms typically have concrete floors and ceilings, with lead lined walls to a height of seven feet. However, mobile C-arms may be brought to areas of the hospital that lack wall shielding. For example, studies may be occasionally performed in the intensive care unit (ICU) when the patient's condition precludes transportation to a remote imaging suite.

If this is a frequent occurrence, one should consider constructing a shielded area within the ICU that provides protection for other employees. Proactive planning with your radiation safety officer or medical physicist can address important topics like the optimal location of the unit and potential shielding needs. Dose to persons not involved with the procedure and to the general public cannot exceed 1 mSv (100 rem) per year. Be sure to consider exposure to those sitting in adjacent offices.

When performing studies without wall shielding several precautions should be made:

- Before turning on the beam, inform the staff so they have the option of moving away as far as practicable and/or putting on a lead apron.
- Personnel who are not needed should leave the area.
- Because of the inverse square law, patients who are more than 3 meters away might not need to be moved or shielded during occasional brief procedures.

Pregnant Personnel

A woman who is pregnant may continue to perform fluoroscopy, or she can ask to be reassigned to a low radiation duty. If a woman wishes to be reassigned she must declare her pregnancy in writing. If this is the case, her supervisor may consider options for her work assignments, but the supervisor is not obligated to do so if the employee's work environment does not present an unusual risk of high exposure. Declaration of pregnancy is entirely voluntary.

If a pregnant woman continues fluoroscopy, she should wear a wraparound apron. If she already wears a chest badge, she should move the badge anterior to the uterus. A second badge can be assigned if she usually only wears a collar badge. The under-apron badge should be exchanged monthly. Exposure to the badge under the apron must not exceed 0.5 rem (5 mSv) during the pregnancy and should not exceed 0.5 mSv (50 mrem) in any month. Note, however, that this limit does not apply to pregnant employees who must themselves undergo medical procedures, and also does not apply to a pregnant woman who has not declared her pregnancy to the Radiation Safety Office.

Since the abdominal wall attenuates x-radiation, the actual fetal dose is usually 25 percent or less of the recorded dose of the badge under the apron. As a result, if a pregnant employee

were exposed to the maximum 0.5 mSv dose each month, the fetus would receive about 1 percent of the expected threshold for effect[14].

Caregivers and Others in the Room

In general, visitors and family members should not enter the fluoroscopy room during a procedure. However, when imaging children, you can use your discretion in allowing an adult family member to wear a lead gown and stand in the room. Position the family member away from the table during the procedure to reduce their exposure to scattered radiation.

A fluoroscope manufacturer's technical representative can enter the room during a procedure, provided he or she wears protective shielding. Still, the representative may not operate the fluoroscope to expose a patient.

You should not require an employee to routinely restrain patients who are being irradiated during a procedure.

Knowledge Check #7

See Knowledge Check answers beginning on page 74.

1. A nurse sits at the head of the fluoroscopy table during interventional procedures so she can keep close watch on patients who are sedated. Her film badge routinely shows high exposures. Which strategies will help this nurse reduce her exposure levels while monitoring the patient? Select the two best strategies from the four choices that follow:
    a. The nurse could observe the patient from behind a protective shield.
    b. The nurse must only enter the procedure room when the X-ray beam is off.
    c. The nurse can check the patient intermittently and then return to a standing position a few feet from the table.
    d. The nurse should only use remote telemetry for patient monitoring.

2. Where is the highest level of scatter radiation found? Select the best answer from the four choices that follow.
    a. Near the x-ray source
    b. Close to the beam entry point on the patient's skin
    c. At the image receptor
    d. At the head of the patient table

[14] Timins JK. Radiation During Pregnancy. *N J Med*. 2001 Jun;98(6):29-33.

3. Which protection measures should you take to avoid radiation-induced cataracts? Select all measures that apply from the four choices that follow.
    a. Stand back as far from the table as is practicable.
    b. Wear leaded eyewear if you must work on the patient close to the imaging field.
    c. Wear a collar badge dosimeter and modify practices to minimize the reading.
    d. Use a transparent radiation barrier to shield your face and neck.

4. What precautions are recommended for a pregnant fluoroscope operator? Select all that apply from the four choices that follow.
    a. She should wear an additional dosimeter under the lead apron.
    b. She cannot operate a fluoroscope.
    c. She must wait until the second trimester before resuming fluoroscopic duties.
    d. She must stop performing fluoroscopy if the estimated fetal dose is likely to exceed 5 mSv during her pregnancy.

5. A portable C-arm fluoroscope is brought into the ICU to aid in central line placement for the patient. Which are the best practices for radiation protection of unshielded personnel nearby? Select all correct answers from the four choices that follow.
    a. All personnel in the ICU must wear lead aprons.
    b. All persons not involved in the procedure should be advised to move at least three meters away.
    c. Staff within three meters of the fluoroscope must wear lead aprons.
    d. Fluoroscopy can only be performed in a space that has been shielded with 1mm lead equivalent to a height of 7 feet.

Chapter 7 Summary

This chapter covered safety concerns and strategies to minimize radiation dose to personnel in the room during fluoroscopic procedures. You should now be able to apply radiation protection practices to minimize risks to the operator and other personnel**.**

Glossary and Resources

Term	Definition
Air Kerma	Kerma stands for Kinetic Energy Released per MAss. Air Kerma is the amount of energy absorbed by air at the assumed location of the skin, usually 15 cm from the axis of rotation of the fluoroscopy arm. See also Reference Point.
ALARA	An acronym for "as low as (is) reasonably achievable." To practice ALARA means to make every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as is practical. This considers economic and patient care factors as well.
Anode	The negatively-charged electrode into which electrons collide to produce x-rays. In x-ray machines this is typically tungsten.
Anti-Scatter Grid	Intercepts the x-rays scattered by the patient that can cause clouding of the image, while allowing transmitted x-rays to pass through. Grids can also remove a significant portion of unscattered x-rays, and therefore patient dose must be increased to maintain image quality.
Automatic Exposure Rate Control	Known as automactic exposure control (AEC), automatic exposure rate control (AERC), or automatic brightness control (ABC). Automatically varies current and voltage when needed for the body part being imaged; the output from the image receptor is continually monitored and the x-ray settings adjust automatically to produce images of consistent brightness and quality. Dependent on proper collimation.
Background Radiation	A measure of the ionizing radiation present in the environment at a particular location which is not due to deliberate introduction of radiation sources.
Boost Mode	See High Dose Rate Mode.
Bremsstrahlung	The x-ray produced when a moving electron's path is altered by the electromagnetic interaction of a nearby positively-charged nucleus. Bremsstrahlung accounts for approximately 80% of the fluoroscopy beam.
Cathode	The negatively-charge electrode from which electrons are accelerated across a voltage field. X-ray production begins when the cathode is heated to release electrons.
Characteristic Radiation	When a moving electron knocks another electron out of its orbital, a higher-shell electron will drop into the empty space. The difference in energy is emitted as an x-ray. Characteristic radiation accounts for approximately 20% of the fluoroscopy beam.
Cinegradiography	The digital recording of a still image or sequence of images by fluoroscope, of quality nearly equal to conventional radiographs. Cineradiography can produce doses 10-60 times greater than standard fluoroscopy. Examples include spot films and digital subtraction angiography.

Collimator	The adjustable lead shutter attached to the beam port of the x-ray source that can be closed down to restrict the size of the x-ray beam and limit the area of the body that is irradiated.
Contrast	The relative difference between light and dark areas of an image and the ability to differentiate gray-scale gradations ranging from white to black. Affected by voltage, scatter, body part thickness, use of an anti-scatter grid, and field size.
Current (mA)	The number of electrons crossing the high voltage field. The current corresponds to the number of x-rays produced. Expressed in milliamperes (mA), where 1 mA = 6.24×10^{15} electrons per second.
Declared Pregnancy	A pregnancy that has been voluntarily stated in writing and submitted to the Radiation Safety Office. Personnel monitoring limits are lower for a declared pregnant person (500 mrem whole-body), but these cannot be enforced unless the pregnancy is declared.
Deterministic Effect	Effects that are expected to occur. There is a threshold dose below which the effect does not occur, and severity increases with dose. Also called probabilistic effects. Deterministic effects from radiation dose include skin burns, sterility, and necrosis.
Display Monitor	A cathode ray tube or flat panel display that shows images, settings in use, and measurements of x-ray dose.
Distance (Radiation Protection)	Increase the distance from the radiation source in order to reduce total dose. See also Inverse Square Law.
Dose (Absorbed)	The amount of radiation energy absorbed by tissue per mass of tissue. Expressed in Gray (Gy) or Rad.
Dose (Effective)	The tissue-weighted and radiation-weighted sum of the absorbed doses in all tissues and organs of the human body. Represents the stochastic health risk of ionizing radiation to the whole body. It takes into account the type of radiation and the radiosensitivity of each organ or tissue being irradiated, and enables summation of organ doses due to varying levels and types of radiation, both internal and external, to produce an overall calculated effective dose. Expressed in Sievert (Sv) or rem.
Dose Area Product	See Kerma Area Product.
Dose Fractionation	Splitting a larger dose into smaller doses over a longer period of time. This allows the DNA of healthy cells, which typically have better repair mechanisms than unhealthy cells, to repair between doses. Many radiation therapy treatments use dose fractionation.
Dosimetry	The process of wearing a radiation badge or badges, which are then used to measure and calculate an estimated radiation dose.
Electromagnetic Radiation	Radiation made up of packets of pure energy. These include radio waves, microwaves, infrared, visible light, ultraviolet light, x-rays, and gamma rays. Electromagnetic radiation is not of sufficient energy to ionize until approximately 13.6 eV, the binding energy of an electron to a hydrogen atom, which falls in the ultraviolet range.

Flat Panel Detector	Transmits images directly to the display monitor without an intervening video camera. It has greater sensitivity to x-rays than does an image intensifier tube and therefore helps to reduce patient dose.
Fluorography	See Cineradiography.
Focal Spot	The area of the anode surface which receives the beam of electrons from the cathode. A smaller focal spot creates better definition, but x-ray output is more limited.
Gray (Gy)	Unit of absorbed dose. 1 Joule per Kilogram. 1 Gray = 100 rad. See also Dose (Absorbed).
Heritable Effects	Radiation-induced mutations of sperm or ova that can be passed on to future generations. These have been demonstrated in lab animals, but have never been observed in humans.
High Dose Rate Mode	Also called Boost Mode. HDR mode increases the intensity of the radiation beam by a factor of two or more by overriding FDA-regulated safety controls to allow for better image quality.
Image Intensifier Tube	X-rays strike a cesium iodide phosphor that converts the radiation into visible light, where the number of photons is amplified by a phototube. The light is detected by a video camera and displayed on a monitor.
Image Receptor	An x-ray detector that converts low intensity x-rays to a signal that may be viewed as an image on a video monitor or that may be stored. There are two types of image receptors: image intensifier tubes and flat panel detectors.
Internal Commission on Radiological Protection (ICRP)	An independent, international, non-governmental organization with the mission to provide recommendations and guidance on radiation protection. The values for determining effective dose from absorbed dose based on tissue radiosensitivity (tissue weighting factors) came from an ICRP report.
Interventional Reference Point	See Reference Point.
Inverse Square Law	The law stating that the radiation intensity is inversely proportional to the square of the distance from the source, i.e. if the distance is doubled, the radiation intensity is decreased by 75%. $$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2} \quad or \quad I_2 = \frac{I_1 D_1^2}{D_2^2}$$ where I = intensity and D = distance.
Ionization	The process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions, often in conjunction with other chemical changes. Electromagnetic radiation has the potential to ionize above about 13.6 eV, the binding energy of an electron to a hydrogen atom.
Isocenter	The axis of rotation of a fluoroscopy C-arm.
Kerma Area Product ($Gy*cm^2$)	The sum of radiation over an area of the body, calculated by air kerma multiplied by field size.
kVp	See Voltage (kVp).

Last Image Hold	The last image is displayed on the monitor when the beam is turned off rather than letting the screen go blank, which allows the operator to study the most recent image without irradiating the patient. This feature is required by the FDA.
Latent Period	The time between radiation exposure and the induction or detection of an effect. The latent period for leukemia is around 5 years, and for solid cancers can be closer to 20 years.
Magnification Mode	The mode in which the image information from only part of the image receptor is used to form an image that is displayed using the entire active area of the display monitor. To magnify, the patient can also be moved closer to the x-ray source and further from the image receptor. Both of these options will increase patient dose.
Noise	The grainy appearance of an image due to random variation in the intensity of individual image pixels that do not provide information about the patient's anatomy or material in the patient. Affected by current and voltage, resolution, duration of the acquisition (pulse width), and scatter.
Occupational Exposure	Exposure to radiation due to work. It does not include background radiation or other radiation received while not performing work, such as a medical procedure. Annual limits are 5,000 mrem to the whole body, 15,000 mrem to the lens of the eye, and 50,000 mrem to the skin and extremities. Pregnant workers (if declared) are limited to 500 mrem whole-body exposure. The public is limited to 100 mrem due to occupational sources.
Patient-to-Receptor Distance	The distance from the patient's skin surface to the detector opposite the source.
Peak Skin Dose	The absorbed dose at the skin location that has received the highest dose. This quantity is used to predict if a skin injury may occur as a result of a fluoroscopic procedure.
Personnel Dosimetry	The radiation body or finger badges worn to measure radiation exposure. Depending on how the badges are instructed to be worn and what kind of protection the operator is wearing (lead glasses, lead apron, etc.) the readings from the badges will be calculated to determine an occupational dose estimate.
Photon	A massless particle representing a quantum of light or other electromagnetic radiation. A photon carries energy proportional to the radiation frequency.
Pulse Mode	The beam is pulsed rather than continuously on, which serves to reduce patient dose.
Rad	Unit of absorbed dose. 100 Rad = 1 Gray. See also Dose (Absorbed)
Reference Point	Also Interventional Reference Point. Usually 15 cm from the axis of rotation of the isocenter.
Rem	Unit of effective dose. 100 rem = 1 Sv. See also Dose (Effective).

Sentinel Event (Fluoroscopy)	Per the Joint Commission, any unexpected occurrence involving death or serious physical or psychological injury, or the risk thereof. This includes prolonged fluoroscopy with cumulative dose >1500 rads (>15 Gy) to a single field, or any delivery of radiotherapy to the wrong body region or 25 percent above the planned radiotherapy dose.
Separator	A spacer attached to the tube housing designed to keep the patient at a reasonable distance from the x-ray source, done specifically to avoid the high skin-dose rates that can be encountered near the tube port.
Shielding (Radiation Protection)	More dense shielding limits x-ray transmission more effectively. Fluoroscopy shielding comes in the form of lead aprons, lead glasses, and mobile lead glass barriers.
Sievert (Sv)	Unit of effective dose. 1 Joule per kilogram. 1 Sv = 100 rem. See also Dose (Effective).
Source-to-Patient Distance	The distance from the x-ray tube to the patient's skin surface. For stationary fluoroscopy systems, this is at least 38 cm by regulation; for mobile C-arm units, this is at least 30 cm.
Spatial Resolution	The ability to portray small features; the "sharpness" of an image. Affected by focal spot size, magnification, motion, and number of pixels.
Stochastic Effect	Effects that occur based on probability, where the risk of an effect increases with total dose, but the severity does not. Stochastic effects from radiation dose include cancer and heritable effects.
Tap Fluoroscopy	The practice in which one periodically taps the foot switch momentarily rather than pressing it continuously. Tap fluoroscopy updates the image on fluoroscopes using the last image hold feature, allowing the image to be inspected while the beam is off.
Time (Radiation Protection)	Minimize the time the beam is on, or minimize the time that staff is exposed to radiation, in order to reduce total dose.
Virtual Collimation	A software "preview" of collimator adjustment in which the exposed field appears as a computer-simulated rectangle overlying the last image held. It allows for collimator adjustment without irradiating the patient.
Voltage (kVp)	The difference in electric potential between the cathode and anode. The voltage between the cathode and anode determines the energy with which electrons strike the anode material. It corresponds to the energy of the x-rays produced. Expressed in kilovolt peak (kVp), where the average energy of the x-rays produced is approximately 1/3 of the peak voltage.
X-Ray	Electromagnetic radiation (photon) of ionizing potential that originates from the electron shell rather than the nucleus. See also Bremsstrahlung and Characteristic Radiation.

X-Ray Tube	A glass vacuum chamber that contains a negatively-charged cathode filament, which is a source of electrons, and a positively-charged tungsten anode, which serves as a target for the electrons. Electrons travel across a high-voltage field from the cathode, where they interact with the anode material (typically tungsten) to give off x-rays. See also Bremsstrahlung and Characteristic Radiation.

Answers to Knowledge Checks

Correct answer to #1-1:

Options (B) and (C) are correct. The entrance dose is about 100 times greater than the exit dose for a 25-cm thick abdomen. This is because for every 4 cm of travel through soft tissues, the dose to tissue from the X-ray beam is reduced by about one-half.

Correct answer to #1-2:

Option (B) is correct, as the dose at the skin location that has received the highest dose is called the peak skin dose. The absorbed dose is the amount of radiation energy absorbed by tissue, and entrance dose is the dose at the skin site where the x-ray beam enters. The entrance skin dose will be essentially the same as the peak skin dose if there is a single x-ray beam projection for the entire procedure. However, if multiple beam projections are used, with the beams incident on different areas on the skin, the peak skin dose will be the largest entrance skin dose. Effective dose is a weighted average of the doses to various organs and is a measure of the estimated risk of cancer. The peak skin dose may be at a location where two x-ray fields overlap.

Correct answer to #1-3:

Options (B) and (D) are correct. X-rays are a form of ionizing radiation, and ionizing radiation is energetic enough to directly detach electrons from atoms.

Correct answer to #1-4:

The statement is true. The two SI units used for patient exposures are the gray and the sievert.

Correct answer to #2-1:

Option (A) is correct. Significant skin effects usually take weeks to become evident. Erythema is evident before skin ulceration.

Correct answer to #2-2:

Option (A) is correct. Radiation sensitivity is largely dependent on cell reproduction rate. Incidental radiation to organs such as the breasts and lungs should be minimized if possible.

Correct answer to #2-3:

Options (B) and (C) are correct. Anticipating transient erythema, you should instruct the patient to check his or her skin for erythema that might develop up to 14 days after the procedure. The patient should call you if symptoms develop at which time you can decide if he or she needs to

appear for a physical exam. It's unlikely that the patient will require a skin graft. One week is too early for a skin exam.

Correct answer to #2-4:

Options (A) and (D) are correct. The risk of stochastic effects such as cancer accumulate over multiple fluoroscopic procedures. The degree to which deterministic effects accumulate over multiple procedures depends upon the intervals between exposures.

Correct answer to #3-1:

Options (A) and (B) are correct. Increasing the pulse rate eliminates jerky-motion from the images, as one may be seen in the structures that are moving, at the expense of greater patient radiation dose. Beam collimation and tissue contrast are independent of pulse rate.

Correct answer to #3-2:

Options (A), (B), and (C) are correct. The collimator is an adjustable lead shutter that can be closed down to limit the area of the body that is irradiated. By collimating the beam to the diagnostically appropriate field of view, you will minimize radiation to the patient, as well as scattered radiation striking the operator and others in the room. Since fewer scattered photons strike the receptor, image contrast may also be improved.

Correct answer to #3-3:

Option (A) is correct. Automatic brightness control (ABC) varies the mA and kV as needed for the density and thickness of the body part being imaged. When the fluoroscope is set to ABC mode, the output from the image receptor is continually monitored and the brightness level is adjusted automatically to produce consistent image clarity.

Correct answer to #3-4:

The correct answers are options (A) and (C) because two focal spot sizes are available on x-ray tubes: a large one, generally about 1 mm in size, and a small one of about 0.5 mm. The small size provides better image definition, but the x-ray output is limited and not sufficient for all tasks. The large size provides less definition, but permits a greater x-ray output when the procedure requires it.

Correct answers to #3-5:

The correct matches are these: a.5, b.3, c.4, d.2, e.1

Correct answer to #4-1:

Option (D) is correct. All three statements that compare fluorography and fluoroscopy are true. Remember, the goal of x-ray imaging is to produce images that are adequate for the clinical task, but are not ideal images.

Correct answer to #2:

Option (C) is the best choice since a major source of noise, commonly the most important, is random variations in the number of x-ray photons detected by individual areas on the image receptor. These variations become apparent if there are insufficient x-ray photons reaching the detector elements of the image receptor. Another source may be electronic noise. Noise is especially apparent when you are subtracting two similar images, as you would do in digital subtraction angiography (DSA). The apparent resolution and image contrast may be degraded by high levels of noise.

Correct answer to #4-3:

The matches are a.3, b.4, c.1, d.2

Correct answer to #4-4:

Option (B) is the correct answer. Lowering kV will increase the image contrast and higher kV will raise the degree of x-ray penetration. If you are imaging a large body part, you may want to choose a lower kV to see the iodine contrast material or metal instrument. By the same token, increasing the mA will improve the conspicuity of low contrast and small anatomical structures, but it will expose the patient to higher risk of injury.

Correct answer to #4-5:

Option (A) is correct. The practice of moving the image receptor farther from the x-ray source for image improvement is known as geometric magnification. As a result of the diverging beam, the size of the patient at the receptor is magnified by the ratio of the distance from the source to the detector divided by the distance from the source to the patient.

Correct answer to #5-1:

Option (A) is the correct answer. The first number has units appropriate to kerma area product. The second number has units of appropriate to the total air kerma delivered to a reference point. These are the values that are commonly displayed by a fluoroscope.

Correct answer to #5-2:

Option (B) is the right answer, as the kerma area product (KAP), also known as dose area product (DAP) is the measure that best reflects the radiation dose received by the whole body. The KAP measures the integral dose delivered over the x-ray field of view.

Correct answer to #5-3:

Option (D) is the correct answer, as placing dosimeters directly on the skin of the patient is the most accurate way to measure the entrance skin dose. This is not commonly done.

Correct answer to #6-1:

Option (B) is the best selection, as this position has the patient as far as possible from the x-ray source and as near to the receptor as possible while still allowing room for the clinician to perform a procedure.

Correct answer to #6-2:

Option (A) is correct: Lateral approaches require a higher dose to maintain similar image quality when compared to antero-posterior approaches. This is due to the thickness of tissue through which the radiation beam must traverse.

Correct answer to #6-3:

Options (B), (C), and (D) are correct. The physician must be notified when the air kerma value reaches 3,000, 6,000, and 15,000 mGy. The decision to continue the procedure must be recorded in the patient's medical record.

Correct answer #7-1:

Options (A) and (C) are correct. While the nurse should be behind a barrier or observing from the control room during a DSA procedure, the nurse can stand a few feet from the table and monitor the patient intermittently during parts of the procedure that use less radiation. Waiting for the beam to be turned off or using remote telemetry may not be practical according to the patient's needs.

Correct answer #7-2:

Option (B) is correct. The highest level of scatter radiation is close to the beam entry point on the patient's skin.

Correct answer to #7-3:

All four measures apply. Use the inverse square law to your advantage by standing back from the table as far as you can. Use a transparent radiation barrier to shield your face and neck, and wear leaded eyewear if you must work close to the imaging field on your patient. Always wear a collar badge dosimeter during procedures, keeping your radiation dose in mind.

Correct answer to #7-4:

Options (A) and (D) are correct. A declared pregnant employee should wear an additional dosimeter under the lead apron, and if estimated doses are expected to surpass 5 mSv during her pregnancy, she must stop performing fluoroscopy.

Correct answer to #7-5:

Options (B) and (C) are correct answers. Before stepping on the pedal, inform the staff that they have the options of moving away at least three meters away or putting on a lead apron. Ideally all fluoroscopic procedures should be performed in a shielded room, but it is acceptable to preform occasional brief procedures in an unshielded room. Consult a medical physicist to perform radiation calculations if this becomes a frequent practice.