self-**directed**
LEARNING

essential**education**

Fluoroscopy:
Operation and Safety of Fixed Fluoroscopy Units

asrt
American Society of Radiologic Technologists

Fluoroscopy: Operation and Safety Of Fixed Fluoroscopy Units

Anne M Scott, BSRS, R.T.(R)

Advances in technology and clinical treatment methods have led to a rise in fluoroscopy use. Coinciding with this trend is an increase in reported radiation-induced injuries from fluoroscopy. Operators of fluoroscopy units, including radiologic technologists, radiologist assistants, radiologists and other physicians, must have a thorough understanding of how imaging chain components and radiation safety features optimize diagnostic imaging quality and keep radiation exposure to as low as reasonably achievable (ALARA). This knowledge is especially important as new equipment features become available.

After completing this article, readers should be able to:

- List the components of fixed fluoroscopy units and describe different available configurations.
- Understand the importance of the as low as reasonably achievable (ALARA) principle and how to use radiation protection features available on fluoroscopy units.
- Discuss the role of fluoroscopy in imaging and interventional procedures.
- Recognize ways to improve fluoroscopic imaging of pediatric patients and keep radiation dose to a minimum.

Fluoroscopy is used most frequently to provide real-time, dynamic imaging of anatomic structures, such as circulatory movement or the motion of hollow internal structures.[1] Today, it is being used for an increasingly wide variety of procedures in diagnostic and interventional radiology.[2,3]

There are 2 basic types of fluoroscopy units, fixed and mobile, each with a multitude of designs. Fixed fluoroscopy units can be found in designated rooms of hospitals, outpatient clinics and imaging centers and may be combination radiography/fluoroscopy (R/F) or C-arm equipment.[4] Mobile units are smaller, C-arm versions of the fixed units, and as the name indicates, they can be moved as needed.[1] Fixed-imaging systems offer several advantages over mobile units, especially for advanced procedures such as endovascular surgery.[5] According to Sternbergh et al, some of these benefits include better image quality, larger image intensifiers that allow a greater field of view, reduced radiation exposure, improved postprocessing capabilities and the lack of susceptibility to overheating and shutdown during lengthy cases.[5] Both types of units require proper training in fluoroscopic procedures and protection of patients and medical personnel from unnecessary radiation exposure.[1]

Radiologist assistants (RAs) and radiologic technologists may operate fluoroscopy equipment, but the physician performing the examination or interventional procedure often operates the unit. In training hospitals and imaging clinics, it is crucial that experienced fluoroscopy operators share their expertise with others whose knowledge of radiation safety and methods of exposure control may not always be thorough or current.[4] Continuing education concerning new uses and developments in safety features is important for the protection of both patients and personnel.

Radiation Effects

Since the invention of the fluoroscope in 1896, many devices and techniques have been developed to reduce occupational and patient radiation exposure during fluoroscopy.[6] With a growing trend in prolonged fluoroscopy-guided interventional

procedures, however, there has been an increase in reports of high skin doses, which can damage skin significanly.[2] The U.S. Food and Drug Administration (FDA) has compiled nearly 100 documented cases of radiation-induced burns and at least 15 cases have been confirmed by European investigations.[3]

Stochastic radiation effects are considered chronic effects and are caused by longer exposure at relatively lower doses.[7] The severity of the effect is not related to the amount of the dose but rather to the probability a radiation-induced cancer or leukemia will occur with exposure.[7] The increased risk of cancer development also depends on the age and sex of the individual at exposure; children are much more sensitive to radiation than adults.[8] It may take between 5 and 25 years for radiation-induced cancer or leukemia to appear.[7]

Deterministic effects are considered acute effects, and their severity increases with the amount of radiation received. Some examples include desquamation and damage to the connective tissues, blood vessels or glands.[7] In 2000 the International Commission on Radiological Protection (ICRP) reported the threshold dose for early transient skin burns (erythema) to be 2 Gy, with an onset between 2 and 24 hours; the threshold dose for temporary or permanent hair loss (epilation) was reported to be 7 Gy, with a 3-week onset. At 1 to 2 Gy, the lens of the eye may develop a detectable opacity or debilitating cataract within 5 years or more.[8]

Radiation dermatitis is a potential complication of fluoroscopic procedures and may be classified as acute, chronic or subacute. Acute dermatitis is caused by a dose of 2 to 8 Gy and presents as waves of erythema that may be accompanied by edema, vesiculation, erosion, ulceration or pain. It takes several weeks to several months for the condition to improve, and in some cases, the skin never returns to normal.[9]

Chronic radiation dermatitis appears several months to years after exposure and results from a cumulative dose of 10 Gy. This type of radiation dermatitis presents as telangiectasia, hair loss, erythema and pigmentary changes. The subacute form demonstrates a combination of the acute and chronic symptoms.[9]

The most common locations of fluoroscopy-associated radiation dermatitis following cardiac procedures are the scapular and subscapular areas, the right lateral trunk below the axilla, the midback and the right anterolateral chest. Patients at greatest risk for these types of injuries are those who have undergone multiple procedures, a prolonged procedure or a percutaneous coronary intervention. There is no specific treatment for patients with subacute or chronic radiation dermatitis, and they are at an increased risk for basal and squamous cell carcinomas.[9]

A follow-up visit should be scheduled 30 days after an interventional fluoroscopy procedure for any patient who receives a radiation skin dose of 2 Gy or more or a cumulative dose of 3 Gy or more. A description of the procedure, operative notes, doses and information about possible short-term and long-term effects should be sent to the patient's primary care provider, along with instructions to notify the fluoroscopy operator if skin effects are observed.[8]

Radiology-related adverse events may occur any time ionizing radiation is used for patient care. If a fluoroscopy unit is involved, the unit should not be turned off or unplugged until all data have been recorded, printed or saved in digital memory. If it is possible that equipment failure caused the adverse event, then the fluoroscopy unit should be impounded for later inspection by authorized personnel or the manufacturer. The goals of an adverse event protocol should be to:

- Alleviate suffering.
- Protect evidence.
- Document what occurred.
- Report the incident to the appropriate parties.
- Analyze the cause of the event.[10]

Fluoroscopy Overview

Fluoroscopy units can be found in many different configurations. The parts of the imaging chain are fairly consistent among fluoroscopy systems, although the system control panel varies from unit to unit. Additional components are available for digital image recording or interventional applications. Some fluoroscopy units have very-high dose rate modes that are used to generate high-quality images, but such images are not often required for simple fluoroscopy studies. It is crucial that operators understand how to manipulate the controls to produce acceptable image quality at the lowest possible dose levels. The manufacturer's application specialists should instruct fluoroscopy staff before new equipment is used to examine patients.[3]

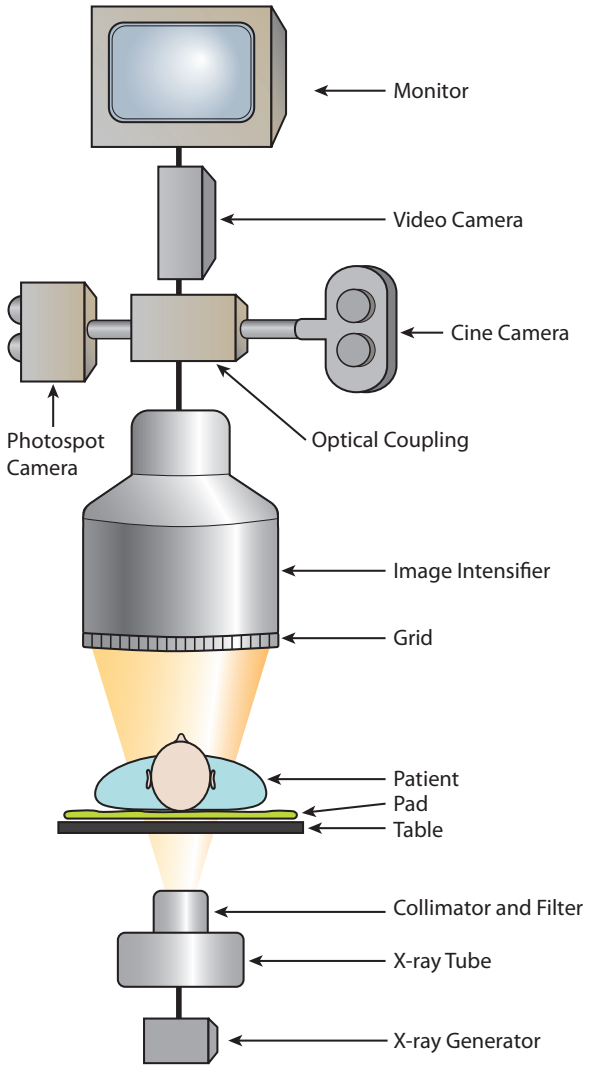

Fig. 1. *Components of the fluoroscopic imaging chain.*

The Fluoroscopy Imaging Chain

The fluoroscopic imaging chain contains several of the same components found in radiography units. A basic fixed fluoroscopy unit contains an x-ray generator, x-ray tube, collimator, filtration, table, grid, image intensifier, optical coupling, video camera and a monitor (Figure 1). Other devices may be attached for image recording such as a spot-film device, film changer, photospot camera, cine camera or analog-to-digital converter.[4] When the x-ray tube is energized, the fluoroscope provides a continuous display of internal structures. Permanent, fixed images may be taken from the system's spot films, cineradiography, and video and digital imaging for future reference.[1]

X-ray Generator

X-ray generators in fluoroscopy units are similar to those used for radiography, but they have additional circuitry to allow low continuous tube current or rapid pulsed exposure and automatic brightness control (ABC). Fluoroscopy generators include single-phase, 3-phase, constant potential and high-frequency types. When a generator is used for both radiography and fluoroscopy, the 3-phase operation is selected for radiographic exposure, and the single-phase operation is chosen for fluoroscopic exposure.[4]

The operator selects the kilovolt peak (kVp) based on the body part being examined. (See Table 1.) Generally a high kVp and low milliampere (mA) are chosen.[1] The generator energizes the x-ray tube through continuous or pulsed exposure.[4] Continuous fluoroscopy requires a steady tube current; during pulsed fluoroscopy, the generator produces short bursts of energy between 3 and 10 milliseconds in length. A common pulse-rate setting

Table 1.

Representative kVp Values for Common Fluoroscopic Examinations

Examination	kVp
Gallbladder	65-75
Nephrostogram, myelogram	70-80
Barium enema (air contrast)	80-90
Upper gastrointestinal	100-110
Small bowel, barium enema (single contrast)	110-120

kVp = kilovolt peak.

is 30 pulses per second, but some units offer settings of 15 or 7.5 pulses per second. The duration of each pulse is called the exposure time and can be determined by the operator. Long pulse widths can result in images with motion artifact.[11]

The tube current for pulsed fluoroscopy ranges from 10 to 200 mA and from about 100 to 1,000 mA for cineangiography. At these settings, the x-ray beam is pulsed on and off rapidly, delivering a lower total radiation dose than conventional continuous fluoroscopy. The total radiation dose is proportional to the pulse rate frequency, which is selected by the operator. An image is not generated between pulses, and the monitor displays the previously stored image until the next pulse generates a new image.[11] Pulsed fluoroscopy improves temporal resolution because motion blur is reduced within each image. Another benefit of pulsed fluoroscopy is the ability to reduce patient dose, especially when the pulse rate is reduced.[4]

Pulsed fluoroscopy generators and those units capable of rapid image acquisition benefit from short exposure pulses. Constant potential generators offer the shortest exposure pulses; exposure pulses from high-frequency and 3-phase generators are slightly longer. Exposure reproducibility is important for fluoroscopic systems performing digital subtraction angiography because differences in tube voltage between the mask and contrast images can result in incomplete subtraction. High-frequency generators are ideal for exposure reproducibility and are compact in size.[4]

The ABC feature keeps the overall image brightness at a constant level.[4] The radiologist can select an image brightness level by adjusting the kVp and mA settings as the image intensifier is panned across structures of differing thickness and attenuation.[1,4]

Several factors can be adjusted to properly penetrate the anatomy of interest. The imaging parameter selected at any given time should be the one that preserves image quality as much as possible. The generator follows a sequence to alter the kVp, mA and pulse width to maintain an entrance exposure at the image receptor that minimizes patient entrance dose. Some units, however, do not adequately decrease the tube current for very small pediatric patients.[12]

Although the x-ray tube may be operated at less than 5 mA during continuous fluoroscopy, the patient dose is considerably higher than plain radiographic exams because the x-ray beam exposes the patient constantly and for a longer time. Therefore, operators are trained to depress the on-and-off foot switch during examinations. Using the foot switch reduces patient exposure and at the same time provides a high-quality examination.[1] Justino suggested a simple rule to train operators: "When the eye is not on the screen, the foot must not be on the pedal!"[11] This directive prevents unnecessary exposure when the fluoroscopy operator is unable to look at the monitor.[11]

An exception to using low mA values is the conventional, cassette-loaded spot film. The film must be positioned between the patient and the image intensifier, and the operator must change the operation of the x-ray tube from low fluoroscopic mA to high radiographic mA. This switch may take several seconds to energize the rotating anode to a higher speed.[1]

Multiple lead diaphragms allow several image formats on a spot film. If the entire film is exposed, the image is called one-on-one; a two-on-one is produced when half the film is exposed at a time. Other formats include four-on-one and six-on-one.[1]

X-ray Tube

The x-ray tube converts electrical energy from the generator into an x-ray beam. The x-ray tube contains a cathode and a positively charged tungsten anode that are physically separated by a gap. Electrical current (expressed in milliampere, mA) passes through a filament in the cathode, causing it to heat up and emit electrons. A voltage (expressed in kilovolts, kV) accelerates the electrons from the cathode across the gap toward the anode. When the electrons strike the anode material, they release their energy in the form of x-ray photons and heat. The number of electrons released per unit of time by the cathode is proportional to the current passing through it, and the energy of each is proportional to the voltage across the gap. Therefore, the mA setting determines the number of electrons emitted; the kV setting controls the penetrability of the beam.[11]

The focal spot is the area of the anode struck by electrons and comes in small (0.3-0.6 mm) and large (1.0-1.2 mm) sizes. The anode surface is angled from 7° to 20° to reduce the effective size of the focal spot as seen from the image receptor. When high tube currents are required, either small or large focal spots may be used for

image recording. Small focal spots minimize geometric blur and are used for fluoroscopy.[4]

Some additional tube characteristics are important for angiography and interventional procedures. These applications require a large heat capacity because rapid image recording causes heat to build up quickly. To adequately dissipate the heat, high-speed anode rotation (more than 10,000 revolutions per minute) and a circulating water or oil heat exchanger with cooling fans may be used. Another tube feature is grid-controlled pulsing that produces very short (millisecond) exposures for cine image recording or pulsed fluoroscopy. These grid-controlled tubes contain a cathode at a variable negative potential that allows the electron flow to be delivered in short exposure pulses.[4]

The heat capacity and focal spot size may be limited by the field-of-view requirements of angiography or interventional systems. A small focal spot size may be required to demonstrate fine vasculature or guide wires, but a large anode angle may be necessary for a large field of view or when a large image intensifier is used. The size of the filament may be increased to improve heat dissipation when using a large anode angle, but this configuration still results in a larger effective focal spot size.[4]

The photons emitted by the x-ray tube are focused into a diverging beam that may penetrate the patient, be absorbed completely by the patient or lose some energy within the patient's tissues and be deflected in another direction. The deflected photons are known as scatter radiation and represent a risk to the patient and personnel. The x-ray beam that reaches the image intensifier is converted back into electrons by the input phosphor and photocathode; the electrons then are accelerated onto the anode. When the electrons strike the anode, visible light is emitted, which is focused and transmitted to a television monitor for viewing or storage.[11]

Collimator

Round and rectangular radiopaque shutter blades of the collimator define the shape of the x-ray beam. The round blades focus the x-ray beam to the circular field of view and the rectangular blades are selected manually to further reduce the beam size. The collimator automatically restricts the x-ray beam to a size no larger than the field of view as the operator makes changes to the magnification mode or source-to-image distance. To decrease scatter and improve image contrast, the operator should further collimate the beam to the area of interest to reduce the exposed volume of tissue.[4]

Equalization filters are commonly available in angiography and interventional fluoroscopy systems. These partially radiolucent blades also are known as wedge or contour filters. They reduce glare from unattenuated radiation near the edge of the patient and improve the operation of the ABC system. The filters may be straight or shaped to better limit the beam to the anatomic parts being viewed.[4]

Filter

Spectral beam filters reduce dose without compromising image quality by decreasing low-energy, or soft, radiation. These x-rays enter the patient's skin but do not have enough energy to reach the image detector. The filters are located in the x-ray tube collimator, and filter thickness is based on the equipment type, examination and patient size.[13] Aluminum and copper are common filtration materials.[4] Copper filters may be 0.1, 0.2, 0.4 or 0.9 mm in thickness and are used in conjunction with 1.0-mm thick aluminum filters. A 0.2-mm copper filter reduces exposure by approximately 50%, and a 2.0-mm copper filter reduces the dose by 70%.[13]

Copper filters used during complex adult interventional procedures are generally 0.1 and 0.4 mm thick; 0.9-mm filters are preferred for pediatric and electrophysiology examinations. For standard adult fluoroscopy procedures, a 0.2-mm copper filter is usually optimal to achieve image quality.[13]

Patient Table and Pad

The patient tables designed for fluoroscopy units must be able to support large patients and also cause minimal x-ray attenuation. Tables are primarily constructed of carbon fiber composite material because it meets these requirements. Minimizing x-ray attenuation reduces tube loading and maintains image contrast because increased tube potential is not needed to penetrate the table. Over-the-table x-ray tube configurations reduce exposure, benefitting the patient.[4]

Support pads also should be designed to minimize attenuation. Thin foam pads may be acceptable for fluoroscopy, but thick gel pads have been associated with excessive attenuation.[4]

A standard fluoroscopy table may be tilted 15° from horizontal to a Trendelenburg (head-down) or reverse Trendelenburg (head-up) position. Some studies, such as myelography and cisternography, require a table that is capable of a 30° reverse Trendelenburg position.[14] The table also may be oriented vertically for certain swallowing studies.[1] The radiologic technologist, RA and radiologist are responsible for positioning proper support devices for patients while using tilt tables.[14]

Grid

Antiscatter grids are used in x-ray systems to increase contrast and improve image quality, but they can increase radiation dose to patients and staff.[2] Grid ratios for fluoroscopy systems range from 6:1 to 10:1, lower than the radiographic ratios of 8:1 to 16:1.[4] The use of grids in fluoroscopy studies may not be necessary, especially when imaging with a reduced field of view or when examining a small patient or body part.[2,4] In particular, operators should consider removing the grid during pediatric exams.[4]

The grid also may be removed without compromising image quality when a large air gap is required between the patient and image intensifier for geometric magnification, or for access to the patient or interventional devices.[4] Equipment operators should know how to take out and replace the grid if it can be removed from the fluoroscopy system.[2]

Image Intensifier

The image intensifier converts the incident x-rays into a miniature visible light image, amplifying image brightness by about 10,000 and drastically improving visibility. Image intensifier components include an input layer, electron lenses, an anode and an output layer, all contained within a vacuum bottle.[4]

The input layer converts x-rays to electrons and is made up of 4 components: the input window, substrate, input phosphor and photocathode. The x-rays first strike the input window, which consists of a thin, curved layer of glass or metal. The x-rays then are converted into light photons as they pass through the 0.5-mm aluminum substrate layer and input phosphor layer, which is made up of needle-like cesium iodide crystals.[4] The photocathode absorbs the light photons and and converts them into electrons.

The electron lenses focus the electrons through the electron optics system. This system creates an electric potential, which intensifies and demagnifies the electron beam to the size of the output layer. The anode then accelerates the electrons through the output phosphor layer, which converts them into visible light photons. The light photons emerge from the image intensifier through a glass output window.[4]

The gain in illumination because of the electron acceleration and image minification is known as brightness gain and ranges from 5,000 to 20,000. Other properties used to describe image intensifiers include contrast ratio, spatial resolution and detected quantum efficiency. The diameter of the image intensifier input window is between 10 and 40 cm, with selection of the diameter based on the maximum field-of-view requirements for the clinical application. For example, a 10- to 15-cm diameter image intensifier may be chosen for extremity studies, whereas a 40-cm diameter is better for studies of the abdomen or peripheral vasculature.[4]

Multiple magnification modes are available on most image intensifiers. They focus the central circular area of the input layer onto the full output layer by adjusting the voltage of the electron optics electrodes.[4] Usually 3 to 5 magnification modes are available, and dose typically increases with greater magnification. When using magnification, the radiation dose increases by the square of the ratio of the image intensifier diameter.[2]

Most manufacturers provide more than one dose level for each magnification mode. A common configuration consists of low, medium and high levels, in which the low setting delivers half the dose of the medium setting and the high setting produces twice the dose of the medium setting. The medium setting is usually the best choice because the low-dose setting can result in a very noisy image, and the high-dose setting should be reserved for cases consisting of very low-contrast information. On some systems, there is a high-dose fluoroscopy mode that is equivalent to the high-dose setting but permits the maximum skin dose to reach a level that is twice the maximum allowed for normal fluoroscopy. When engaged, this setting produces a warning sound and should be used only with very large patients or thick body regions.[2]

Image magnification can increase blur and degrade spatial resolution unless a very small focal spot is used.[2] Excessive panning also can be a problem when trying

to demonstrate adjacent structures that are outside the magnified field of view.[11]

Another way to magnify the image during fluoroscopy is geometric magnification. Geometric magnification uses the diverging x-ray beam to project a smaller region in the patient to a larger area on the image intensifier. As the patient moves closer to the x-ray source, both image magnification and skin dose increase when the source-to-image receptor distance is fixed. Many fluoroscopes used for interventional studies can change the positions of the tube and receptor independently.[2]

One magnification method that does not increase dose, but results in reduced image quality, is the replay zoom feature. This feature displays a nonmagnified image on the monitor, but in a magnified view. The image does not contain more data, or pixels, but instead replaces each pixel with a larger block on the screen. The resulting image is visibly rough, but can be helpful for certain applications such as measuring small vessels.[11]

Optical Coupling

An optical distributor transmits the images from the image intensifier to the camera or other image recording devices in the fluoroscopic system.[4,15] The distributor may include a beam-splitting mirror that directs some of the light from the image intensifier output window to an image recording device and the rest of the light to the video camera. A circular aperture is used to adjust the light level to meet the requirements of the video camera.[4]

Depending on the size of the aperture setting, the ABC system increases radiation exposure to maintain the light level at the camera.[4] When fewer x-rays are detected, the generator increases the quantity or intensity of the x-rays to maintain image brightness.[11] The system is preprogrammed to alter the kVp, mA and pulse width in a combination that produces the selected dose rate. The dose rate may be set to low, medium or high by the equipment operator.[15]

Television System

The output image from the image intensifier is viewed using a closed-circuit television system. The system contains a video camera capable of converting the image to a voltage signal and a monitor that displays the image from the received signal. Several people can view the fluoroscopic image in real time on a single or multiple monitors. Some fluoroscopic units are equipped with an analog-to-digital converter to digitize the video camera voltage signal. The digitized signal then can be used for additional processing and electronic image recording.[4]

Image Recording

A variety of recording devices are available in fluoroscopy systems, including spot-film devices, film changers, photospot or digital photospot cameras and cine cameras. Depending on the examination and the operational characteristics of the device, one or several of these recording methods may be used.[4]

Spot-film devices use film-screen cassettes to acquire radiographic images. The cassettes are positioned in front of the image intensifier, and collimation may be varied to produce multiple image formats. There is a slight delay between fluoroscopic viewing and image recording. The quality of the image recorded is the same as a radiograph, and large-film image recording is possible. These devices are used for gastrointestinal imaging, genitourinary imaging, arthrography and myelography.[4]

Film changers also are called rapid film, serial film, cut-film or Puck film changers. These devices move films quickly into position from a supply magazine at a rate selected by the operator. The rate may be as fast as 4 films per second. The films then are placed into a take-up magazine to be transported to a film processor. Film changers can be used for dynamic vascular imaging with iodinated contrast material.[4]

Photospot cameras require less patient exposure than cassette-loaded spot films. They expose only one frame at a time when activated, receiving the image from the output phosphor of the image intensifier. Film sizes are 70 and 105 mm, with the larger film format resulting in increased patient dose but better image quality. The photospot camera does not interrupt the fluoroscopic examination as the cassette-loaded spot films do. The cameras record images at a rate of 12 images per second, and generally are used for the same type of exams as spot-film devices.[1]

The acquisition, or cine, mode allows permanent storage of fluoroscopic images. This mode should be used sparingly because about 15 times more radiation per frame is needed to obtain quality diagnostic images than fluoroscopy mode. The cine mode is always pulsed, with typical settings of about 15 frames per second for

adult studies and 15, 30 or 60 frames per second for pediatric studies. For cardiac catheterization, the frame rate is based on the movement of cardiac structures, such as prosthetic valve leaflets, or the vascular flow rate. Examples of high flow rate include arteriovenous fistulas or a patient with tachycardia.[11]

Digital Fluoroscopy

Traditionally, in digital fluoroscopy, an analog-to-digital converter changed analog video signals to digital signals and then stored the digitized data in the computer's memory.[4] However, newer fluoroscopy systems increasingly have digital imaging equipment such as a charge-coupled device video or a flat-panel detector. By digitizing the video signal, image processing techniques such as last-image hold, gray-scale processing, temporal frame averaging and edge enhancement can be used to enhance image quality. The resolution is limited, however, by the resolution of the video camera.[16]

Last-image hold reduces radiation exposure by providing the digital information from the last image frame to the video system. Gray-scale processing, or window width and level adjustment, is used to alter the brightness and contrast of the digital image. Temporal frame averaging decreases image noise by displaying an image created by averaging the current frame with one or more previous frames. This technique works best for static images because the lag time may be too long for imaging dynamic processes. Edge enhancement helps define boundaries between objects of different pixel values by subtracting a blurred version of the image from the original and then adding the resulting image back to the original.[16]

Digital subtraction angiography (DSA) provides enhanced imaging of vasculature by subtracting digital fluoroscopic images in real time after contrast injection. Image processing techniques used in DSA include road mapping, image fade, mask pixel shift, frame summation and vessel measurement.[16]

Road mapping is a beneficial tool for placing catheters and wires in complex and small vasculature. This technique identifies the image frame with maximum vessel opacification and uses it as the road-map mask. The mask is subtracted from the subsequent live fluoroscopic images to produce real-time images overlaid on the static image of the vasculature. Image fade then may be used to adjust the brightness of the static vessel in the road-map overlay. Mask pixel shift can be used to correct artifacts due to patient motion that occurs between precontrast and postcontrast image acquisition.[16]

Image summation combines two or more frames of a DSA sequence into a single image. This technique allows all the vessel segments to be visualized in one image. Otherwise, only some of the vessels in the vessel track might be seen at a given time during contrast injection. Vessel size can be measured only if the image pixel size is properly calibrated. To perform the calibration, an object of known dimension is placed in the imaging field of view, and its measurements are used to determine a calibration factor, expressed in millimeters per pixel. The measurements of the anatomy in pixels are multiplied by the calibration factor. The operator should account for errors due to differences in magnification of the reference standard and the anatomy of interest.[16]

Fluoroscopic Equipment Configurations

Fluoroscopy systems are specifically designed for certain clinical examinations and interventional procedures. The x-ray tube in a R/F unit may be located either below or above the table, with the most common setup being an undertable x-ray tube. In this configuration, the x-ray tube and collimator are mounted below the tabletop, and the image intensifier is mounted above the table. The image intensifier is attached to a carriage unit that may be panned over the patient. An overtable x-ray tube design also is used in fluoroscopy-only configurations. Figure 2 shows a fluoroscopy unit designed specifically GI procedures.[4]

Additionally, the R/F unit can contain an overhead x-ray tube that can be used for standard radiography, with a Bucky incorporated into the table (Figure 3 and 4). Other common components of R/F units are a tilting table and image recording devices. R/F units that have an x-ray tube mounted above the patient and the image intensifier mounted below permit better access to the patient, making these units more useful for interventional procedures. The x-ray tube also may be tilted for angled projections and tomograms. Overtable tube configurations increase radiation exposure to personnel because scatter radiation is projected back toward the x-ray tube. Some of these systems are capable of remote control operation so the operator can remain behind a shielded viewing window during the exposure.[4]

Fig. 2. *Undertable x-ray tube digital fluoroscopy system. (Photo courtesy of Siemens Healthcare, Malvern, Pennsylvania.)*

Fixed C-arm positioners may be mounted from the ceiling or floor (Figure 5). The C-arm configuration allows the tube and image intensifier to be angled in all directions around the patient. The table has a floating tabletop so the patient may be moved while the position of the C-arm stays fixed. A variety of image recording devices may be used with this setup, including a film changer, cine camera or digital image acquisition for

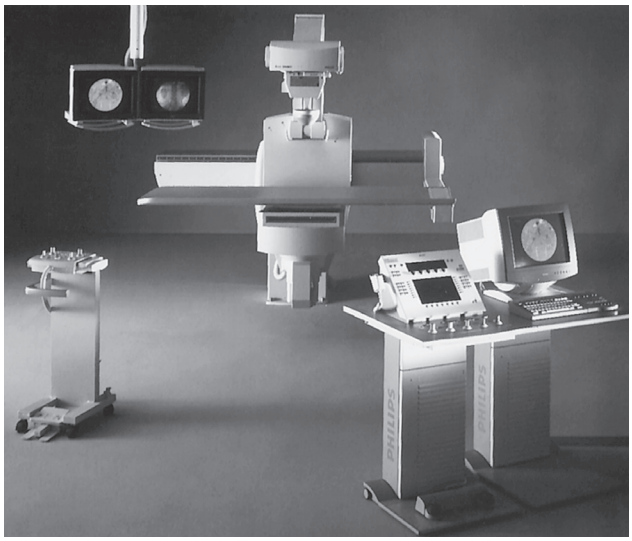

Fig. 4. *Overtable x-ray tube R/F system. The system can be controlled from within the procedure room with the pedestal control panel (left) or from outside the room from the remote desk controls (right). (Photo courtesy of Philips Healthcare North America, Andover, Massachusetts.)*

Fig. 3. *Overtable x-ray tube digital R/F system. (Photo courtesy of Siemens Healthcare, Malvern, Pennsylvania.)*

DSA. Cardiac, peripheral and neuroangiographic and interventional procedures are commonly performed using a fixed C-arm.[4]

Cardiac catheterization and pediatric interventional configurations may be equipped with biplane fluoroscopy units in which two C-arms are positioned perpendicular to one another. For cardiac catheterization, the floor-mounted C-arm is positioned with the image intensifier

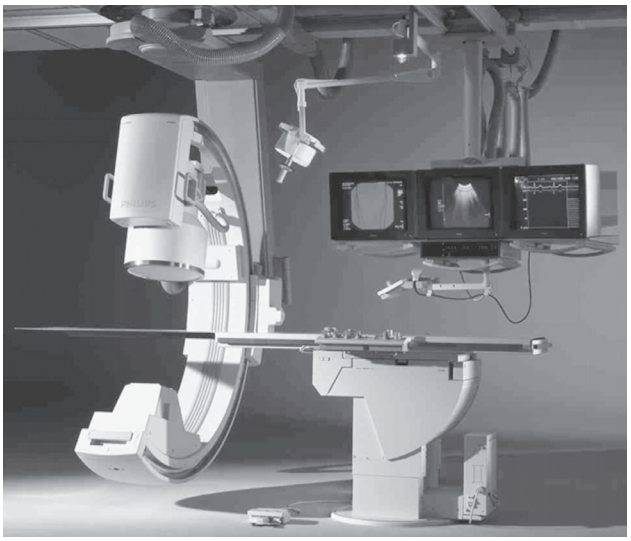

Fig. 5. *Fixed C-arm positioner with ceiling mount. This example includes an ultrasound unit and patient monitoring system. (Photo courtesy of Philips Healthcare North America, Andover, Massachusetts.)*

anterior to the patient and the x-ray tube under the table. The second C-arm (or U-arm) is mounted from the ceiling, positioned perpendicular to the first, with the x-ray tube located to the patient's right and the image intensifier on the patient's left. This position minimizes magnification of the heart because the image intensifier is positioned on the side closest to the heart. Some interventional suites position the lateral gantry with the image intensifier on the operator's side, which reduces exposure to personnel.[11]

Each C-arm rotates on its arc to provide either lateral or craniocaudal angulation, with the degree of angulation controlled by the operator. The operator also can adjust the image receptor to isocenter (the point in space about which the imaging planes rotate). Some modern units may be preprogrammed to position the C-arms at consistent positions without exposing the patient to additional radiation.[12]

The Z-arm positioner is similar to the C-arm but has a parallelogram support. This configuration allows better access to the patient's head because it is capable of larger angulations.[4]

A modified C-arm fluoroscopy configuration, called the tilt C-arm or multipurpose fluoroscopy system, also is available. The C-arm positioner of this unit has an attached, tiltable patient table. This system allows both general R/F and complex angiographic and interventional procedures.[4]

Fluoroscopy Radiation Protection Features

Several features in fluoroscopy systems are designed to reduce patient radiation dose and occupational exposure, including:

- Maximum possible source-to-skin distance (SSD).
- Primary protective barrier.
- Filtration.
- Collimation.
- Automatic exposure control (AEC) lock-in.
- Exposure control.
- Bucky slot cover and protective curtain.
- Cumulative timer.
- Dose area product meter.[1,13]

In some cases, grid removal also can reduce the dose by a factor of 2 or more.[2]

The SSD must be at least 38 cm on stationary fluoroscopes.[1] The maximum distance between the x-ray tube and patient, and minimum distance between the patient and image intensifier, should be used.[8] Because exposure to the image intensifier must be maintained, the mA increases as distance between the x-ray tube and the image intensifier increases.[1] This relationship is described by the inverse square law, which states that the intensity of the x-ray beam at a given point is inversely proportional to the square of its distance from the radiation source. For example, if the SSD increases from 20 cm to 40 cm during abdominal fluoroscopy of a 20-cm thick patient, the entrance skin exposure (ESE) decreases from 128 milliroentgen (mR) to 72 mR.[1]

Primary Protective Barrier

The fluoroscopic image receptor must be 2-mm lead equivalent and is a primary protective barrier, intercepting the useful x-ray beam.[1,17] The x-ray tube is coupled and interlocked with the image receptor so that the tube cannot be energized if the image receptor is in the parked position.[1] All other barriers in fluoroscopy suites are considered secondary, meaning they are intended to intercept scatter and leakage radiation.[17]

Filtration

The total filtration, which includes the tabletop, patient cradle or other material positioned between the x-ray tube and the tabletop, must be at least 2.5-mm aluminum equivalent.[1] However, to reduce patient dose, recommendations suggest that the minimum half-value layer (HVL) should be 3.0 mm aluminum at 80 kVp (Table 2).[4] The HVL should be measured when the total filtration is unknown.[4] The filtration should be evaluated annually and when changes are made to the x-ray tube or tube housing.[1]

Collimation

The fluoroscopic x-ray beam must be collimated so that an unexposed border is visible on the image monitor when the input phosphor of the image intensifier is 35 cm above the tabletop and the collimators are fully open. When automatic collimating devices are used, the unexposed border should be visible at all heights above the tabletop. The collimator shutters should adjust according to changes in height above the tabletop.[1]

When the beam-collimating shutters are closed too tightly into the field of view, the AEC system responds

Table 2.

Suggested Minimum Half-value Layers for 3-phase and High-frequency Generators[1]

Operating kVp Value	Minimum Half-value Layer (mm aluminum)
30	0.4
50	1.5
70	2.0
90	3.1
130	4.2

kVp = kilovolt peak.

by increasing the x-ray exposure to the image receptor and, consequently, to the patient. This results in an overexposed image and increased exposure to the patient.[13] In such cases, reducing the collimation somewhat may resolve the problem.[11]

One example of how the correct image brightness can be maintained with tight collimation is the Eleva system (Philips Healthcare, Andover, Massachusetts), which provides real-time electronic communication between the image receptor and the generator. The system recognizes the position of the collimation shutters and monitors the brightness in the remaining area of the measuring field even when the shutters are almost closed.[13]

AEC Lock-in

The AEC system maintains consistent image brightness by altering x-ray exposure to the image receptor. A feature of grid-controlled fluoroscopy, the AEC lock-in allows the operator to freeze the function of the AEC system and maintain optimal image quality when dense contrast agents or opaque objects, such as lead gloves, enter the field of view.[13]

Exposure Control

The fluoroscopic x-ray beam can be stopped by the foot pedal or the pressure switch on the fluoroscopic image receptor. Both mechanisms, which are referred to as "the dead man type," terminate the exposure if pressure is released.[1]

Additionally, some fluoroscopy units have a pulsed fluoroscopy mode that emits the x-ray beam in short bursts rather than in a steady stream. The pulsed mode may produce lower-quality images, and some manufacturers compensate by increasing the mA setting, which ultimately defeats the purpose of the mode. Using the pulsed mode to reduce dose only works if the radiation exposure is set at low frame rates.[6]

Some units contain in-pulse control technology that adjusts exposure settings in real time, eliminating unnecessary exposure to the patient. The operator selects parameters such as patient size and type of exam before fluoroscopy exposure, and then the in-pulse control alters the beam's penetration to provide diagnostically relevant information. The feature helps eliminate the need for repeat exposures due to poor image quality.[13]

Another useful technique for reducing fluoroscopy time is called last-image hold. During surgery or interventional procedures, this allows the surgeon or radiologist to view the last image without making another exposure.[6] Although image quality usually is lower than that of radiographic exposures, the last image often can provide sufficient diagnostic information.[13]

Bucky Slot Cover and Protective Curtain

When the Bucky tray is moved to the end of the exam table during fluoroscopy, there is a 5-cm opening at the side of the table near gonadal level of the operator. The opening should automatically be covered with at least 0.25-mm lead equivalent. On R/F tables, there should be a protective curtain of at least 0.25-mm lead equivalent between the operator and the patient.[1]

Cumulative Timer

To ensure that the operator is aware of the relative beam-on time during each examination, a cumulative timer produces an audible signal when fluoroscopic time exceeds 5 minutes. The technologist should record total fluoroscopy beam-on time for each patient examination.

It should not be necessary to exceed 5 minutes, with the exception of difficult interventional procedures.[1]

Dose Area Product

The dose area product (DAP) is an indicator of radiation risk. This measurement, which is expressed in cGy-cm^2 (R-cm^2), incorporates both radiation dose and the volume of tissue irradiated. The DAP increases as the field size increases because more tissue is exposed. DAP meters are becoming common on fluoroscopy systems to monitor radiation output. These devices are radiolucent and are placed next to the x-ray source below the collimator.[1]

The DAP value can be the same from a high dose over a small field or a low dose over a large field, but the skin entrance dose is much greater in the first case.[15] Therefore, the risk of injury to the skin where the beam enters may be determined by dividing the DAP measurement by the area of the beam at the skin.[1]

For each mA of operation at 80 kVp, the intensity of the x-ray beam at the tabletop should not exceed 21 mGy$_a$ per minute (2.1 R/min). There may be an optional high-level control available, in which case the maximum tabletop intensity allowed is 200 mGy$_a$ per minute (20 R/min). When the image is recorded, as in cineradiography or videography, there is no limit for x-ray beam intensity.[1]

Radiation dose measurement is becoming an increasingly important factor in radiation protection. The DAP may be most beneficial for establishing a benchmark.[18] Regular review of DAP meter readings and use of dose reduction techniques help establish doses as low as reasonably achievable.[19] It may become another responsibility of the radiologic technologist to record DAP meter measurements.[18]

Equipment Quality Tests

The Conference of Radiation Control Program Directors recommends performing image quality tests daily as part of the warm-up procedure before examining patients. Monthly system checks are conducted to evaluate system and monior resolution. Visual checks performed quarterly or after service or maintenance include inspecting all switches, pedals, locks and centering devices, lights, and meters on the table, tube and image intensifier. Other quarterly checks include the audible signal of the timer and the high-level exposure settings. Also, grids should move in and out of the useful beam easily, and the Bucky should move smoothly along the track. Technique charts should be accurate, and indicators on the control panel should function correctly. Annual tests perfomed by a medical physicist should include exposure rate measurements, image evaluation, fluoroscopy and spot-film collimation accuracy, kVp and half-value layer accuracy, and function of the 5-minute timer.[20]

Other quality control tests include checking the performance of automatic brightness control and the focal spot size, which should be 1.2 mm for large focal spots and 0.5 mm for small focal spots. When evaluating the dose rate for undertable tube fluoroscopy units, the dose rate should be measured 1 cm above the tabletop. On C-arm fluoroscopes, the dose rate should be measured 30 cm from the input surface of the image intensifier. The entrance dose rate for the patient should not exceed 0.1 Gy (10 rad) per minute, unless the optional high-level control is engaged for film recording of fluoroscopic images.[21]

Radiation Safety for Patients and Personnel

The National Cancer Institute reported that increased fluoroscopy use for a variety of medical conditions has increased the radiation dose to patients and health care personnel. In addition, reports of serious skin injuries and the possibility of late radiation effects have led to concern over the amount of radiation exposure to patients and health care providers.[8]

Thus, the proper use of radiation by operators of fluoroscopy units is critical, and imaging personnel must have appropriate training concerning the potential for radiation exposure during each examination.[6] The American College of Radiology (ACR) guidelines for all diagnostic radiology procedures stress the responsibility of radiologic professionals to minimize radiation dose to individual patients, staff and the public, while maintaining diagnostic image quality. The primary protective measure for radiologists, RAs and radiologic technologists is to follow the as low as reasonably achievable (ALARA) principle. By following this principle, fluoroscopy operators can minimize the risk of deterministic and stochastic effects from radiation exposure.[7]

The need for appropriate training is illustrated in one recent study. Radiographers were asked where they

should stand during upper gastrointestinal (GI) and lower GI fluoroscopic procedures for best radiation safety practice. For the upper GI exam, only 82.1% of those surveyed answered correctly that they should stand behind the physician or in the control room, and only 69.4% responded with the correct answer when asked about lower GI procedures. In the same study, only 80.9% knew to place the image intensifier as close to the patient as possible when using an undertable x-ray tube.[22]

The use of protective shielding, such as lead aprons and thyroid shields containing 0.5 mm lead, also should be routine to reduce occupational exposure to between 10% and 25%.[1,18] According to the National Institute of Occupational Safety and Health (NIOSH), "No part of the [fluoroscopy operator's] body should be directly exposed to radiation. If there is a danger of exposing a body part, appropriate protection must be used."[23] Lead aprons and gloves should be checked annually for cracks.[23] Personnel should wear the occupational radiation monitor at the collar to estimate dose to head and neck tissues.[1]

Before beginning any fluoroscopy procedure, every person in the room should be shielded and those who do not need to be near the patient should move as far as possible from the primary beam or behind protective shields.[11] The exposure rate for a radiologist, RA or radiologic technologist in the usual location next to the patient is 3 mGy_a per hour (300 mR/hr).[1]

When positioning patients during fluoroscopy procedures, imaging personnel should move the patient to the approximate position before exposure. If adjustments are necessary, the patient should be moved and then fluoroscopy should be used briefly to check the position. Exposure also should not be made when an assistant helps move the patient. The operator should wait for the assistant to be out of the way of the primary beam before checking the position. Similarly, adjustments to collimation should not be made under continuous fluoroscopy. Instead, operators should use an approximate setting initially and then alter the collimators before the fluoroscopic exposure.[11]

During fluoroscopy the principles of time, distance and shielding can help reduce patient and occupational exposure. The operator can limit beam-on time by using precise technique and activating the fluoroscopic beam intermittently.[7] The use of fluoroscopy should be limited to the necessary evaluation of moving structures, and the last-image hold option should be used to review findings.[8] Additionally, the operator should record the fluoroscopy time in the log, using information from the 5-minute reset timer.[7]

Radiologic technologists and other personnel should step away from the fluoroscopy table whenever their assistance is not required, because scatter radiation coming from the primary beam's entry point is a large source of occupational exposure. The image intensifier should be as close to the patient as possible to reduce magnification, improve image quality and reduce patient dose.[6] The use of electronic magnification should be limited to protect the patient.[8]

If the unit is a C-arm design with an undertable x-ray tube and the image intensifier above, most of the scatter radiation is directed downward. When the C-arm is in a lateral position, however, personnel should be at a maximum distance from the source. This configuration usually requires the image intensifier to be located on the same side of the table as the technologist.[6]

For pregnant personnel, the monthly equivalent dose to the embryo or fetus should not exceed 0.5 mSv (0.05 rem) per month or 5 mSv (0.5 rem) over the course of the pregnancy.[7,24] In utero radiation exposure can lead to leukemia and morphological abnormalities in the organ systems. In addition, doses to the fetus between 0.1 and 0.19 Sv (10 and 19 rem) have been linked to small head sizes, and mental retardation has been linked to doses above 1.5 Sv (150 rem).[23] For these reasons, a second radiation monitor should be worn at waist level, under the protective apron, to monitor exposure. Wraparound protective aprons may be more comfortable during late pregnancy.[7]

Damilakis et al investigated the dose to the conceptus (ie, embryo or fetus, sac, cord and membranes) from occupational radiation exposure. Their study calculated the average doses at waist level for specific projections used during fluoroscopically guided electrophysiological procedures. The researchers suggested that supervisors estimate the conceptus dose before the employee declaration of pregnancy and determine the maximum workload allowed for each month following the declaration of pregnancy. The maximum permissible workload varies among individuals and depends on factors such as the energy of the x-rays used, the position of the pregnant worker and the use of shielding.[24]

The patient's pregnancy status should be addressed before a fluoroscopic procedure. If there is any possibili-

ty the patient is pregnant, abdominal or pelvic radiologic examinations should be conducted within 28 days of the patient's last menstrual period, and certain exams, such as barium enemas, should be conducted within 10 days of the patient's last menstrual period. This timing reduces the likelihood of irradiating an embryo.[7]

The patient's gonads always should be shielded during procedures when the clinical objectives of the examination are not compromised.[25] In most fluoroscopy procedures, the lead apron should be placed on the tabletop underneath the patient's body because the x-ray tube is positioned below the table.

Fluoroscopy Procedures

Common imaging and interventional fluoroscopy procedures include gastrointestinal studies, interventional pain management, percutaneous needle biopsy, angiography and neuroradiology, and cardiac catheterization. Interventional fluoroscopy has replaced surgical procedures in an expanding number of medical specialties.[8] Some examples include angioplasty, stent placement, embolization and vascular access device insertion.[26] Advantages of fluoroscopy over invasive surgery include the the use of small incisions, a greatly reduced risk of infection and shorter recovery times.[8]

The fluoroscopy examination room should be completely prepared before the patient enters for the procedure. These preparations include:

- Adusting the equipment controls to the appropriate settings.
- Making sure footboard and shoulder supports are available.
- Checking the availability of spot films.
- Preparing any contrast material required.[25]

According to Sternbergh et al, a dedicated technologist should operate fixed fluoroscopy equipment, archive the images and maintain the inventory of disposable supplies for vascular procedures. Radiologic technologists in this role should receive proper training to safely use fluoroscopy equipment and to minimize errors that can lead to unnecessary radiation exposure.[5]

Gastrointestinal Studies

A recent report noted a slow and steady decline in the volume of barium studies performed in the United States over the past 25 years. The study concluded that endoscopy and other imaging procedures, such as computed tomography (CT) and magnetic resonance (MR) imaging, are ordered more frequently than barium studies because of their higher reimbursement rates and the relative ease with which they can be performed. A resulting problem is that fewer qualified radiologists are available to perform barium studies and teach medical residents how to perform the procedure and interpret images.[27]

However, barium studies are highly diagnostic if performed correctly, expose the patient to less radiation than CT, are less expensive and result in fewer complications than endoscopy. For these reasons, Levine et al advocate better training in GI fluoroscopy for radiologists and RAs, especially hands-on training in the safe and appropriate use of fluoroscopy units.[27] Radiologic technologists could play an important role by sharing their expertise and knowledge of the fluoroscopy unit with residents who might not have received adequate training.

Motion is a significant factor in determining exposure time during GI radiography. The operator must adjust the exposure time to account for peristalsis, which varies according to region of the intestinal tract, the patient's body habitus, pathologic changes, body position and respiration. In general, motor activity is greatest in the stomach and proximal part of the small intestine and decreases along the intestinal tract.[25]

For esophageal examinations, an exposure time of 0.1 second or less is used for upright examinations but may be longer if the patient is recumbent. When imaging the stomach and small intestine, the exposure time should be no longer than 0.2 second for patients with normal peristaltic activity and 0.1 second or less if the patient has hypermotility.[25]

Interventional Pain Management

Fluoroscopy procedures used in pain management imaging and treatment include myelography and cisternography, arthrography, diskography and epidural nerve blocks.[28]

Myelography requires contrast-enhanced continuous beam fluoroscopy to evaluate the subarachnoid space of the interior of the spinal canal; cisternography is used to study the cisterns and skull base. Myelography may help detect spine and intervertebral disk abnormalities or clarify ambiguous CT or MR images.[28]

Both procedures involve a lumbar puncture and injection of a nonionic, water-soluble iodinated contrast medium into the intrathecal space under fluoroscopic guidance. The opacified cerebrospinal fluid is demonstrated by tilting the examination table to show the desired region of the spinal subarachnoid space (cervical, thoracic or lumbar) or the intracranial basal cisterns. According to ACR practice guidelines, the basic requirements for these procedures are:

- High-quality fluoroscopic imaging equipment.
- Film or digital records of the examination.
- A tilt table capable of inclining the head -30° downward.
- A proper support device for securing the patient to the tilt table.[14]

Contraindications for this procedure include pregnancy and the use of certain medications.

Arthrography involves injecting iodinated contrast into joint spaces during fluoroscopy. In addition to evaluating joints, this procedure is used before surgery to characterize joint vasculature precisely.[28]

Diskography is an imaging-guided clinical procedure. It involves the fluoroscopically guided injection of a contrast medium into the vertebral disk's nucleus pulposus.[28] Some clinical practice guidelines require fluroscopy guidance because of the chance of inaccurate needle placement.[15] The goal of the injection is to provoke a response to help determine whether localized disk degeneration is responsible for the patient's pain. For example, resistance to the contrast injection indicates that the disk is not disrupted and therefore not the source of pain. In addition, the procedure can detect small annular tears. The kVp and mA techniques used for diskography depend on the area of the spine to be examined.[28]

Epidural nerve blocks involve anti-inflammatory steroid injections into the epidural space under fluoroscopic guidance. These procedures treat patients suffering from spinal stenosis and lumbar degeneration.[28]

Fluoroscopy-guided Percutaneous Needle Biopsy

Fluoroscopic guidance improves the accuracy of percutaneous needle biopsy, especially for lesions in difficult-to-reach areas such as the lungs and abdomen. Real-time imaging allows the operator to view the exact needle placement. Although CT-guided needle biopsy of pulmonary masses has replaced fluoroscopic guidance in many facilities, Kurban et al found that fluoroscopy was accurate, safe and offered a low-dose alternative to CT for pulmonary lesion biopsy. Their study reported an average effective radiation dose of 0.029 mSv, roughly equivalent to one chest radiograph. The average dose for CT-guided procedures was 5.1 mSv, about 210 to 270 times the radiation dose of fluoroscopy-guided needle lung biopsy. Other advantages of using fluoroscopy instead of CT included faster procedure time, lower cost and easier access to the modality.[29]

Angiography and Neuroradiology

Angiography and neuroradiology are two branches of interventional radiology that use fluoroscopy to visualize vessels. These imaging and interventional procedures require advanced radiographic and fluoroscopic equipment. The equipment often includes two ceiling track-mounted x-ray tubes and an image intensified fluoroscope mounted on a C-arm or L-arm.[1]

A typical voltage setting for the x-ray tube during vascular fluoroscopy is between 70 and 110 kV, and the current is normally set between 150 and 500 mA.[19] The x-ray tube has a small target angle, large-diameter anode disc and cathodes designed for magnification and serial radiography. During small vessel magnification imaging, a focal spot of 0.3 mm or smaller is needed for spatial resolution. The operator can improve image contrast in these studies by using a source-to-image receptor distance of 100 cm and an object-to-image distance of 40 cm. This technique removes some scatter by taking advantage of the air gap technique.[1]

The controls for positioning the patient table are located on the side of the table and also on the floor switch. The floor switch controls allow the operator to maintain a sterile field while positioning the patient. Some versions of patient couches come with computer-controlled stepping capability, which is needed to permit imaging from the abdomen to the feet after a single contrast injection. The timing and position of the patient couch must coincide with the image receptor.[1]

Digital image receptors currently are the most common devices, but some units still use cinefluorographic cameras, primarily for cardiac catheterization procedures. The digital image receptor has either a television camera pickup tube or a charge-coupled device (CCD).

CCDs are photosensitive silicon chips used in applications that convert light to a digital video image.[1]

Digital subtraction angiography is used to evaluate vessels without overlying structures obscuring the view. It is a valuable tool to diagnose and treat many conditions, including aneurysms and pseudoaneurysms, vascular occlusions, arteriovenous malformations and some tumors. The DSA technique usually first acquires a noncontrast image, also known as the mask image. Next a contrast medium is injected into the patient to better demonstrate the structures of interest. The mask image then is digitally subtracted from the contrast image, leaving only the vessels of interest visible on the monitor.[19]

Many image intensifier formats are available for DSA, and the choice of field size is at the discretion of the personnel performing the procedure. Livingstone and Mammen suggested that acquiring the mask image while injecting contrast rather than waiting for the mask image to appear might reduce exposure. They also emphasized proper collimation and limiting the use of magnification modes if the diagnostic quality of the images is not compromised.[19]

The eyes and thyroid gland are most vulnerable to radiation damage during cerebral angiography because of the beam proximity to these structures and their intrinsic radiosensitivity. Bismuth shields have recently become a method for protecting the patient's radiosensitive organs including the eyes, thyroid and breasts; however, Shortt et al found that eye shielding is not beneficial during cerebral angiography because the shielding interferes with diagnostic capability. If shields are placed on the image intensifier side of the patient, they fall in the primary beam, leading to increased patient dose because of the AEC. Shortt et al did report, though, that a circumferentially placed lead thyroid shield was an effective and inexpensive method for reducing the patient's thyroid dose.[30]

Because practitioners are in close proximity to the patient during many cardiac and interventional procedures, they must take special care to limit exposure to scatter radiation. Lead gowns, thyroid collars and glasses can be used for protection, and unshielded or partially shielded tissues may be protected with sterile, disposable, radiation-absorbing drapes.[31] According to NIOSH, occupational exposure is a concern in angiography because of reported exposures of 1 to 10 mrem inside the lead apron and eye exposures of up to 57 mrem.[23]

Cardiac Catheterization

The fluoroscopy equipment for vascular angiography and cardiac catheterization procedures must display images with maximum resolution because of small cardiac anatomy. Most catheterization imaging procedures use multiple focal spot, high-speed rotating fluoroscopic tubes that offer extremely short exposure times. The image intensifier in these fluoroscopy systems should provide maximum recorded detail and generally has either 2, 3 or 4 magnification modes to allow enhanced visualization of small anatomic structures. A television camera is coupled to the output phosphor of the image intensifier; the camera feeds the signal to television monitors for real-time imaging during the procedure.[26]

Images are captured through cineangiography with videotape or digital image recording. Cineangiographic images are permanently recorded on 35-mm, black-and-white movie film. A high-resolution motion picture camera attached to the image intensifier tapes at 30 or 60 frames per second. Digital imaging has largely replaced cineangiographic imaging, with the permanent images stored on compact discs (CDs) or digital video discs (DVDs).[26]

Pediatric Considerations

Some pediatric patients undergo as many as 10 complex interventional procedures to manage congenital diseases before reaching adulthood.[12] Procedures such as cardiac catheterization have played an important role in diagnosing and treating these patients, improving their survival.[11] At the same time, children are about 10 times more sensitive to radiation than adults and have a longer lifespan in which to develop radiation-related sequelae.[11,12] These factors mean that radiation dose must be kept to a minimum. To follow ALARA and maintain optimal image quality, radiology personnel must be familiar with specially designed pediatric fluoroscopy equipment and radiation protection techniques. This knowledge also helps reduce occupational dose because personnel are in greater proximity to the primary beam and scatter radiation during interventional procedures.[11]

According to Strauss, most fluoroscopy units can provide good image quality for pediatric patients, but design deficiencies or inappropriate equipment configuration when imaging small body parts can result in excessive radiation dose levels.[12]

A fluoroscopy system for pediatric use should contain a generator that provides a large dynamic range of milliampere-seconds (mAs) values per exposure as a function of patient thickness, measured at the umbilicus, from less than 10 cm to more than 30 cm. Also, the pulse width should be limited to less than 10 milliseconds to properly freeze patient motion. Variable-rate pulsed fluoroscopy may be used to reduce radiation dose and improve image quality. To reduce motion blur, the pulse width should be no greater than 4 to 5 milliseconds in infants and children, compared with the maximum setting of 8 milliseconds for adults. The pulse rate may be reduced according to the operator's ability to handle the loss of temporal resolution. Additionally, 3 focal spot sizes between 0.3 mm and 1.0 mm should be available.[12]

The number of iodine injections in pediatric interventional studies is severely limited because of the higher concentration of iodine required to illuminate smaller vessel diameters and the toxicity of the contrast medium. This challenge has led to the use of 2 imaging planes that allow the recorded information to be doubled per iodine injection. In many pediatric interventional laboratories, there are 2 C-arm units, either ceiling suspended on a set of rails or floor mounted.[12]

For imaging studies using iodine, 70 kVp is ideal, provided about 3-mm equivalent aluminum filtration is used. To maintain a kVp of 60 or above, the tube current during pulsed fluoroscopy should be 10 mA or less, using a 0.3-mm focal spot.[12]

Because many fluoroscopy units are programmed to optimize exposure for adult imaging studies, they can deliver an elevated radiation dose to pediatric patients. When the image is too bright, Strauss suggests first modulating the tube current to its minimum value, then reducing the pulse width to its minimum value and finally reducing the high voltage to provide the correct entrance exposure to the image receptor. Conversely, if the image is not bright enough, Strauss recommends modulating the tube current to its maximum value, then increasing the pulse width to its maximum value and finally increasing the high voltage.[12]

Conclusion

Fluoroscopy use continues to rise as new technologies and clinical applications are developed. Radiation dose to patients and health care personnel has increased with this trend. There are multiple fixed fluoroscopy system configurations available. Personnel operating these units must understand how to use the equipment's safety features and adjust exposure settings to provide the highest quality images while keeping radiation dose to a minimum. In addition, radiology personnel should receive up-to-date education as new components in the fluoroscopy imaging chain are developed.

References

1. Bushong SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 9th ed. St Louis, MO: Mosby Inc; 2008.
2. Mahesh M. Fluoroscopy: patient radiation exposure issues. *Radiographics.* 2001;21(4):1033-1045.
3. Archer BR. Radiation management and credentialing of fluoroscopy users. *Pediatr Radiol.* 2006;36(suppl 2):182-184.
4. Schueler BA. The AAPM/RSNA physics tutorial for residents: general overview of fluoroscopic imaging. *Radiographics.* 2000;20(4):1115-1126.
5. Sternbergh WC, Tierney WA, Money SR. Importance of access to fixed-imaging fluoroscopy: practice implications for the vascular surgeon. *J Endovasc Ther.* 2004;11:404-410.
6. Chaffins JA. Radiation protection in the OR. *Radiol Technol.* 2008;79(5):415-428.
7. Brusin JA. Radiation protection. *Radiol Technol.* 2007;78(5):378-392.
8. National Cancer Institute. Interventional fluoroscopy: reducing radiation risks for patients and staff. NIH publication No. 05-5286. www.cancer.gov/cancertopics/interventionalfluoroscopy. Published March 2005. Accessed May 13, 2010.
9. Jogi R. Erythema and bruising that turned painful and pruritic. *Clinical Advisor.* www.clinicaladvisor.com/erythema-and-bruising-that-turned-painful-and-pruritic/article/117980/. Published July 23, 2008.Accessed May 13, 2010.
10. Sitzman BT. Adverse event protocol for interventional pain medicine: the importance of an organized response. *Pain Med.* 2008;9(suppl 1):108-112.
11. Justino H. The ALARA concept in pediatric cardiac catheterization: techniques and tactics for managing radiation dose. *Pediatr Radiol.* 2006;36(suppl 2):146-153.
12. Strauss KJ. Pediatric interventional radiography equipment: safety considerations. *Pediatr Radiol.* 2006;36(suppl 2): 126-135.
13. Stueve D. Management of pediatric radiation dose using Philips fluoroscopy systems DoseWise: perfect image, perfect sense. *Pediatr Radiol.* 2006;36(suppl 2):216-220.
14. American College of Radiology. Practice guideline for the performance of myelography and cisternography. www.acr.org/

SecondaryMainMenuCategories/quality_safety/guidelines/dx/head-neck/myelography.aspx. Accessed May 13, 2010.
15. Fink GE. Radiation safety in fluoroscopy for neuraxial injections. *AANA J.* 2009;77(4):265-269.
16. Pooley RA, McKinney M, Miller DA. The AAPM/RSNA physics tutorial for residents: digital fluoroscopy. *Radiographics.* 2001;21(2):521-534.
17. Ballinger PW, Frank ED. *Merrrill's Atlas of Radiographic Positions and Radiographic Procedures.* Vol. 1. 9th ed. St Louis, MO: Mosby Inc; 1999:36-50.
18. Colangelo JE, Johnston J, Killion JB, Wright DL. Radiation biology and protection. *Radiol Technol.* 2009;80(5):421-441.
19. Livingstone RS, Mammen T. Evaluation of radiation dose to patients during abdominal embolizations. *Indian J Med Sci.* 2005;59(10):527-533.
20. Conference of Radiation Control Program Directors. *Quality Control Recommendations for Diagnostic Radiography. Volume 3. Radiographic or Fluoroscopic Machines.* www.crcpd.org/Pubs/QC-Docs/QC-Vol3-Web.pdf. Published July 2001. Accessed June 3, 2010.
21. Kumar P. Radiation safety issues in fluoroscopy during percutaneous nephrolithotomy. *Urol J.* 2008;5(1):15-23.
22. Slechta A, Reagan J. An examination of factors related to radiation protection practices. *Radiol Technol.* 2008;79(4):297-308.
23. National Institute for Occupational Safety and Health. Guidelines for protecting the safety and health of health care workers. NIOSH Publication No. 88-119. www.cdc.gov/niosh/docs/88-119. Published September 1988. Accessed May 13, 2010.
24. Damilakis J, Perisinakis K, Theocharopoulos N, et al. Anticipation of radiation dose to the conceptus from occupational exposure of pregnant staff during fluoroscopically guided electrophysiological procedures. *J Cardiovasc Electrophysiol.* 2005;16(7):773-780.
25. Ballinger PW, Frank ED. *Merrrill's Atlas of Radiographic Positions and Radiographic Procedures.* Vol. 2. 9th ed. St Louis, MO: Mosby Inc; 1999:92-156.
26. Ballinger PW, Frank ED. *Merrrill's Atlas of Radiographic Positions and Radiographic Procedures.* Vol. 3. 9th ed. St Louis, MO: Mosby Inc; 1999:240-334.
27. Levine MS, Rubesin SE, Laufer I. Barium studies in modern radiology: do they have a role? *Radiology.* 2009;250(1):18-22.
28. Furlow B. Pain management imaging. *Radiol Technol.* 2009;80(5):447-467.
29. Kurban LA, Gomersall L, Weir J, Wade P. Fluoroscopy-guided percutaneous lung biopsy: a valuable alternative to computed tomography. *ACTA Radiol.* 2008;8:876-882.
30. Shortt CP, Malone L, Thornton J, Brennan P, Lee MJ. Radiation protection to the eye and thyroid during diagnostic cerebral angiography: a phantom study. *J Med Imaging Radiat Oncol.* 2008;52:365-369.
31. Simons GR, Orrison WW Jr. Use of a sterile, disposable, radiation-absorbing shield reduces occupational exposure to scatter radiation during pectoral device implantation. *Pacing Clin Electrophysiol.* 2004;27:726-729.

Anne M. Scott, BSRS, R.T.(R), is a part-time writer and stay-at-home mother of two in Cape Carteret, North Carolina. She has written three continuing education articles for Radiologic Technology: *Improving Communication for Better Patient Care, Thyroid Cancer in Adults and Diagnosis and Treatment of Ankle Fractures. Ms. Scott was last employed as a radiologic technologist in the sports medicine clinic at Duke University Medical Center in Durham, North Carolina.*