Fluoroscopy and Interventional Imaging
Bushberg – Chapter 9
RSNA & AAPM Physics Curriculum: Module 13

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a copy of this lecture may be found at:
http://courses.washington.edu/radxphys/PhysicsCourse.html

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Sources of information on Fluoroscopy

- Bushberg Chatper 9
- AAPM/RSNA web module 13
- AAPM/RSNA Physics Tutorials
  - Fluoroscopy: Patient Radiation Exposure Issues
    July-Aug 2001, Vol 21, Issue 4
  - Digital Fluoroscopy
    March-April 2001, Vol 21, Issue 2
  - Fluoroscopy: Recording of Fluoroscopic Images and Automatic Exposure Control
    Jan-Feb 2001, Vol 21, Issue 1
  - Fluoroscopy: Optical Coupling and Video System
    Nov-Dec 2000, Vol 20, Issue 6
  - X-ray Image Intensifiers for Fluoroscopy
    Sept-Oct 2000, Vol 20, Issue 5
  - General Overview of Fluoroscopic Imaging
    July-Aug 2000, Vol 20, Issue 4

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Physics Curriculum: Module 13: Fluoroscopy & Interventional Imaging Fundamental Knowledge

- Describe and identify the basic components of a fluoroscopic system.
- Explain how the geometric features contribute to the resulting image.
- Explain the features and functions of image intensifier (II) systems.
- Explain the features and functions of flat panel detector systems.
- Describe the different operating modes used in fluoroscopy imaging.
- Identify the components that determine image quality in a fluoroscopy system and the causes of image degradation.
- Discuss basic image processing methods used in fluoroscopy and describe how they are used clinically.
- Review the various application requirements for fluoroscopy and interventional radiology systems.
- Name the factors that affect patient dose during a fluoro and IR procedures.
- Describe concepts of exposure and how patient radiation dose is estimated in fluoroscopy and interventional procedures.
- Describe the artifacts that can occur with II and flat-panel fluoro systems.

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Physics Curriculum: Module 13: Fluoroscopy & Interventional Imaging Clinical Application

- Differentiate among the various image acquisition parameters used in specific clinical applications of fluoroscopy and interventional radiology.
- Describe where the operator should stand to minimize personnel dose when performing an IR procedure with a C-arm positioned horizontally.
- Discuss radiation safety considerations and methods to modify a procedure to minimize the dose for operators of short stature.
- Describe the geometric and clinical equipment settings which can be implemented to minimize patient peak skin dose in fluoro and IR.

Physics Curriculum: Module 13: Fluoroscopy & Interventional Imaging Clinical Application

- Identify the technique factors and appropriate system features to use to optimize image quality while minimizing patient dose.
- Describe the geometric factors that affect operator dose during an IR procedure.
- What steps can be taken to minimize the dose to the fetus of a pregnant patient who needs a fluoro or IR procedure?

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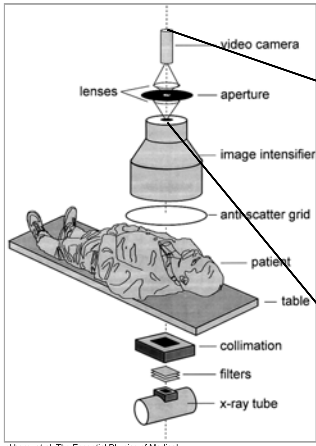
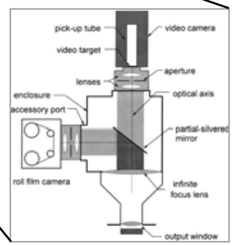
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)



- Image intensifier system components:
  - II – vacuum bottle (housing); input screen (x-ray to e-); electronic lenses; output phosphor (e-s to visible light)
  - Lenses and aperature
  - Optical coupling w/ accessory port
  - Viewing electronic output image – video or more commonly charged-coupled device (CCD) detectors



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 232, 239.

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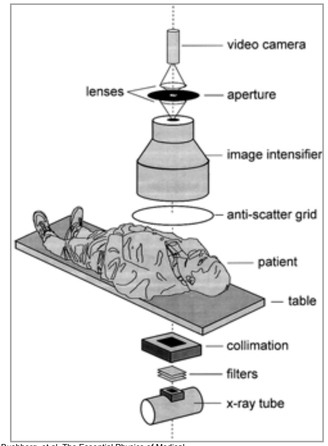
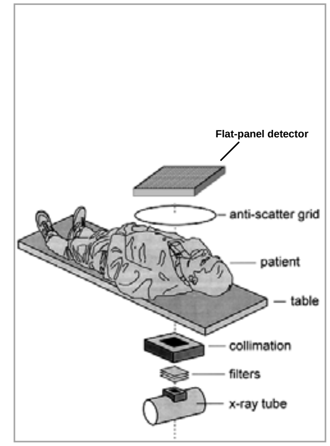
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)





c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 232.

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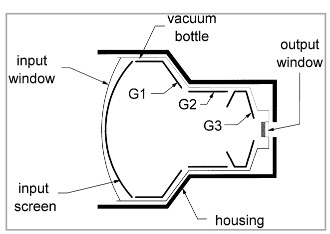
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

II Systems

- ***<u>Image Intensifier</u>***
  - <u>In vacuum</u> – electrons (e-s) are influence by environment
  - <u>Input screen</u> – converts x-rays to e-s
    - 1 mm aluminum window (part of vacuum bottle)
    - Support layer – supports input phosphor and photocathode; thin enough to allow most x-rays to pass through
    - Input phosphor – Cesium Iodine (CsI) crystal that converts x-rays to light; long, needle-like crystals that "channel" light with minimal lateral spreading
    - Photocathode – layer of antimony and alkali metal that emits electrons when struck by light; 10-20% conversion efficiency



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 233.

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Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

Input Phosphor Energy Conversion

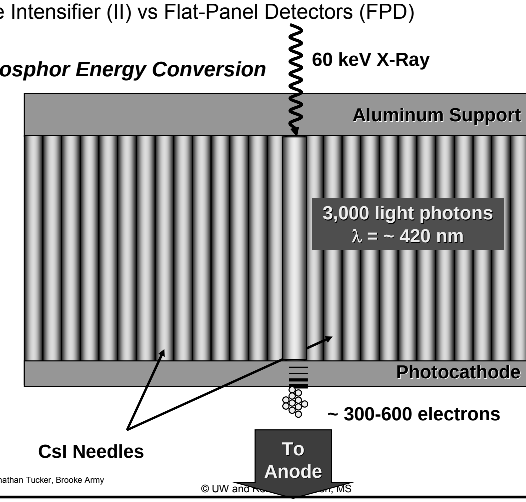

Figure courtesy from Jonathan Tucker, Brooke Army Medical Center, SA, TX

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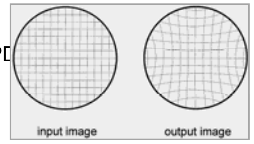
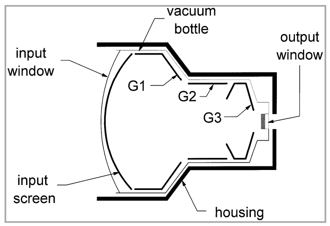
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)



II Systems
- ***Image Intensifier***
  - *In vacuum* – electrons (e^-s) are influence by environment
  - *Input screen* – converts x-rays to e^-s
  - *Electronic lenses*
    - 5 components drive the e^-s through the II: the input screen, the II anode near the output window, and 3 sets of electrodes which shape the electric field
    - 25 kV – 35 kV electric field between input and output; e^-s accelerate through vacuum toward and arrive at the anode w/high velocity and kinetic energy to interact with the output phosphor (*electronic gain*)
    - Focusing achieved by electronic lens require input screen to be curved – results in pincushion distortion



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 233-35.

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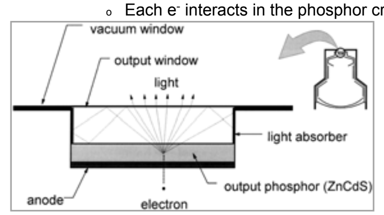
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

II Systems
- ***Image Intensifier***
  - *In vacuum* – electrons (e^-s) are influence by environment
  - *Input screen* – converts x-rays to e^-s
  - *Electronic lenses*
  - *Output phosphor* – converts e^-s to visible light
    - Zinc cadmium sulfide (ZnCdS)
    - Anode – thin coating of aluminum on the vacuum side of output phosphor
    - Each e^- interacts in the phosphor creating ~1000 light photons



- Some fraction of the output light emitted by ZnCdS phosphor is reflected at the glass window; known as veiling glare, which reduces image contrast

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c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 235.

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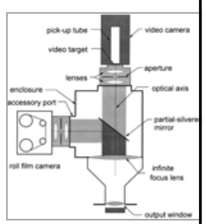
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)



II Systems
- **Image Intensifier**
- **Lens and aperature – focus light onto focal plane of the camera lens**
- **Optical coupling & distribution mechanisms**
  - Photo spot cameras – image archive; made directly from output phosphor (full resolution of II, not affected by video system)
  - Digital photo-spot – image archive w/ CCD cameras w/ 1024^2 or 2048^2 pixel formats
  - Spot-film devices
  - [Digital] cine-radiography cameras – records rapid sequence of images (30 frames per sec (fps) to 120 fps or higher)

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 239.

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Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

II Systems
- **Image Intensifier**
- **Lens and aperature**
- **Optical coupling & distribution mechanisms**
- **Video camera – provides display by relaying output image to a TV monitor**
  - *Video lag* – residual image info for previous frames
    - Pro: smoothes quantum noise
    - Con: motion artifact and blurring
  - *Video resolution*
    - Vertical – governed by # of scan lines in a TV; US has 470 usable lines, but by Kell factor only 70% appreciated visually (343 lines or 173 lp)
      - Example: for a 9" (228.6 mm) the resolution = 172 lp / 228.6 mm = 0.75 lp per mm
    - Horizontal – how fast the video electronics (camera, cable, and monitor) respond to changes in light intensity

c.f. Van Lysel. - AAPM/RSNA Physics Tutorial for Residents: Fluoroscopy: Optical Coupling and the Video System, Radiographics 2000; 20:1769-1786.

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Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

II Systems – Characteristics of Performance

- *Conversion factor*
  - Output to input ratio: Cd-sec per mR-m^2; typically 100-200 Cd-sec/mR-m^2
  - Measure of the electronic gain: input of II is exposure (mR/sec) and output is luminance (candela per meter^2 = cd/m^2)
  - Degrades over time → replace II
- *Brightness gain (BG)*
  - Product of electronic and minification gains
    - Electronic gain (acceleration of electrons from input to output phosphors) is typically 50
    - Minification gain is the ratio input phosphor area to the output phosphor area; changing the diameter of the output phosphor area affect the resolution
      - Ex: for a 9" II and 1" output phosphor (typical size), the minification gain is 81
      - Ex; for 7" II and 1" output phosphor, the minification gain is 49
    - If the effective diameter of the input phosphor is decreased (i.e. using mag modes), THE BRIGHTNESS GAIN DECREASES

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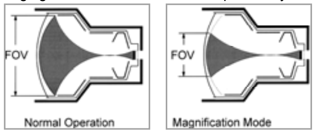
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

II Systems – Characteristics of Performance

- *Conversion factor*
- *Brightness gain*
- *Field of view (FOV) & magnification modes*
  - FOV is the size of the input phosphor, therefore affect the brightness gain
    - Large IIs (up to 16") used in GI or GU – viewing the entire abdomen
  - Magnification is achieved by collimating the x-ray field and changing the voltage of the electrodes in the II to adjust the electron focusing
    - Because input phosphor size affects BG, the automatic brightness control (ABC) boost the output exposure rate to compensate
      - Ex: 12" II with mag modes of 9" and 7" – changing from 12" to 9" increases the exposure rate by $(12/9)^2$ = 1.8; changing from 12" to 7" increases exposure by 2.9.
- *Contrast ratio*
  - Indirect measure of veiling glare



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 237.

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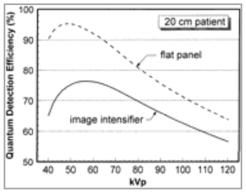
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)



II Systems – Characteristics of Performance

- *Conversion factor*
- *Brightness gain*
- *Field of view (FOV) & magnification modes*
- *Contrast ratio*
- *Quantum detection efficiency (QDE)*
  - *Recall – ratio of the number of detected photons to the number of incident photons (not DQE which is a measure of both system signal and noise)*
  - X-rays pass through vacuum window and input screen substrate (support) before interacting in the CsI to produce electrons
  - *Note: flat-panel detectors have higher QDE because it's a thin film transistor technology w/ only a carbon-fiber face plate for protection*
- *S-distortion*

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 238.

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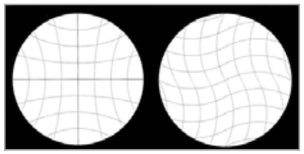
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

II Systems – Characteristics of Performance

- *Conversion factor*
- *Brightness gain*
- *Field of view (FOV) & magnification modes*
- *Contrast ratio*
- *Quantum detection efficiency (QDE)*
- *S-distortion*
  - Due to external magnetic fields
  - Spatial warping of image in an S-shape through the image



c.f. AAPM/RSNA Physics Tutorial for Residents: X-ray Image Intensifiers for Fluoroscopy. Radiographics. 20. September 2000.

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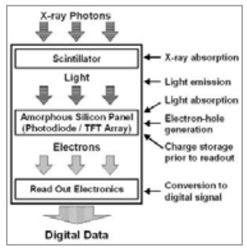
Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

Flat-Panel Detector (FPD) Systems

- Solid-state devices
- *Thin, carbon fiber* – protects CsI phosphor and photodiode array
- INDIRECT digital detector
  - *Input phosphor* – CsI converts x-rays to light photons
    - X-rays interact in CsI and create ionizations; some deposited energy is emitted as light
  - *Photodiode array*
    - An array of detector elements – each element is 200 microns (0.2 mm)
    - Absorbs light and converts energy into free electron charge that is stored in each cell of the array
    - Charge stored is proportional to the incident light, which is proportional to the # incident (absorbed) x-rays



c.f. Granfors & Albagli. *Scintillator-based flat-panel x-ray imaging detectors.* Journal of the Society for Information Display. June 2009.

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Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

Flat-Panel Detector (FPD) Systems – Characteristics of Performance

- *Resolution*
  - Since there is no geometric minification (recall: for II systems, input phosphor diameter to output phosphor diameter), resolution does not change with FOV
  - Radiation dose
    - Although it isn't necessary, FPD systems can increase radiation output for smaller FOVs to reduce noise (similar to II systems)
    - Binning – for systems where 4 DELs are combined, the FPD system can reduce the dose by 50%
- *FPD replaces everything!* – no II, video camera, or peripheral devices

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Fluoroscopy System Components
Image Intensifier (II) vs Flat-Panel Detectors (FPD)

Flat-Panel Detector (FPD) Systems – Characteristics of Performance

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Fluoroscopy
Modes of Operation

- *Continuous*
  - Typically 0.5-4 mA or higher
  - A video camera displays at 30 frames per second (fps) with 33 milliseconds (msec) per frame acquisition time
  - Blurring present due to patient motion
  - Maximum dose rate = 10 R per min (CFR)
- *High dose rate*
  - *Specially activiated fluoroscopy ("enable" buttons or separate pedal)*
  - Maximum dose rate = 20 R per min (CFR)
  - Audible signal required (CFR)
  - Can be used for obese patients
- *Pulsed fluoroscopy*
  - 30 fps at ~10 msec per frame acquisition time
  - Exposure time is shorter, therefore less blur due to motion
  - 30 fps, 15 fps, 7.5 fps, etc
  - Instrumental in reducing patient dose

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Fluoroscopy
Modes of Operation

- *Continuous vs. pulsed*
  - Continuous – 30 fps w/ 33 msec per frame @ 2 mA (0.66 mAs per frame)
  - Pulsed – 30 fps w/ 10 msec per frame @ 6.6 mA (0.066 mAs per frame)
    - Same exposure to patient, but less motion artifact
- If temporal resolution is not needed (e.g. guiding a catheter from the femoral artery to aortic arch), use pulsed fluoro to reduce patient (and personnel!) dose

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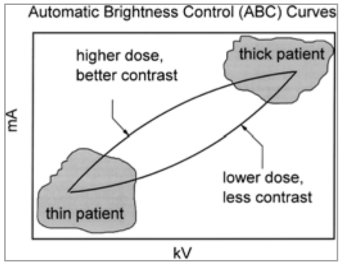
Fluoroscopy
Automatic Brightness Control (ABC)

- Goal is to keep the # photons constant → maintains SNR regardless of patient thickness (or attenuation)
- Feedback from light output of II to generator to regulate technique
  - Change kV or mA or both
  - For pulsed system, may regulate pulse width (on-time per frame) or pulse height (mA)
  - For large patients, if 10 R/min limit is reached, ABC circuitry may open the aperature to increase image brightness or electronic gain in video camera may be adjusted → both increase image noise



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 247.
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Fluoroscopy
Factors affecting Image Quality

- *Spatial resolution*
  - System detector limitations – FOV, matrix, DELs, video capabilities, binning
    - e.g.: FPD detector element sizes
      - GI studies @ 2.5-3 lp per mm
      - Using mag, the resolution improves to @ 3.5-6 lp per mm
      - Television systems limit resolution to about 1-2 lp per mm for GI systems and 2-4 lp per mm for angio systems
  - Focal spot size and geometry – keep patient adjacent to detector!! This reduces focal spot blur
  - Motion, temporal factors affecting image blur
  - In general, pulsed fluoro reduces motion blur → should improve resolution

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Fluoroscopy
Factors affecting Image Quality

- *Contrast*
  - Scattered x-rays (grid), veiling glare
  - kVp and filtration – if the average (effective) energy of the x-rays is increased, then contrast decreases
  - Collimation – decreases scatter contribution
  - Radiation dose and noise – increasing the mA, decreases the noise and therefore improved contrast
  - Image processing – smoothing algorithms and frame averaging reduces image noise, which improves contrast; edge enhancement algorithms increase image noise, therefore contrast degrades
  - Contrast media (iodine, barium, or air) enhances contrast of anatomical structures

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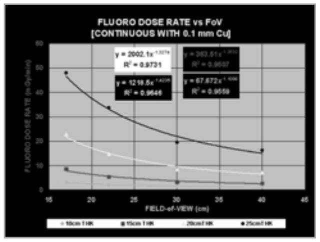
Fluoroscopy
Factors affecting Image Quality

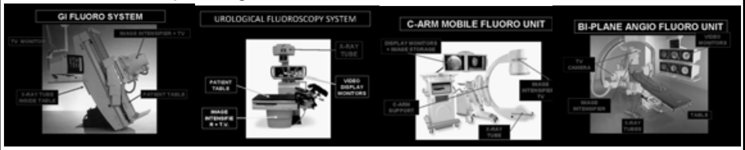


- *Patient radiation dose*
  - Geometry
    - Decreased SID → ↓ dose
    - Image receptor close to patient
  - FOV selection – generally, smaller (mag) FOVs increase the dose (however, FPDs may not increase x-ray output)
  - ABC systems – see slide 22
  - X-ray beam kVp and filtration
  - Aperture – smaller aperture blocks more light from output phosphor, and decreases dose rate (the aperture is used to balance an acceptable amount of noise w/ an acceptable level of patient dose rate)
  - Pulse fluoro
  - Conversion gain – as an II ages, the amount of light produced in the input phosphor decreases and the conversion gain decreases… this results in GREATER RADIATION DOSE because the II is less efficient

c.f. AAPM/RSNA Web Module 13. Section IX.B. © UW and Renée Dickinson, MS 25

Fluoroscopy
Suite designs

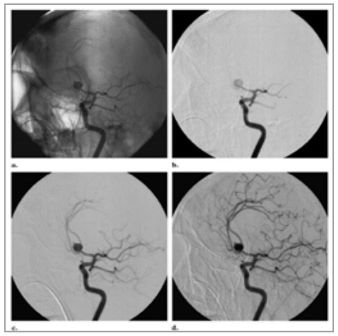
- GI suites – table rotates patient from head-up/head-down positions; large II or FPD
  - Verses angiography suites where table "floats" instead of rotating
- Remote fluoro suites – reduction of dose to personnel; generally with tube above the table, but not always (e.g. TiltC)
- Cardiac Cath Labs – generally smaller II or FPD, allowing for more cranial-caudal tilt
- Biplane suites
- C-arms – operating rooms or intensive care units



c.f. AAPM/RSNA Web Module 13. Section II. © UW and Renée Dickinson, MS 26

Fluoroscopy
Imaging Techniques

- *Digital Subtraction Angiography (DSA)* – real-time subtraction of pre- and post-contrast injection images to improve the perception of low-contrast vessels
  - Removal of background anatomy and tissue
  - Increased image noise
  - Clinically used for diagnostic and therapeutic applications of vessel visualization throughout the entire body

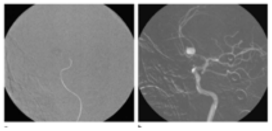


DSA cerebral arteriogram. a. Unsubtracted digital fluoro. b-d. Subtracted DSA images obtained at 3 progressive time points during contrast injection.

c.f. AAPM/RSNA Physics Tutorial for Residents: Digital Fluoroscopy. Radiographics. Vol 21. March 2001. © UW and Renée Dickinson, MS 27

Fluoroscopy
Imaging Techniques

- *Road mapping*
  - A DSA sequence is performed and the frame w/ maximum vessel opacification is identified
  - The road map mask is subtracted from subsequent live fluoro images to produce real-time subtracted fluoro images
    - e.g.: a wire is "steered" by using the road map for cues on maneuvering through vasculature

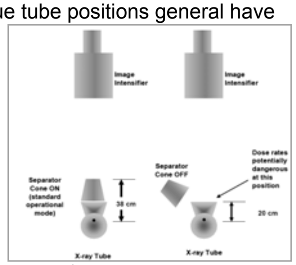


- *3D rotational angiography*
- *Philips Xper CT*

c.f. AAPM/RSNA Physics Tutorial for Residents: Digital Fluoroscopy. Radiographics. Vol 21. March 2001. © UW and Renée Dickinson, MS 28

Fluoroscopy – the Ten Commandments

- *As patient size increases* – image quality decreases, patient dose increases, personnel dose increases
- *Use appropriate dose and dose-rate settings* – pulsed vs continuous, standard FOV vs mag modes
- *Exposure time* – total fluoro time, but also distributing dose over the skin (can you rotate/move tube to a different position??)
- *X-ray tube position* – raise/lower patient away from x-ray tube to decrease ESD; lateral and oblique tube positions general have higher ESDs



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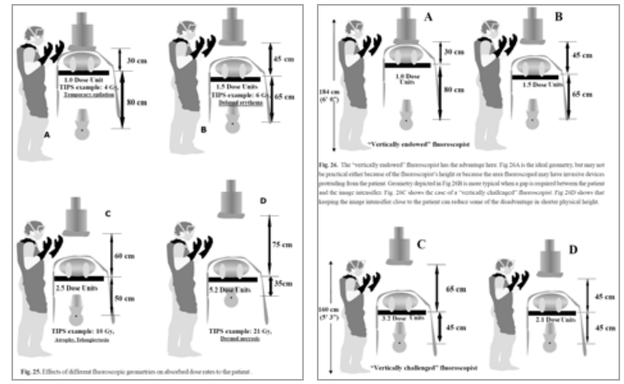
Fluoroscopy – the Ten Commandments

- *Proximity of II or FPD to Patient* – improves image quality and decreases radiation dose



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Fluoroscopy – the Ten Commandments

- *Magnification*
  - Electronic mag – generally higher doses when using mag modes
  - Geometric mag – increase distance between patient and II; typically increases dose by the square of the magnification
- *Grid* – remove grid for thin patients or if the image contrast is not affected by the scatter
- *Collimation!!*
- *Personnel Safety* – use distance and shielding whenever possible; always wear lead aprons

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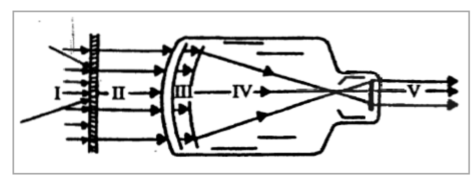
Review Questions

For the image intensifier shown, match the following: (answers may be used more than once)

A. Light photons.
B. X-ray photons.
C. Microwaves.
D. Electrons.
E. Infrared photons.



- I represents B.
- II represents B.
- III represents A.
- IV represents D.
- V represents A.

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Review Questions

The maximum resolution of fluoroscopy images displayed on television in the 6" field of view with a 1024 line system with a Kell factor of 0.7 is about ______ lp/mm.

A. 0.7
B. 1.2
C. 1.8
D. 2.4
E. 2.9

1024 x 0.7 = 717 lines or 358 line pairs useful for resolution
For 6” field, resolution = (358 lp) / (6in * 25.4 mm) = 2.35 lp/mm

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Review Questions

A 9-in. multi-mode image intensifier (II) is switched to the 6-in. mode. As a result, the image will be ________ , and the automatic brightness control system (ABC) will _________ the exposure to the II and the patient.

A. magnified, decrease
B. magnified, increase
C. minified, increase
D. magnified, not change
E. minified, decrease

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Review Questions

Pulsed fluoroscopy at 15 fps is utilized primarily to ___________.

A. Reduce motion blur.
B. Increase kW rating.
C. Increase kVp stabilization.
D. Reduce focal spot sizes.
E. Reduce patient dose.

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Review Questions

For fluoroscopy performed in the 6-in. II mode and displayed on a 525 line TV monitor, spatial resolution is most limited by the _______.

A. Scatter from the patient
B. Grid
C. II tube
D. Optical system
E. TV system

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Review Questions

The fluoroscopic operating factors displayed on a monitor are 120 kVp and 10 mA. Which of the following is true?

A. The skin entrance dose is unusually low.
B. The five-minute timer is broken.
C. The skin entrance dose is extremely high.
D. The display must be wrong.
E. The anti-scatter grid is not in the beam.

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