The AAPM/RSNA Physics Tutorial for Residents

General Overview of Fluoroscopic Imaging[1]

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Fluoroscopy is used to visualize the motion of internal fluids, structures, and devices. During a fluoroscopic examination, the operator controls activation of the x-ray tube for real-time imaging of the patient. The article provides a general overview of fluoroscopic imaging from its initial development to modern use. Early fluoroscopes produced a dim image on a fluorescent screen that required dark adaptation of the physician's eyes to optimize viewing conditions. Image intensifiers were later developed to replace the fluorescent screen and increase image brightness. Modern fluoroscopy systems include an image intensifier with television image display and a choice of several different types of image recording devices. Fluoroscopic equipment is available in many different configurations for use in a wide variety of clinical applications.

Abbreviations: ABC = automatic brightness control, FOV = field of view, R/F = radiography/fluoroscopy

Index terms: Fluoroscopy • Physics

RadioGraphics 2000; 20:1115–1126

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Introduction

The primary function of fluoroscopy is real-time imaging to provide visualization of dynamic processes as they occur. For some clinical applications, a fluoroscope is used to determine a diagnosis from live display of patient anatomy. For other applications, fluoroscopy is used to position the patient for subsequent image recording or devices for interventional procedures. Generally, fluoroscopic equipment is operated by the physician performing the examination. This method differs from that used for other imaging modalities, in which a technologist operates the equipment and acquires the images. Therefore, it is important that the physician is familiar with the basic operation of fluoroscopic imaging chain components to optimize image quality while minimizing radiation exposure.

Fluoroscopy and radiography share some of the same imaging chain components, but differences exist. The primary difference is that the radiation exposure rate is much lower for fluoroscopy compared with radiography. Fluoroscopy of an average-sized adult abdomen typically requires approximately 45 mGy/min. For an abdominal radiograph, the entrance skin exposure to the patient is approximately 3 mGy with an exposure time of 200 msec for an exposure rate of 900 mGy/min, which is 20 times higher than the rate for fluoroscopy. However, the total exposure for a radiograph is much lower than a typical fluoroscopic examination because the fluoroscopic exposure time is extended. For 10 minutes of abdominal fluoroscopy, the total patient exposure is approximately 450 mGy, compared with 3 mGy for a radiograph. To avoid radiation injury to the patient, low fluoroscopic exposure rates are required. As a result, there are a significantly lower number of photons available to produce the fluoroscopic image compared with radiography. Therefore, the fluoroscopic image receptor must have a very high brightness gain to provide a visible image.

This article is the first in a series of six that will review fluoroscopic imaging, including detailed descriptions of image intensifiers, video components, image recording devices, digital fluoroscopic components, and radiation exposure. A general overview of fluoroscopy is provided here, beginning with the historical development of the fluoroscope and a discussion of relevant properties of the human visual system. The components contained in a modern fluoroscopic system are described, along with a review of common fluoroscopic equipment configurations that are currently used in clinical practice.

Figure 1. Photograph shows an early (1933) fluoroscopic system in use before the development of image intensification. An actual fluoroscopic examination with this device would have occurred in a darkened room. (Reprinted, with permission, from the Mayo Foundation.)

Historical Development

The first fluoroscopes consisted of an x-ray tube and fluorescent screen. The fluorescent material in early screens was barium platinocyanide, which was subsequently replaced by cadmium tungstate and later zinc-cadmium sulfide. This later substance produced a yellow-green emission. The term fluorescence describes a material that immediately emits visible light in response to some stimuli (such as electric current, chemical reaction, or x rays). The radiologist positioned the screen between the patient and himself or herself with the x-ray tube behind the patient. A lead glass layer was included to reduce exposure to the radiologist. Figure 1 shows a fluoroscopic system in which the screen is positioned on an independent stand. Other early fluoroscope screens were held by the radiologist or worn on the head like goggles (1,2).

The major problem with first-generation fluoroscopes was production of an image with sufficient brightness. To maximize visualization, the radiologist had to adapt his or her eyes to the dark by remaining in a dark room for at least 10 minutes before conducting fluoroscopic examinations. Later, red adaptation goggles were introduced to allow the fluoroscopist to engage in some activity while retaining dark adaptation. Retention of dark adaptation could be accom-

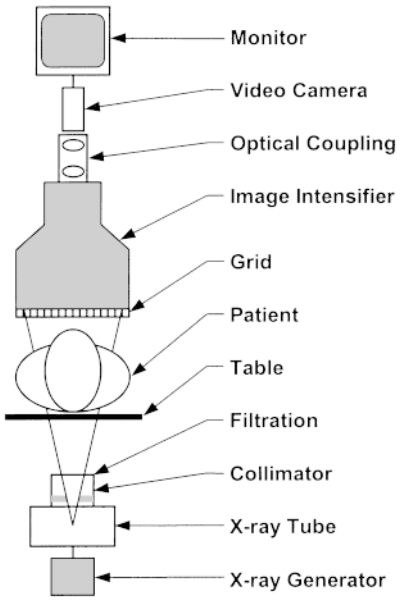


Figure 2. Diagram shows the components of a fluoroscopic imaging chain.

plished with red light because the retina is relatively insensitive to visible light waves of longer length.

Even with advances in the fluorescent materials and screen design, it was not possible to improve the performance of early fluoroscopes because of the deficiencies of the human eye at low light levels. Components in the retina (rods and cones) allow the eye to act as two separate vision systems, thus giving the eye the ability to perceive information over a wide range of illumination levels. However, in dim light, both spatial resolution and contrast perception are decreased. Cones require less illumination so they are used primarily for bright, daylight conditions (photopic vision). Rods are more sensitive to light, making them useful for low light conditions (scotopic vision). Cones are densely packed at the center of the retina and more widely spaced on the periphery. This concentration allows for the best spatial resolution near the center of the retina. However, rods are located outside the center of the retina, resulting in lower spatial resolution for scotopic vision. Also, cones are better able to perceive differences in brightness levels for better contrast resolution during photopic vision.

To overcome the deficiencies of viewing the dim fluorescent screen image, image intensifier devices were developed and introduced in 1953. These devices provide sufficient brightness gain to allow use of photopic vision for improved spatial and contrast resolution. Early image intensifiers used a system of optical lenses and mirrors to magnify and view the output image. The major problem with these viewing systems was that the viewing angle was narrow. As a result, the operator's position needed to be frequently adjusted as the image intensifier was moved. In addition, only one person at a time could observe the image, making it very difficult to communicate observations to others for teaching or discussion. These shortcomings were later removed by using a video camera to view the output image and display it on a monitor.

Additional advancements in fluoroscopic imaging have occurred in recent years. Image intensifiers are now available in larger sizes that allow visualization of the entire abdomen. Video camera and monitor performance improvements have resulted in greater spatial and contrast resolution. The introduction of video signal digitization has allowed application of digital image processing techniques for improved fluoroscopic image quality and digital image recording. Fluoroscopic units utilizing a flat-panel detector instead of an image intensifier and video camera are currently being developed.

Fluoroscopic Imaging Chain

The components included in a modern fluoroscopic imaging system are shown in Figure 2. Some components are similar to those included in systems used exclusively for radiography, whereas others are unique to fluoroscopy. Typically, additional apparatus are attached to allow for image recording, such as a spot-film device, film changer, photospot camera, cine camera, or analog-to-digital converter. The following section contains a description of the function of each component.

X-ray Generator

The x-ray generator allows selection of kilovolt peak (kVp) and tube current (mA) that is delivered to the x-ray tube. The design of the generator is similar to that of generators used for radiography, with added circuitry for fluoroscopic operation, including either low continuous tube current or rapid pulsed exposure and automatic brightness control (ABC). Generator types that may be used for fluoroscopy include single phase, three phase, constant potential, and high frequency (3). For some generators that provide both radiographic and fluoroscopic exposure, three-phase operation may be used for radiography and single-phase operation for fluoroscopy.

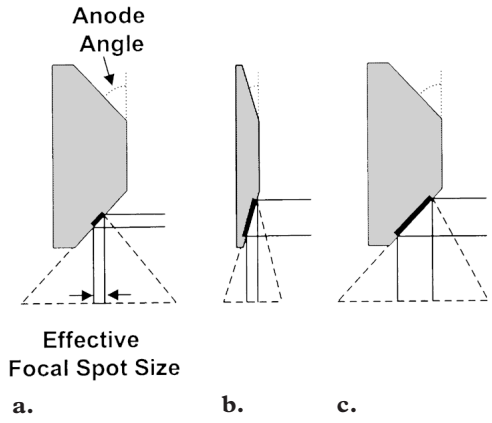


Figure 3. Effect of anode angle on heat capacity and effective focal spot size. Effective focal spot size is the focal spot area projected perpendicularly onto the image receptor. Diagram on the left **(a)** shows a large anode angle, which provides large radiation field coverage and a small effective focal spot size. However, the actual focal spot track on the anode is narrow, resulting in low heat capacity. The center diagram **(b)** illustrates a configuration with the same effective focal spot size and a small anode angle. This configuration results in greater heat capacity but small field coverage. To satisfy the requirements of both large field coverage and large heat capacity, the filament size must be increased, resulting in a larger effective focal spot size, as shown in **c**.

Two methods are used to energize the x-ray tube for fluoroscopy: continuous and pulsed exposure. For continuous fluoroscopy, the generator provides a steady tube current while the fluoroscope is activated. Images are acquired at a rate of 30 frames per second, resulting in an acquisition time of 33 msec per image. For pulsed fluoroscopy, the exposure is delivered in short pulses, 3–10 msec in length. Typically, a pulse rate of 30 pulses per second is used, with some units allowing the selection of lower pulse rates (15 or 7.5 pulses per second). One advantage of pulsed fluoroscopy is improvement in temporal resolution. Motion blur occurring within each image is reduced because of the shorter acquisition time, making pulsed fluoroscopy useful for examining rapidly moving structures such as those seen in cardiovascular applications. In addition, pulsed fluoroscopy can be used as a method of reducing radiation dose, particularly when the pulse rate is reduced.

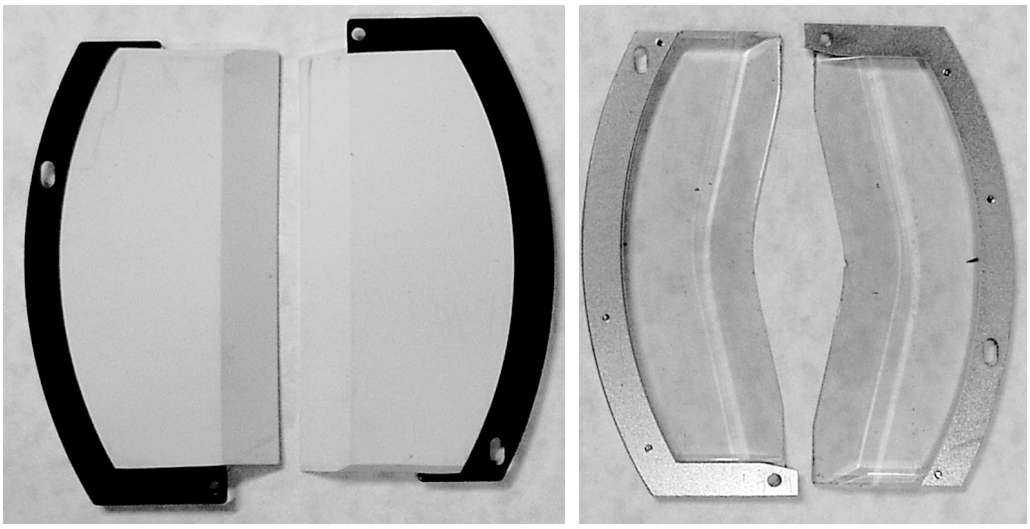
Criteria that should be considered when selecting a generator type for fluoroscopic equipment include exposure time and reproducibility, generator size, and cost. For systems capable of pulsed fluoroscopy or rapid recording image acquisition (film changer, cine, or digital recording), a short exposure pulse is desirable to minimize motion blur. Constant potential generators are capable of the shortest exposure pulses, with high-frequency and three-phase types producing slightly longer pulses. Good exposure reproducibility is critical for fluoroscopic systems equipped with digital subtraction angiography (DSA), because differences in tube voltage between mask and contrast images can cause incomplete subtraction. High-frequency generators provide superior exposure reproducibility along with the most compact size, lowest purchase price, and low repair costs. As a result, high-frequency generators are commonly used in new radiographic equipment.

Another important feature of a fluoroscopic x-ray generator is ABC, which acts to keep the overall image brightness seen on the monitor at a constant level as the image intensifier is panned over body parts of differing thickness and attenuation. Constant brightness is achieved by automatically adjusting the kVp and mA settings as needed to maintain the x-ray exposure level at the entrance to the image intensifier.

X-ray Tube

The x-ray tube converts electrical energy provided by the generator into an x-ray beam (4). Within the x-ray tube, electrons are produced by a heated filament and accelerated toward a positively charged tungsten anode. The interaction of the electrons with the anode results in the emission of x rays. The entire assembly is placed within an evacuated envelope and shielded housing. The area of the anode that is struck by electrons is referred to as the focal spot. A small focal spot size is desirable so that geometric unsharpness is minimized. To reduce the effective size of the focal spot, as seen from the image receptor, the anode surface is angled (Fig 3). X-ray tubes are produced with anode angle ranges of 7°–20°. The selection of x-ray tube characteristics varies, depending on the specific clinical application. For radiography and fluoroscopy systems, bi-focus tubes are common. A small focal spot (0.3–0.6 mm) is used for fluoroscopy, and either the small or the large focal spot (1.0–1.2 mm) can be used for image recording when high tube currents are needed.

For clinical applications involving angiography and interventional procedures, additional x-ray tube characteristics become important (5). Because of rapid image recording requirements, heat can build up quickly, requiring an x-ray tube with a large heat capacity. To improve heat dissipation, high-speed anode rotation may be used (over 10,000 rpm). In addition, a circulating water or oil heat exchanger with cooling fans is commonly installed. X-ray tubes for these appli-



a. **b.**

Figure 4. Photographs show two types of equalization filters. These lead-rubber **(a)** and lead-acrylic **(b)** blades are mounted at the collimator with controls provided to adjust the blade location and rotation in order to conform to patient regions of low attenuation.

cations may also be configured with grid-controlled pulsing to produce very short (millisecond) exposures for cine image recording or pulsed fluoroscopy. In a grid-controlled tube, the cathode is at a variable negative potential, capable of pinching the electron flow off and on for short exposure pulses.

For an x-ray tube in a dedicated angiography or interventional system, maximum field-of-view (FOV) size requirements may limit the heat capacity or minimum focal spot size available. Depending on the particular application, a small focal spot may be essential for sharp images of fine vasculature or guide wires. When a large FOV is needed to image with a large image intensifier or film changer, the anode angle must be large enough to allow adequate coverage without cutoff of the beam intensity. However, for the same effective focal spot size, a large anode angle (Fig 3a) results in a reduced focal spot track width, compared with a small anode angle (Fig 3b). The smaller focal spot track reduces the rate of heat dissipation, which lowers the heat capacity of the tube. Alternatively, the focal spot track can be enlarged by increasing the size of the filament while maintaining the large anode angle (Fig 3c), but the effective focal spot size also increases.

Collimator

The collimator contains multiple sets of radiopaque shutter blades that define the shape of the x-ray beam. Two sets of blades are generally present within the collimator: round and rectangular. A round iris conforms the x-ray beam to the circular FOV. Rectangular blades can be brought in manually to further reduce the beam size. The collimator automatically limits the x-ray beam to no larger than the FOV as changes are made in the magnification mode selection or source-image distance. However, it is beneficial for the operator to further collimate the beam to the area of clinical interest. Collimation reduces the exposed volume of tissue, resulting in reduced scatter production and improved image contrast. It also reduces regions of glare from unattenuated radiation near the edge of the patient's body. In addition, coning the x-ray beam to the area of clinical interest will reduce overall patient dose by minimizing direct exposure and scatter exposure to sensitive organs that may be adjacent to the beam.

Most fluoroscopy systems used for angiography and interventional applications also contain equalization filters. These filters, also called contour or wedge filters, are partially radiolucent blades used to provide further beam shaping in addition to collimation. Equalization filters reduce glare from unattenuated radiation near the edge of the patient and equalize light exposure to the video camera. As a result, they improve operation of the ABC system. The filters are made from tapered lead-rubber or lead-acrylic sheets. The edges of the blades may be straight or shaped to conform to anatomic parts (Fig 4).

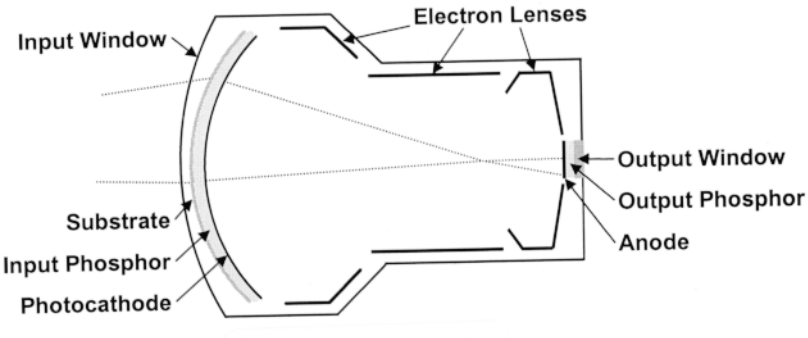


Figure 5. Diagram shows the components of an image intensifier. The paths of several incident x rays, converted to electrons at the input layer, are shown as dotted lines.

Tissue equalization may also be accomplished by placing bolus material next to the edge of the patient. However, use of equalization filters is preferable to this method because the added attenuating material results in increased scatter production.

Filters

Filtration material is added to attenuate low-energy x rays from the beam. Low-energy x rays are absorbed in patient tissue without being transmitted to the image receptor, contributing to patient dose with little improvement in image quality. The penetrating ability of an x-ray beam is determined by measuring the half-value layer (HVL), where the HVL is the thickness of some attenuating material that reduces the beam intensity by one-half at a specified kilovolt peak. Federal regulations require that the minimum HVL for both radiography and fluoroscopy be 2.3 mm Al at 80 kVp. However, it is recommended that the minimum HVL be increased to 3.0 mm Al at 80 kVp to reduce patient dose, particularly for fluoroscopy (6).

Aluminum is the most common added filtration material. Copper can also be used for improved low-energy x-ray filtering (7). The use of copper filtration material has become more prevalent in fluoroscopy systems used for high-dose procedures such as angiography and interventional applications.

Patient Table and Pad

Patient tables for fluoroscopic systems must provide adequate strength to support large patients and, at the same time, result in minimal x-ray attenuation. Carbon fiber composite material satisfies both these requirements. Nominal x-ray attenuation is needed to reduce x-ray tube loading and to minimize image contrast loss that may be caused by an increase in tube potential needed to penetrate the table. Low x-ray attenuation also results in reduced patient exposure in over-table x-ray tube configurations.

Patient support pads should also be made of a material that provides minimal x-ray attenuation. Thin foam pads are generally acceptable, but thick gel pads have been found to result in excessive attenuation (8).

Grid

Anti-scatter grids are used to improve image contrast by reducing the scattered x rays that reach the image receptor. However, use of grids requires an increase in radiation exposure. The grid ratios for fluoroscopy range from 6:1 to 10:1, which is generally lower than common radiographic grid ratios (8:1 to 16:1). For fluoroscopy, removal of the grid may be desirable to reduce patient dose when the amount of scatter produced is low (9). Image contrast loss will be minimal when the FOV is reduced or the patient or body part examined is small. In addition, a grid is not needed if a large air gap between the patient and the image intensifier is required for geometric magnification, access to the patient, or access to interventional devices. With the grid removed, patient exposure can be reduced by about 50% (10). Although some fluoroscopy systems allow for easy grid removal, exchanging the grid can be cumbersome or impossible on others.

Image Intensifier

The image intensifier converts incident x rays into a minified visible light image and, in the process, amplifies the image brightness by about 10,000 times for better visibility to the viewer. The major components of an image intensifier include an input layer to convert x rays to electrons, electron lenses to focus the electrons, an anode to accelerate them, and an output layer to convert them into a visible image (Fig 5). All the components are contained within an evacuated bottle.

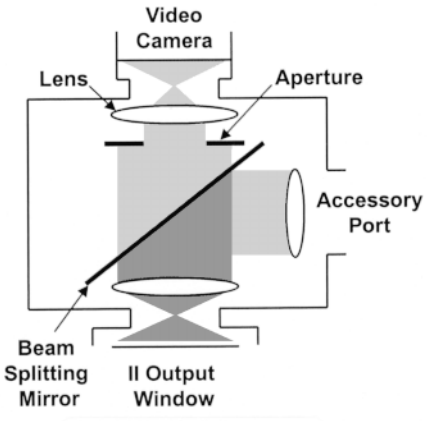


Figure 6. Diagram depicts an optical coupling system between an image intensifier (*II*), video camera, and optional image recording device (photospot camera or video camera).

The input layer is made up of four different components: the input window, substrate, input phosphor, and photocathode. First, x rays strike the input window, which is made of a curved, thin layer of metal or glass. Next, they pass through the 0.5-mm-thick aluminum substrate layer and input phosphor layer, where they are converted into light photons. The input phosphor is made of cesium iodide, which is deposited as long, needlelike crystals to channel the light photons to the next component layer with minimal spreading to reduce blur. The light photons emitted from the input phosphor are then absorbed in the photocathode and converted into electrons.

The electrons emerging from the photocathode are focused and accelerated through the vacuum to the output layer by the electron optics system. This system consists of three charged electrodes and an anode plate at the output layer. These components create an electric potential, which intensifies and demagnifies the electron beam to the size of the small output layer. At the output phosphor, the electrons are converted into visible light photons. These photons are then transmitted out of the image intensifier through a glass output window.

As a result of the acceleration of the electrons and image minification, the illumination level of the output image compared with that of the input image is greatly increased. This illumination increase, known as brightness gain, ranges from 5,000 to 20,000. The conversion factor is another measure of image intensifier brightness gain. In modern image intensifiers, conversion factors are 100–300 cd · m^{-2}/mR · s^{-1}, where cd · m^{-2} is the unit of measure of the light output of the image intensifier and mR · s^{-1} is the unit of measure of the x-ray exposure rate into the image intensifier. Image intensifiers are also described by their contrast ratio, spatial resolution, and detected quantum efficiency. (Further details related to the imaging characteristics and performance of image intensifiers can be found in references 11–13.)

Image intensifiers are available with different diameter input windows of 10–40 cm. The selection of the diameter depends on the maximum FOV requirements of the clinical application. Fluoroscopic systems designed for extremities may be configured with a 10–15-cm-diameter image intensifier, whereas a 40-cm-diameter unit is useful for imaging the abdomen or peripheral vasculature. Most image intensifiers also allow selection of a magnification mode. In magnification mode, the central circular area of the input layer is focused onto the full output layer by adjusting the voltage of the electron optics electrodes. Multiple magnification mode sizes are available on most fluoroscopic systems.

Optical Coupling

The optical coupling system distributes light from the image intensifier output window to a video camera and other image recording devices (Fig 6). The optical distributor may include a partially silvered, beam-splitting mirror, which directs a portion of the light from the image intensifier output window to an accessory device for image recording and passes the remainder to the video camera. A circular aperture is also included to set the proper light level required by the video camera. The aperture setting affects the appearance of noise in the fluoroscopic image.

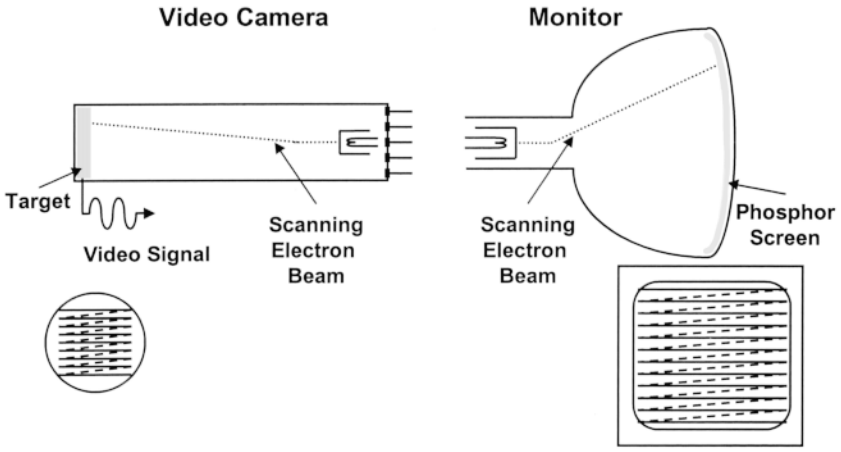


Figure 7. Diagram illustrates a television system consisting of a video camera (left) and monitor (right). The horizontal raster scanning pattern of the electron beam across the video camera target is shown, along with the corresponding raster scan on the display monitor.

When the aperture is set to a small size, much of the light from the output window is blocked from reaching the video camera. As a result, the ABC system increases the radiation exposure to maintain the light level at the camera, producing a fluoroscopic image with low noise. Alternatively, when the aperture is set wide open, the radiation exposure level is low and more image noise is apparent.

Television System

A closed-circuit television system is used to view the image intensifier output image. The television system consists of a video camera that converts the image to a voltage signal and a monitor that receives the signal and forms the image display (Fig 7). The television system allows for real-time viewing of the fluoroscopic image by several people at once from one monitor or multiple monitors. In addition, fluoroscopic units can be equipped with an analog-to-digital converter to digitize the video camera voltage signal for additional processing and electronic image recording.

The basic video camera consists of a vacuum tube cylinder (approximately 2.5 cm in diameter) with a photoconductive target and a scanning electron beam. The optical coupling lens focuses the image intensifier output image onto the target, forming a latent charge image from the charge carriers within the photoconductive layer. This latent image is read out by the electron beam, which scans across the target in a series of horizontal raster lines. As the scanning electron beam moves across the target, a current signal is produced that represents the two-dimensional image as a continuous series of raster lines with varying voltage levels. In recent years, a new type of camera has been developed to replace the traditional vacuum tube design. Charge coupled device (CCD) cameras consist of a solid-state array of light sensors, which store the image as pixels until they are read out as voltage pulses representing the two-dimensional image. Compared with traditional video cameras, CCD cameras are smaller, are more rugged, require less power, and have a longer lifetime.

The voltage signal produced by the video camera is converted into a visible image by the monitor. The monitor consists of a vacuum chamber with a phosphor screen and scanning electron beam. The electron beam moves across the phosphor screen in horizontal raster scan lines with the intensity variation controlled by the camera voltage signal, thus reproducing the image from the video camera target. (For additional information on fluoroscopic television systems, refer to references 11, 14, and 15.)

Image Recording

A fluoroscopic imaging system may include additional devices to record images during an examination. Recording methods include spot film devices, film changers, photospot cameras, cine cameras, and digital photospots. The selection of the optimum recording method for a particular clinical application depends on the operational characteristics of the device and image quality requirements of the examination.

Spot film devices are used to acquire a radiographic image with a screen-film cassette that is moved into position in front of the image intensifier. Collimation can be automatically varied to produce multiple image formats (for example, four images on one film). The operation of the

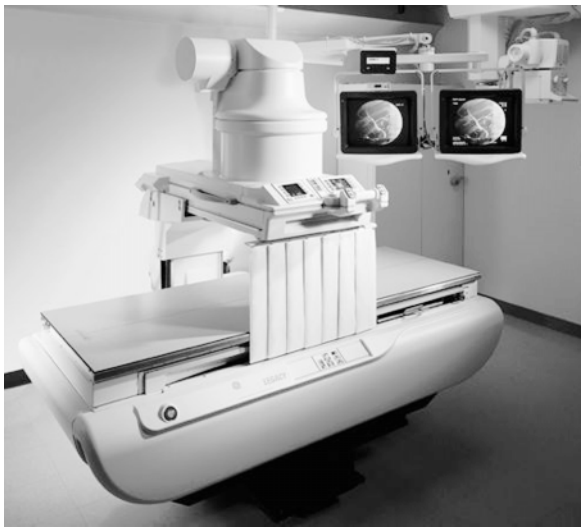


Figure 8. Under-table x-ray tube R/F system. Photograph shows an example of an R/F table that includes a spot film device and side-mounted video camera. (Courtesy of GE Medical Systems, Milwaukee, Wis.)

device results in a slight delay between fluoroscopic viewing and image recording, but the image quality is the same as a radiographic film and large-film image recording is possible. Clinical applications of spot film devices include gastrointestinal imaging, genitourinary imaging, arthrography, and myelography.

Film changers also acquire a radiographic film either in front of the image intensifier or with it moved out of position. Film changers are known by many different names (rapid film changer, serial film changer, cut-film changer, Puck [Elema-Schonander] film changer, BCM [B. C. Medical] long cassette changer); however, the basic operation for each is similar. Films are moved rapidly into position from a supply magazine at a selectable rate up to four films per second and then transferred to a take-up magazine for manual transport to a film processor. The primary clinical application of film changers is dynamic vascular imaging with iodinated contrast material.

Photospot cameras record the image intensifier output on rolled or cut film to produce images about 10 cm in diameter. The photospot camera is mounted on the optical distributor accessory device port to record images rapidly during the fluoroscopic examination. Photofluorography is generally used for the same clinical examinations as spot film devices. A cine camera may also be mounted as an accessory image recording device to acquire images on 35-mm film. Cinefluorography is typically used for cardiac catheterization procedures to record rapid rate images of the beating heart.

In newer fluoroscopic systems, these film recording methods are replaced with digital image recording. Digital photospots are acquired by recording a digitized video signal and storing it in computer memory. The operation is fast and convenient, plus image quality can be enhanced by the application of various image processing techniques, including window-level, frame averaging, and edge enhancement. However, the spatial resolution of digital photospots is less than that of film images.

Fluoroscopic Equipment Configurations

Fluoroscopic equipment has evolved over the years to become more useful for clinical examinations. As a result, several different equipment configurations have been developed to meet the requirements of specific diagnostic and interventional applications. The basic configurations include radiography/fluoroscopy (R/F) tables with either an under-table or over-table x-ray tube and fixed C-arm, mobile C-arm, and mini C-arm positioners. Each configuration includes the basic fluoroscopic imaging chain components reviewed above, with certain variations. The following section reviews a number of fluoroscopic equipment configurations currently in use.

R/F Units with Under-Table X-ray Tube

The R/F system is the most common fluoroscopic equipment configuration. It is used for a wide range of diagnostic and interventional procedures, including gastrointestinal, genitourinary, arthroplasty, myelography, and device placement. The x-ray tube and collimator are mounted below the tabletop with the image intensifier tower mounted above the table on a carriage that can be panned over the patient (Fig 8). In addition to the standard fluoroscopic imaging chain, R/F systems include an overhead x-ray tube that can be used for regular radiography with a Bucky incorporated into the table. Other common features include a tilting table and image recording devices. Spot film recording is the most common, but as digital imaging systems become more prevalent, R/F systems without a spot film device are becoming available.

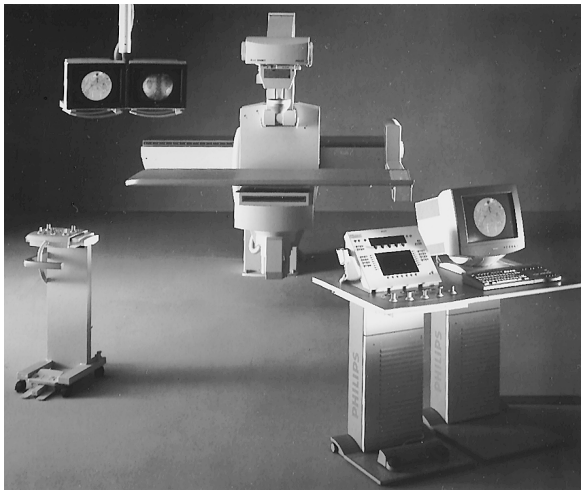


Figure 9. Over-table x-ray tube R/F system. Photograph shows a sample system that can be controlled from within the procedure room with the pedestal control panel (left) or from outside the room from the remote desk controls (right). (Courtesy of Philips Medical Systems North America, Shelton, Conn.)

R/F Units with Over-Table X-ray Tube

Another R/F configuration includes an x-ray tube mounted over the table with the image intensifier below (Fig 9). The clinical applications of this system are similar to those of under-table x-ray tube R/F systems, with some added flexibility. In particular, this configuration results in increased patient access, which is helpful for interventional procedures. Radiography can be performed with the same x-ray tube and a Bucky incorporated into the table. The x-ray tube can be angled to acquire angulated projections or tomograms.

Over-table tube configurations result in increased radiation exposure for personnel in the procedure room compared with under-table tube systems, since scattered radiation from the patient is more concentrated in the direction back toward the x-ray tube. Some over-table tube systems are also equipped for remote control operation so that the operator can conduct the examination from behind a shielded viewing window.

Fixed C-arm Positioners

C-arm positioners allow angulation of the fluoroscopic imaging chain about the patient in all directions. Because of its flexibility, the C-arm configuration has been incorporated into a number of different types of fluoroscopy systems. Figure 10 is an example of a fixed C-arm unit that is mounted from the ceiling. Floor-mounted models are also available. The system includes a patient table with a floating tabletop, which allows the operator to move the patient easily while the C-arm positioner remains fixed. Common applications for fixed C-arm units include cardiac, peripheral, and neuroangiographic and interventional procedures. Various image recording devices may be incorporated, including a film changer, cine camera, or digital image acquisition for DSA. An alternate positioner similar to the C-arm is the Z-arm, which has a parallelogram support (Fig 11). Compared with the C configuration, this design is capable of larger angulations and increased space for patient head access.

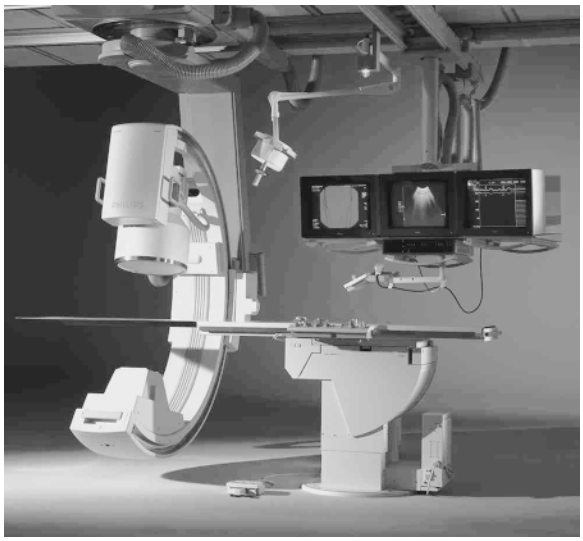


Figure 10. Fixed C-arm positioner with ceiling mount. This example includes an incorporated ultrasound unit and patient monitoring system. (Courtesy of Philips Medical Systems North America, Shelton, Conn.)

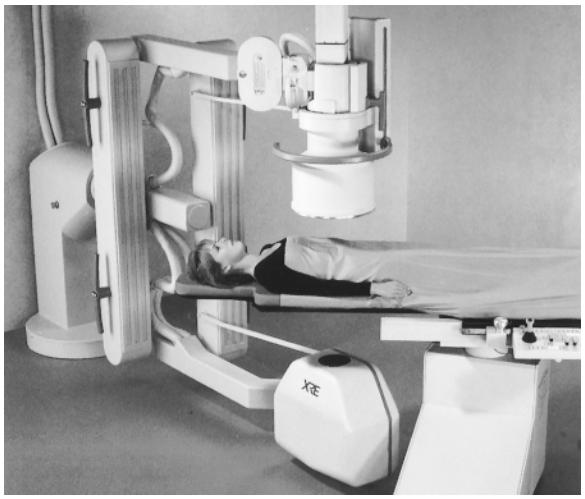


Figure 11. Fixed Z-arm or parallelogram positioner. Photograph shows a 35-mm cine camera attached to the optical coupling accessory port between the image intensifier and video camera (Courtesy of TREX Medical Corporation, Littleton, Mass.)

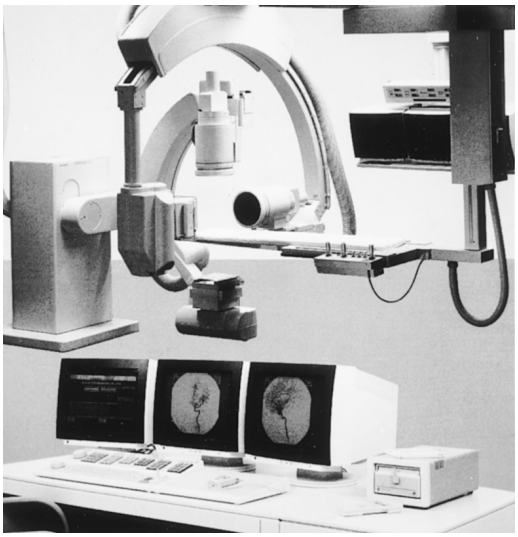


Figure 12. Biplane positioners with frontal and lateral C-arms. This sample configuration includes a ceiling-suspended patient table. (Courtesy of Siemens Medical Systems, Iselin, NJ.)

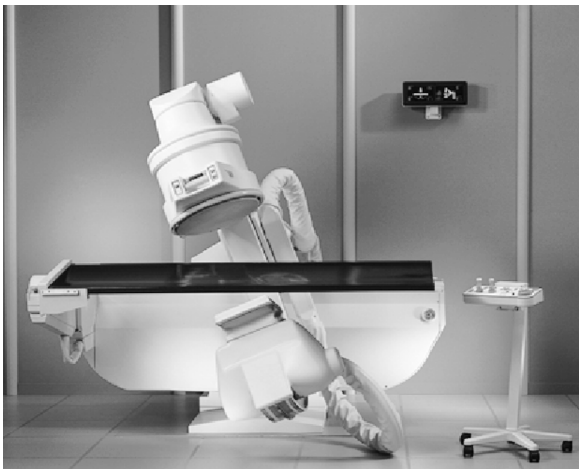


Figure 13. Multipurpose fluoroscopy system. Photograph shows a tilt C-arm unit designed for multiple applications, including basic R/F examinations and interventional procedures. (Courtesy of GE Medical Systems, Milwaukee, Wis.)

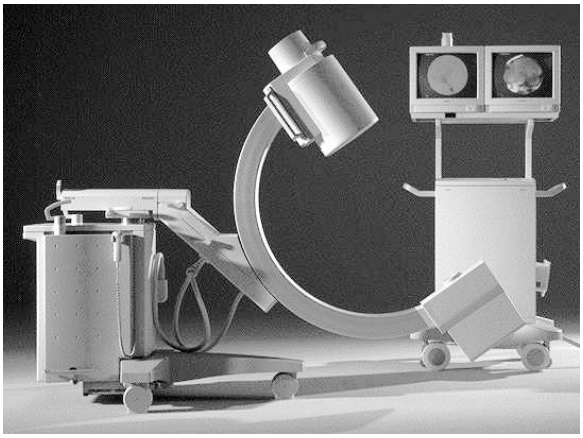


Figure 14. Mobile C-arm unit. The control panel and monitor cart of this C-arm positioner can be moved independently. (Courtesy of Philips Medical Systems North America, Shelton, Conn.)

Fluoroscopy systems with two C-arm positioners are also available (Fig 12). Biplane systems are used primarily for dedicated cardiac or neuroangiography and interventional procedure rooms. By using two separate imaging chains, it is possible to view frontal and lateral projections of the patient without introducing a delay while a single positioner is moved. In addition, biplane positioners allow recording in two projections during a single injection of iodinated contrast material, which is particularly important for pediatric patients for whom the volume of contrast media allowed is limited. With the biplane configuration, one of the x-ray tube–image intensifier units is a floor-mounted C-arm positioner, whereas the other is a ceiling-mounted U-arm. The positioners are capable of individual or simultaneous motion and operation.

In recent years, a modified C-arm fluoroscopy configuration designed for multiple applications has become available. This configuration includes a C-arm positioner with an attached patient table, capable of imaging chain angulation and table tilt (Fig 13). The system is equipped to perform both general R/F and more complex angiographic and interventional procedures. These systems are also referred to as tilt C-arm positioners.

Mobile C-arms Positioners

Mobile C-arm units provide fluoroscopic imaging for orthopedic and vascular surgical procedures, in addition to placement of devices such as pacemakers or feeding tubes. Some mobile C-arm systems are also configured for angiographic and interventional procedures with high exposure rate output and DSA imaging capabilities. As seen in Figure 14, mobile C-arm units offer a compact design, imaging chain angulation, and image recording by either spot film or digital image acquisition. Mobile fluoroscopy units have also been configured with small image intensifiers, 10–15 cm in diameter. These mini C-arm systems are

designed for imaging extremities for which only low exposure levels are needed (Fig 15).

Summary

Early fluoroscopic imaging required direct viewing of a fluorescent screen. Since the image brightness of this system was insufficient, it was necessary for the operator to become dark-adapted before performing the examination. Modern fluoroscopic imaging uses an image intensifier to amplify image brightness and a television system for image viewing. Fluoroscopic imaging systems are available in many different configurations designed to meet the needs of various clinical applications.

Fluoroscopy is one of the few modalities that provide live imaging of the patient. In addition to real-time diagnosis, it is useful for positioning of the patient and performing interventional procedures. Because radiologists are the equipment operators, an understanding of the physical characteristics of fluoroscopic imaging systems is important to perform examinations in a safe and efficient manner.

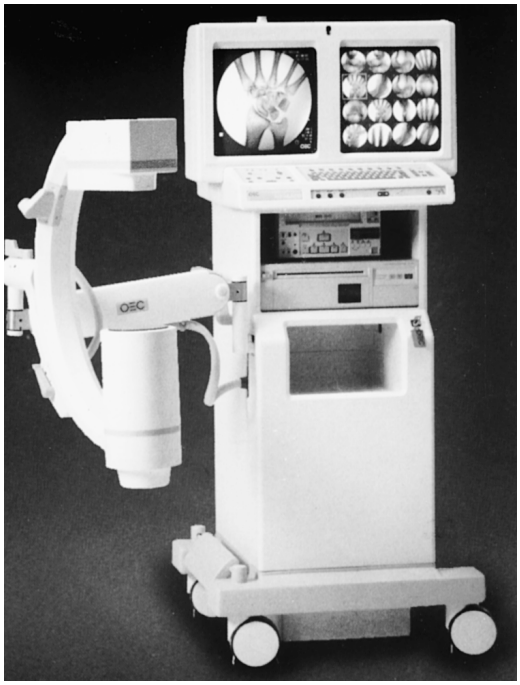


Figure 15. Mini C-arm unit. Photograph shows a compact mobile C-arm system with a small image intensifier. (Courtesy of OEC Medical Systems, Salt Lake City, Utah.)

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