This chapter is a natural extension of Chapter 21, where the principles of real-time imaging—fluoroscopy are described. We need to emphasize that fluoroscopy is almost performed in the presence of the radiologist. Therefore, the technical details presented in this chapter are focused on personnel and patient safety, since some of those procedures require a long beam-on time.

Fluoroscopy units used in hospitals, although based on common principles, can differ substantially depending on the clinical application [2]. These applications can range from gastrointestinal (GI), genito-urinary (GU), cystography, and lithotripsy, to more complex suites of equipment dedicated to peripheral and cardiac angiography and catheterization, cardiac electrophysiology, and neurovascular imaging.

This chapter will not deal with fluoroscopic units with the X-ray source under the treatment table and the image receptor above the table, as used in radiology departments for GI and GU applications. We consider this type of fluoroscopic unit obsolete, and they are usually offered by some manufacturers for only limited and specific applications in private clinics. In modern hospitals, they are replaced by remote-controlled fluoroscopic systems. However, for very specific applications like lithotripsy, for example, the practice of positioning the X-ray source under the table and image detector above the patient will likely remain. This application needs fluoroscopic imaging for positioning the table with the patient in an exact location where the ultrasound gun can be most effective to treat kidney stones. From the imaging point of view, the procedure is very short, and the stone embedded in the kidney offers a very good contrast that does not require high-quality images. This means that the fluoroscopy part of the unit is very simple and does not need a detailed description.
27.1 Remote-Controlled Fluoroscopic Systems

27.1.1 Technical and Functional Description of Remote-Controlled Fluoroscopic Systems

This type of fluoroscopic system is usually located in general radiology departments, side-by-side with radiography rooms. Patients imaged in such fluoroscopic rooms do not require anti-septic measures and the duration of the examination is usually short. These systems are designed for remote operating by specialist physicians, such as the gastroenterologist or urologist. They are completely motorized and are operated from the control room, which is completely shielded. This fluoroscopic system minimizes radiation exposure to the physician and other personnel. Any operation can be performed from a sitting position without wearing a lead apron.

This type of system will always have the X-ray tube positioned above the table while the image detector (image intensifier based detector or flat panel detector [FPD]) is under the table or built into the table—as can be seen in Figure 27.1. If a FPD is used, its location may not even be apparent. However, the imaging detector must be capable of following the position of the X-ray tube during its travel over the table. These types of systems are not suitable for table-side patient interventions by radiology personnel because scattered radiation originating in the patient is much higher than with the X-ray tube located under the table. Hence, these fluoroscopic systems are mainly dedicated to GI or GU studies or any other applications which do not require direct physician manipulation of the patient.

These types of fluoroscopic machines are offered by the major medical equipment manufacturers such as Siemens, Philips, GE (General Electric), and Toshiba and some smaller companies such as Shimadzu, GMM (General Medical Merate). Some of the major medical equipment manufacturers may discontinue this product line based on market saturation considerations.

The table can be tilted up to the vertical position, either head down (Trendelenburg) or feet down—see Figure 27.2. If the study involves a barium swallow, the physician can study the pathology as the patient swallows and can visualize the surfaces of the stomach lining on which barium exerts the maximum pressure. Also, these systems are equipped with a remotely actionable and retractable motorized compression cone, which can exert controlled pressure on different body parts, giving the radiologist more information about internal organs in GI studies.

Originally, remote fluoroscopic systems were designed as radiographic–fluoroscopic rooms, also called “R–F rooms,” utilizing an overhead tube mounted on a ceiling rail system which could be aligned with a wall-mounted image receptor. If the image receptor is a computed radiography (CR) cassette, the cassette holder is commonly called “bucky.” The wall-mounted image receptor also could be tilted and acquire radiographic images separate from the table. Radiographic images could be acquired on the fluoroscopic table too using the imaging detector available in the table (screen–film, CR, built-in, or portable digital radiography [DR]). To support the radiography capability of the fluoroscopy table of these devices, they are equipped with an automatic exposure control (AEC) system, that has multiple X-ray dose detectors, such as the radiographic tables, air kerma level settings (analogous with the older film density levels settings), and the mandatory anti-scatter grids. In addition, to enhance the radiographic performance of the fluoroscopic unit, the X-ray tube can rotate in the cranio-caudal plane, making the system capable of taking radiographic images under non-perpendicular angles, and some models, like Shimadzu SONIALVISION G4.
Clinical Fluoroscopy Units

One of the newer radiography installation models by Siemens—the Multitom RAX (Robotic Advanced X-ray)—is equipped with a ceiling-mounted X-ray tube and a FPD which is, independently, also ceiling-mounted. This system has many of the capabilities of remote-controlled fluoroscopy; however, the table does not tilt. It is completely automated and has cone beam CT and angiographic capabilities (www.healthcare.siemens.com/robotic-x-ray/twin-robotic-x-ray/multitom-rax/features, consulted April 2017).

Remote-controlled fluoroscopic systems always have a duplicate control panel in the fluoroscopic room which perfectly replicates the commands available in the control room, for cases such as uncooperative patients, neonate infants where bedside assistance to the patient is necessary, or in cases where table maneuvering from the control room would be dangerous for both patient and personnel. In addition, X-ray exposure can be activated from either the control room or the fluoroscopic room in those cases where personnel presence is necessary in the room. Also, in situations when personnel must be inside the room assisting the patient, the fluoroscopic room is equipped with a replica of the X-ray display monitors available in the control room. Because of the possibility that a physician or technologist must be in the remotely controlled fluoroscopic room, these rooms are equipped with ceiling-mounted leaded glass to protect the faces of personnel from scattered radiation.

The X-ray tube usually has a variable height related to the tabletop. This distance can vary, depending on the manufacturer, from 90 to 150 cm. The greater the X-ray target-to-table distance, the smaller the entrance skin exposure (ESE) to the patient, and the better the spatial resolution of the image.

In addition, the X-ray tube can travel parallel to the table axis. The tabletop can slide in both parallel and perpendicular directions to the axis.

Regardless of the fluoroscopic device type, purpose, or application type, each fluoroscopic suite must have an intercom communication system between the control room and fluoroscopic room to enable communication between patient–physician or personnel in the fluoroscopic room and personnel in the control room.

27.1.2 Dose Considerations of Remote-Controlled Fluoroscopic Systems

Like all fluoroscopic systems, remote-controlled fluoroscopic devices are equipped with different levels of exposure rate settings, magnification modes, automatic filter change systems, automatic focal point setting systems, different pulse rate choices and radiographic grade acquisition modes, both single radiographic image (“photospot”) or radiographic image sequence mode [5]. Older fluoroscopic systems usually have a normal fluoroscopic exposure rate level and a high-grade exposure rate level, and eventually a low-dose exposure rate level. They also have a continuous exposure mode [2].

Newer models offer several choices of exposure rate level (dose level) based on patient-size dependent protocols. The appropriate technique settings are automatically programed once the technologist estimates the patient size. Table 27.1 displays the exposure rate variation as a function of dose level and FOV.

Flat panel-equipped fluoroscopic systems are typically of $43 \times 43$ cm² size. Those built in Europe, such as Siemens Luminos...
TABLE 27.1
Automatic Exposure Rate Control (AERC) Stabilized Exposure Rate for Different Dose Levels

<table>
<thead>
<tr>
<th>FOV (cm)</th>
<th>Dose Level 1 Exposure Rate (mR/min)</th>
<th>Dose Level 2 Exposure Rate (mR/min)</th>
<th>Dose Level 3 Exposure Rate (mR/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41 × 41</td>
<td>275.5</td>
<td>331.4</td>
<td>501.4</td>
</tr>
<tr>
<td>30 × 30</td>
<td>374.4</td>
<td>451.4</td>
<td>616.0</td>
</tr>
<tr>
<td>22 × 22</td>
<td>521.8</td>
<td>587.3</td>
<td>734.9</td>
</tr>
<tr>
<td>15 × 15</td>
<td>753.5</td>
<td>844.4</td>
<td>1090.4</td>
</tr>
</tbody>
</table>

Setup conditions: Focus–Image Distance (FID) = 150 cm, Focus–Chamber Distance (FCD) = 113 cm, Chamber–Table Distance (CTD) = 30 cm, phantom (PMMA), thickness = 20 cm, pulse rate = 15 pps.

Note: Dose level 2 generates a 10%–20% higher exposure rate than dose level 1, whereas dose level 3 leads to a 40%–80% higher exposure rate than dose level 1. These exposure rate increases can vary with the pulse rate.

27.2 Multipurpose Fluoroscopic Systems

27.2.1 Technical and Functional Description of Multipurpose Fluoroscopic Systems

Multipurpose fluoroscopic systems are remote-controlled units that are also placed in the radiology department in the same location as the radiography rooms. However, their functionality is extended in terms of where the X-ray tube is positioned, that is, under the table and above the table. Although they are still considered to be R–F fluoroscopy systems, they can be used in some simple interventional cases as well, such as, for example, orthopedic interventions, and they could come with angiographic and cardio capabilities. They are designed for hospital use and could serve as a backup for angi-suites. Two major manufacturers are offering this type of fluoroscopy unit: Siemens and Toshiba. Siemens produces the Artis Zee, while Toshiba produces the Ultima-i. This paragraph will present the main features of these machines. Exhaustive technical details are available on the following website:


Applications for these fluoroscopic units require more advanced features than the simple remote-controlled fluoroscopic systems and include three focal spots, typically for Siemens, a large focal spot (1 mm), a small focal spot (0.6 mm), and a “micro” focal spot (0.3 mm) and, for Toshiba, a large focal spot (1 mm), a small focal spot (0.6 mm), and a “micro” focal spot (0.4 mm). The Siemens fluoroscopy unit, which has 48 × 48 cm² FPD, has more FOVs, typically 48 × 48 cm², 42 × 42 cm², 32 × 32 cm², 22 × 22 cm², 16 × 16 cm², and 11 × 11 cm², while Toshiba has a 43 × 43 cm² FPD with FOVs of 42 × 42 cm², 34 × 34 cm², 25 × 25 cm², and 18 × 18 cm². Finally, they also typically feature more flexibility in X-ray tube movements. The tube and the imaging detector (image intensifier or flat panel) are mounted on a C-arm, and besides the possibility of traveling parallel and perpendicular to the table, they can also rotate in the left and right anterior oblique (RAO/LAO) and cranio crano-caudal (CRA/CAU) directions. The RAO/LAO rotation can be seen in Figure 27.3 (Toshiba Ultima-i).

The focus-image distance is variable by sliding the imaging detector on a rail system and changing the distance relative to the X-ray tube. In cases where the tube is positioned above the table, the position of the image detector relative to the tube can be increased or decreased in conjunction with the table elevation, thereby keeping the distance between the detector and table at a constant minimum. This feature helps to reduce the ESE to the patient. Even though the tube is usually relatively thin, the resistant carbon fiber plate can accommodate hyperbaric patients. Multipurpose fluoroscopic systems can also have the table tilted by up to 90° and have full GI/GU fluoroscopic functions, which include the retractable compression cone. Figure 27.4 shows the Toshiba Ultima-I in an intermediary tilted position.

Some remote-controlled fluoroscopic units do not feature compression cones because of lack of interest from the physicians. Figures 27.5 and 27.6 depict the two positions of the X-ray tube relative to the table.

Most of the multipurpose fluoroscopic systems have at least three monitors in the fluoroscopic room, which are duplicated in the control room: one for the real-time fluoroscopic image, one for the last image hold, and one for playback of the last radiographic image acquisition series.
FIGURE 27.3 Toshiba Ultimax-I multipurpose fluoroscopic unit rotated in the RAO/LAO plane.

FIGURE 27.4 Toshiba Ultimax-I in a tilted position.
27.2.2 Dose Considerations of Multipurpose Fluoroscopic Systems

Multipurpose fluoroscopic systems are relatively new: about 15 to 20 years on the market. The newest systems feature three exposure rate levels: low, normal, and high. Siemens Artis Zee is equipped with a large variety of Cu filters with thicknesses from 0.1 mm to 0.9 mm and pulse rates from 3 pps to 15 pps, while Toshiba Ultimax-I is equipped with Ta 0.015 mm (approx. 2 mm Al equivalent), Ta 0.03 mm (approx. 4 mm Al equivalent).
equivalent), a 0.2 mm Al and a 1.2 mm Al filter. The physicist doing dosimetry measurements with multipurpose measuring tools should take extra precautions because the Ta filtered X-ray beam is not usually on the correction list of these instruments and kVp and HVL measurements can end up with significant errors. To achieve a good signal-to-noise ratio (SNR), the pulse width can also vary. The technologist operating the fluoroscopic system does not need to change any of these settings since the system comes with preprogrammed protocols for virtually every possible application. These typically provide an optimal image brightness and contrast; nonetheless, one can keep the chosen exposure rate level by changing practically every input parameter of the machine, including kVp, mA, pps, pulse width, X-ray beam filtration. ESE to the patient can be reduced by high filtration of the X-ray beam, low mA, and higher kVp. Table 27.2 shows the dependence of the stabilized exposure rate on the FOV and the fluoroscopic input parameters for a low exposure rate setting.

For a high exposure rate level option, less X-ray beam filtration is used and lower kVp, as can be seen in Table 27.3 (settings and measuring conditions are the same as for Table 27.2).

From Tables 27.2 and 27.3, one can observe that, by changing the dose level options, the exposure rate has changed by approximately an order of magnitude.

**TABLE 27.2**

Data for Siemans Artis Zee Multipurpose Fluoroscopic Device, Tube Under the Table

<table>
<thead>
<tr>
<th>Field Size (cm)</th>
<th>Exposure Rate (mR/min)</th>
<th>Pulse Rate (pps)</th>
<th>mR/Frame</th>
<th>kVp</th>
<th>mA</th>
<th>Pulse Width (ms)</th>
<th>Cu Filter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>0.09</td>
<td>7.5</td>
<td>0.21</td>
<td>86.7</td>
<td>36.0</td>
<td>3.5</td>
<td>0.9</td>
</tr>
<tr>
<td>42</td>
<td>0.09</td>
<td>7.5</td>
<td>0.20</td>
<td>86.7</td>
<td>35.8</td>
<td>3.5</td>
<td>0.9</td>
</tr>
<tr>
<td>32</td>
<td>0.14</td>
<td>7.5</td>
<td>0.32</td>
<td>86.7</td>
<td>59.7</td>
<td>3.5</td>
<td>0.9</td>
</tr>
<tr>
<td>22</td>
<td>0.20</td>
<td>7.5</td>
<td>0.47</td>
<td>86.7</td>
<td>93.6</td>
<td>3.4</td>
<td>0.9</td>
</tr>
<tr>
<td>16</td>
<td>0.31</td>
<td>7.5</td>
<td>0.71</td>
<td>86.7</td>
<td>95.6</td>
<td>5.4</td>
<td>0.9</td>
</tr>
<tr>
<td>11</td>
<td>0.43</td>
<td>7.5</td>
<td>0.99</td>
<td>86.7</td>
<td>96.7</td>
<td>7.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>

The tabletop exposure rate was measured. Measuring conditions: 20 cm PMMA Phantom used, FID = 100 cm, FCD = 70 cm. The table shows an extremely low tabletop exposure rate using a highly filtered X-ray beam (0.9 mm Cu) and high kVp (86.7) for a relatively small phantom thickness.

**TABLE 27.3**

Data for a High Contrast Fluoroscopic X-ray Beam

<table>
<thead>
<tr>
<th>Field Size (cm)</th>
<th>Exposure Rate (mR/min)</th>
<th>Pulse Rate (pps)</th>
<th>mR/Frame</th>
<th>kVp</th>
<th>mA</th>
<th>Pulse Width (ms)</th>
<th>Cu Filter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>1.20</td>
<td>15</td>
<td>1.3</td>
<td>70.0</td>
<td>95.0</td>
<td>4.3</td>
<td>0.2</td>
</tr>
<tr>
<td>42</td>
<td>0.99</td>
<td>15</td>
<td>1.17</td>
<td>68.4</td>
<td>96.6</td>
<td>6.2</td>
<td>0.3</td>
</tr>
<tr>
<td>32</td>
<td>1.45</td>
<td>15</td>
<td>1.76</td>
<td>68.4</td>
<td>111</td>
<td>8.2</td>
<td>0.3</td>
</tr>
<tr>
<td>22</td>
<td>2.29</td>
<td>15</td>
<td>2.54</td>
<td>68.4</td>
<td>163</td>
<td>8.2</td>
<td>0.3</td>
</tr>
<tr>
<td>16</td>
<td>3.20</td>
<td>15</td>
<td>3.79</td>
<td>68.8</td>
<td>245</td>
<td>8.3</td>
<td>0.3</td>
</tr>
<tr>
<td>11</td>
<td>4.84</td>
<td>15</td>
<td>5.92</td>
<td>70.5</td>
<td>242</td>
<td>8.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The higher tabletop exposure rate using a less filtered X-ray beam (0.2–0.3 mm Cu) and lower kVp value (68.4–70.0) is apparent. It can be seen that the current can go up to almost 250 mA. Pulse width is increasing during magnification mode to keep the signal-to-noise ratio (SNR) constant.

27.2.3 Image Quality of Multipurpose Fluoroscopic Systems

Newer multipurpose fluoroscopic systems feature an increased number of magnification modes, depending on the size of the FPD. As mentioned above, the Siemens 48 × 48 cm² FPD can have a magnification appropriate for FOVs of 48 × 48 cm², 42 × 42 cm², 32 × 32 cm², 22 × 22 cm², 16 × 16 cm², and 11 × 11 cm². The limiting spatial resolution for each FOV is shown in Table 27.4.

In Table 27.4, it can be seen that, once the system reaches maximum spatial resolution, that is, reaches the Nyquist frequency for a given FPD sampling rate, further magnification will not improve the spatial resolution. For the Siemens FPD, the Nyquist frequency is 3.4 lp/mm. Table 27.4 results are within the measurement error. The lower spatial resolution for larger field sizes is the result of binning pixels together to lower the quantum noise and increase the SNR. Once, by increasing magnification, the spatial resolution limit has been reached, a further increase of the magnification will result in a higher dose per pixel to maintain the SNR. This will lead to increased patient ESE without obtaining more detail in the image.

27.3 Mobile Fluoroscopy Devices

27.3.1 Mobile C-Arms

Mobile C-arms are mobile fluoroscopic systems mainly used in intensive care units and operating rooms [2]. They can be used in a multitude of applications like intraoperative, orthopedic, and trauma, and the most advanced units can perform interventional radiology, vascular applications, neurosurgery, craniomaxillofacial surgery, and interventions on the spine. The shift to use more and more laparoscopic types of surgery makes the use of fluoroscopic systems in operating rooms practically permanent. Since surgeons do not diagnose based on images, they do not normally need high-quality images. Their surgery instruments are clearly visible on the images so they mostly need fluoroscopic X-ray beams. The radiographic X-ray mode is very seldom used. The exceptions to this rule are when high-precision intervention is applied on the patient, such as for the spine or for some orthopedic cases, or when the system supports angiography applications like digitally subtracted angiography (DSA). Then the user will need higher quality image sequences. Since surgeons use a short beam-on time per procedure, and because of the large size of the
operating rooms, most of the operating rooms are not shielded. Only newer operating rooms that have a permanent fluoroscopic system installed are usually shielded. The most popular C-arms on the market are manufactured by Philips, Siemens, Ziehm Imaging, and GE. Philips offers C-arms with both types of image receptor: the Veradius with FPD and the BV Pulsera with image intensifier. Siemens manufactures the “Cios” mobile C-arm, featured both with FPD—the “Cios Alfa”—and image intensifier—the “Cios Arcadis Orbic 3D, and Cios Select. GE and Toshiba only offer image intensifier-equipped mobile C-arms. GE manufactures the OEC 9900 Elite and OEC 9800 Plus models while Toshiba produces the Surginix and the Clearscope, although the latter might not be available in every country because of health authority approval or market saturation considerations. Exhaustive technical details can be found on the manufacturers’ websites.


27.3.1 Technical and Functional Description of the Mobile C-Arm Fluoroscopic System

These devices are all wheel-mounted and made of two separate units: the C-arm itself and the control unit with the display monitors. The two pieces are linked with a detachable cable. The C-arm operates on relatively low power and can be plugged into standard power wall outlets. Most image intensifier-equipped C-arms have imaging detectors of 20 cm (some with 9”, 23 cm) and 30 cm diameter FOV, while the FPD equipped image intensifiers have a 20 × 20 cm² and 30 × 30 cm² FOV. Larger detectors would be impractical because they would interfere with the activity of the surgeons and the operating room personnel, without adding more useful information. The C-arm itself can rotate in two planes: RAO/LAO and CRA/CAU. The height of the isocenter is adjustable. Older models equipped with image intensifiers can work in continuous X-ray fluoroscopic mode and pulsed fluoroscopic mode [4]. Newer units equipped with FPDs usually feature only the pulsed fluoroscopic mode, typically between 3 and 15 pps, but if the mobile C-arm has cardio options, the pulse rate can go up to 30 pps. Some advanced models, such as the Siemens Cios Alfa, can go as low as 0.5 pps. The X-ray tubes of the higher end mobile C-arms have a rotating anode for better heat management and a remarkable 0.3/0.6 mm focus size. Since the size of the imaging detector is limited, there are only three FOVs and three corresponding magnification modes: a 30 × 30 cm² FPD will typically have 30 × 30 cm², 20 × 20 cm², and 15 × 15 cm² field sizes. The corresponding size intensifier will have 12” = 30 cm, 9” = 23 cm, and 7” = 18 cm diameter field sizes. For safety reasons, beam-on is signaled acoustically and visually to the personnel in the room. Additionally, if the high-grade fluoroscopic X-ray beam is on, the acoustic signal becomes faster to make the user aware of the higher exposure rate use. All mobile C-arm fluoroscopic systems can acquire radiographic quality images either as spot images or image sequences at different frame rates. The most advanced FPD equipped mobile C-arms, like Ziehm Vision RFD 3D, can perform cone beam CT imaging. See more details at: https://www.ziehm.com/uploads/media/US_ZiehmVisionRFD3D_brochure_2017-03-31.pdf (consulted April 2017). This cone beam CT imaging feature is also offered by Siemens Arcadis Orbic 3D; however, this one is equipped with an image intensifier—see Figure 27.7.

Since it was demonstrated that cone beam CT perfusion imaging is not inferior to multidetector CT perfusion [10] imaging, cone beam CT-based perfusion imaging is becoming more and more common on the more recent and more advanced mobile C-arms. A typical FPD equipped C-arm fluoroscopic system is shown in Figure 27.8.

27.3.1.2 Dose Considerations of the Mobile C-Arm Fluoroscopic System

Most mobile C-arms feature a low exposure rate mode (in the case of GE OEC 9900, it represents 50% of the normal exposure rate, regardless of whether it is continuous or pulsed) and a high exposure rate mode (High Grade Fluoro). The high-grade fluoroscopic mode provides, in some models, up to roughly six times the exposure rate provided in the normal fluoroscopic mode. Table 27.5 shows the dependence of the exposure rate on the magnification and the dose level option for a GE OEC 9900.

The newer editions of mobile C-arm fluoroscopic systems, equipped with a FPD, demonstrate a better detection efficiency, so the high-grade fluoroscopic mode does not need to be more than 2.5 × the normal fluoroscopic mode, as can be seen in Table 27.6.

The newest mobile C-arms equipped with FPDs are using iterative noise reduction software that can lead to an up to 50% patient ESE reduction. Also, the newest ones are equipped with removable anti-scatter grids, which can produce a similar patient ESE reduction. There are studies that demonstrate that mobile FPD equipped C-arms deliver a significantly lower dose to the patient for peripherally-inserted central catheter arrangements than a conventional angiography machine [9].

27.3.1.3 Image Quality of Mobile C-Arm Fluoroscopic Systems

Mobile C-arm fluoroscopic systems have a similar spatial resolution to remote fluoroscopic systems or multipurpose systems. The limiting spatial resolution of the FPD equipped mobile C-arms is determined by the Nyquist frequency corresponding to the flat panel pixel size. For the Ziehm Vision RFD and the Siemens Cios Alfa, the pixel size is 194 µm and the corresponding Nyquist frequency is 2.6 lp/mm. However, on the display monitor, after image post processing, the acquisition mode can reach a limiting spatial resolution of 3.1 lp/mm. The Philips
Clinical Fluoroscopy Units

FIGURE 27.7 Siemens Arcadis Orbic 3D. One can observe the main components of the C-arm and the command post with the two monitors: one for the real-time fluoroscopic/radioscopic image, and the other for the last-image hold, the recorded radioscopic image sequence, and the cone beam CT sequence replay.

FIGURE 27.8 The Siemens Cios Alfa is a typical FPD-equipped mobile C-arm. The small size of the FPD compared with an image intensifier can substantially increase the free space between the tube and the imaging detector.
TABLE 27.5
Exposure Rates of Mobile C-Arm Fluoroscopic Systems in Different Operating Modes

<table>
<thead>
<tr>
<th>Magnification Mode</th>
<th>Normal Exposure Rate (R/min)</th>
<th>Low Dose Exposure Rate (R/min)</th>
<th>High Grade Exposure Rate (R/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>0.815</td>
<td>0.377</td>
<td>5.298</td>
</tr>
<tr>
<td>M1</td>
<td>1.383</td>
<td>0.548</td>
<td>8.248</td>
</tr>
<tr>
<td>M2</td>
<td>1.712</td>
<td>0.910</td>
<td>9.491</td>
</tr>
</tbody>
</table>

The data show that the low dose was constantly around 50% of the normal dose setting, and the high-grade exposure rate is around six times the normal exposure rate. Acquisition parameters were: 18 cm PMMA phantom, FID = 100 cm, FCD = 68 cm, with 8 pps settings.

TABLE 27.6
Data Acquired from a Philips Veradius C-Arm Equipped with a Flat Panel Detector

<table>
<thead>
<tr>
<th>Field of View (cm)</th>
<th>Normal Fluoro Exposure Rate (R/min)</th>
<th>Hi Grade Fluoro Exposure Rate (R/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>0.37</td>
<td>0.86</td>
</tr>
<tr>
<td>18</td>
<td>0.44</td>
<td>1.1</td>
</tr>
<tr>
<td>13</td>
<td>0.59</td>
<td>1.38</td>
</tr>
</tbody>
</table>

FID = 100 cm, FCD = 72 cm, with high quality (HQ) and 8 pps settings. An 18 cm PMMA phantom was used.

Veradius has a slightly smaller pixel size of 184 µm and a corresponding slightly higher Nyquist frequency of 2.7 lp/mm. The SNRs achieved on all FOVs are remarkably good, especially given the low power consumption.

27.3.2 Mobile Mini C-Arms

Mini C-arms are very versatile fluoroscopic systems, with applications limited to orthopedic and pediatric cases. Their maximum FOV is 15 cm. They are very light and can be positioned easily. The model shown in Figure 27.9 is an older model from GE equipped with an image intensifier. Given the very close distance between the X-ray tube and the image detector, the exposure rate is extremely low: in the order of µR/min. These devices usually provide two FOVs and, because there cannot be a large variation of tissue thickness imaged, there are no different dose level options. Having a very small FOV, the spatial resolution of the mini C-arms is slightly higher than their larger peers, going up to 4 lp/mm.

27.3.3 Mobile O-Arms

This type of mobile fluoroscopic system is designed for guidance in high-precision surgery, where 3D views of the pathology are very important. Head or spine trauma patients or neurosurgery can also benefit from 3D images during treatment.

27.3.3.1 Technical and Functional Description of the O-Arm Fluoroscopic System

This mobile unit is another, rather specialized, type of mobile fluoroscopic system, used mainly in operating rooms. It is a fully motorized device, made to acquire real-time 2D/3D images through cone beam CT acquisition on a FPD. The imaging panels revolve inside a ring opposite to the X-ray tube. Figure 27.10 shows an O-arm in closed position.

The O-ring can be opened to enable positioning of the patient on the table inside the O-ring. After closing the ring around the table with the patient, the system can be positioned over the treatment site in an optimal imaging position by moving the ring up and down or side-to-side. This imaging positioning process is facilitated using a static, fluoroscopic beam delivered by the X-ray tube. The ring can also be tilted in both directions if the acquisition plane needs to be other than perpendicular on the table axis.

27.3.3.2 Dose Considerations of the O-Arm Fluoroscopic System

O-arms are designed mainly to acquire 3D images and use 2D images only for positioning purposes. They also come with a
“standard-dose mode” and a “low-dose mode,” which limits the dose to the patient to 50% of the standard dose mode.

Physicians need to be made aware that this mobile fluoroscopic system is not just another mobile fluoroscopic device and use it as such. The limited way the table can be adjusted inside the ring between the X-ray tube and the imaging detector diametrically opposed can lead to very significant ESE to the patient compared to an ordinary mobile C-arm, where the imaging detector can be placed right next to the patient.

27.4 Interventional Fluoroscopy

Interventional fluoroscopy is arguably the most important application of fluoroscopy. It is applied for treatment of the whole vascular system, the heart, and for the treatment of some types of cancer delivering drugs through blood vessels right into the tumor. Interventional fluoroscopy is applied to the heart, typically in a so-called “Cardio Catheterization Suite.” Fluoroscopy for pacing and recording electrodes placed in the heart to stimulate and measure electrical properties is performed in the so-called “Cardio Electrophysiology Laboratory.” Any other vascular pathology is dealt with in the “Peripheral Angiography Suites [2].”

27.4.1 Peripheral Angiography Suites

These types of units are offered by the main players in the medical imaging equipment field: Siemens, Toshiba, and GE. Siemens offers the Artis Zee suite, which essentially has the same graphic user interface as the multipurpose Artis Zee and shares most of the components used in that type of device. For more technical details, visit the Siemens website: https://www.healthcare.siemens.com/angio/artis-interventional-angiography-systems/artis-zee/technical-details (consulted April 2017). GE offers the Innova IGS 540/530/330 angiographic suite. More details can be found on the site http://www3.gehealthcare.com/en/products/categories/interventional_image_guided_systems/igs_for_interventional_radiology_and_oncology (consulted April 2017).


27.4.1.1 Technical and Functional Description of Peripheral Angiography Suites

Peripheral angiography is used for any blood vessel in the body outside the heart [4]. This fluoroscopic system (X-ray tube and image detector) is also mounted on a C-arm, which in turn can be mounted on the floor or on the ceiling—see Figure 27.11. These C-arms are mostly floor-mounted because most manufacturing companies also offer biplane angiographic suites and the second C-arm is always ceiling-mounted. Of course, they can offer the ceiling-mounted C-arm as a standalone single plane.
FIGURE 27.11  The Siemens Artis Zee single plane peripheral angiographic suite.

FIGURE 27.12  The Toshiba Infinix CF-i/BP biplane peripheral angiographic suite.
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Angio-suite. Biplane angiographic suites are two completely independent imaging chains with two C-arms, generators, tubes, fluoroscopic detectors—see Figure 27.12. One of the C-arms is ceiling-mounted, usually the lateral C-arm, which can be swung out when only a single plane treatment is needed. The other, usually antero-posterior (AP), C-arm is floor-mounted. The two, independent X-ray tube–detector systems can work simultaneously, taking orthogonal views or any oblique view of the region of interest with a single injection of the contrast material. During biplane angiography, to avoid cross talking between the two fluoroscopic systems, the pulse sequence is adjusted in such a way that the imaging system of one C-arm will not record the scattered radiation of the other C-arm system. Biplane angiography suites are mainly used in complex cases of neuro angiography.

The angiographic table cannot be rotated but its height can be adjusted and it can be translated longitudinally and laterally, allowing the patient to be imaged head-to-toe. The C-arm can also be translated over the entire length of the stationary table, and can be rotated to offer RAO/LAO views and tilted to offer CRA/CAU views. In general, the dimensions of the imaging detector for peripheral angiography can go up to 48 cm, but for neuro angiography these are limited to 30 cm. Angiography suites are equipped with multiple display monitors, which can separately display the live fluoroscopic image, the last image held, record live images, the last record image sequence, and in some cases, the patient vital signs. Newer models use one comprehensive display that can be custom-divided for the different functions as per radiologists’ preference. Because interventional angiography always uses iodine contrast media, these suites are equipped with power injectors, which can be ceiling-mounted or table-mounted. Because of the small size of the objects to be visualized, peripheral angiography suites are implemented with more, or similar, magnification modes than multipurpose fluoroscopic units. One of the newer FPD-equipped models has magnification modes corresponding to six FOVs including 48 × 48 cm, 42 × 42 cm, 32 × 32 cm, 22 × 22 cm, 16 × 16 cm and 11 × 11 cm.

The lateral detector in biplane angiographic systems is usually smaller than the AP detector, which will offer less magnification modes than the AP detector.

Biplane angiographic suites can present a patient radioprotection issue. If both planes are used, the table must be positioned in such a way that the patient is in the lateral X-ray beam. This means that the height of the table is fixed, regardless of whether this position is ideal from a patient radioprotection point of view in the AP direction or not (if it is at the closest point to the image detector). To provide more flexibility to handle the patient radioprotection problem, it is preferable to have a variable-height lateral C-arm, where the table height can be adjusted according to patient size to the closest position to the AP detector, while the lateral C-arm can be raised accordingly. In very long cases, this feature can save significant ESE to the patient. The Toshiba Infinix CF-i/BP has this feature.

To save ESE to the patient, most peripheral angiographic devices are using heavily filtered X-ray beams with up to 1 mm Cu filter. During the imaging process, these filters can be dynamically changed in real time when the imaged thickness of the patient changes. To maintain a constant SNR during different procedures, the automatic exposure rate control (AERC) can simultaneously adjust the mA, the kVp, and pulse width in real time [6,8,14]. Practically all new angiographic fluoroscopy devices equipped with a FPD are provided with a cone beam CT capability [10]. This feature helps the radiologist to visualize the digitally subtracted blood vessels in 3D, even rotate them in space to arrive at a cross-section in any desired plane. If this feature is applied in a biplane C-arm suite, the lateral C-arm is swung out and the AP C-arm will perform the rotational image acquisition.

Angiographic studies do not need extreme pulse rates. The common pulse rates applied to angiographic imaging are: 3, 7.5, 10, and 15 pps. These pulse rate options adequately cover all non-cardio applications.

27.4.1.2 Dose Considerations of Peripheral Angiography Systems

In general, interventional fluoroscopy is the highest dose-to-patient modality in X-ray based imaging [7,13]. Therefore, besides image quality, patient ESE is the main issue the manufacturers must address. Since a single angiographic study—especially a neuro angiographic study—can take more than an hour fluoroscopic beam-on time, and additionally several radiographic image acquisition sequences, each type of study is preprogrammed to minimize the ESE to the patient. Protocols are set up for small patients, medium sized patients, and large patients, or low-dose fluoro, medium-dose fluoro, and high-dose fluoro. Each type of protocol defines the pulse rate for the appropriate procedure and the AERC will adjust the other parameters to keep the ESE to the patient as low as possible while keeping the image SNR to the optimal level. Table 27.7 shows how the exposure rate depends on the FOV and the dose level setting.

There is a significant dose penalty for using higher magnification modes. The ESE of the patient increases by a factor of five at the highest magnification mode. Hence, the radiologist should be aware of these dose penalties. If the duration of the investigation is long and requires many radiographic image acquisition sequences, it is imperative that the beam-on time, on magnification modes, is kept as short as possible.

In some special cases, when the imaged volume is smaller—like neuro angiography cases—the anti-scatter grid can be removed, saving up to 50% ESE to the patient.

27.4.1.3 Image Quality of Peripheral Angiographic Fluoroscopic Systems

The spatial resolution of the angiographic fluoroscopic systems, at the highest magnification mode, is 3.4 lp/mm, limited by the Nyquist frequency. This gives the radiologist the opportunity to follow the catheter inside the blood vessels and to discern smaller blood vessels in digitally subtracted image sequences which have radiographic image quality. As discussed in the multipurpose paragraph, the largest magnification modes are not always capable of offering better spatial resolution than the smaller ones because of the limits imposed by the FPD pixel size.

27.4.2 Robotic Arm Angiography Suites

From the X-ray imaging point of view, there is no fundamental difference between a robotic arm angiographic unit and a ceiling/floor mount C-arm angiographic unit, as seen in Figure 27.13.
Both are indeed C-arms but, from a mechanical point of view, the robotic arm has more degrees of freedom and can position the C-arm in multiple ways to decrease the chance that equipment is in the way of the radiologist or technologist. This type of installation is offered only by Siemens, and the model is called Siemens Artis Zeego. More technical specifications can be found at: https://www.medimagingsales.com/wp-content/uploads/2014/11/Siemens-Artis-Zeego-Tech-Specs.pdf (consulted April 2017).

### 27.4.3 Cardiology Catheterization Suites

The main player in this field is Philips, who offers models such as the Philips Allura Xper FD10/FD20, Azurion 7/3. More details can be found at the site: [http://www.usa.philips.com/healthcare/solutions/interventional-xray/percutaneous-coronary-intervention#Systems](http://www.usa.philips.com/healthcare/solutions/interventional-xray/percutaneous-coronary-intervention#Systems) (consulted April 2017).

#### 27.4.3.1 Technical and Functional Description of the Cardio Catheterization Suites

Cardio catheterization suites or laboratories are very similar to the angiographic suites. Any differences lie in technical details. The image detectors are smaller than the angiographic detectors because the volume of the heart needs a smaller FOV, 20 cm, as can be seen in Figure 27.14. This has the consequence that there will be fewer magnification modes, typically three,
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27.4.3.2 Dose Considerations of the Cardiac Catheterization Systems

As for the angiographic suites, the cardiac catheterization suites are preloaded with protocols which pre-establish most of the parameters of the X-ray beam. They also feature three ESE levels corresponding to three patient sizes: small, medium, and large. The AERC can change the mA, kVp, pulse width, and the Cu filter thickness during the procedure. Except neuro angiography, cardiac catheterization procedures tend to be longer than peripheral angiography procedures and additional precautions need to be taken to avoid patient skin injuries. In their more recent models, most manufacturers provide software that can denoise the fluoroscopic images and offer the same image quality at half of the exposure rate of the former versions [3].

One of the more successful implementations of this type of software is the Philips ClarityIQ [12]. This software is described as performing the following corrections in real-time: (1) patient or accidental table motion on live images; (2) noise and artifacts on moving structures and objects; (3) image enhancement and the sharpening of edges. With image processing, a lower patient dose is required to create an image that is comparable in image quality to an image created without image processing at higher patient dose levels.

The following image processing technology is used in ClarityIQ: (1) real-time pixel shift (P) with automatic motion control (AMC); (2) motion compensation (M); (3) noise reduction (N); (4) image enhancement (I).

27.4.3.2.1 Real-Time Pixel Shift with Automatic Motion Control

In DSA procedures, subtraction is done to enhance visualization of vessels by removing disturbing background structures like soft tissue or bones from the image. Real-time pixel shift aligns images with each other before subtraction, so that fewer motion artifacts will appear. The AlluraClearity system performs pixel shifting automatically and in real time using the AMC feature. The AMC feature compares images taken prior to injection (mask image) with images containing contrasted vessels (live image or contrast image). AMC finds the optimal alignment with sub-pixel accuracy before subtraction. AMC is performed on every single image in the run—fully automatically, in real time—without requiring any user interaction.

These techniques lead to a reduction of subtraction artifacts and produce a better starting image for additional image processing elements to act upon, which allows, for instance, stronger noise reduction and contrast enhancement.
27.4.3.2.2 Noise Reduction Techniques

Noise is a random phenomenon. Noise reduction first makes a distinction between the random nature of the noise and the more-or-less constant signal for X-ray absorption of the anatomy and objects, such as catheters or coils. The different characteristics between noise and signal are used to filter out a large part of the noise. This results in enhanced image quality. Noise reduction consists of both temporal and spatial noise reduction. Temporal noise reduction refers to processing that is carried out over time, over subsequent images, while spatial noise reduction refers to processing carried out over an area within one image. The algorithms distinguish between signal/objects and noise. As noise is random, it can be reduced by averaging pixel intensity over multiple pixels in time or in space, termed filtering. The filtering algorithms applied are adaptive, meaning they perform different operations on noise than they do on real signal, for example, from a vessel or catheter.

27.4.3.2.2.1 Temporal Noise Reduction Temporal noise reduction reduces noise by averaging several frames over time: the more frames that are averaged, the higher the noise reduction. The SNR is increased by approximately the square root of the number of frames averaged (\( \sqrt{n} \)). That is, if 16 frames are averaged (\( n = 16 \)), the SNR would be increased by a factor of four. When motion is detected, the temporal filter is switched off in the region of the image where motion is detected. This prevents “ghosting,” but at the same time, it reduces the number of frames that can be used for temporal noise reduction in the presence of motion. Some algorithms offer a motion compensation feature that registers the moving structures before averaging, so that more frames can be used and stronger temporal filtering can be applied.

27.4.3.2.2.2 Spatial Noise Reduction Spatial noise reduction finds the noise within a single image and filters out the noise pixel by pixel, by averaging it with the pixels surrounding it in its so-called neighborhood. For (potentially) clinically relevant features, the averaging adapts to structures, such as vessels and guide wires, to avoid blurring. When performing spatial noise reduction, it takes a significant processing power to average the neighborhood for every single pixel in the image. These processing power requirements increase with the square size of the size of the neighborhood. Since more surrounding pixels are used for averaging, more noise is reduced. Considering a larger neighborhood also makes it possible to identify clinically relevant structures with greater specificity, so that stronger spatial filtering can be applied with less blurring of the signal.

27.4.3.2.3 Image Enhancement

The algorithm performs edge enhancement, contrast enhancement, harmonization (reducing background contrast), brightness control, and other image enhancements. Image enhancement has a limited effect on the objective image quality, as it mainly enhances subjective image quality. It allows images to be adapted to the user’s preference and experience. Some users like very sharp images, while others prefer high contrast or low noise images. If one of the attributes is enhanced, the others are automatically reduced. Image enhancement makes use of spatial frequencies. Typical technology usually makes use of advanced algorithms to apply more powerful enhancements across all frequencies. This greatly enhances the visualization of small details for applications such as neuroradiology.

Additionally, for cardiac fluoroscopy, the dose reduction in the AlluraClarity system is achieved by using a highly filtered X-ray beam created by, for example, the use of a 0.4 mm Cu filter. When copper filtration is used, 1 mm of aluminum is also used, which is roughly equal to an additional 0.1 mm of copper. A radiation quality of 0.4 mm Cu, in reality, corresponds to 1 mm Al + 0.4 mm Cu = 0.5 mm Cu equivalent.

For neuro DSA exposure, the AlluraClarity system uses a reduced tube current instead of high copper filtration. This makes the use of the small focal spot of the tube possible. In addition, the lower tube current delivers a correspondingly lower exposure rate, typically half of the exposure rates of the non AlluraClarity systems. The main advantage of using a small focal spot is the increased sharpness of the image, which is very important when visualizing tiny cerebral vasculature.

27.4.4 Cardio Electrophysiology Laboratory

A cardio electrophysiology laboratory is very similar to a cardio catheterization laboratory and is used to insert pacemakers and recording electrodes into the heart to stimulate and record the electrical properties of various cardiac functions. These studies can also take an extended period, sometimes up to hours, so as described in earlier paragraphs, extra precautions need to be taken into consideration to avoid patient skin injuries. Also because of long cases, cardiologists have the option of using special personal X-ray shields, for example, a leaded, ceiling-mounted cylindrical device with a leaded glass window to allow close observation of the patient. This precaution avoids the need for them to wear the lead apron for extended periods of time. Some electrophysiology laboratories are equipped with two control rooms to ease monitoring the functional parameters of the heart. Advanced electrophysiology laboratories can use remote fluoroscopy coupled with high-field strength magnets, which can steer the catheters into a target area in the heart with very high accuracy.

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