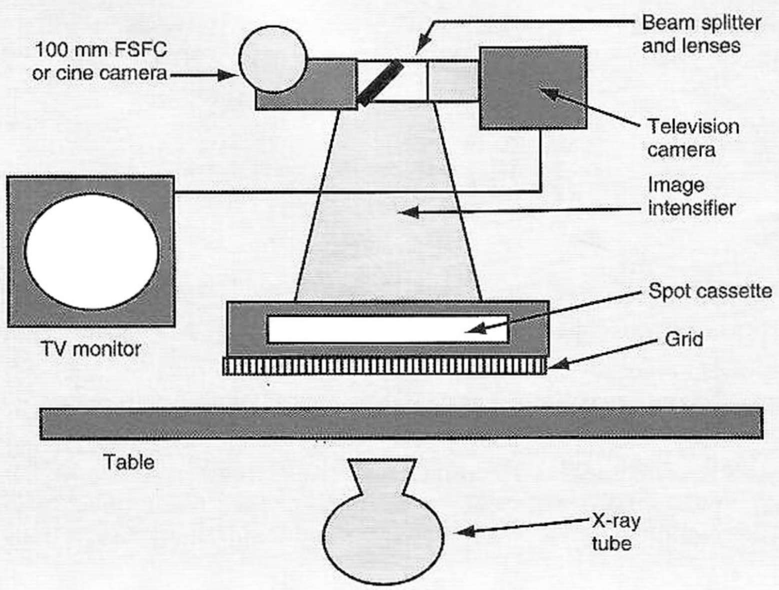
Fluoroscopy Systems

A. Basic Concepts

1. Fluoroscopy systems are specialized for the following purposes: positioning for catheter placement, positioning for radiography and digital subtraction angiography (DSA), trauma surveys, and dynamic studies such as swallowing examinations and heart evaluations.
2. Fluoroscopy systems are designed to take many continuous low-mA or pulsed higher mA images over a period of many minutes.
3. A comparison with radiographic imaging is shown in the table.

PARAMETER	FLUOROSCOPY SYSTEM	RADIOGRAPHY
Focal spot size	0.2–0.6 mm	0.6–1.2 mm
kVp used	60–130	50–150
mA used	0.1–5 mA (continuous)	20–1000 mA
	0.5–180 mA (pulsed)	
Exposure times	Multiples of 5 minutes	0.001–4 sec/image
Filter	Min.–0.9 mm Cu added	Min.–2 mm Al added
SID	80–120 cm	100 or 180 cm
Minimum SSD	20–50 cm	68 cm (chest >)
Typ. ESE	3–6 R/min	0.401–0.8 R/image
Image receptor	(II + TV) or FPD	CR, DR, or film

4. The configuration of a fluoroscopic system is shown in the figure.



5. Modern fluoroscopy systems use a DR-type receptor called a ***flat panel display (FPD)*** instead of a system with an image intensifier (II), beam splitter, lenses, aperture, and television. As with regular DR systems, the spatial resolution is lower, but the dynamic range is greater than that of the II systems.

6. Components of fluoroscopy systems are listed here along with their function.

   X-ray tube: target where x-rays are produced

   Collimator: device that restricts the size of the x-ray beam

   Filters: substances that remove low-energy x-rays to make the beam more penetrating

   Table: surface on which the patient is placed

   Grid: thin plate containing lead strips that remove many of the scattered x-rays

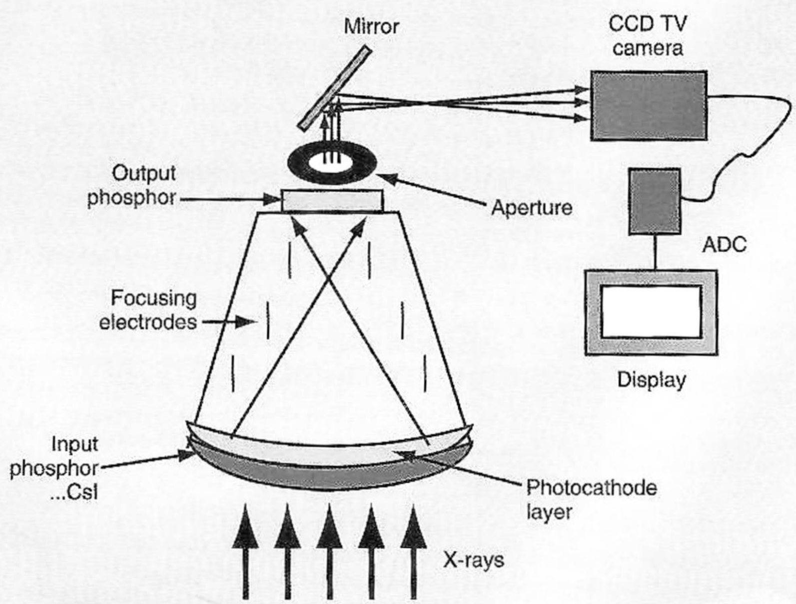
   Image intensifier: device that captures x-rays passing through the patient and converts the x-ray distribution into a bright light image

   Lens system: device that takes light from the image intensifier and directs and focuses the light image onto the television camera

   Aperture: plate that restricts the light to increase the radiation dose so that quantum mottle is at acceptable levels and distortion at the edge of the lenses is limited

   ADC: component that processes analog-to-digital conversion of the electronic signals

   Television system: system that receives the light image, converts it to an electronic image, and sends it to the television display monitor



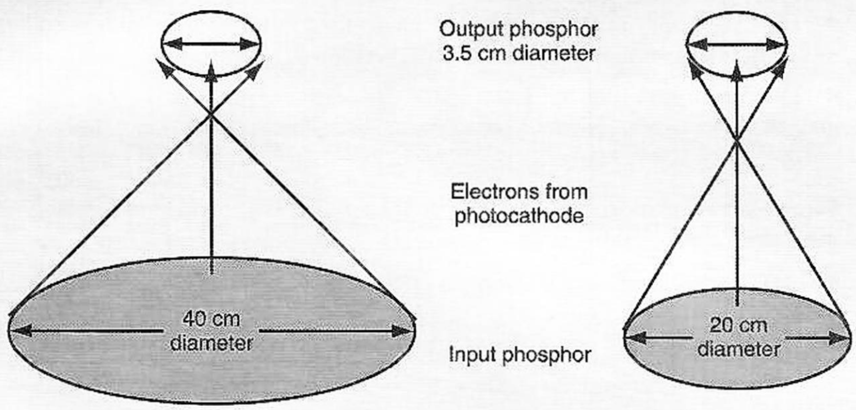
7. The process of image formation in the image intensifier is as follows:
   - X-rays enter thin glass or titanium ***window of image intensifier***.
   - X-rays deposit energy in the ***input phosphor*** of cesium iodide, and a fraction of energy is emitted as light. The amount of light is proportional to amount of input x-rays.
   - Light is then captured in a ***photocathode*** (e.g., antimony sulfide compounds), where light results in electron emission. The number of electrons emitted is in proportion to the amount of light deposited.

- ***High voltage*** between the photocathode and the output phosphor accelerates the electrons, and they gain energy. This is called ***flux gain*** and increases the energy by 50- to 100-fold.
- ***Focusing electrodes*** focus and invert the position of the electron onto the output phosphor. The inside of the image intensifier is a vacuum, so that accelerated electrons do not bump into air atoms and slow down.
- The ***output phosphor*** (e.g., $ZnCdSO_2$) is much smaller than the input phosphor (typically 22 to 35 mm). The output converts a portion of the energy deposited in the phosphor to light.
- Some of the increase in light from the output phosphor occurs because the electrons emitted from a large photocathode are confined in the small area of the output phosphor; this is called the ***minification gain***. The minification gain is equal to the ratio of the area of the input ***field of view (FoV)*** divided by the area of the output phosphor. For example,

  Input area = $\pi D^2/4 = \pi \times (40 \text{ cm diameter})^2/4 = 1257 \text{ cm}^2$

  Output area = $\pi d^2/4 = \pi \times (3.5 \text{ cm diameter})^2/4 = 9.6 \text{ cm}^2$

  Minification gain = $1257/9.6 = 130.9$



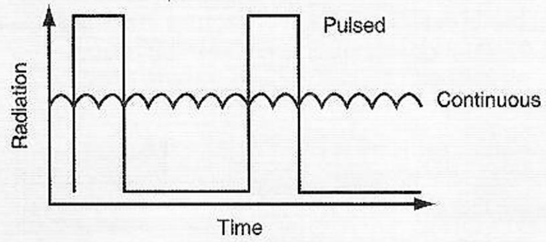
- ***FoV*** is selected by means of the ***electron magnification*** buttons on the image intensifier. For each "mag mode," the collimators and image intensifier focusing electrodes adjust the image to a smaller portion of the patient's body and spread it over the entire output surface; another way to describe this is ***less minification gain. Image intensifiers can have two, three, or four FoVs***. For example, an image intensifier can use a circular area on the input phosphor of 40, 28, 20, or 14 cm in diameter to image the patient.
- ***Flux gain*** is the energy gained by electrons accelerated by the high voltage applied across the image intensifier.
- ***Brightness gain*** is the overall gain in light intensity provided by the image intensifier.

  Brightness gain = flux gain × minification gain

8. The energy conversion process in an image intensifier is as follows:

- X-rays are incident through the input surface into the input phosphor.
- X-ray energy is converted into light in the input phosphor.
- Light is converted into electrons in the photocathode.
- The energy of the electrons is increased by the high voltage (flux gain).
- The electron energy is converted back to light in the output phosphor.

9. ***Automatic brightness control (ABC)*** is an automatic feedback system that senses the light from the output phosphor and adjusts the radiation to maintain a fairly constant light level.
   - The ABC can adjust kVp only, mA only, or a combination of mA and kVp (isowatt) or, in pulsed fluoroscopy, a combination of x-ray beam filter, kVp, mA, and pulse width.
   - As the FoV is decreased (mag mode), the minification gain decreases in magnitude. Thus, the brightness gain decreases at smaller FoVs.
   - The ABC system then increases the radiation to the patient to compensate for the loss in minification gain. Typically, each step in mag mode results in about a 40% to 100% increase in radiation dose to the patient.
   - That is, ***the smallest FoVs are associated with the largest fluoroscopic entrance skin exposure (ESE) radiation dose rates and the most electronic magnification of the image***.
10. ***Maximum entrance skin exposure rate (ESER)*** of fluoroscopy systems is set by federal regulations.
    - 5.0 R $\geq$ ESER for manually controlled systems.
    - 10.0 R $\geq$ ESER for ABC systems with one operational level.
    - 10.0 R $\geq$ ESER for the low level of a two-level ABC system; 20.0 R $\geq$ ESER for the high level of a two-level ABC system.
    - The 5-minute timer must sound to remind radiologists of fluoroscopy time.
    - Source-to-skin distance (SSD) must be $\geq$15 inches to reduce radiation dose, except for special surgical units (20 cm).
11. ***F-number (F#)*** is used to describe the light-gathering property of lenses and apertures.
    - F# is the ratio of the focal length of the lens divided by the lens diameter.
    - The objective lens (at the output phosphor of the image intensifier) is placed one optical focal length away from the output phosphor. The light that exits is in parallel rays.
    - The aperture is a plate with a hole in it that blocks some of the parallel light.
    - The lens at the television camera refocuses the parallel light onto the camera detector.
    - The combined lens system and the aperture have effective F#s.
    - Larger F#s gather less light than lower F#s.
    - Relative light gathering = $[\text{F\# }1/\text{F\# }2]^2$.
    - As the F# increases because of a change in the aperture, the radiation dose to the patient increases.
12. ***Pulsed fluoroscopy*** is a system used to reduce the radiation dose to the patient (see figure on next page).
    - Pulsed fluoroscopy reduces motion blur.
    - Because there are long periods of no radiation between pulses, the radiation dose to the patient is less.
    - Pulsed fluoroscopy at 30 pps is about 20% to 30% less than continuous fluoroscopy; 15 pps is about 40% to 60% less; and 7.5 pps is about 75% less.
13. Modern ***fluoroscopic television systems*** use ***charge-coupled device (CCD)*** cameras. Older television systems used tubes such as vidicons and plumbicons.
    - The image consists of ***raster lines***, and each line is composed of ***dots***.
    - Vertical spatial resolution = [number of raster lines $\times$ KF]/[2 $\times$ FoV(mm)] where KF = Kell factor ~ 0.7.



- ***Kell factor*** is the fraction of television lines actually used in image formation. For a 525-line system, only about 360 to 400 lines are actively used in imaging.
- ***To have equal vertical and horizontal resolution, the number of dots per line = number of active raster lines.***
- ***Horizontal spatial resolution*** is proportional to bandwidth (BW)/[(frames/sec) × (number of lines) × FoV (mm)].
- Most televisions display 30 full images each second.
- Interlaced television displays every other line and frame in 1/60 second. Then the alternate lines are scanned in the next 1/60 second.
- Progressive television display scans the raster lines sequentially.
- Bandpass (or bandwidth) = (30 frame/sec) × (number of raster lines) × (number of dots/line)
- For example, BW = 30 × 400 × 400 = 5,000,000/sec = 5 MHz

14. ***Image degradation*** in fluoroscopy "image intensifier + television systems" is related to the following:

- ***Pincushion distortion***: straight lines curved in large FoV
- ***Vignetting***: image brighter in center than at edge
- ***Retrograde light flow***: light from output phosphor illuminates photocathode
- ***Burn spots***: excessive radiation continually on one spot destroys phosphor
- ***Lag***: persistence of fluoroscopic image because of slow phosphorescent decay
- ***Unsharpness***: focal spot blur and lens/electrodes not focused
- ***Flare (glare)***: high brightness at edge of anatomy or in lung field

15. ***Spatial resolution*** is influenced by the following:

- Image intensifier resolution is better than television system resolution, which limits the system.
- Spatial resolution is better in smaller FoVs because of the limitations of television.
- Horizontal resolution is better for high bandwidth.
- The number of raster lines affects the vertical resolution. The number of dots per line affects the horizontal resolution.
- Typical spatial resolutions of the image intensifier + television system for fluoroscopy are shown in the table (for assumed equal numbers of dots and lines and FPD with 200-micron pixels).

	SPATIAL RESOLUTION (LP/mm) AT 45 DEGREES		
FoV (cm)[in]	525-LINE TV	1023-LINE TV	FLAT PANEL
(40) [15.7]	0.7	1.1–1.4	2.5
(28) [11.0]	1.0	1.5–2.0	2.5
(22.9) [9.0]	1.2	1.8–2.4	2.5
(20) [7.9]	1.4	2.1–2.8	2.5
(14) [5.5]	2.0	3.0–4.0	2.5
(11.4) [4.5]	2.5	3.8–5.0	2.5

- Because the size of a flat panel detector is fixed at around 200 microns, flat panel spatial resolution does not change much with FoV selection.

16. The entrance skin exposure rate (ESER) for the patient is influenced by the following:

- Smaller FoVs deliver a higher ESER.
- Larger F#s deliver a greater ESER.
- More raster lines use a greater ESER to reduce the quantum mottle.
- Lower pulsed fluoroscopy rates deliver less radiation, and higher pulse rates deliver more radiation.
- Higher brightness gains for the image intensifier deliver less radiation.
- ABC systems, which use more x-ray beam filtration and higher kVp values, deliver much lower ESE radiation levels in fluoroscopy.
- Newer image intensifiers have better conversion gain and deliver a smaller ESER.
- Lowering the image intensifier so that it is closer to the patient delivers less radiation.
- ***Last frame hold (freeze frame)*** can limit fluoroscopy time and reduce radiation dose.
- Limiting the fluoroscopy time reduces the radiation dose.
- Larger patients force the ABC system to deliver a large radiation dose.
- In the lateral projection, scattered radiation to the staff is greatest on the side closest to the x-ray tubes and less on the side closest to the image intensifier.

17. Special features of ***flat panel display fluoroscopy*** systems include the following:

- Spatial resolution does not change with FoV.
- There are no areas of saturation ("blooming") related to the larger dynamic range and window/level adjustments.
- Some image persistence (lag) is visible.
- No pincushion or spatial distortion exists.
- FoV does not provide "mag," but the image is interpolated and expanded to fill the display.
- Radiation dose does not have to increase with FoV, but it usually does increase to limit perception of image noise.

B. Questions

16-1. If a smaller FoV is selected for a fluoroscopy image intensifier system, the spatial resolution will ______ and the patient's radiation dose will ______.

(a) Increase, increase (b) Increase, decrease (c) Decrease, increase
(d) Decrease, decrease (e) Remain the same, increase

16-2. If a smaller FoV is selected for a fluoroscopy flat panel system, the spatial resolution will ______ and the patient's radiation dose will ______.

(a) Increase, increase (b) Increase, decrease (c) Decrease, increase
(d) Decrease, decrease (e) Remain the same, increase

16-3. Deficiencies of a fluoroscopy image intensifier include all of the following, *except* ________.

(a) Vignetting (b) Pincushion distortion (c) Lag
(d) Electronic defocusing (e) Specular reflection

16-4. All of the following factors affect the radiation dose to the patient during fluoroscopy, *except* ________.

(a) Aperture size (b) Light flux gain (c) Conversion gain
(d) Pulse rate (e) SSD

16-5. A fluoroscopic image intensifier increases brightness gain by ______ and ________.

(a) Aperture reduction, grids (b) Variable iris, retrograde light flow
(c) Magnification gain, decreased FoV (d) Minification gain, flux gain
(e) Fractals, filtration

16-6. The spatial resolution of a fluoroscopy television depends on all of the following, *except* ________.

(a) Number of raster lines (b) Bandpass (c) FoV (d) F#
(e) Number of video frames/sec

16-7. The ________ has the lowest spatial resolution of the items listed.

(a) Image intensifier (b) 525-line television system (c) Cassette spot film
(d) 100-mm fluoroscopic spot film camera (FSFC) (e) Objective lens

16-8. All of the following represent different types of television cameras used in fluoroscopy units, *except* ________.

(a) Orthicons (b) CCDs (c) Vidicons (d) Plumbicons
(e) Heptacons

16-9. The maximum ESER permitted by regulations for a standard one-level ABC fluoroscopy system is _______ per minute.

(a) 2.0 R (1.74 cGy) (b) 5 R (4.35 cGy) (c) 10 R (8.7 cGy)
(d) 20 R (17.4 cGy) (e) 30 R (26.1 cGy)

16-10. The maximum ESER permitted by regulations for a two-level system operated in the high-level mode of ABC fluoroscopy is _______ per minute.

(a) 2.0 R (1.74 cGy) (b) 5 R (4.35 cGy) (c) 10 R (8.7 cGy)
(d) 20 R (17.4 cGy) (e) 30 R (26.1 cGy)

16-11. The lowest radiation dose to the patient per single image of the abdomen for an average-sized patient is provided by __________.

(a) Fluoroscopy (b) DSA (c) Film-screen cassette
(d) CT scan (e) CR

16-12. Raising an image intensifier so that it is farther away from the patient during fluoroscopy results in ___________.

(a) Higher radiation doses (b) Less focal spot blur
(c) Less minification gain (d) Less magnification of the anatomy
(e) All of the above

16-13. Typical 525-line fluoroscopy television systems with equal horizontal and vertical spatial resolution have a bandpass (bandwidth) of about ________ MHz, and 1023-line systems have a bandpass of ________ MHz.

(a) 1, 4 (b) 4, 8 (c) 5, 20 (d) 10, 20 (e) 10, 40

16-14. For ABC fluoroscopy, as the patient's thickness increases, the radiation dose to the patient will ________ and the image contrast will ________.

(a) Increase, increase (b) Increase, decrease (c) Decrease, increase
(d) Decrease, decrease (e) Increase, remain the same

16-15. Pulsed fluoroscopy is important because it ________.

(a) Reduces radiation dose to the patient (b) Improves image contrast
(c) Improves spatial resolution (d) Uses lower mA
(e) Has wider dynamic range

16-16. A typical gastrointestinal fluoroscopic examination with barium delivers a total radiation dose of about ________ cGy at the skin entrance point.

(a) 1.5 (b) 5.0 (c) 10.0 (d) 25.0 (e) 50.0

16-17. If the aperture of a fluoroscopy system with an F# of 1.6 is replaced with one with an F# of 3.2, the radiation doses to the patient will ________.

(a) Decrease by 1/4 (b) Decrease by 1/2 (c) Increase by 2 times
(d) Increase by 4 times (e) Remain the same

16-18. The automatic brightness control of modern fluoroscopy systems regulates all of the following, *except* ________.

(a) kVp (b) mA (c) Filtration (d) FoV (e) Pulse width

16-19. Switching from continuous fluoroscopy to pulsed fluoroscopy at 15 frames per second affects the radiation dose to the patient as follows:________

(a) Increases it by 50% (b) Increases it by 25% (c) Has no effect
(d) Decreases it by 25% e) Decreases it by 50%

16-20. In comparison with a conventional fluoroscopy system, a digital (filmless) cardiac cine system has the following characteristic: ________.

(a) Higher power rating (b) Larger FoVs (c) Lower lag
(d) Greater dynamic range (e) Larger focal spot size

16-21. Decreasing the F# of an aperture of a fluoroscopy system results in ________.

(a) Better spatial resolution (b) More quantum mottle
(c) Less image aberration (d) Increased magnification
(e) Higher radiation doses to the patient

16-22. In digital subtraction angiography, the contrast-filled vessels are only 1% higher in contrast than the mask. If the mask subtracts 99% of the background from the images, the vessel contrast increases to ____%, and the quantum mottle increases by ______ times more.

(a) 10, 2 (b) 20, 4 (c) 30, 5 (d) 40, 6 (e) 50, 7

16-23. In comparison with image intensifier fluoroscopy, flat panel fluoroscopy systems have all of the following characteristics, *except* ______.

(a) Less spatial resolution (b) Less blooming
(c) Less pincushion distortion (d) No lag (e) Larger dynamic range

16-24. In comparison with an ABC system with fixed kVp and variable mA, when imaging a large patient with an ABC system with fixed mA and variable kVp, the image has _____ contrast, and the radiation dose to the patient is _____.

(a) Increased, increased (b) Increased, decreased
(c) Decreased, increased (d) Decreased, decreased
(e) The same, decreased

16-25. The bandpass of a fluoroscopic system affects ________.

(a) Vertical spatial resolution (b) Horizontal spatial resolution
(c) Both vertical and horizontal spatial resolution
(d) Neither horizontal nor vertical resolution (e) Artifacts

16-26. In comparison with a 40-cm FoV, a 20-cm FoV has a brightness gain that is________ that of the large FoV.

(a) One fourth (b) One half (c) The same as (d) 2 times (e) 4 times

16-15. Pulsed fluoroscopy is important because it ________.

(a) Reduces radiation dose to the patient (b) Improves image contrast
(c) Improves spatial resolution (d) Uses lower mA
(e) Has wider dynamic range

16-16. A typical gastrointestinal fluoroscopic examination with barium delivers a total radiation dose of about ________ cGy at the skin entrance point.

(a) 1.5 (b) 5.0 (c) 10.0 (d) 25.0 (e) 50.0

16-17. If the aperture of a fluoroscopy system with an F# of 1.6 is replaced with one with an F# of 3.2, the radiation doses to the patient will ________.

(a) Decrease by 1/4 (b) Decrease by 1/2 (c) Increase by 2 times
(d) Increase by 4 times (e) Remain the same

16-18. The automatic brightness control of modern fluoroscopy systems regulates all of the following, *except* ________.

(a) kVp (b) mA (c) Filtration (d) FoV (e) Pulse width

16-19. Switching from continuous fluoroscopy to pulsed fluoroscopy at 15 frames per second affects the radiation dose to the patient as follows:________

(a) Increases it by 50% (b) Increases it by 25% (c) Has no effect
(d) Decreases it by 25% e) Decreases it by 50%

16-20. In comparison with a conventional fluoroscopy system, a digital (filmless) cardiac cine system has the following characteristic: ________.

(a) Higher power rating (b) Larger FoVs (c) Lower lag
(d) Greater dynamic range (e) Larger focal spot size

16-21. Decreasing the F# of an aperture of a fluoroscopy system results in ________.

(a) Better spatial resolution (b) More quantum mottle
(c) Less image aberration (d) Increased magnification
(e) Higher radiation doses to the patient

16-22. In digital subtraction angiography, the contrast-filled vessels are only 1% higher in contrast than the mask. If the mask subtracts 99% of the background from the images, the vessel contrast increases to ____%, and the quantum mottle increases by ______ times more.

(a) 10, 2 (b) 20, 4 (c) 30, 5 (d) 40, 6 (e) 50, 7

16-23. In comparison with image intensifier fluoroscopy, flat panel fluoroscopy systems have all of the following characteristics, *except* ______.

(a) Less spatial resolution (b) Less blooming
(c) Less pincushion distortion (d) No lag (e) Larger dynamic range

16-24. In comparison with an ABC system with fixed kVp and variable mA, when imaging a large patient with an ABC system with fixed mA and variable kVp, the image has _____ contrast, and the radiation dose to the patient is _____.

(a) Increased, increased (b) Increased, decreased
(c) Decreased, increased (d) Decreased, decreased
(e) The same, decreased

16-25. The bandpass of a fluoroscopic system affects ________.

(a) Vertical spatial resolution (b) Horizontal spatial resolution
(c) Both vertical and horizontal spatial resolution
(d) Neither horizontal nor vertical resolution (e) Artifacts

16-26. In comparison with a 40-cm FoV, a 20-cm FoV has a brightness gain that is________ that of the large FoV.

(a) One fourth (b) One half (c) The same as (d) 2 times (e) 4 times

C. Answers

16-1. Answer = (a). Both vertical and horizontal resolution is dependent on [1/FoV (mm)]. Hence, smaller FoVs have better spatial resolution (except for flat panel systems). The minification gain is directly related to the ratio of [input diameter/output diameter]^2. As the FoV of the input diameter becomes smaller, the minification gain decreases, and the brightness gain decreases. As the ABC system senses the reduction in light exiting the image intensifier, the diminished light output is compensated for by more radiation, which brings the light levels back to normal.

16-2. Answer = (e). For flat panel fluoroscopy systems, the spatial resolution does not change with FoV. The spatial resolution is dependent on the pixel size, which is fixed. The radiation dose does not need to increase with flat panel systems; however, the radiation dose is increased to minimize the perception of quantum mottle as the image is expanded and interpolated in size.

16-3. Answer = (e). Specular reflection is an image problem in ultrasonography. Vignetting means that the image brightness fades from the center toward the edges. Pincushion distortion causes the bending of straight structures at the edges. Lag is persistence of the previous image because of slow phosphorescent decay with time. Electronic defocusing is setting the focus point for the electrodes at improper voltages, which results in image blur and loss of spatial resolution.

16-4. Answer = (b). Aperture size controls the image intensifier light to the ABC systems, which regulates the radiation. Light flux gain is a fictitious phrase. Flux gain is a real term, and it refers to the gain in light energy related to the voltage across the image intensifier. Conversion gain is a measure of the light output from the image intensifier for a certain amount of incident radiation; the radiation dose to the patient is related to efficiency of the image intensifier. The radiation dose to the patient is directly related to the selected fluoroscopy pulse rate. The SSD is the source-to-skin distance; the radiation dose increases when the patient is closer to the x-ray tube.

16-5. Answer = (d). The flux gain is the gain in kinetic energy of the electrons accelerated by the voltage across the image intensifier. The minification gain is the concentration of all the electrons released over a large input surface into a very small output phosphor of the image intensifier. Grids and variable iris are not a physical part of the image intensifier. Fractals are a mathematical tool for modeling the branching seen in physical structures, such as the lung.

16-6. Answer = (d). Both vertical and horizontal resolution is inversely proportional to the FoV. Vertical resolution is directly related to number of raster lines. Horizontal resolution is related to bandpass divided by video frame rate, number of lines, and FoV. See notes in this chapter.

16-7. Answer = (b). Any type of lens has a superb spatial resolution. The best resolution at the output phosphor of an image intensifier is about 5 to 6 LP/mm. The spatial resolution of a 525-line television depends on the FoV; the best resolution for a 4.5-inch (11.4-cm) FoV is about 2.2 to 2.5 LP/mm. Cassette spot films have the same resolution as regular film-screen combinations, about 4 to 8 LP/mm. A 100-mm fluoroscopic spot film camera has almost the same (slightly less) resolution as the image intensifier because it images the output phosphor through a lens and beam splitter.

16-8. Answer = (e). Orthicons were the first, very large television camera tubes; these tubes have not been used for years. CCDs are charge-coupled devices, which accumulate charges generated by light exposure in solid-state bins. Vidicons are tubes with antimony sulfate surfaces; these tubes have reduced sensitivity, reduced contrast, increased lag, and less image noise. Plumbicon tubes have lead oxide surfaces; these tubes have improved contrast, reduced lag, and increased image noise in comparison with vidicons. Heptacons is a fictitious word.

16-9. Answer = (c). See note in this chapter (**A10**).

16-10. Answer = (d). See note in this chapter (**A10**).

16-11. Answer = (a). The radiation exposure rate to patients undergoing fluoroscopy is about 3 to 6 cGy per minute, and the image rate is 30 images per second. Thus, radiation exposure to the patient per image is equal to (50 mGy/min)/(1800 images/min), or about 0.03 mGy/image. DSA delivers about 10 mGy/image. The radiation levels with a film-screen system are about half the value of the levels with CR. Therefore, film-screen radiation levels would be about 4.0 mGy/image, and CR would deliver about 8.0 mGy per image. CT scans of the body deliver an entrance exposure of about 20 to 40 mGy per image.

16-12. Answer = (a). As the image intensifier moves farther away from the x-ray tube, the radiation output must be increased to maintain a constant level of radiation at the input surface. The focal spot blur increases because the magnification increases. The minification gain does not change with a distance (source-to-image) change.

16-13. Answer = (c). For equal resolution, the number of raster lines must equal the number of dots per line. To double the number of lines from 525 to 1023, the number of dots must also be increased. The amount of data increases by $2 \times 2 = 4$ times. See note in this chapter (**A13**).

16-14. Answer = (b). In imaging thick patients, the transmitted radiation is decreased, and the number of scattered x-rays is increased. The ABC system boosts the amount of radiation by increasing kVp, mA, and pulse width to compensate for attenuation of the x-rays. The increased kVp and scattered x-rays reduce the image contrast.

16-15. Answer = (a). Pulsed fluoroscopy does not affect contrast, spatial resolution, or dynamic range at all. The mA values are higher in pulsed fluoroscopy, but the radiation pulse is "on" only 3 to 10 msec every 33 msec (for 30 pps) or 66 msec (15 pps). The fact that the radiation is turned off for appreciable periods reduces the radiation dose to the patient.

16-16. Answer = (d). For gastrointestinal examinations, the typical fluoroscopy time is about 5 minutes, and there are about 10 to 12 spot films. Assume that the typical entrance dose for fluoroscopy is about 4 cGy per minute and that 4 or 5 spot films equal 1 minute of fluoroscopy. Total fluoroscopy time would be 5 minutes plus 2 minutes for spot films, or 7 minutes. (4 cGy/min) $\times$ 7 minutes = 28 cGy entrance dose.

16-17. Answer = (d). As the F# increases, the radiation dose to the patient increases because less light is gathered. A larger aperture number means a smaller hole in the metal plate. The radiation dose increases as the square of the aperture ratio: $[3.2/1.6]^2 = 4.0$.

16-18. Answer = (d). The ABC controls everything except the FoV, which is selectable. The ABC works with all FoVs selected.

16-19. Answer = (e). As the pulse rate of fluoroscopy decreases, the radiation dose to the patient decreases directly with the relative pulse rate. A 50% decrease in pulse rate from 30 to 15 pps would be expected to reduce the radiation dose by about 50%.

16-20. Answer = (d). Higher power x-ray generators and x-ray tubes are not necessarily placed on digital systems. FoVs of digital cardiac systems are generally smaller than or equal to those of image intensifier systems. Flat panel systems can have noticeable lag. The focal spot sizes of the x-ray tubes of digital systems are the same as those of conventional image intensifier systems.

16-21. Answer = (b). A smaller F# aperture collects more light and allows the edges of the lens to be used. The edges of the lens have the most aberration; hence, aberration increases. The effects of using a larger F# on spatial resolution or magnification are minor. Magnification is controlled by FoV or moving the patient away from the image intensifier. Because the larger aperture (smaller F#) gathers more light, the radiation doses to the patient decrease, and fewer x-rays are used to create the images. When fewer x-rays are used to form the images, the quantum mottle increases.

16-22. Answer = (e). After subtracting 99% of the background, 1% of the background and 1% of the contrast remain. The ratio of contrast to total radiation is 50%. The relative noise percentage is equal to 100%/$[\text{number of x-rays}]^{0.5}$. The total number of x-rays used in image formation is 2%, or a factor of 50 times fewer x-rays. Noise increases by the square root of 50, or about 7 times more quantum mottle.

16-23. Answer = (d). Because of the fixed pixel size and the arrangement of pixels in a matrix, the spatial resolution does not change with FoV, and there is little or no distortion. The larger dynamic range (12 bits) prevents saturation of the detectors and blooming. However, FPD detectors do contain a CsI scintillator, which has some afterglow that causes lag; the readout/nulling of the pixels and frame averaging to reduce image noise also contribute to the lag.

16-24. Answer = (d). If only the mA is adjusted, the kVp is fixed. Subject contrast is affected by kVp and filtration of the x-ray beam. Therefore, with fixed kVp, contrast remains similar. With variable kVp, the kVp increases with larger patient size, and the contrast degrades. However, because higher kVp x-rays are more penetrating, fewer x-rays can be used, which lowers the radiation dose to the patient.

16-25. Answer = (b). See note in this chapter (**A15**).

16-26. Answer = (a). A smaller FoV is associated with less minification gain. The gain is proportional to the ratio of the diameters squared, or $[20/40]^2 = 1/4$. The flux gain does not change; thus, the overall effect is to have only 25% of the original brightness gain.