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Fluoroscopy:

Mobile Unit Operation and Safety

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Fluoroscopy: Mobile Unit Operation and Safety

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Fluoroscopy is a branch of radiology that allows physicians to see dynamic processes. Mobile fluoroscopic units, commonly referred to as "C-arms," help make fluoroscopy available throughout a medical facility. To successfully operate this equipment in a variety of situations, the radiologic technologist or radiologist assistant must have in-depth knowledge of mobile fluoroscopy equipment.

This article discusses components that are common to most mobile fluoroscopy units. The operation of these units involves understanding specifics about the source, detector, optics and indicator systems. In addition, operators should be familiar with features of mobile fluoroscopy equipment that limit radiation exposure to patients and clinical personnel.

After completing this article, readers should be able to:

- Describe the various components of a mobile fluoroscopic unit.
- Summarize the physical properties of mobile fluoroscopy image production and display.
- Position the mobile fluoroscopic unit to limit radiation exposure to the patient and medical staff.
- Discuss dose limits and radiation safety concepts related to mobile fluoroscopy imaging.

Conventional radiography provides remarkable diagnostic information on static anatomy. However, if used to demonstrate a dynamic process, standard radiography produces a blurry image with motion artifact. In contrast, fluoroscopy offers real-time visualization of dynamic processes. The first recorded fluoroscopic procedure was performed with a cardboard box fluoroscope invented by Wilhelm Conrad Roentgen in 1895. Thomas Edison then developed conventional fluoroscopy in 1896, using a newer type of fluorescent screen. In 1937 Irving Langmuir was awarded the first patent for a fluoroscopic image intensifier. However, this initial design did not provide enough image intensification for clinical use and was modified by JW Coltman in 1948. Coltman's modifications resulted in a brightness gain of more than 1,000.

The first commercial image intensifier was produced by Westinghouse in 1953.[1] The addition of the image intensifier to the fluoroscope paved the way for the widespread use of fluoroscopy. The image intensifier allowed the operator to perform the procedures with photopic vision and decreased the amount of radiation exposure necessary to produce a diagnostic image. In 1955 the medical C-arm, which consisted of an image source and image receptor, was introduced.[2]

As fluoroscopy utilization increased, so did the desire and necessity to use the technology in areas of the hospital other than the radiology department, for example, in the surgical suite. In its company medical history, OEC Medical Systems Inc states that "… in the early 1970s, OEC introduced the first real-time [mobile] fluoroscopic imaging equipment in the United States … ."[3] The use of mobile fluoroscopy became popular in the early 1980s when mobile C-arms were used in the operating suite for select orthopedic procedures.[4] Mobile C-arms are used today throughout the world in a variety of settings, such as hospital operating suites or outpatient clinics, to provide fluoroscopic guidance during orthopedic, neurologic, endovascular, urologic, neurovascular, spinal and cardiac

Figure 1. *A typical mobile C-arm unit in the clinical setting.*

procedures.[2] In addition, mobile fluoroscopy equipment is operated by a variety of professionals, including radiologist assistants (RAs) and radiologic technologists.

Mobile Fluoroscopy Units

Each mobile fluoroscopic assembly is made up of several components, including a control panel, C-arm and monitor. Typically, the mobile fluoroscopic unit consists of 2 separate pieces: a C-arm and a control panel with monitors (see **Figures 1-3**). The operator inputs patient information and alters imaging factors that affect C-arm function at the control panel. Some smaller C-arm systems, such as those used in orthopedic distal extremity cases, consist of only 1 unit. These units are designed so that a small C-arm attaches to the control panel and monitor assembly. The 2 components communicate with one another via a cable that connects the C-arm to the control panel and monitors.

Control Panel

Control panels are located on both the monitor assembly and the C-arm to facilitate positioning the mobile fluoroscopy unit. Although control panel layout varies by manufacturer, each control panel performs the same basic functions. For example, equipment

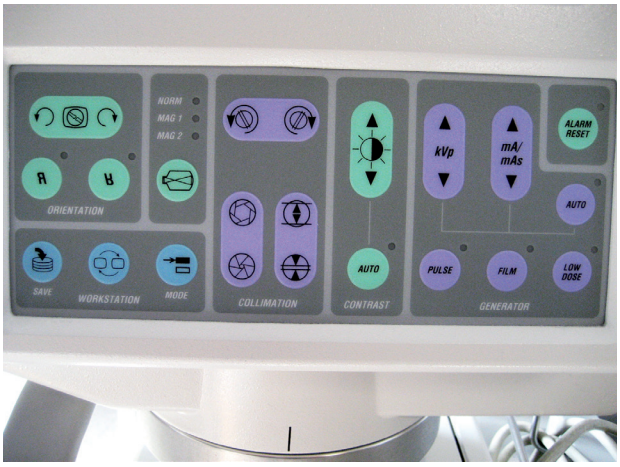

Figure 2. *Above. Mobile fluoroscopy control panel. This control panel is separated into 5 different categories: orientation, collimation, contrast, generator and workstation.*

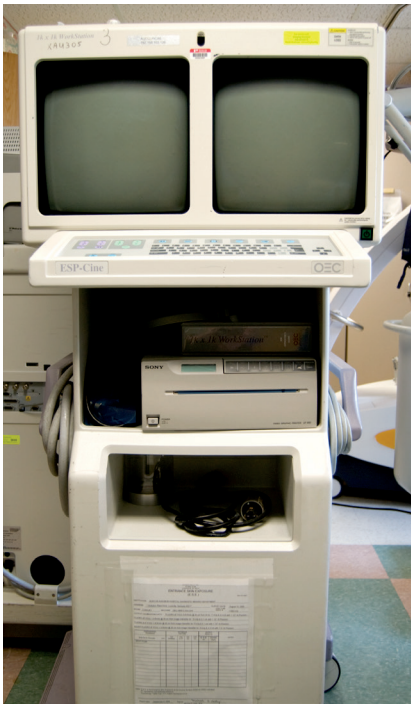

Figure 3. *Right. The monitor displays the images produced by the mobile fluoroscopy unit.*

manufactured by GE Healthcare organizes the C-arm control panel into 5 main categories: orientation, collimation, contrast, generator and workstation.

The operator can manipulate image orientation by rotating the image or altering the position in which the image is displayed on the monitor. The image can be rotated clockwise or counterclockwise by pushing the buttons with an open-circle arrow. Image

display position is altered by pushing the buttons that display "R" in various positions. Manipulating image orientation is useful because patient position varies. By manipulating image orientation, the operator can ensure that the image is displayed appropriately, regardless of patient positioning.

The control panel also allows the operator to adjust the x-ray unit collimators. Adjusting the collimators serves 2 functions: radiation protection and improved visualization. The technologist can limit the dimensions of the x-ray beam as it exits the tube by adjusting the collimators. Decreasing the size of the exiting beam restricts the area on the patient that receives radiation.

Appropriate use of collimation improves the image in 2 ways. First, many clinicians find "dead space" on an image to be visually distracting. This is space on an image that contains no pertinent information. By increasing collimation and decreasing dead space, the operator helps place the focus on the anatomy of interest. Second, proper use of collimation can ensure that the automatic brightness control (ABC) or automatic exposure control (AEC) systems function properly to provide optimal display of the relevant anatomy. If the operator uses appropriate collimation, only the relevant anatomy is irradiated, and the ABC or AEC systems adjust visualization and exposure factors as needed to demonstrate the area of interest.

The contrast portion of the control panel includes controls that permit the operator to alter the brightness and darkness of the displayed image. The ability to manipulate display contrast can help the operator account for variables such as the light level in the room and physician preference.

The generator controls adjust technical image production factors such as kilovolt peak (kVp) and milliampere seconds (mAs), and to select pulsed fluoroscopy. Carlton defines kVp and mAs as "prime factors" because they affect x-ray transmission and are controlled by the operator.[5] Adjusting the kVp directly affects the speed and energy of the electrons through the x-ray tube.[6] In other words, as the technologist increases or decreases the kVp, the energy and penetrating ability of the x-ray photons increase or decrease. The radiologic technologist or RA can adjust the kVp to account for variables such as body part thickness when operating a mobile fluoroscopy unit.

Carlton describes milliamperage (mA) as "the number of electrons crossing the tube from cathode to anode."[5] Therefore, mAs is simply milliamperage per seconds, or mA × s = mAs. Assuming that all other exposure factors are kept constant, adjusting the mAs directly affects the exposure rate. If the radiologic technologist or RA doubles the mAs, patient exposure doubles. When operating a mobile fluoroscopic unit, the technologist can adjust the mA to alter patient exposure and image quality as necessary.

With normal fluoroscopy operation, the exposure rate is continuous. When the operator selects pulsed fluoroscopy, there are breaks, or pulses, in exposure, much like the light from a strobe light. A strobe light produces flashes of light separated by periods of darkness compared with the continuous light of a lamp. The dark intervals are similar to the breaks in exposure during pulsed fluoroscopy. Using pulsed fluoroscopy greatly reduces radiation exposure to the patient by limiting the time and the amount of radiation to which the patient is exposed.

Radiation Source

Mobile fluoroscopy units consist of an anode-cathode tube assembly similar to that of fixed fluoroscopic systems. An x-ray tube is "a glass vacuum tube in which x-rays are generated."[7] During x-ray production, "electrons are accelerated from the hot cathode filament toward the anode surface, where x-rays are produced mainly by bremsstrahlung and to a smaller extent by characteristic radiation."[7] A modern x-ray tube contains 6 essential parts: a high vacuum inside a container, a cathode filament, a rotating anode, a tube shield, high-voltage cables and a tube port (see **Figure 4**).

The high vacuum is usually contained within a glass or metal tube. This vacuum allows the electrons to travel from the cathode filament to the anode and then through the tube port without colliding with gas molecules.

In an x-ray tube, the electrons flow from the cathode, or negative electrode, to the positive electrode, or the anode.[8] The cathode usually consists of a tungsten filament and a focusing cup, which directs electrons toward the anode.[9] Essentially, an external power

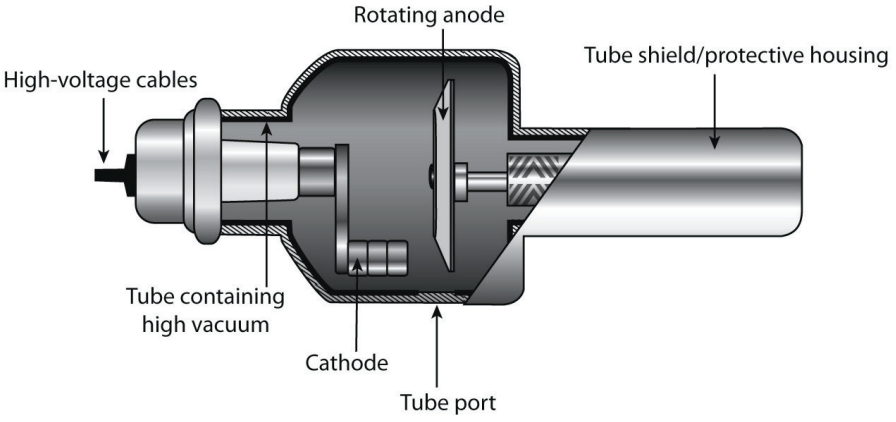

Figure 4. *Diagram of a typical x-ray tube, which serves as the radiation source for the mobile fluoroscopic unit.*

source heats the filament until thermionic emission occurs, causing electrons to leave the filament. The focusing cup then directs these fast-moving electrons toward a target on the anode. The electrons from the cathode filament stop suddenly on the target surface of the anode.[5] It is the rapid deceleration of these electrons that leads to the production of x-ray photons.

The tube is encased by a protective housing, or tube shield, to ensure that x-ray photons do not escape undirected from the x-ray tube. Carlton explains that this protective housing "controls leakage and scatter radiation, isolates the high voltages, and provides a means to cool the tube."[7] Graham and Cloke describe several essential criteria that the x-ray tube housing must meet. The protective housing must:

- Present no danger of electrical shock if touched during operation.
- Limit significant amounts of scatter radiation.
- Provide a secure support for the radiographic assembly.
- Allow adequate cooling and expansion of cooling oils.[10]

Maximizing the energy that an electron can transfer as it travels from the cathode filament to the anode requires maximizing the velocity at which the electrons travel. High-voltage cables help accelerate the electrons by applying a high-voltage charge to the anode. As the positive charge increases, the attraction force of the anode on the negatively charged electrons is stronger. As the attraction increases, so does the speed with which the electrons travel from the cathode filament to the anode, thus increasing the energy the electrons can transfer.[11,12] The use of high-voltage cables also can prolong tube life by decreasing potential for voltage breakthroughs.[7]

The tube port, or window, often is described simply as the exit for the x-rays.[13,14] More specifically, however, the x-ray tube port is the opening in the lead shielding of the x-ray tube housing through which the useful x-ray beam leaves. X-rays that escape the tube housing from areas other than the tube port are considered leakage radiation.[15]

Image Intensifier/Flat Panel Detector

Before the use of image intensifiers, fluoroscopic screens produced dim images. Radiologists had to adapt to the dark to compensate for the dimness of the screens. Dark adaptation is a process by which the observer sits in a darkened room before the procedure to allow his or her eyes time to adjust to the darkness. Spending time in a dimly lit environment activates the rods of the eyes. This type of sight is known as scotopic vision, or vision in which the eyes use only the retinal rods as light receptors. Often, radiologists wore red-tinted glasses to help the eyes adjust.[16]

The process of dark adaptation had 2 major drawbacks. First, the time required for dark adaptation resulted in workflow inefficiencies. Second, scotopic vision can lead to serious errors in image interpretation because visual acuity is controlled by the cones of the eye, not the rods.[5] The cones are activated during photopic vision. Photopic vision is normal daylight

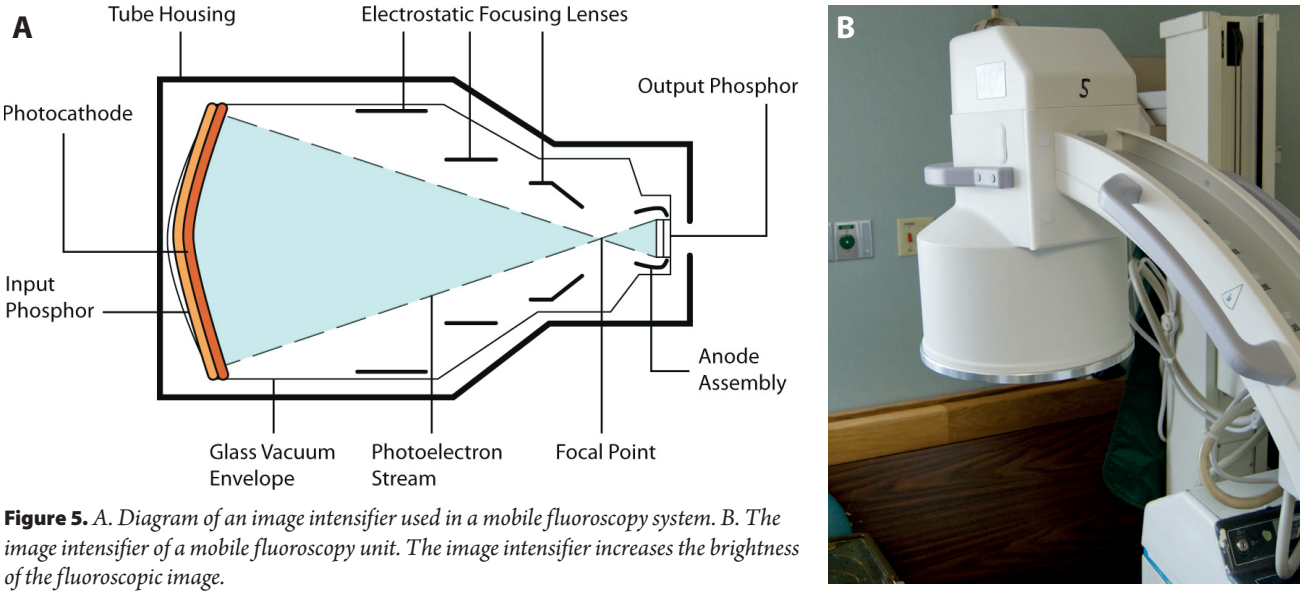

Figure 5. *A. Diagram of an image intensifier used in a mobile fluoroscopy system. B. The image intensifier of a mobile fluoroscopy unit. The image intensifier increases the brightness of the fluoroscopic image.*

vision or sight under sufficient illumination so that the cones are active and the eyes perceive hue.[17] Image intensification enabled photopic vision during fluoroscopic procedures, thus increasing visual acuity. A higher level of visual acuity increases the radiologist's ability to detect fine detail.[5,18-20]

Image Intensifier

The modern image intensifier consists of several components, each serving a unique function. These include the input phosphor, photocathode, electrostatic focusing lenses, anode, output phosphor and glass envelope (see **Figure 5**).[20]

The input screen of an image intensifier tube consists of a concave surface and a photocathode. The concave surface is coated with an input phosphor, typically cesium iodide (CsI). This surface must be concave to prevent image distortion. If there are differences in the distances between relative points of the input and output screens, those points with greater distances appear more magnified, and points with lesser distances appear less magnified. Therefore, a concave shape must be used so that each point on the input screen is equidistant from its relative point on the output screen.

The function of the input phosphor is to absorb x-ray photons and convert them to light photons. The mass attenuation coefficient of CsI closely matches the spectrum of the remnant beam (the x-rays that have penetrated the patient). This, coupled with the high atomic number of CsI, results in increased absorption efficiency, which is associated with lower patient dose.[20]

The photocathode typically is composed of cesium and antimony; it absorbs light and emits electrons. When a surface, usually metallic, absorbs electromagnetic radiation at a sufficiently high frequency (eg, light), the surface then emits electrons, a process called photoemission.[21] By the time of emission, the x-ray photons from the remnant beam have started many steps in the image intensification process. These x-ray photons were absorbed by the input phosphor, which then emitted light photons. The light photons were absorbed by the photocathode and emitted as photoelectrons. From this point, the photoelectrons are directed toward the output screen. The electrostatic lenses and the anode help to focus and accelerate the photoelectrons from the photocathode toward the output screen.

The electrostatic lenses focus the photoelectrons as they are accelerated toward the anode. Focusing helps the photoelectrons pass through a hole in the center of the anode. Any changes in the magnetic or electrical field affecting the electrostatic lenses can impair the

ability of the lenses to focus the photoelectrons, resulting in a distorted final image.

A 25,000-volt bias accelerates the photoelectrons toward the anode. As the photoelectron beam accelerates, its energy increases, enhancing the ability of the photoelectron stream to emit light at the output phosphor. As the photoelectrons pass through the hole in the anode, they strike the output screen.

The output screen is a glass screen with a silver-activated zinc-cadmium sulfide phosphor layer. The photoelectrons are converted into light photons as they strike the output phosphor. An opaque filter limits the amount of light photons directed back toward the input phosphor. This action helps to prevent image degradation.

The following is a brief review of the image intensification process:

- X-rays exit the patient, forming the remnant beam, which strikes the input phosphor.
- The input phosphor absorbs these x-ray photons and emits light photons.
- The light photons then strike the photocathode, which absorbs the light photons and emits photoelectrons.
- The photoelectrons are directed by the electrostatic focusing lenses and accelerated toward the anode by a voltage bias.
- After passing through a hole in the center of the anode, the photoelectrons interact with the output phosphor, which converts the photoelectrons to light photons.

The primary purpose of an image intensification system is to increase the brightness of the resulting image without significantly increasing the radiation dose to the patient. Total brightness gain is a measurement of the image intensifier's ability to convert the x-rays from the remnant beam into the brightest possible image. In short, total brightness gain is the product of flux gain and minification gain (total brightness gain = flux gain × minification gain).

Minification gain occurs because the input screen of the image intensification system is larger than the output screen. Therefore, all the x-ray photons striking the input screen must be focused so there is no loss of resulting light photons from the output screen. Mathematically speaking, minification gain is equal to the square of the input screen diameter divided by the square of the output screen diameter (minification gain = input screen diameter^2 ÷ output screen diameter^2).

Flux gain is "the ratio of the number of light photons at the output phosphor of a radiographic image intensifier tube to the number at the input phosphor."[22] For example, if the output phosphor generates 100 light photons for every photoelectron that interacts with it, the flux gain would be 100/1, or simply 100. Hendee states that the average brightness gain ranges from 1,000 to 6,000[23]; Carlton reports an average brightness gain of 8,000 to 25,000.[5]

Image Intensification Artifacts

Although the image intensification process offers many benefits to the modern radiology department, it is not a perfect system. The use of an image intensifier can potentially cause several image artifacts[20]:

- Lag. This artifact degrades the resolution of the final image and is caused by luminescence after x-ray stimulation.
- Vignetting. A loss of image brightness or intensity around the periphery of the image is called vignetting. It can occur in 2 situations: when there is scatter light in the optical coupling device between the image intensifier and the optical recording device or as a result of pincushion distortion.[24]
- Pincushion distortion. This artifact occurs because the input screen is curved and the output screen is planar, resulting in more accurately focused central electrons and peripheral electrons that tend to flare out from their course. This arrangement causes unequal magnification and a curving, or warping, of the image, predominantly at the periphery.[25]
- Veiling glare. All processes that contribute to image scatter, except the x-ray scatter process, constitute veiling glare. These processes include optical scatter in the input phosphor, electron scatter within the tube and optical scatter in the output optics. They result in reduced contrast between objects of different radiographic opacities.[26]
- S distortion. When an external electromagnetic source acts on the electrons traveling within the

Figure 6. *Flat panel detector. The flat panel detector may one day replace the image intensifier as the standard image receptor in the mobile fluoroscopic system.*

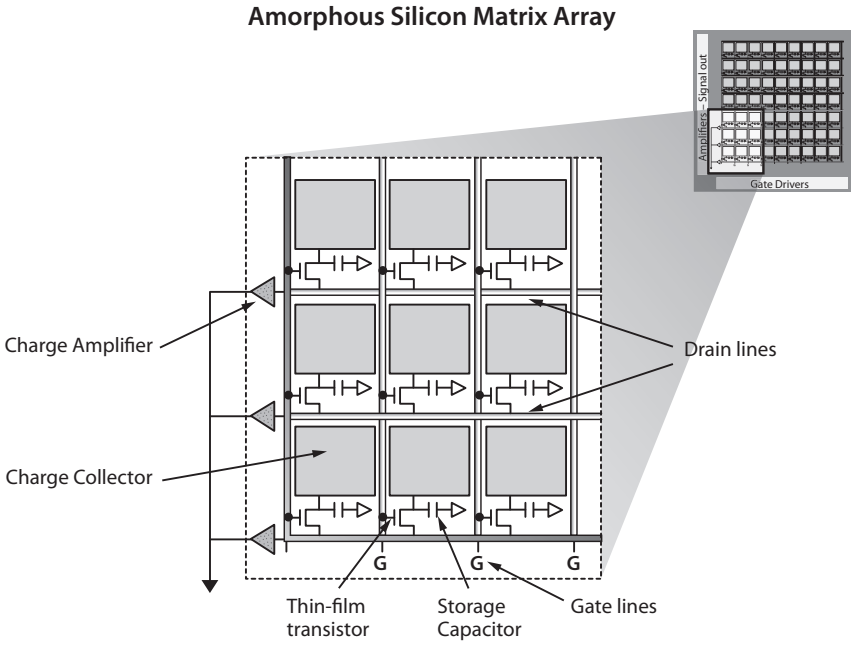

Figure 7. *Flat panel detector matrix array.*

image intensifier, S distortion occurs. The external source causes the electrons within the image intensifier, particularly those on the periphery, to deviate from their ideal course, resulting in spatial warping of the image along an S-shaped axis.[20,27]

Flat Panel Detectors

Although the image intensification system has been used for fluoroscopy since its introduction in the late 1940s, flat panel detectors may one day replace image intensifiers (see **Figure 6**). All flat panel detectors used in radiology convert a flux of x-rays into an electrical charge. This electrical charge is digitized in the detector's readout matrix.[28]

Flat panel detectors contain amorphous silicon thin-film transistors (TFT). Each transistor matrix array is arranged in a row-and-column grid consisting of numerous individual detector elements. The rows of this grid are formed by gate lines that operate the TFT. The columns of the grid are linked by drain lines that are connected to the TFT output. The drain lines connect to charge amplifiers, which receive the charge from the detector elements (see **Figure 7**).

The components of the detector elements are arranged on an amorphous silicon substrate and include a transistor, charge collector and storage capacitor. During exposure the row gate lines are turned off and the storage capacitor of each detector element stores the charge that is created by x-ray absorption. When the x-ray exposure is stopped, the gate lines are turned on individually in succession. This allows the charge stored in the capacitors to travel through the transistors and down the drain lines to the charge amplifiers. At this point, digitization occurs and the image is built row by row. For modern fluoroscopy, which deals with speeds of 30 frames per second, the data must be acquired from all detector elements within 33 milliseconds.[29]

Flat panel detectors currently use 2 different methods to convert x-rays to an electrical charge: indirect conversion and direct conversion. In indirect conversion, a phosphor, also known as a scintillator, interacts with the incoming x-rays to produce light photons. Then, a photodetector, such as an amorphous silicon photodiode array or a charge-coupled device (CCD), converts this light into an electrical charge. An x-ray

photoconductor directly converts the x-ray photons into an electrical charge in the direct conversion method.[30] This photoconductor typically consists of amorphous selenium positioned between 2 electrodes. Advantages of the direct conversion method include a simpler TFT structure and high spatial resolution. Disadvantages of direct conversion are lag and the risk of overcharging and destroying a TFT.[29]

Comparing Image Capture Systems

Ultimately, mobile fluoroscopy providers must consider the pros and cons when comparing image intensification systems and flat panel detectors. Flat panel detectors lack the geometric distortion of image intensifiers and resolve many of the image artifacts associated with the image intensification system. Limiting image artifacts helps create detailed, high-quality images that the radiologist can use to measure anatomy and assess pathology (most image intensification systems do not allow the radiologist to perform measurements on spot images).

Flat panel detectors also offer a larger, rectangular field of view, with up to 50% more coverage than a typical image intensification system, and a smaller, more compact design. However, although flat panel detectors perform well in situations requiring high exposures, such as cineradiography and digital subtraction angiography, they have historically produced lower-quality images with a low signal-to-noise ratio when used at lower exposure settings, such as those needed for continuous fluoroscopy. Only newer flat panel detectors can achieve a good signal-to-noise ratio when operating under low exposure conditions. This fact, coupled with the high cost of flat panel detectors relative to image intensification systems, has left open the debate regarding which system will be preferred in the future.[28,29,31,32]

Optics System/Video Interface

Once the output screen of the image intensifier produces light, the light must be transferred to an image viewer or a recording device. In a system with an image intensifier, a video camera is typically attached to the output phosphor of the intensifier. In conventional fluoroscopy, the analog signal from the video camera is then transmitted to a viewing monitor. Historically, video tubes were used for display; however, current mobile fluoroscopy equipment typically uses a video camera with a CCD to create the fluoroscopic image. The CCD is mounted via an image distributor to the output phosphor of the image intensifier.[5]

CCDs are integrated circuits that transfer individual charge packets over a physical distance while maintaining the integrity of the original charge packet.[33] More specifically, the circuit is made up of electrical connectors, or gates, mounted on a silicon plate. When voltage is applied to the gates, the area in the silicon beneath each gate traps electrons. As light strikes the silicon, the electrons are released in proportion to the light's intensity. Voltage variations over the gates move the stored charge to the periphery of the CCD. Once the stored charge reaches the periphery, it is integrated, amplified, and digitized, resulting in a final digital signal. The final signal then must be converted to a visible image that is usually displayed on either a cathode ray tube (CRT) or liquid crystal display (LCD) monitor.

Charge-coupled devices have several advantages over a video tube camera system for mobile fluoroscopy. CCDs eliminate lag, are more sensitive, have lower operating voltages, are smaller and more rugged, produce images that can be digitally manipulated, and have a longer lifetime.[34-36]

Image Recording, Display and Storage

Storing images and data from a mobile fluoroscopy unit begins with recording images using either a spot-film device or through digital image acquisition.[35] Images can be archived following acquisition using a hard drive, universal serial bus (USB) flash drive, digital video disk (DVD) writer or by printing images on high-quality video paper or film.[37]

Older generations of fluoroscopy equipment typically were film based; today's fluoroscopy units generally use a video viewing system. The following information on film-based systems is provided for historical context.[5]

In older systems, a spot-film device is attached to the mobile fluoroscopy unit; it moves an x-ray cassette into position for exposure during the examination.[38] The spot film is a radiograph of a particular anatomic area that is captured by using rapid fluoroscopic exposure and limiting the radiation passing through the

anatomical area. The spot film provides a permanent record of a briefly observed abnormality or helps improve the definition and detail of a small anatomic area.[39] Fluoroscopic imaging typically is used to demonstrate dynamic or real-time processes; however, spot films capture static images. If desired, the operator can acquire spot films in a rapid sequence to simulate a dynamic series. Traditionally, most fluoroscopic spot films are obtained in 1 of 3 formats: cassettes, 70-mm roll film or 105-mm chip film.

Spot-film recording with a cassette uses a conventional film-screen cassette to acquire a static image during a fluoroscopic sequence. The most common film size is 24 x 24 cm (9 x 9 in), but other sizes, such as 18 x 24 cm (8 x 10 in) and 24 x 35 cm (10 x 14 in), are used. The radiologic technologist or RA loads the cassette into the front of the image intensifier and then moves the cassette out of the primary beam and into a lead-lined compartment during fluoroscopy to prevent exposure from the primary beam or scatter radiation.

The technologist then selects which area of the film to expose. Typical spot-film devices allow several different exposure settings, including full frame (1-on-1), 2 vertical or horizontal exposures on 1 film (2-on-1) or dividing the film into quadrants, producing a 4-on-1 image. Once the user has selected the desired layout, the operator moves the cassette into place using a positioning mechanism within the spot-film device. Collimation to the appropriate size occurs automatically, and a formatting mask protects the remainder of the film from exposure. After the cassette is exposed, the operator must remove it from the spot-film device and replace it with an unexposed cassette.[5,36]

The use of spot-film cassettes during fluoroscopy has several disadvantages compared with other image recording methods. These include higher mA, higher tube loading (and a corresponding decreased tube life), higher patient exposure, low acquisition rate, long exposure delay and the delay and inconvenience caused by manually loading each cassette.[33]

The processes for using 70-mm roll film or 105-mm chip film are similar. A photospot camera is mounted on the optical coupling system of the image intensification unit. The beam-splitting mirror directs the image from the output phosphor of the image intensifier toward the photospot camera. An iris balances image noise in relation to patient dose by controlling the amount of light that reaches the camera lens and, therefore, the camera. The photospot camera uses a fine-grain film because the light output from the image intensifier is significantly brighter than that from a typical fluorescent screen. The film helps offset the decreased resolution caused by image minification.[36]

Photospot cameras have several advantages over spot-film devices. Benefits include cheaper film that requires less storage space, higher frame rates (up to 12 frames per second) with longer runs, reduced patient exposure, lower tube loading and no exposure delay.[33,36] However, the photospot camera system produces a minified image, has decreased resolution and requires more handling by the operator.[36]

Digital Fluoroscopy

As with the transition from film-based radiography to digital radiography (both computed and direct radiography), the medical imaging industry has shifted from using film-based fluoroscopic systems to digital systems. Currently, most mobile fluoroscopic units are based on digital technology. Digital fluoroscopy uses a digitized signal to produce computer-generated digital images that are displayed on a CRT screen.[40] In digital fluoroscopy systems, the x-ray tube current may be much higher than that used in standard fluoroscopy (eg, during digital subtraction angiography). Therefore, to control light exposure from the output screen, the optical system is equipped with an adjustable iris diaphragm.

The literature describes the digital fluoroscopy process in various ways, often depending on the manufacturer. In digital fluoroscopy, the incoming analog signal (image) from the CCD camera is processed by an analog-to-digital converter, which changes the analog signal to a digital binary equivalent. This digital signal then can be processed and stored in a computer and manipulated and transferred without loss of signal quality.

Digital fluoroscopy systems are commonly used to record image sequences that display rapidly changing image content (eg, passage of contrast through vessels). Thus, lag (or inertia) must be limited as much as

possible. Electronic noise also must be low, as it could add noise to subtracted images. To account for these 2 factors, digital fluoroscopy systems typically use a Saticon TV camera tube. The input screen material in this tube is selenium-arsenic-tellurium (SeAsTe), a combination that produces low electronic noise and a low quantum noise level.[40]

Because digital fluoroscopy systems often operate in pulsed mode, there are certain criteria for adequate image display. The video camera tube must be able to store the image from the input screen. Unlike conventional fluoroscopy, digital fluoroscopy uses a noninterlaced readout, also known as progressive scan mode. This means that instead of interpreting the image by scanning the even-numbered lines followed by the odd-numbered lines as in conventional fluoroscopy, the digital fluoroscopy system scans the lines in a progressive, or line-by-line, fashion. However, if the image were displayed in this format, flicker would be a problem. After the image is scanned progressively, an interlaced display mode displays it as 2 interlaced images to reduce flicker.[40]

Digital fluoroscopy also can acquire digital photospot images. During this process, the real-time video mode is deactivated, and the operator makes a short exposure with a high tube current (mA). The resulting image then is scanned by the camera and written to computer memory. Typically, these digital photospot images have a matrix of either 1024 x 1024 or, less commonly, 2048 x 2048. Often, with a mobile C-arm unit, digital photospot images can be printed using a laser camera or uploaded into a picture archiving and communication system (PACS) for further evaluation and interpretation.[41]

Advantages of using a digital fluoroscopy system include magnification, filtration enhancements, reduced image noise, the ease and speed of storing and transferring images electronically, the ability to view images immediately and the ability to alter image density and contrast.[5,36,41]

Locks and Angle Indicators

The mobile C-arm is a highly flexible piece of imaging equipment that can be used in a variety of situations. Each C-arm is equipped with various locks and angle indicators that allow the operator to manipulate and position the equipment based on the requirements of the procedure (see **Figure 8**). It is helpful for the technologist to be familiar with these indicators, along with how to manipulate C-arm position. A C-arm also typically has positioning handles that help the operator maneuver the equipment. For the sake of clarity, the following information assumes that the technologist has positioned the C-arm unit at a 90° angle to the patient (ie, perpendicular to the exam table) and that the patient is in a supine position. If all angle indicators are at zero and all locks are engaged, an anteroposterior (AP) projection can be performed. Although this article discusses the features common to most C-arm units, there is a wide variety of C-arm configurations and manufacturers.

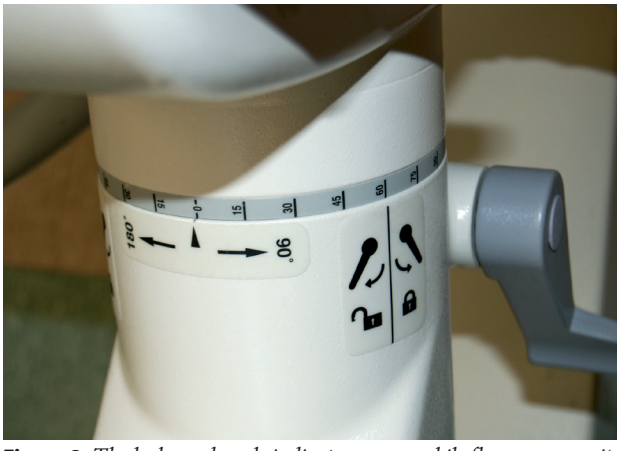

Figure 8. *The locks and angle indicators on a mobile fluoroscopy unit help the operator position the C-arm based on the requirements of each procedure.*

Directions of C-arm Mobility

The C-arm assembly can be maneuvered into a variety of positions and orientations. Each direction or type of movement is controlled by a series of brakes located on the C-arm unit. Often, each individual brake is a handle that the operator can manipulate manually. Each brake handle on the C-arm has indicators that identify whether the brake is locked or unlocked (see **Figure 9**). A locked brake prevents movement, and an unlocked brake allows the operator to manipulate the equipment.

Figure 9. *Example of the brake handles and lock indicators on a mobile fluoroscopy unit.*

Each movement mechanism on the C-arm assembly has associated angle or distance indicators that show the degree of movement. Some C-arm assemblies use a color-coded system that shows which locks relate to which movement direction. To use the mobile fluoroscopy unit, the operator might need to simultaneously use various mechanisms of motion.

Orbital rotation of the C-arm allows the operator to take lateral and oblique images. During orbital rotation, the x-ray tube and image intensifier or flat panel detector glide along the natural curve of the "C." This rotation is one of the most frequently used movements of the C-arm because AP and lateral projections are often essential in radiologic imaging (see **Figure 10**).

To better visualize this movement, make a "C" shape with your left hand. Imagine that your 4 fingers represent the image receptor and your thumb represents the x-ray tube. Make sure that your fingers and thumb all are pointing medially. Extend your wrist so that the "C" becomes a "U." This mimics the general movement of the C-arm as it performs orbital rotation. Orbital rotation can further be broken down into overscanning (ie, moving the body of the C over the patient) or underscanning (ie, moving the body of the C under the patient). Some sources give the average orbital rotation as 115° [42,43]; the maximum orbital rotation is given as 165°.[44]

Figure 10. *During orbital rotation, the x-ray tube and image intensifier or flat panel detector glide along the natural curve of the C arm. A. Overscan. B. Underscan.*

A C-arm unit also can be adjusted around the horizontal axis. To understand this principle, imagine that you are standing in front of a C-arm unit, observing the position of the x-ray tube and the image receptor. Rotating about the horizontal axis allows the x-ray tube and the image receptor to switch positions. In other words, assume that the image receptor is positioned toward the ceiling and the x-ray tube is positioned toward the floor. When rotating about the horizontal axis, the image receptor and x-ray tube travel a plane that results in the image receptor positioned toward the floor and the x-ray tube positioned toward the ceiling (see **Figure 11**).

To further demonstrate, re-form the letter C with your hand. Turn your hand so that your 4 fingers and thumb all are pointing toward you. Now, internally

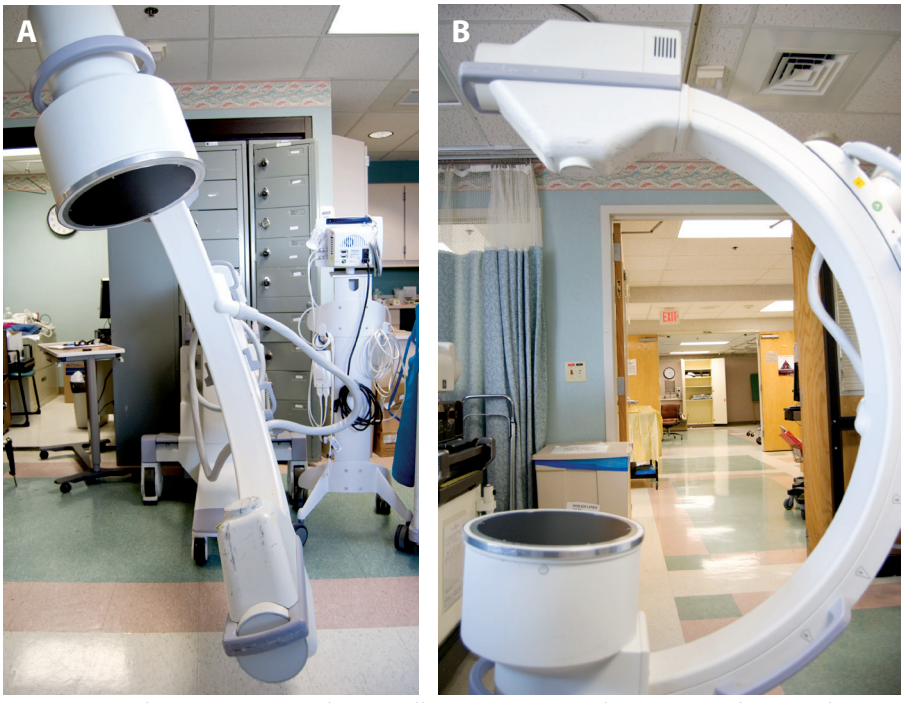

Figure 11. *A. The C-arm can rotate horizontally on its axis. B. Final position once the C-arm has performed full horizontal rotation.*

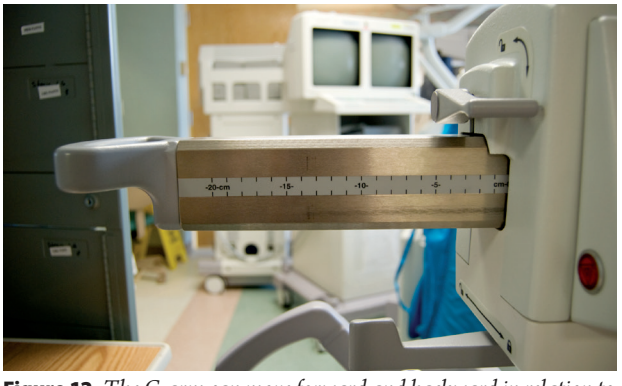

Figure 12. *The C-arm can move forward and backward in relation to the base of the unit, a feature called telescoping.*

rotate your shoulder and raise your elbow, so that you are effectively turning the C upside down. Your 4 fingers (the image receptor) should now be on the bottom and your thumb (the x-ray tube) should be on top. The path of your fingers and thumb represents the path that the C-arm takes when it rotates about the horizontal axis. Sources in the literature describe a horizontal rotation of ± 180°,[45] ± 210°[42] and approximately 270°.[43]

The C-arm also can telescope in and out. This movement permits the C-arm to advance or retract without moving the base of the unit. The function helps make minor adjustments when the operator needs to position the image receptor and x-ray tube slightly more medial or lateral in relation to the patient (see **Figure 12**). In other words, this function allows the operator to position the C-arm into various sagittal planes in relation to the patient.

To see this concept, make a C shape with your hand. Keep your elbow flexed at an acute angle, with your fingers and thumbs pointed forward. While keeping your hand at a stable vertical height, gradually extend your elbow. This movement mimics that of the C-arm as it telescopes or travels horizontally. The average horizontal travel distance is 20 cm.[42,43] One strategy operators may use is to advance the horizontal travel mechanism to its halfway point (average of 10 cm) before positioning the base and aligning the C-arm with the anatomy of interest. This helps the operator make minor medial-to-lateral adjustments (about 10 cm in either direction) without having to move the base of the C-arm unit.

Mobile fluoroscopy units also are configured with a lock that controls side-to-side movement of the entire C assembly (image receptor and x-ray tube) without moving the base of the C-arm unit. This type of movement often is referred to as "wig-wag." Adjusting the wig-wag allows the operator to position the C-arm assembly into a more proximal or distal position without having to move the base of the unit.

To understand this movement, make a C shape again with your hand. Extend your arm so that your fingers

and thumb both point forward. While keeping your arm straight (no bend in your shoulder, elbow or wrist) move your hand back and forth to the right and left. This motion demonstrates the C-arm movement when performing the wig-wag maneuver. The average wig-wag for C-arm units is ± 12 cm (total of 24 cm)[42] to ± 26 cm (total of 52 cm).[43]

The wheels on the base of each C-arm unit allow the entire unit to be positioned. The wheels are equipped with brakes (usually foot pedals) that can be engaged to stop gross movement of the C-arm assembly. Often, mobile units also have handles that the operator uses to steer the wheels in various directions. For example, if the operator wants to move the mobile fluoroscopy equipment to the left, the handles can be turned to the left, which in turn points the wheels to the left, so that the C-arm unit base is easier to move in that direction (see **Figure 13**).

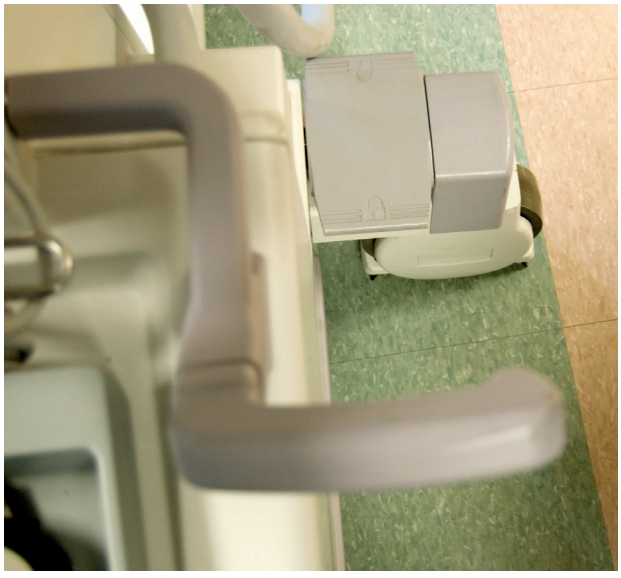

Figure 13. *The handles on a C-arm help steer the base of the unit. Note how the handle and wheel are turned in the same direction. Also note the pedal brake associated with the wheel.*

Exposure Controls

Source-to-Skin Distance Control

In mobile fluoroscopy, source-to-skin distance (SSD) is the distance between the x-ray tube and the patient. The angulation and position of the C-arm dictate the x-ray tube position in relation to the patient; it may be placed above, below, beside or in a variety of other positions. According to the U.S. Food and Drug Administration (FDA), the minimum SSD when using a mobile fluoroscopic device must be no less than 30 cm (12 in). The FDA provides an exception for specific surgical cases in which surgery can only be performed if the SSD is less than 30 cm. In these cases, the FDA states that a shorter SSD is acceptable, but only to a minimum of 20 cm.

Small C-arm units, often referred to as extremity C-arms, can be used for surgical procedures on the extremities. Because these units are smaller than typical mobile fluoroscopy units, the distance between the radiation source and image receptor is decreased relatively. Therefore, when using extremity C-arms, an SSD of 30 cm might be impossible. The FDA makes a special exception in these situations. When using a C-arm with a maximum source-to-image receptor distance (SID) of less than 45 cm, the FDA states that the SSD shall be no less than 19 cm (approximately 7.5 in). Furthermore, when these particular C-arms are used and having an SSD of 19 cm or more would render the case impossible, the FDA permits an SSD of 10 cm or more.[46]

The purpose of the FDA regulations is to decrease the patient's radiation exposure (ultimately the entrance skin exposure, or ESE). There is an inverse relationship between the SSD and the ESE. In other words, as SSD increases, ESE decreases. More specifically, ESE is the product of radiation output at the radiation entrance surface and the mAs used for the projection.[47] For example, assume that the SSD is 70 cm and the ESE is 4.8 rad/min. Keeping all other exposure and patient factors constant, if the operator reduces the SSD to 60 cm, the ESE increases to 5.6 rad/min. Furthermore, if the SSD was reduced further to 55 cm, the ESE would increase to 5.9 rad/min. However, increasing the SSD from 70 cm to 80 cm, decreases the ESE from 4.8 rad/min to 4.3 rad/min.[48]

The various methods for measuring the exact ESE are beyond the scope of this article. To adjust the SSD, each mobile fluoroscopy unit is equipped with controls that raise or lower the C-arm unit. These controls usually are 2 separate buttons, marked with

up or down arrows. The average C-arm height range is 46 cm (18 in).[42,43]

Radiation Field Control

One way to limit radiation exposure to the patient is to control the radiation field. A number of features in typical x-ray tubes help adjust both the size and strength of the radiation field.

The FDA has very specific regulations for fluoroscopy beam dimensions. According to the FDA, the following applies to fluoroscopic imaging systems (other than radiation therapy units) that use circular image receptors, such as image intensifiers, and were manufactured before June 10, 2006: "Neither the length nor the width of the x-ray field in the plane of the image receptor shall exceed that of the visible area of the image receptor by more than 3 percent of the SID. The sum of the excess length and the excess width shall be no greater than 4 percent of the SID."[46] The FDA has similar guidelines for fluoroscopy systems that use rectangular image receptors, such as flat panel detectors and were manufactured on or after June 10, 2006.[46]

The process of limiting the irradiated field size is called beam restriction. The purpose of beam restriction is to ensure that only the area of interest is irradiated, thus limiting patient exposure. Standard x-ray tubes have 3 basic types of beam restrictors: aperture diaphragms, cones and collimators. An aperture diaphragm is a flat piece of lead with an opening in the center. Various configurations are available, and the size and shape of the opening determines the size and shape of the x-ray beam.

Beam-limiting cones are lead-lined devices that are typically either cone shaped or cylinder shaped. These devices slide onto the collimator housing or tube head and shape the primary beam to the size of the cone opening. However, aperture diaphragms and cones are impractical for a mobile fluoroscopy unit. Because the C-arm can be placed in a variety of different positions and must produce exposures of various dimensions and intensities, mobile equipment typically uses collimators to limit the beam. Collimators consist of multiple sets of shutter blades that alter the shape of the x-ray beam. The shutter blades are made of a highly absorbing, or radiopaque, material such as lead. The first set of shutter blades is positioned close to the x-ray tube port to limit the amount of off-focus radiation escaping from the x-ray tube.

Using a round set of shutter blades to match the x-ray beam to the circular shape of the image intensifier is commonly referred to as iris collimation.[35] Two sets of rectangular shutter blades then are used to alter the length and width of the primary x-ray beam. Specifically, one set controls the width of the beam and the other controls the length. These collimators generally are referred to as leaf collimators.

The proper use of collimation can reduce both direct exposure to the patient and the amount of scatter radiation produced. Reducing scatter radiation also improves image contrast. The collimation system controls for mobile fluoroscopy units are located on the control panel. Typically, one set of buttons controls the iris collimation and another set controls the leaf collimation.[5,35,43,46,49]

Another aspect of controlling the radiation field involves controlling beam strength. The beam leaving the x-ray source is heterogeneous, possessing a wide range of energies. In other words, some of the x-ray photons in the beam are low energy and others are high energy. The low-energy x-ray photons are more likely to be absorbed by the patient, thus increasing the patient dose without adding to image quality. Ideally, these low-energy photons should be removed from the x-ray beam before reaching the patient, a process known as filtration, or beam hardening.

Filtration involves inserting a material in the path of the primary beam to remove the low-energy x-ray photons. A wide variety of materials can be used as filters, but aluminum is the standard filter material. Filter materials are typically expressed in aluminum equivalent. For example, if 1.5 cm of plastic provides the same filtration as 0.5-mm aluminum, then the filtration ability of the plastic is referred to as 0.5-mm aluminum equivalent.

Filtration also can be expressed as a half-value layer (HVL). HVL represents the amount of filtration material necessary to reduce the strength of the primary beam to one-half its original value. HVL also can be expressed in terms of aluminum equivalent. According to federal regulations, the minimum required HVL

for fluoroscopy is 2.3 mm aluminum equivalent at 80 kVp. Although this is the minimum required HVL, some sources suggest that the HVL at 80 kVp should be increased to 3.0 mm aluminum equivalent to reduce patient dose.[35]

Total filtration is further classified into 2 categories: inherent filtration and added filtration. Inherent filtration refers to the permanent filtration provided by the x-ray tube and housing. The typical inherent filtration of an x-ray tube is approximately 0.5- to 1.0-mm aluminum equivalent.[5] Added filtration includes filters placed between the tube housing and image receptor. For example, collimators add filtration. Based on the various procedures for which they are used, mobile fluoroscopy devices operate within a wide range of kVp values. National Council on Radiation Protection and Measurements (NCRP) guidelines state that equipment operating at certain kVp levels must have the following minimum total filtration amounts:

- Below 50 kVp requires total filtration of 0.5-mm aluminum equivalent.
- 50 to 70 kVp requires 1.5-mm aluminum equivalent.
- Above 70 kVp requires 2.5-mm aluminum equivalent.[49]

For example, the x-ray source assembly of one C-arm model has an inherent filtration of 0.6-mm aluminum equivalent ± 0.5 mm and added filtration, resulting in a total filtration of 5.5-mm aluminum equivalent.[43]

Exposure Rate Control

Although exposure factors typically are low in mobile fluoroscopy (ie, generally < 5 mA), the duration of exposure leads to a relatively high patient dose. Federal regulations have been enacted to limit exposure to the patient. These regulations help control the maximum exposure rate of both mobile and fixed fluoroscopy systems. The FDA has stated that fluoroscopy equipment "shall not be operable at any combination of tube potential and current that will result in an AKR [Air Kerma Rate] in excess of 88 mGy [milligray] per minute."[46] This translates to a maximum exposure rate of 10 roentgen (R) per minute. This maximum allowable exposure rate typically is listed as 10 R/min.

The FDA allows 2 exceptions to this rule. The first exception pertains to recording images. More specifically, there is an exception if the equipment was manufactured before June 10, 2006, and image recording uses photographic film or a video camera when the x-ray source is operated in pulse mode. If the equipment was manufactured on or after June 10, 2006, the FDA allows an exception "during the recording of images from the fluoroscopic image receptor for the purpose of providing the user with a recorded image(s) after termination of the exposure."[46] Currently there is no entrance skin exposure (ESE) rate limit when recording fluoroscopic images.

The second exception involves using high-dose fluoroscopy. High-dose fluoroscopy mode offers a "boost" to typical exposure parameters to reduce quantum mottle, thus increasing image detail. This mode is used in a variety of situations, such as angiography, when a higher level of detail is needed than can be obtained with conventional exposure factors. With this fluoroscopy mode, the FDA allows a maximum exposure rate of 20 R/min (air kerma rate of 176 mGy/min).

To ensure that high-level fluoroscopy is not activated accidentally, the FDA requires several safety measures. Units that are capable of performing high-level fluoroscopy must be equipped with a special switch or button to activate this mode that is different from the switch used to operate the standard fluoroscopy mode. In addition, this mode requires continuous manual activation to function. In other words, the operator must constantly apply pressure or depress the appropriate switch or button to activate the high-level fluoroscopy mode (see **Figure 14**). Finally, the equipment must have a continuous audible signal that can be heard by at least the C-arm operator when high-level fluoroscopy mode is in operation.[46]

In addition to setting maximum exposure rates for mobile fluoroscopy devices, the FDA also has several other regulations to decrease patient exposure. Technically speaking, a primary barrier is any surface that can be struck by the useful beam. A way to think about the concept of a primary barrier is to imagine that any surface perpendicular to the path of the primary beam can serve as a primary barrier. For example, if an x-ray tube port points at a particular wall during exposure, then that wall is considered a primary barrier and must meet the appropriate regulations. Typical primary

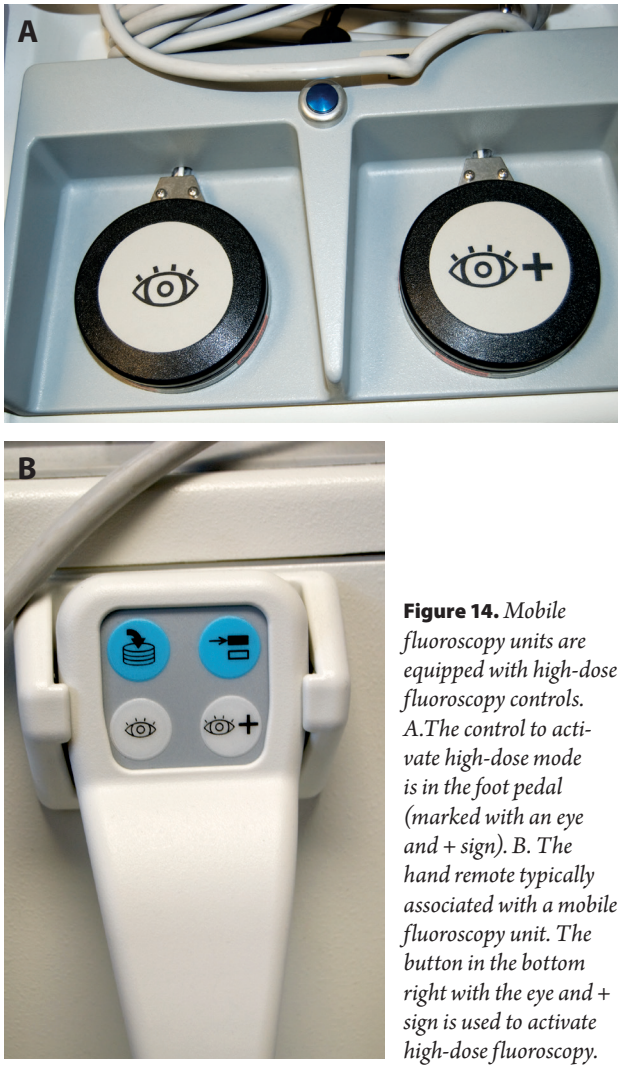

Figure 14. *Mobile fluoroscopy units are equipped with high-dose fluoroscopy controls. A.The control to activate high-dose mode is in the foot pedal (marked with an eye and + sign). B. The hand remote typically associated with a mobile fluoroscopy unit. The button in the bottom right with the eye and + sign is used to activate high-dose fluoroscopy.*

protective barriers are walls at least 7 ft tall that contain 1/16 inch lead.[47,49] All staff members should make every effort to avoid exposure to the primary beam.

An image intensification system should have a primary protective barrier of at least 2-mm lead equivalent.[47] The primary protective barrier must intercept the entire cross section of the fluoroscopic beam at any possible SID. In a mobile fluoroscopy system, this barrier typically is the image intensifier or the flat panel detector assembly. In other words, the dimensions of the primary beam cannot extend beyond those of the image intensifier or flat panel detector. Thus, iris collimators must be used on C-arm units with image intensifiers because the primary beam must conform to the circular shape of the image intensifier. Regardless of the SID, beam-limiting devices must be able to reduce the field size to at least 5 x 5 cm.

Often, in modern mobile fluoroscopy equipment, the x-ray beam field size automatically adjusts as the SID or image receptor size changes. The manufacturer may provide an override capability in the event of system failure. The override switch must be labeled "For X-ray Field Limitation Failure" and provide the operator with a visible signal indicating that the automatic field adjustment is overridden.

The exposure switch for the mobile fluoroscopy unit requires continuous pressure to maintain the exposure. This type of switch often is referred to as a "dead man" switch. These exposure buttons replace simple on-and-off switches and require pressure for the entire duration of the exposure.

The equipment must have an audible signal that alerts the C-arm operator after 5 minutes of fluoroscopy exposure. If the exposure continues after this 5-minute interval, the signal continues to sound until it is reset. The audible signal usually is reset manually, but in some instances an automatic reset can be used. In either case, the audible signal sounds for at least 2 seconds before it can be reset.

Mobile fluoroscopy units that were manufactured on or after June 10, 2006, must display the fluoroscopy exposure time (often simply referred to as "fluoro time") at the operator's workstation. The time usually is displayed in minutes and tenths of seconds (eg, a display of 1.2 minutes actually indicates an exposure time of 1 minute, 12 seconds). The fluoroscopy exposure time must be displayed continuously and updated at least every 6 seconds. Although the time remains until reset, it typically resets automatically with the beginning of a new procedure.

Finally, a last-image hold (LIH) display system must be present on all fluoroscopic equipment manufactured on or after June 10, 2006. Essentially, an LIH system can retain an image for storage that was generated during fluoroscopic exposure without requiring a separate or new exposure. The FDA has established several regulations concerning the LIH image. The

system must allow any factors that can be selected by the operator, such as number of images, method of combining images or radiographic technique factors, to be manipulated before the fluoroscopic exposure occurs. Unless separate displays are provided for the LIH image and the fluoroscopic image, the LIH image is replaced by the fluoroscopic image when fluoroscopic imaging is resumed. A user must be able to determine whether the displayed image is a fluoroscopic image or an LIH image. In the author's experience, the LIH image and the fluoroscopic image appear as "negatives" of one another, providing an easy means of differentiation.[5,33,46]

Protective Equipment and Clothing

When a patient undergoes a conventional radiography exam (eg, chest or extremity radiography) in the radiology department, he or she typically is the only person present in the exam room during the exposure. A staff member, technologist or family member remains in the exam room during an exposure only when absolutely necessary to assist in patient positioning or to calm the patient. However, when mobile fluoroscopy is used, several hospital staff members often are present in the room for the duration of the exposure time. For example, when a mobile fluoroscopy unit is used in an operating suite, the RA, radiologic technologist, surgeon, residents, anesthesiologists, nurses, surgical technologists and others can be in close proximity to the patient during x-ray exposure. It is imperative to minimize secondary radiation exposure to hospital staff.

Most occupational exposure during mobile fluoroscopy is from secondary radiation in the form of leakage or scatter radiation. To protect themselves from exposure to secondary radiation, staff members present during fluoroscopic exposure should use devices such as protective lead aprons, thyroid shields, lead gloves and lead glasses. Protective aprons are commonly available in 0.25-, 0.5- or 1.0-mm lead equivalent thicknesses. Because the peak energy of the x-ray beam used in mobile fluoroscopy often is 100 kVp or greater, a protective apron of at least 0.25-mm lead equivalent must be worn by individuals present during exposure (aside from the patient). Naturally, protective aprons with a higher lead equivalent provide more protection, but often are heavier and more expensive than other aprons (see **Table 1**). In the procedure room, personnel absorb 0.1% of the patient dose from scatter (at 1 m). Lead aprons of 0.25-mm and 0.5-mm lead equivalent attenuate 80% and 95% of the scattered radiation, respectively.[50]

Table 1

Protection Provided by Lead Aprons[49]

Apron Thickness (mm lead equivalent)	X-ray Attenuation at 75 kVp (%)	X-ray Attenuation at 100 kVp (%)
0.25	66	51
0.5	88	75
1.0	99	94

kVp = kilovolt peak

Radiologic technologists and RAs should consider the design of the protective apron when moving around the room during fluoroscopic exposure. Some protective aprons only cover the front of the wearer. Operators who wear this type of apron must remember that their backs are not protected from radiation exposure, and they should not turn their backs to the radiation source or patient. This might require individuals to walk backward when moving about the exam room to ensure adequate radiation protection.

Other protective aprons have a wraparound design that protects all sides of the wearer. Although these aprons typically are heavier, they often are preferred because they allow staff to move about the room more freely. Wraparound aprons come in single and 2-piece (vest/kilt) models. Regardless of the style chosen, the protective apron must properly fit the person wearing it. The armholes should not be too wide and the neckline should not be too low because of the possibility of increased radiation exposure. A 2-piece apron must overlap sufficiently to prevent radiation exposure to the wearer's midsection. It also is recommended that protective aprons extend down to the midfemur.[51]

A neck/thyroid shield should be worn along with the protective lead apron. These shields protect the thyroid area and should be of 0.5-mm lead equivalent.[47] In general, thyroid and collar shields are recommended if the monthly radiation dose measured at the collar level of

the practitioner exceeds 400 mrem.[48] Thyroid shields are somewhat uncomfortable, but they can reduce the effective dose significantly.

Although hands should be kept out of the primary beam when possible, lead gloves should be worn whenever the hand is placed near the primary beam. Recommendations vary as to the lead equivalent required for gloves, but sources cite a range of 0.25- to 0.5-mm lead equivalent.[5,33,48,52] Medical personnel often do not wear traditional lead gloves because they are bulky, heavy and limit the wearer's manual dexterity. To remedy this problem, leaded surgical gloves have been developed that offer some protection from scatter radiation but are thinner, lighter and do not restrict dexterity. It is important to note that these gloves provide minimal protection if the hands are placed within the primary beam.[48]

Leaded glasses also are available as an accessory radiation protection device. These glasses serve a dual protective function: they shield the eyes from scatter radiation and from body fluids. Several designs of lead glasses are available; those with side shields are best for procedures that require practitioners to turn their head. These glasses should have a minimum 0.35-mm lead equivalent, although other protective thicknesses are available.[47]

Protective aprons and other personal protective equipment should be inspected at least annually to ensure that their shielding capability has not been compromised. For example, at least once a year protective aprons should be inspected with fluoroscopy to identify any cracks that might have formed. Extensive damage to protective equipment can render it useless and should be noted.

Ways To Minimize Radiation Exposure

Medical imaging professionals are responsible not only for producing images of diagnostic quality, but also for limiting radiation exposure to patients and staff as much as possible, a concept known as the ALARA (as low as reasonably achievable) principle. Although the maximum ESE allowed by the FDA for a fluoroscopy procedure is 10 R/min and 20 R/min for high-level fluoroscopy, operators can use several practices to reduce patient exposure to much lower levels.

As the C-arm is positioned during a procedure, the site where the ESE is measured changes. For example, if a procedure begins with the image receptor above the patient and the x-ray source below the patient, the ESE is measured from the skin surface adjacent to the exam table. If the operator then manipulates the C-arm to acquire a lateral image with the image receptor on the patient's left side, the ESE is measured from the patient's right side. The ESE always is measured from the surface closest to the x-ray source. Recognizing this fact helps the operator use ESE-limiting techniques regardless of the position of the C-arm and patient.

As previously discussed, the SSD affects the ESE rate. As SSD increases, the ESE rate decreases. In other words, the farther the x-ray source is from the patient, the lower the ESE rate. Most contemporary C-arm units are equipped with an x-ray source covering that does not allow the SSD to be lower than federal regulations permit.

There are several practical ways to decrease the ESE. Assuming that the image receptor is positioned above the patient, the operator can lower the C-arm unit as much as possible (to the degree that it does not hinder the procedure). The operator also can raise the exam table as high as possible, although often in mobile fluoroscopy situations, the operator cannot control the exam table height. Simply asking the medical practitioner involved in the procedure to raise the table can help to decrease ESE.

The distance from the object imaged (generally regarded as the patient, or more specifically, the anatomy of interest) to the image receptor is commonly referred to as the object-to-image distance, or OID. As in conventional fixed unit fluoroscopy, when this distance consists of air, it can be thought of as an air gap. OID and ESE rates are directly related. In other words, as OID decreases, the ESE rate decreases; conversely, as OID increases, the ESE rate increases. The operator should try to keep the image receptor as close to the patient as possible to minimize ESE.

The basis of this relationship involves scatter radiation. As the remnant beam exits the patient, it contains x-ray photons of various energies. The higher-energy photons continue along a straighter path and interact with the image receptor. Photons with lower energies

exit the patient at various angles and are less likely to be intercepted by the image receptor. If the image receptor does not receive the energy from these scattered photons, the AEC system automatically increases technical exposure factors to compensate for the loss, resulting in an increased ESE rate to the patient.

A study by Wagner et al in 2000 discussed the effects of an air gap on ESE dose rate.[53] Using a 280-mm water phantom, the researchers assumed the average ESE dose rate was 4.8 R/min at 0 cm OID. As the air gap increased to 5 cm (2 in), 10 cm (4 in) and 13 cm (5 in), the ESE rate increased to 5.7 R/min, 6.6 R/min and 7.3 R/min, respectively. The changes represent increases in ESE exposure rate of 19%, 39% and 53%, respectively.[48,53] From this study, researchers found that by positioning the image receptor 13 cm (5 in) closer to the patient, the C-arm operator could reduce the ESE rate by more than 50%. Thus, decreasing the OID to as close as practically feasible helps keep the ESE as low as possible.

Mobile fluoroscopy operators can select various field-of-view sizes (magnification modes). There is an indirect relationship between the field of view and the ESE rate. A larger field of view results in a lower ESE rate. This association reflects the physical properties of the image intensification system. When operating the C-arm unit with a full-size field of view, the photoelectrons from the entire input phosphor are accelerated and focused on the output phosphor. If the operator selects magnification mode, an increased voltage supplies the focusing lenses, thus moving the focal point of the electrons farther away from the output phosphor. Only a portion of the electrons from the more central area of the input phosphor reach the output phosphor. Because fewer electrons reach the output phosphor, the resulting image is dimmer. To compensate for the dimmer image, the AEC system increases the mA, thus increasing patient exposure.[47] The practical application is that magnification modes should be used only when necessary. Using a larger field of view enables the operator to decrease the patient's ESE.

The effect of dose levels on ESE has been studied for an image capture rate of 15 frames per second and an attenuator of 8 inches of water at various modes and fields of view (see **Table 2**).[48] The results demonstrate

Table 2

Effect of Field of View and Dose-level Modes on Entrance Skin Exposure Rates[49]

Field of View (in)	Entrance Skin Exposure (R/min)		
	Low-dose Mode	Normal-dose Mode	High-dose Mode
5	4.7	5.9	8.9
7	4.3	5.8	7.3
9	4.0	5.2	6.9

R = roentgen

several factors that can be applied to radiation protection methods. For each individual dose mode, the ESE rate decreases as the field of view increases. This result further verifies the practice of using the largest field of view appropriate for a given exam. In addition, the dramatic increase in the ESE rate for each given field of view as the dose mode progresses from low to high is remarkable. When changing from low-dose mode to high-dose mode for the 5-, 7- and 9-in fields of view, the ESE rate increased 90%, 70% and 73%, respectively.

In addition to reducing the ESE, the operator is responsible for reducing total radiation exposure to the patient as much as possible. One of the most effective ways to do this is to minimize beam-on, or exposure, time. The exposure switch should be activated only when the radiologist or other practitioner is looking at the imaging monitors. As soon as the practitioner looks away from the monitor, radiation exposure no longer is necessary and should be stopped.

Pulsed fluoroscopy mode should be used whenever possible. During pulsed fluoroscopy, x-rays are delivered in a series of rapid bursts. For example, if the operator selects a 2 frame-per-second pulse mode, only 2 image frames are produced in a given second of beam-on time. These gaps in exposure time greatly reduce patient exposure compared with using a constant exposure mode. During the gaps in exposure the fluoroscopy assembly automatically displays an LIH image on the monitor.

It is important to note there is not a direct linear relationship between reducing the frames-per-second rate

and reducing radiation exposure. In other words, it would seem that changing the frame-per-second rate from 20 to 10 would reduce exposure by one-half. However, as the frame-per-second rate is decreased, a manufacturer's built-in feature often increases the mA to maintain an appropriate level of image noise. According to Mahesh, reducing the pulse rate from 30 to 15 frames per second actually represents a reduction of only 25% to 28%.[54]

Using the last-image hold function, which is configured automatically on most mobile fluoroscopy units, also can significantly reduce beam-on time. The image monitor continues to display the last image obtained until a new exposure is made. This allows the practitioner to study the given image without further exposing the patient.

The operator should use the fluoroscopic exposure time display and the 5-minute audible exposure time alarm to remain aware of beam-on time. Because the display is located on the C-arm control panel, it often is visible only to the operator. If the operator becomes concerned about radiation exposure time, he or she should alert the practitioner. Many times the practitioner is focused on the procedure and might be unaware of the alarm before the reset is activated (after 2 seconds); therefore, a best practice might consist of the operator alerting the practitioner every time the alarm sounds. By stating the fluoroscopy time when the alarm sounds (eg, "5 minutes x-ray exposure" or "10 minutes x-ray exposure"), the operator can ensure that everyone in the room is aware of the cumulative radiation exposure time.

If a procedure requires a prolonged exposure time, the operator should try to vary the entrance site of the radiation whenever possible. This practice can help decrease the radiation exposure to a given volume of tissue and minimize the risk of radiation-induced skin injury.

The use of proper collimation also helps reduce total radiation exposure to the patient because only the anatomy that is relevant to the procedure is irradiated. Although collimation decreases the overall radiation exposure to the patient, it actually increases the ESE rate.[52,55] This concept might seem counterintuitive until one considers that collimation reduces the amount of irradiated tissue and therefore reduces the amount of scatter radiation the image receptor receives. To account for the reduced exposure to the image receptor, the AEC system increases the fluoroscopic tube output, which then increases patient ESE. Although use of proper collimation can increase the ESE, it generally is considered good practice because collimation reduces the total exposure to the patient.

Exposure factors typically are set automatically by the mobile fluoroscopy unit. However, some units let the operator adjust both mA and kVp. The operator can reduce the radiation exposure rate to the patient by increasing the kVp. As kVp increases so does the x-ray beam's penetrability. In other words, x-ray beams produced with a higher kVp are more likely to penetrate and pass through the patient than x-ray beams produced at a lower kVp. The beam becomes harder and is less likely to produce scatter radiation. Use of a lower kVp setting requires a higher mA setting to maintain image brightness. As discussed previously, a higher mA setting produces more x-ray photons in the beam and, therefore, more exposure to the patient.[47,56] When possible, the mobile fluoroscopy unit should be operated at a high kVp and low mA to reduce patient exposure.

Throughout a fluoroscopy procedure, the operator may be asked to capture a permanent spot image. Spot images should only be taken when absolutely necessary for the patient's medical record, and when possible, the technologist should consider the various methods for acquiring these images. Fluoroscopy equipment might have a mechanism for capturing an LIH image without further radiation exposure to the patient. This method should be used when feasible.

Spot filming, cinefluorography and digital recording of images all require higher dose rates per image than simple fluoroscopy visualization, so operators must understand the radiation safety practices that minimize radiation exposure to the patient.[55] One source describes cinefluorography using a minimum exposure per frame (20 μR) and a rate of 60 frames per second. In this situation, the exposure rate equals 7.2 R/min.[5] This rate falls below the FDA standard of 10 R/min for normal fluoroscopic viewing, but is significantly greater than the average. The average ESE rate for fluoroscopic viewing has been described as 3 R/min,[54] 2 R/min[47] and 1 to 3 R/min.[5] It is possible that for a given procedure, the radiation dose from acquiring spot films is equal to

the total dose from the viewing portion of the fluoroscopy procedure.[50] There currently are no federal regulations that limit the maximum ESE rate while capturing fluoroscopy images.

Frame grabbing is a fluoroscopic technique that allows the practitioner to obtain a permanent image of anything viewed during a live fluoroscopy sequence.[56] Imagine that a period of live fluoroscopy viewing is separated into individual frames, like a picture "flip book." Any one of these images can be selected and stored for permanent record instead of re-exposing the patient. An example is a situation in which a practitioner notices that during a 4-second fluoroscopy exposure, 1 second of image data needs to be studied or retained for permanent record (eg, during a contrast injection for venography). Instead of re-exposing the patient using a recording method, the practitioner can grab images from the original sequence. Most fluoroscopy recording methods result in a significantly higher ESE rate than simple fluoroscopic viewing. Using the frame-grabbing method of image capture helps reduce radiation exposure to the patient and should be used when possible.

Image integration is a process that combines multiple "old" images to produce a single "new" image. By using this process, the operator can reduce the exposure factors and still produce a quality image with less overall exposure to the patient. Disadvantages of this method include fewer final images for review and a potential stroboscopic impression when viewing rapidly moving objects.[56]

Digital, or recursive, filtering produces a fluoroscopic image by using new data and a mixture of previously stored images. Although the operator can select the proportional mixture of images, typically less information is used from older images, and more data come from recent images. New exposures are not required to produce each image, which can greatly reduce radiation exposure to the patient.[56]

Like other equipment in the radiology department, mobile fluoroscopy equipment should undergo routine quality control inspections. The efficiency of an image intensifier decreases as the unit ages. As this occurs, the AEC system increases the fluoroscopic technique and/or exposure time to maintain appropriate image brightness, resulting in increased patient exposure. Routine quality control and monitoring of equipment performance over time can help to identify declines in image intensifier efficiency at an early stage.[55,56]

Exposure to Scatter Radiation

In addition to protecting the patient from radiation exposure, the mobile fluoroscopy operator must protect all staff present for the procedure. Fluoroscopy often results in the most occupational radiation exposure of any radiologic imaging modality. Assuming that medical personnel follow proper protocol and avoid the primary beam, the major source of occupational radiation exposure is scatter radiation from the patient. According to Schueler, the "entrance skin port should be considered the major radiation source for occupational exposure."[52] The production of scatter radiation is directly related to patient thickness — increased thickness leads to increased scatter production. Although there is little the operator can do to control this variable, there are several other ways to reduce scatter radiation production and exposure to medical staff.

Isodose curves illustrate the scatter radiation exposure rate in relation to the patient. These plots are useful in mobile fluoroscopy because they help demonstrate how C-arm orientation and setup, as well as staff positioning, affect scatter radiation production and exposure.

Medical personnel should be as far as possible from the exposure source to minimize occupational exposure. Because the most common source of exposure to medical personnel in mobile fluoroscopy settings is scatter radiation from the patient, medical staff should be as far as possible from the patient during fluoroscopy exposure. This concept is further explained by the inverse square law. According to the inverse square law, radiation intensity is inversely proportional to the square of the distance from the source.[47] Radiation exposure is reduced because as the distance from the source increases, the total area this radiation occupies also increases.

For example, if you shine a flashlight on a wall and stand close to the wall, the illuminated circle appears relatively small and is close in size to the diameter of the flashlight lens. Stepping away from the wall, and thus increasing the distance of the wall to the source, causes

the area of the illuminated circle to increase because of beam divergence. The circle on the wall appears larger. The light is less intense at any point in the larger circle compared with the light intensity at any point in the smaller circle. The larger circle might even appear dimmer overall than the smaller circle. With respect to fluoroscopy, increasing the distance from the radiation source means that the same number of photons must cover an increased area.

Mathematically speaking, the inverse square law can be expressed as the following equation: $I_1 / I_2 = (d_2 / d_1)^2$. In this equation I_1 represents the intensity of exposure at the original distance from the radiation source d_1 and I_2 represents the intensity of exposure at the new distance from the radiation source d_2. Although this equation can be used to calculate any changes in radiation exposure related to distance changes, a basic rule of thumb is that doubling the distance from the exposure source reduces dose by a factor of 4, making the dose one-fourth the original dose.

This simple rule is particularly practical when the original distance is very close to the patient. If a member of the medical team stands 1 m from the patient during mobile fluoroscopy exposure and then increases the distance to 2 m by simply taking 1 step away from the patient, the occupational exposure would be one-fourth its original intensity. In this situation, scatter radiation exposure can be reduced 75% by simply taking 1 step away from the patient. It is important to remember that the reverse is true when an individual moves closer to the patient. In the situation described above, taking a step toward the patient that decreases the distance from 2 m to 1 m increases exposure to 4 times the original amount. The inverse square law is an essential radiation protection concept in mobile fluoroscopy and should be applied in all situations.

The position of the C-arm in relation to the patient also has a significant effect on exposure to personnel. The side of the patient closest to the radiation source serves as the source of the majority of the scatter radiation produced. In other words, when using mobile fluoroscopy equipment, the exposure from scatter radiation is greater on the x-ray tube side of the C-arm than on the image receptor side. This is an important concept to remember when considering various positioning issues. When the C-arm is oriented vertically, the x-ray source should be positioned below the table with the image receptor above the patient if possible. With this configuration, the majority of scatter radiation is directed down and toward the floor. If the C-arm configuration is reversed, with the x-ray source above the table and the image receptor below the table, the majority of the scatter radiation is directed upward toward staff members' upper bodies.

When the C-arm requires lateral or oblique positioning, it can be difficult to determine the appropriate place for medical staff to stand to reduce their exposure to scatter radiation. As a rule of thumb, there is less scatter radiation on the image receptor side of the C-arm. Therefore, with lateral or oblique C-arm positioning, personnel should try to remain on the image receptor side of the C-arm. The operator also should remember this rule when positioning the C-arm. If feasible, the C-arm should be positioned so that the image receptor is closest to the staff in the room.

When the C-arm is placed in an oblique position, the exposure is not distributed uniformly. Assuming that the image receptor is positioned near the patient, the scatter exposure rate on the image receptor side is approximately 5 times lower than the scatter exposure rate on the side of the x-ray source.[33,57] This fact means that when placing the C-arm in an oblique position, the medical staff can lower their scatter radiation exposure rate by 80% simply by standing on the same side as the image receptor. By properly positioning the C-arm in relation to the patient and staff, the operator can help minimize exposure to all medical personnel.

Any factors that reduce scatter radiation also decrease the occupational exposure of personnel in the room. Schueler reported that the amount of scatter radiation produced depends on the patient's ESE rate, the patient's entrance skin area and the energy of the x-ray beam.[52] Each of these factors shares a direct relationship with scatter production. Therefore, any practice that decreases ESE rate, entrance skin area or the energy of the x-ray beam also decreases the exposure of medical staff to scatter radiation.

Another way to evaluate scatter reduction methods is to assume that the lowest diagnostic dose given to the smallest amount of tissue results in the least amount of

scatter production. This idea is related to the dose-area product concept. Dose-area product is "the product of the entrance skin dose and the cross-sectional area of the x-ray beam."[58] Scatter levels are directly proportional to dose-area product.[59] Therefore, any factor that reduces the entrance skin dose or the cross-sectional area of the x-ray beam also decreases scatter production.

Limiting Use of High-dose Mode

Some mobile fluoroscopy units allow the operator to choose between dose modes or dose-level settings (ie, low-dose mode, medium or normal-dose mode and high-dose mode). Having thorough knowledge of these dose modes helps the operator use the dose-level settings appropriately and reduce radiation exposure to the patient as much as possible. Normal-dose mode is the most generally used mode because it provides an average ESE rate to the patient while still producing quality images. Low-dose mode reduces the ESE rate but also can result in less detail and make the image appear grainy or noisy. High-dose mode provides more detailed images but significantly increases patient ESE.

High-dose mode is also known as high-level control fluoroscopy, or boost position. High-dose fluoroscopy typically is used in situations that require a higher exposure rate to provide a greater degree of detail for small or low-contrast objects.[47] For example, high-dose fluoroscopy is used in interventional imaging when it is critical to visualize small catheters.

The use of high-dose fluoroscopy can greatly increase the radiation exposure to the patient and should be used sparingly. The specific ESE rate during a given high-dose fluoroscopy procedure is based on several variables such as patient thickness and manufacturer settings. Mahesh compared average ESE rates between normal-mode and high-dose fluoroscopy and found that during normal-mode fluoroscopy, the ESE rate typically ranges from 1 to 5 R/min, but during high-dose fluoroscopy, the ESE rate typically ranged from 10 to 20 R/min. This equates to an ESE rate of 60 to 300 R/hr and 600 to 1200 R/hr, respectively.[54] The FDA allows a maximum ESE rate of 20 R/min (an air kerma rate of 176 mGy/min) with high-dose fluoroscopy, but also issued specific guidelines to govern the use of high-dose fluoroscopy in an effort to help to reduce patient exposure.[46]

Sherer et al described the use of various fluoroscopic modes and the amount of beam-on time required to reach the threshold for radiation-induced skin injuries.[47] The authors assumed a normal fluoroscopy dose rate of 2 R/min and a high-dose fluoroscopy dose rate of 20 R/min. According to this assumption, it takes one-tenth of the exposure time to reach the threshold for radiation-induced skin injuries when using high-dose fluoroscopy than it would take in normal fluoroscopic mode. For example, the threshold for radiation-induced early transient erythema is about 200 R.[47,54] Using normal fluoroscopy mode takes 1 hour, 42 minutes to reach this threshold. High-dose fluoroscopy mode, however, takes only 10.2 minutes to reach the threshold for early transient erythema. The threshold dose for permanent epilation is 700 R. This degree of skin injury would take 5 hours, 48 minutes of exposure under normal fluoroscopy mode, but only 34.8 minutes with high-dose fluoroscopy. The ESE rate difference between normal fluoroscopy mode and high-dose fluoroscopy can be dramatic. Thus, high-dose fluoroscopy should be used as sparingly as possible to help reduce patient exposure and minimize the risk of radiation-induced skin injuries.

Monitoring Radiation Exposure

Four organizations are primarily responsible for evaluating the relationship between radiation equivalent dose and the resulting biologic effects:

- International Commission on Radiological Protection (ICRP).
- National Council on Radiation Protection and Measurements (NCRP).
- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).
- National Academy of Sciences, National Research Council, Committee on the Biological Effects of Ionizing Radiation (NAS/NRC-BEIR).

Radiation exposure limits are set by state mandate or congressional act based on the recommendations of these organizations.

In the United States several agencies are responsible for enforcing radiation exposure limits, including the:

- Nuclear Regulatory Commission (NRC) and agreement states.
- Environmental Protection Agency (EPA).
- U.S. Food and Drug Administration (FDA).
- Occupational Safety and Health Administration (OSHA).

Furthermore, the NRC mandates that each facility providing radiologic imaging services have a radiation safety committee that is responsible for the facility's radiation safety program. A radiation safety officer typically heads the radiation safety committee.

It generally is thought that the potential for injury from occupational radiation exposure should be as low in the medical imaging environment as it is in other "safe" employment environments.[48] Dose limits have been implemented for employees who are subject to occupational exposure. These exposure limits can change over time, and personnel working in the medical imaging environment should always be aware of the current standards. Currently, a worker's exposure from personal medical procedures is not taken into account for occupational exposure dose limits.

Dose equivalent is used to indicate the detrimental effects of an absorbed radiation dose on biological tissue. Dose equivalent is expressed in sievert (Sv), which is the International System of Units (SI) unit of measurement, or more commonly, as the roentgen equivalent man, or rem. The conversion between rem and sievert is 1 rem = 0.01 Sv. The current effective dose limit for occupational exposure is 5 rem (0.05 Sv) per year, or a cumulative limit of 1 rem × the individual's age. For example, the annual limit for a 50-year-old employee is 5 rem (0.05 Sv) or a lifetime total of 50 rem (0.5 Sv). These equivalent dose limits are further broken down for specific body regions. The limit for the lens of the eye is 15 rem (0.15 Sv) per year. The skin, hands and feet may receive 50 rem (0.5 Sv) per year.[47,48,60-63]

Personnel who are likely to receive 10% or more of the annual occupational effective dose limit are required to wear an exposure monitoring device. Because fluoroscopy is associated with the highest rate of occupational exposure of any radiologic modality, personnel involved in fluoroscopy procedures should monitor their exposure.

A device used to measure radiation exposure typically is referred to as a dosimeter. Different types of dosimeters include film badge dosimeters, thermoluminescent dosimeters (TLDs), optically stimulated luminescence (OSL) dosimeters and electronic personal dosimeters.[57] When a protective apron is worn, the fluoroscopy operator should wear the dosimeter on the anterior surface of the body, outside the apron at collar level. Some facilities require their staff members to wear 2 separate dosimeters. In these situations, the primary dosimeter still is worn at the collar level to monitor dose equivalent to the thyroid gland and eyes. The second dosimeter is worn on the anterior surface of the body at waist level beneath the lead apron to monitor dose equivalent to the lower body trunk. If the staff member's hands must be close to or within the primary beam, an extremity dosimeter or TLD ring badge should be worn to monitor exposure to the hands.

Each specific type of dosimeter has advantages and disadvantages, including heat sensitivity, minimum dose measureable, maximum readout period (monthly, quarterly, etc), the ability to re-read dose, fading and whether a permanent record of exposure is recorded. According to federal and state regulations, each facility is responsible for recording and maintaining the results of individual personnel monitoring programs.[47,57]

Conclusion

Mobile fluoroscopy is commonly used to image a variety of medical conditions in various clinical situations. To ensure a successful mobile fluoroscopy procedure, the radiologic technologist or RA should be familiar with C-arm operation and safety. Professionals operating a C-arm unit should understand each piece of the mobile fluoroscopy imaging chain, including equipment operation, image production, image display and capture. In addition, the C-arm operator should have a detailed knowledge of all aspects of radiation protection related to operating the mobile fluoroscopy unit. This includes SSD control, radiation field control, maximum exposure rates, lead apron requirements, equipment setup and technique, scatter production and exposure, and personnel monitoring of radiation exposure. Having in-depth knowledge of each of these elements helps the C-arm operator produce quality fluoroscopic

images while protecting patients and medical staff from unnecessary radiation exposure.

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