MRAD 254: Fluoroscopic Imaging

Outcome 1: Fluoroscopic Equipment, Conventional and Digital

MRT Program

Objectives

1.1) Differentiate fluoroscopic examinations from regular static examinations

1.2) Explain the operation of image intensifiers

1.3) Describe image acquisition storage and display parameters

1.4) Summarize how primary factors affect image quality

1.5) Compare fluoroscopic unit configurations and design

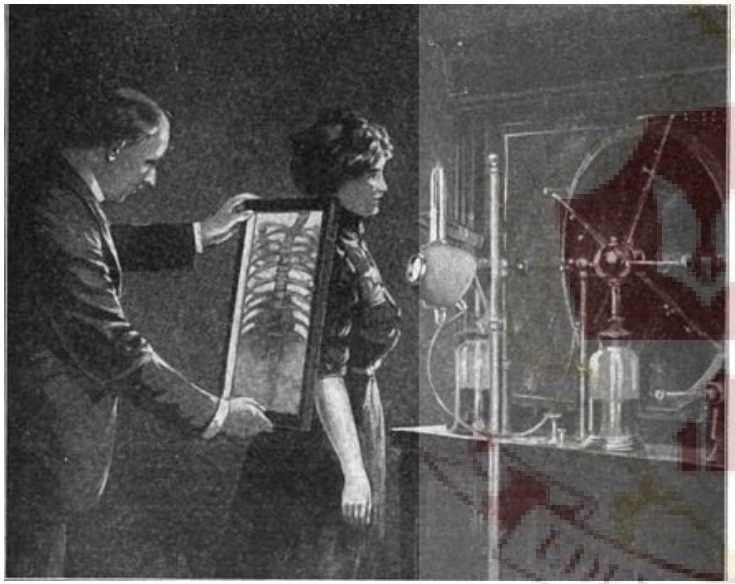
Fluoroscopy

- What is fluoroscopy?
  - When dynamic/moving images are displayed in real time
  - Like a video vs a still picture

- What is the purpose of fluoroscopy?
  - To actively study the motion of organs and the movement of contrast media within anatomic structures in real time.
  - Functional exam

History of Fluoroscopy

- 1896- Fluoroscope was invented
  - "Direct" viewing
- 1948- Image Intensifier (I.I.) is developed
  - aka. "Conventional" fluoroscopy
  - "Direct & Indirect" viewing capabilities
  - Not routinely seen in DI until 1960's
- 1970- Computer components are added
  - "Digital" Fluoroscopy is born
  - CCD chip replaces video equipment
- 2000's-present day: Dynamic flat panel image receptors (FPIR) are introduced
  - Provides many advantages over traditional image intensifiers





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Fluoroscopic Equipment

- Tube & Generator
- Image Receptors can consist of either:
  - Image Intensifier tube
  - Flat Panel IR (FPIR)
- Coupling devices – Lens/Fiber optics
- Charge-coupled Device
- ADC (analog to digital converter)
- Array computer
- Multiple viewing monitors (flat screen)
- Operating console (enables post-processing)

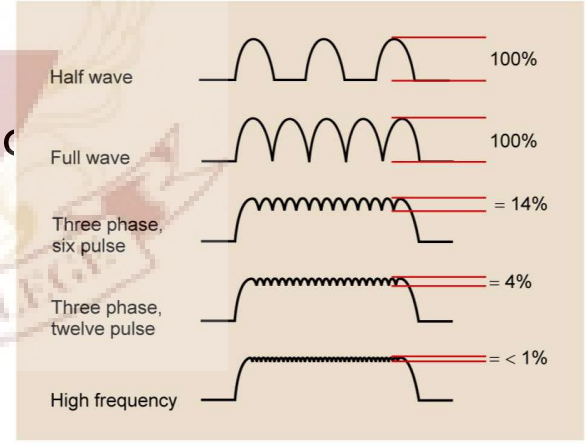
Tube and Generator - Conventional

- "Conventional fluoroscopy" was used in the early generations of fluoroscopy
  - 1896 – 1970's

- Uses a much lower mA than general radiography
  - 0.5 - 5mA (GR = 50 - 300)
  - Reduced because of the much longer exposure times
  - Do not need as powerful a "burst" of X-rays to get a diagnostic image
  - Dose is much higher than general radiography due to high exposure times
  - Need a higher heat capacity (at least 500,000HU vs. general radiography which is approx. 300,000HU)

Tube and Generator - Digital

- "Digital Fluoroscopy" has been used since the 1970's
  - Similar to conventional fluoro except image is digitized to allow remote control of the system and post processing.
- Increased viewing capabilities and manipulation requires more information in the image
- Fluoroscopy tube operates in "radiographic radiographic mA (50 – 300mA)
  - Draws an enormous amount of power
- Must have a high frequency generator



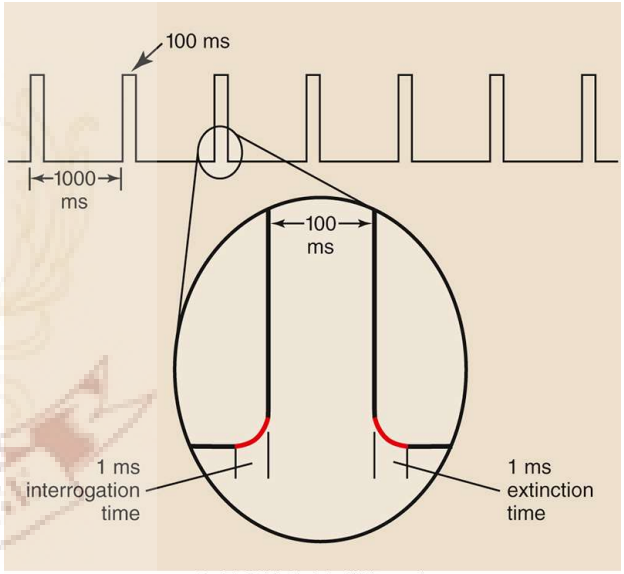
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Digital Fluoroscopy

- High mA + long exposure times = Massive dose and heat production
- Pulsed Progressive Fluoroscopy avoids this
- Generator automatically turns the beam off and on multiple times each second
  - Happens too quickly to be discerned by the human eye
- Programmed into the generator
  - Not controlled by the user

Pulsed Progressive Fluoroscopy

- Interrogation time:
  - The time required for the X-ray tube to be switched on and reach the selected kVp and mA
- Extinction time:
  - The time required for the X-ray tube to be switched off
- Interrogation and Extinction times are less than 1ms each
- Duty Cycle:
  - The period of time when the X-ray tube is energized



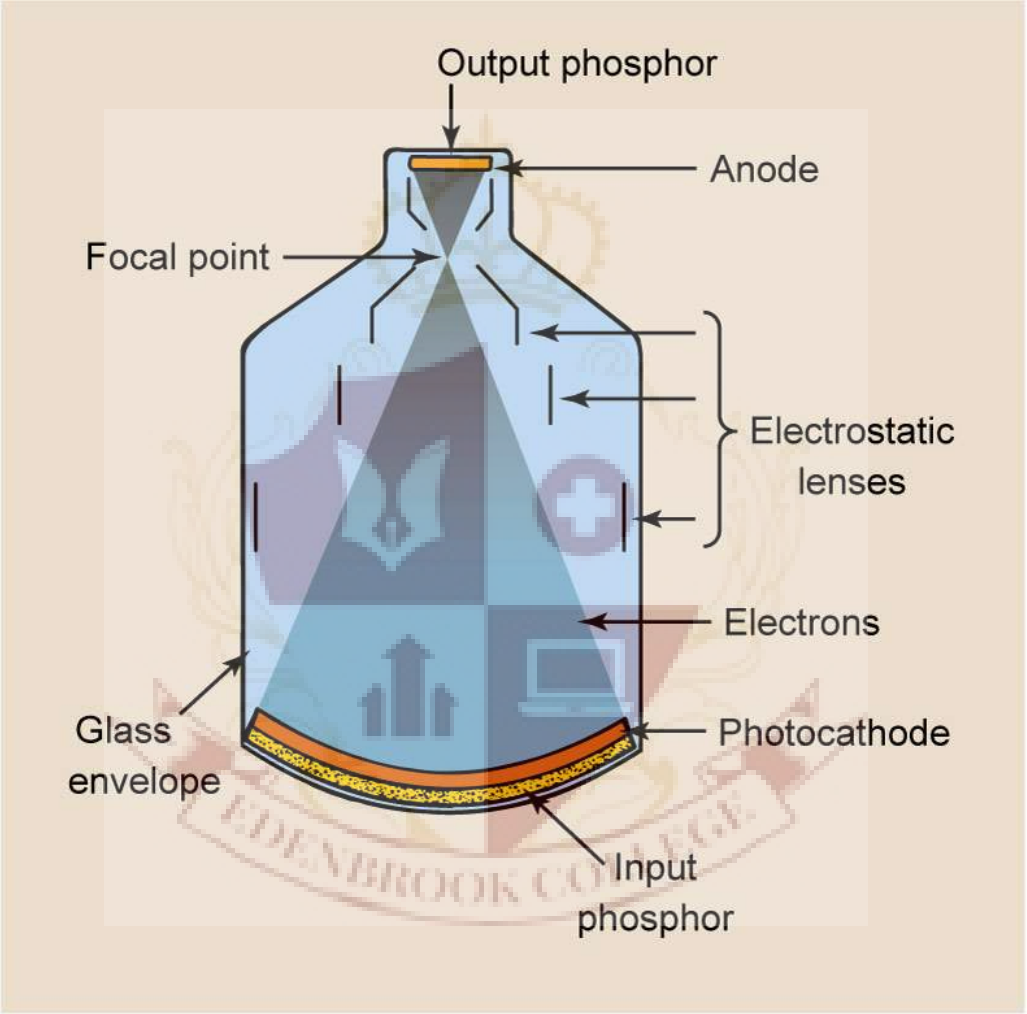
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Image Intensifier (I.I.) Tube

- Purpose
  - Electronically brighten the fluoroscopic image – enable "daylight" viewing
- How does it do that?
  - It receives the image-forming x-ray beam and converts it into a visible light image of high intensity
  - Resultant image is a minified version (at output phosphor)
- Size of the tube is approximately 6-16inches (15-40cm) in diameter and 50cm in length

What makes up an image intensifier?

- Primary components of the Tube type I.I.
  - Glass or metal envelope
  - Input phosphor
  - Photocathode
  - Electrostatic focusing lenses
  - Anode
  - Output phosphor



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Envelope

- Glass or metal housing that contains all components of the image intensifier
- Vacuum sealed to allow free flow of electrons from photocathode to the anode
- Upon installation, the tube is mounted into a metal housing to protect it from rough handling and breakage

Input Phosphor

- Has a glass or thin aluminum base
- Coated with Cesium Iodide (CsI)
  - CsI crystals are grown as tiny needles, and are tightly packed
  - Tiny "light pipes" funnel the light in the correct direction
  - Improves spatial resolution
- Upon entry into the tube, the x-rays strike the input phosphor, which absorbs them and converts their energy into visible light
- The input phosphor is bonded directly to the photocathode with a transparent adhesive layer

Photocathode

- Constructed out of antimony and cesium compounds
- Light photons from the input phosphor immediately strike the photocathode
- Light photons release electrons from the photocathode though the process of photoemission
- Many light photons are needed to emit one electron
- The number of electrons emitted by the photocathode is directly proportional to the intensity of light that reaches it

Electrostatic Focusing Lenses

- Located along the length of the I.I.
  - Inside the envelope
- Negatively charged metal plates
  - Repels electrons
  - The charge on the lenses accelerates & focuses the electron stream toward the output phosphor
- Maintaining proper electron travel is called electron optics, utilising the electrostatic focusing lenses

Anode

- Positively charged circular plate with a hole in the middle that electrons pass through to the output phosphor

- Attracts electrons emitted from the photocathode
  - Potential difference between the anode & photocathode (approx. 25-35kV)

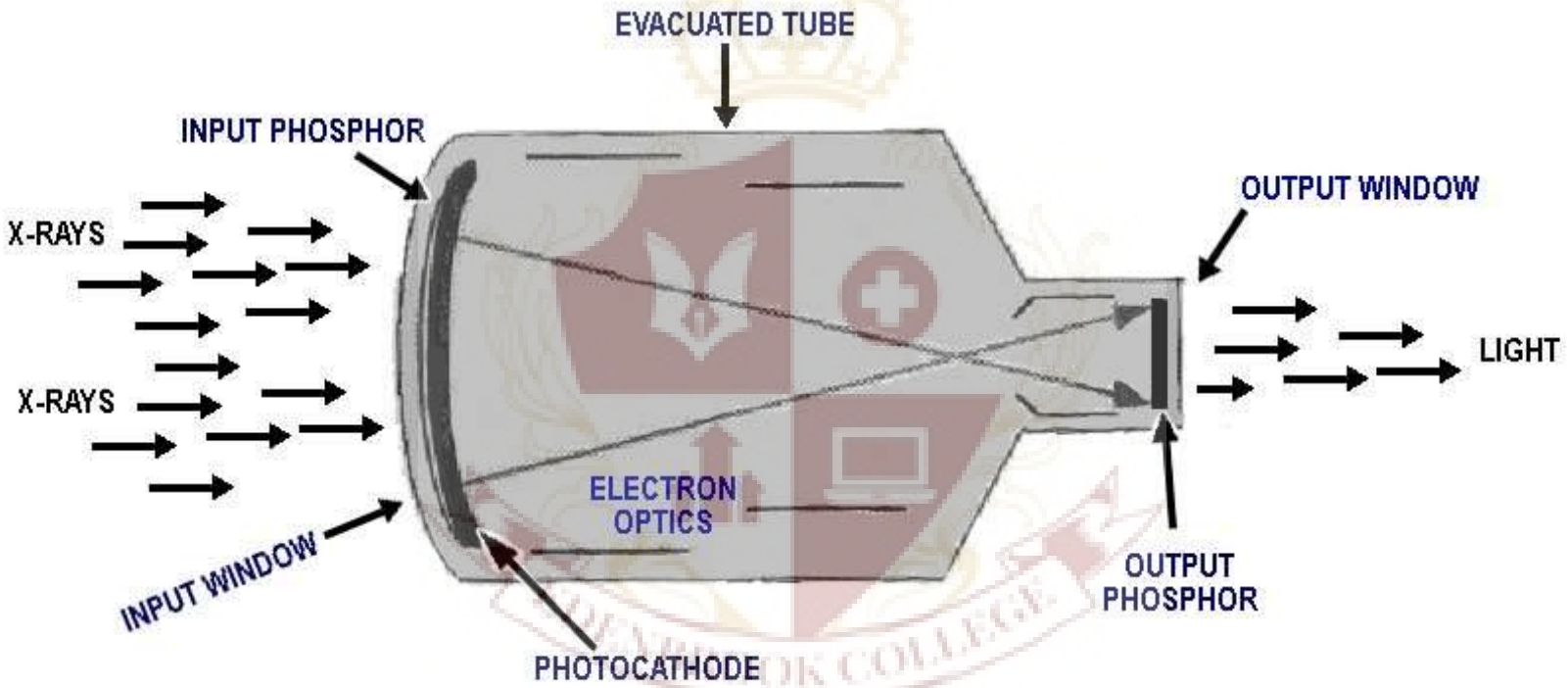
Output Phosphor

- Glass or aluminum coated with zinc cadmium sulphide
  - Usually 2.5 or 5cm in diameter
- Located behind the anode, it receives electrons from the photocathode
- Emits 50-75X more light than what was received by the photocathode in the yellow-green portion of the light spectrum, which is visible to video cameras and the human eye

Optical Focus

- Where the narrowed beam of electrons comes to a point and crosses over
- Crossing over of the electrons at the focal point inverts the image
- Right becomes left. Superior becomes inferior
- Image is upside down and reversed!

DIAGRAM OF AN IMAGE INTENSIFIER



Brightness Gain

- Brightness gain can be referred to as how bright an image with an I.I. is compared to a non I.I. image
- Primary brightness gain occurs from the acceleration & focusing of the photoelectrons
  - Acceleration = flux gain
  - Focusing = minification gain
- The product of the two factors is the brightness gain
- The brightness gain of most I.I.'s is 5,000-30,000
  - It decreases with tube age and use – each decrease will increase pt. dose

Minification Gain

The image from the larger input phosphor is condensed onto the smaller output phosphor. Since the image is emitted from a smaller area, it appears to be brighter

- This increase is called ***minification gain*** and is calculated by the equation

Minification Gain =

$$\left[\frac{d_i}{d_o}\right]^2$$

Where:

- *di = diameter of input phosphor*
- *do = diameter of output phosphor*

- Example:

The diameter of the input phosphor is 23 cm.

The diameter of the output phosphor is 2.5 cm

Calculate the Minification gain.

Input phosphor 23cm x 23cm = 529 cm^2

Output phosphor 2.5cm x 2.5cm = 6.25 cm^2

Ratio = Input/Output = 529 cm^2 / 6.25 cm^2

Minification gain = 84.64

remember ratios have no unit

Flux Gain

A high voltage accelerates the electrons from the photocathode and their kinetic energy is increased, multiplying the light photons proportionally and brightening the image.

- This increase in brightness is the ***flux gain.*** It is the ratio of the number of light photons at the output phosphor to the number of x-rays at the input phosphor.

$$\textbf{Flux Gain} = \frac{\text{Number of output light photons}}{\text{Number of input x-ray photons}}$$

- Example

What is the flux gain for an image intensifier that emits 700 000 light photons when struck with 200 x-ray photons?

Flux Gain = 700 000 / 200 = 3500

- Brightness Gain = Minification gain x Flux Gain

- If an image intensifier has a minification gain of 84.64 and a flux gain of 3500, what is the brightness gain?

Brightness Gain = 84.64 x 3500

Brightness Gain = 296 240

Automatic Brightness Control

- Aka Automatic Brightness Stabilization (ABS)
- Similar to a general radiography AEC phototimer system
- Chamber is placed in front of the output screen & measures the current flowing through the I.I.

or

- Chamber is positioned after the output screen measuring the brightness
- As the current or intensity fall outside the established parameters the primary beam is adapted
  - Exposure factors are adjusted

ABC In Action

- https://www.youtube.com/watch?v=Ri8bBhw9msQ

- Watch as the brightness of the image subtly adjusts as the patient moves around, as well as when the tube is moved superiorly and inferiorly on the patient.
  - The brightness stays roughly the same despite the difference in thickness between the cervical area and the chest.

Magnification Mode

- Increases the voltage on the electrostatic lenses
- More electron acceleration
- Focal spot closer to the input screen
- Enhances the image & increase the capability for a more accurate diagnosis
- Increases the spatial resolution from 4-5 lp/mm to 6 lp/mm
- Common sizes:
  - 25cm/17cm
  - 25cm/17cm/12cm

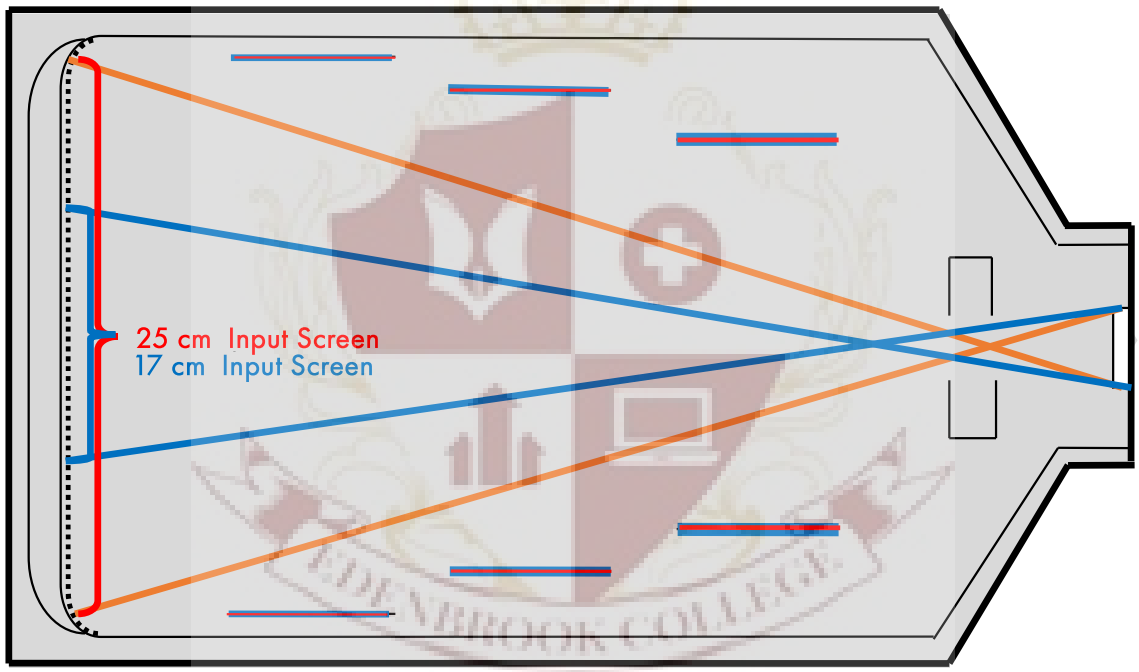
Magnification Mode

- Better spatial resolution
- Better contrast resolution
- Higher patient dose





Magnification Mode – Multifield I.I.



Magnification Factors

- Magnification Factor Formula

$$M.F. = \frac{\text{Full Field Diameter}}{\text{Magnification Field}}$$

$$= \frac{25 \text{ cm (full field)}}{17 \text{ cm (1}^{st} \text{ Mag)}}$$

$$= 1.5 \quad \text{Mag. Factor}$$

Magnification Factors

- Patient Dose Formula

$$\text{Dose} = \frac{(\text{Full Field Diameter})^2}{(\text{Magnification Field})^2}$$

$$= \frac{(25)^2}{(17)^2} = \frac{625}{289}$$

= 2.2 times the dose

Image Intensifier Simplified

- X-rays pass through the patient
- X-rays are absorbed by input fluorescent screen
- A light image is produced. Direct viewing possible (old school) using a conventional fluoroscopic screen
- The light photons strike the photocathode
- Photoelectrons are emitted by the photocathode
- These electrons are attracted to the accelerating anode
- At the same time the electrons are focused onto the output fluorescent screen by the electrostatic lenses
- The electrons strike the output screen
- Light photons are emitted from the output screen

Flat Panel Image Receptor

- Replaces the I.I. and signal adaptors (CCD and ADC)
- Acts similarly to an indirect digital radiography detector
  - Image is exposed, read and displayed almost immediately
- Smaller, lighter & easier to move than an I.I.
- Unaffected by external magnetic fields (unlike an I.I.)
- Pulsed mode capabilities where exposure time can be continuously varied, reducing dose to patient
- Very expensive!

I.I vs FPIR



Courtesy GE Healthcare.

Charge-Coupled Device (CCD)

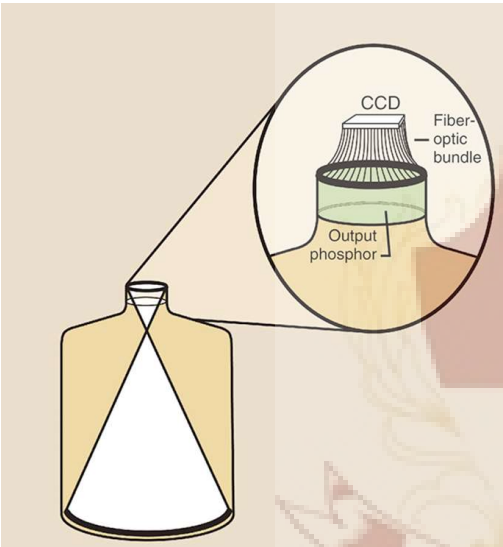
- Used instead of a TV camera tube (Vidicon)
  - You can read about vidicons and other analog display devices on pages 411 - 414 of your Bushong textbook (not testable)

- Active component of a CCD is a layer of crystalline silicon
  - Converts the light signal at the output phosphor into an electrical charge.
  - Each electrical charge is sampled, pixel by pixel in order to produce a digital image (via an Analog Digital Converter)

Advantages of a CCD (over analog devices)

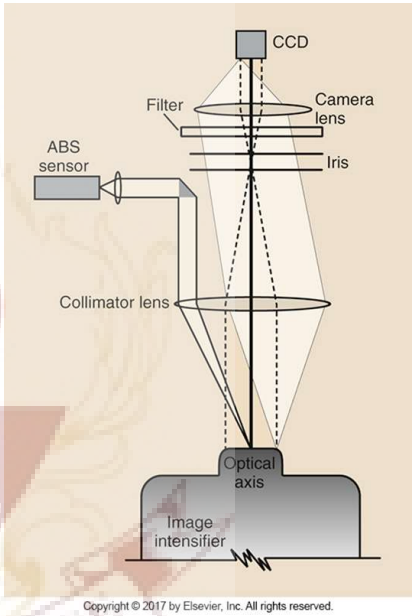
- Better contrast and spatial resolution
  - 1024 matrix displays 10 lp/mm
  - Conventional fluoro 4-6 lp/mm
- High SNR
- No maintenance or warm up
- Greater sensitivity to light (DQE)
- Linear response
  - Predictable response to exposure factor changes
- Lower patient doses
- No image distortion or lag
- Image quality doesn't degrade over time

DF Coupling Devices



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Fiberoptics



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Lens coupling

Analog to Digital Convertor

- ADC
- Located between the CCD & the array computer
- Converts the analog electrical signal from the CCD to a digital signal for computer processing

Acquisition Computer

- Uses an array processor
- Capable of processing thousands of functions simultaneously
- Receives dynamic data from the ADC and processes it quickly for image display and storage

Acquisition Computer

- Applies algorithms to the incoming digital signal when "creating" the image
- Post-processing alters the image to enhance diagnostic interpretation
- The images displayed can be post-processed
  - Last-image hold, greyscale image manipulation and edge enhancement

DF Television Monitors

- Analog monitors (CRT) operate with heated filaments and flowing currents. Always some background electronic noise.
- Digital TV camera tube read in "progressive mode". Electron beam sweeps the target assembly from top to bottom every 33ms.
  - This is described in more detail on page 425 of Bushong
- CRT monitors have been almost completely replaced by flat screen digital monitors.
  - Lightweight, easily suspended and maneuvered around a room
- Usually one inside the room and outside

Image Quality

- Monitors are the primary limitation of spatial resolution

- Electronic video images are comprised of two components:
  - **Signal** – An accurate pattern of data representing the image information recorded
  - **Noise** – A chaotic pattern of data, carrying no useful information about the recorded image

- Image Lag
  - The persistence of luminescence of the screen after the X-ray stimulation has been terminated
  - Can occur with rapid movement causing blurred or "ghost" images on the monitor

Signal to Noise Ratio

- Measure of how much useful information is displayed compared to useless
- Conventional TV camera tubes have SNR of 200:1
- Digital fluoroscopy has a SNR of 1000:1
- Better signal to noise ratio = better visibility of fine detail

Automatic Gain Control (AGC)

- Brightness of the image can be controlled by varying the sensitivity on the monitor
- Exposure factors are not affected
- Only the video signal is adjusted
- Can be done automatically by the monitor or manually by the user

Brightness (ABS) vs. Gain Control (AGC)

- 2 methods can be used to control the brightness of the displayed image:
  - Automatic Brightness Control
    - Adjusts exposure factors to maintain image brightness
  - Automatic Gain Control
    - Adjusts the video/digital signal

Quantum Mottle

- Also called photon starvation
- Seen in both fluoro and general X-ray.
- Too few X-ray photons hitting the IR (or I.I.)
- Image looks grainy or mottled
- How do we fix this?
  - Increase mA
- Page 164/165 of Bushong has a good explanation

Console

- Will contain ways to change exposure factors, frame rate, and other equipment functions
- Allows you to enter patient information to link images to a specific person.
- They all look a little different, but do basically the same thing



(Courtesy Siemens Healthcare.)

Capabilities of DF

- Last Image Hold
  - Software permits the last frame to remain on the monitor when the X-ray beam is shut off until the next live image is taken
- Image Grab/Snapshot Mode
  - Allows a frame to be saved on the static monitor from the live monitor
- Both can reduce dose to the patient
- Post-processing

Using Digital Fluoroscopy

- Usually two different exposure switches or buttons
- One will give you live fluoro
  - Lower resolution, but lower patient dose
- One will give you radiographic exposures with higher mA
  - Higher resolution, but higher patient dose
  - Exposures can be done singly or in a series
  - Can adjust how many frames/second the system will expose

Early Fluoroscopy

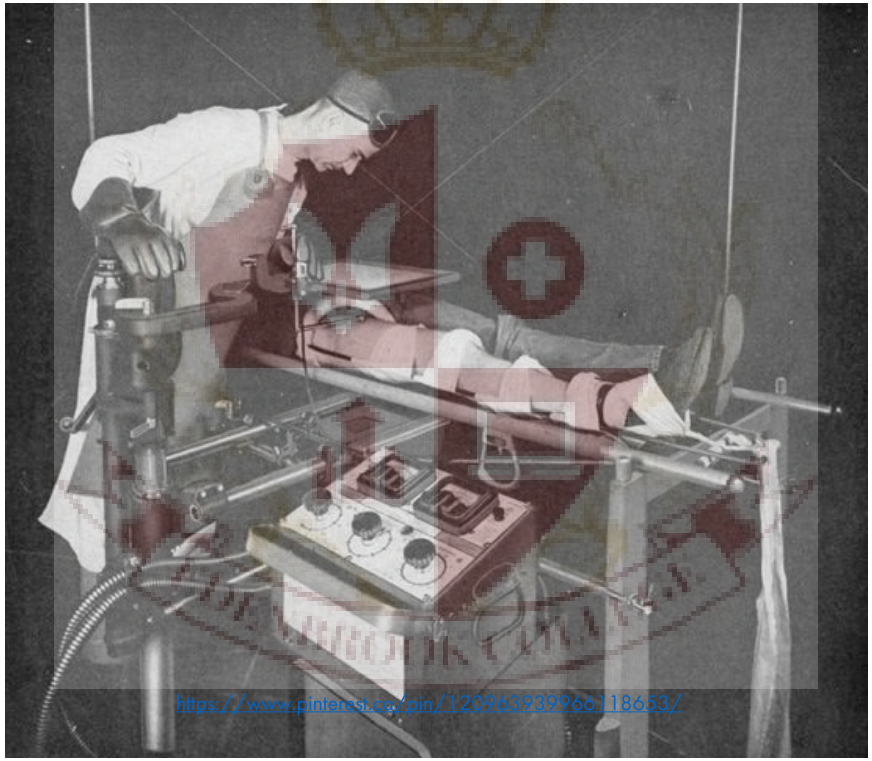
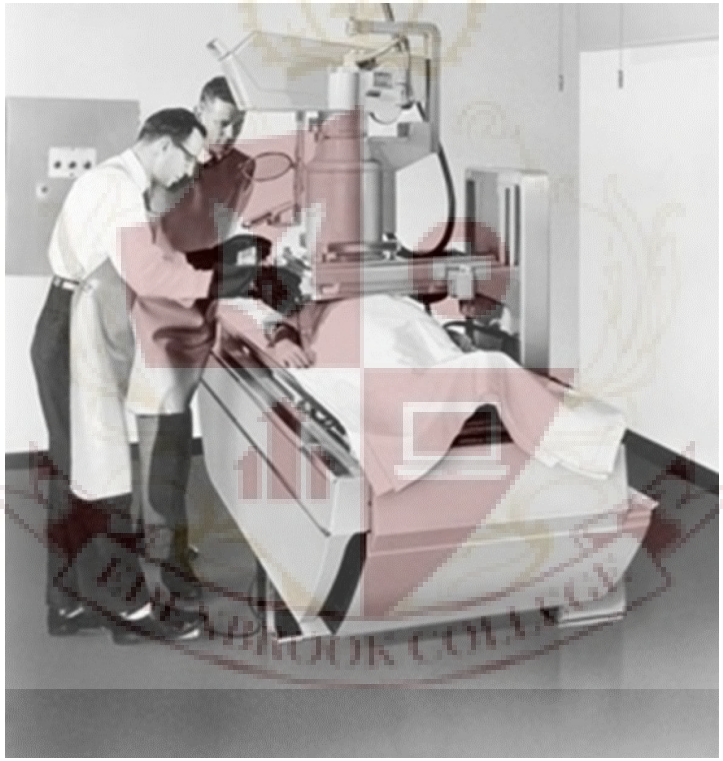
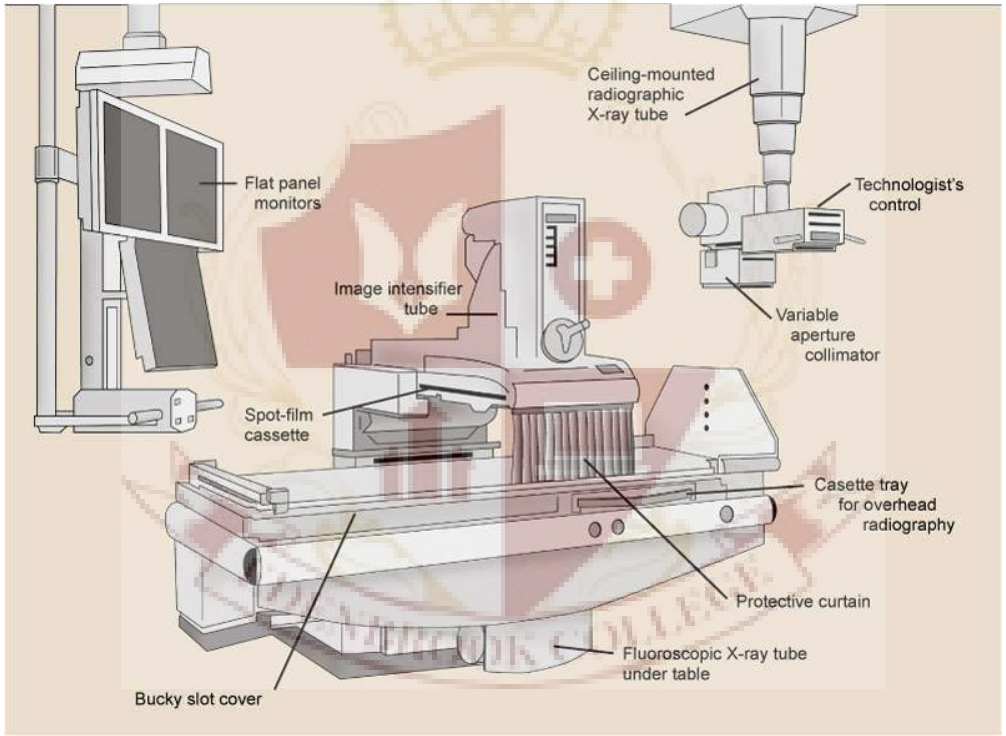


Image Intensifier



Under Couch (Bed) Tube



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Under Couch Fluoroscopy

- I.I. is over top of the bed, tube under it
- Lead curtains between the patient and operator
- Controls on the I.I. housing
- Often has a separate radiographic tube and cassette slot under tabletop
- Cassette tray slides up and down the length of the table for positioning

Under Couch - Advantages

- Less dose to the operator
  - Patient between beam and operator
  - Lead curtain blocks scatter
- Separate radiographic tube allows for X-table imaging
- Whole table rotates to a vertical position for standing images
- Image intensifier moves up and down
  - Control OID

Upright Under Couch Tube

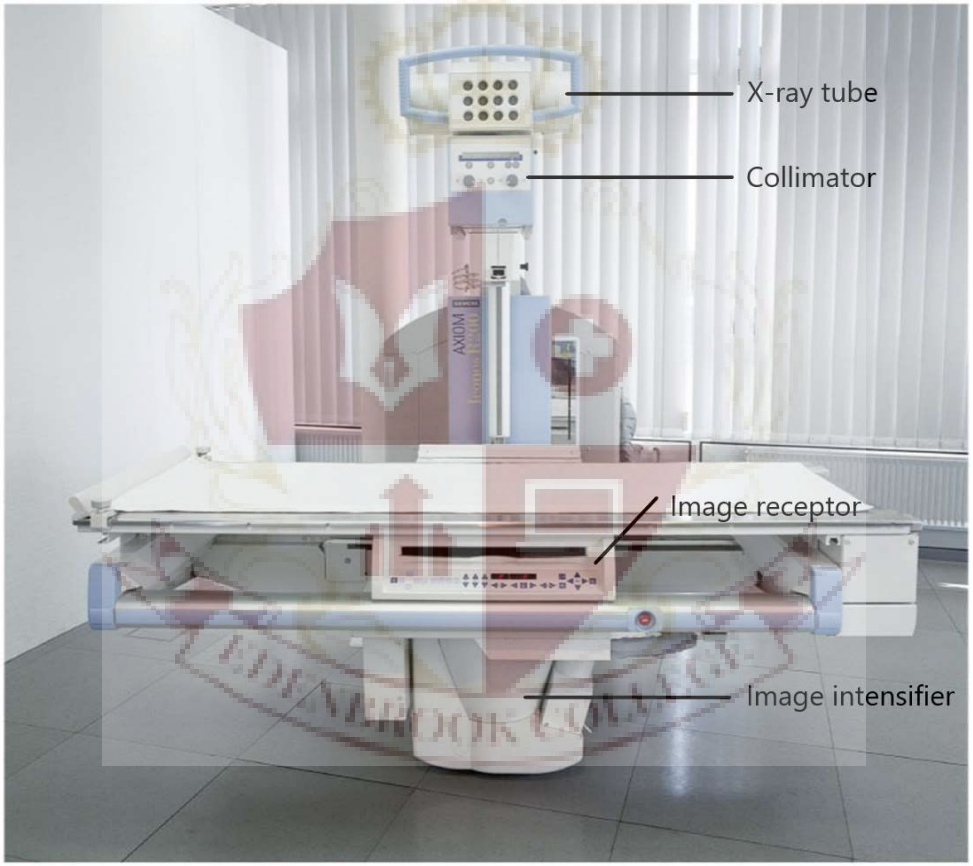


https://www.hopkinsmedicine.org/radiology/patient-information/exams-procedures/barium-swallow.html

Under Couch - Disadvantages

- Must be operated from inside the room
- No angulation of beam is possible
- Very confining
- Limited space for larger patients
- Switching to radiographic mode is time consuming

Over Couch Tube



Courtesy Siemens Medical Solutions USA.

Over Couch Fluoroscopy

- Tube is over table and I.I. is under
- Cranio-caudal angulation of the beam is possible
- Can be remotely controlled from a panel outside the room
  - Still has controls inside the room for when necessary
- No separate radiographic tube for X-ray exposures
- Also rotates to vertical position

Over Couch - Advantages

- Raise and lower tube head
  - Safer for patients
  - Room for larger patients
- Less confining
- Less dose to patient
  - Scatter scatters!
- Fewer staff in the room during exam

Over Couch - Disadvantages

- Pt can feel abandoned
  - Often still a tech in the room to prevent this
- More dose to staff in the room
- No overhead tube for radiographs

C-arm Tube



https://www.kpihealthcare.com/products/c-arm/ge/gec-9900/



https://blog.peekmed.com/c-arm-x-ray-machines/

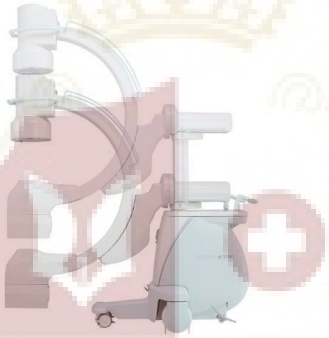
C-arm Fluoroscopy

- Mobile or fixed imaging systems
  - We will discuss the mobile system because the fixed is very similar to an Over Couch system, but with more angling capabilities
- Separate imaging system and monitor
  - Move independently of each other
- Mobile version used in Operating Rooms
- Becoming more common in clinics for pain management injections

C-arm Movement



C-arm rotation



UP/Down travel



Swiveling



Axial rotation

https://www.shimadzu.com/med/products/c-arm/m-k25cur00000057ii.html

C-arm – Advantages

- Extremely versatile!
- Can be moved to anywhere you want it
- Fits into smaller spaces
- Angulations allow for visualization in situ
- Easily draped for entry into the sterile field

C-arm - Disadvantages

- Must be operated from inside the room
  - Has a remote on a wire, but not very long
- Image quality not as high as some fixed units
  - Good for visualization, but not diagnosis

Flat Panel Image Receptor



https://www.deltamedicalsystems.com/Products-Solutions.aspx

Flat Panel IR Fluoroscopy

- No Image Intensifier
- Uses an image receptor composed of cesium iodide and silicon
  - Similar to general radiography detectors
- Used in interventional radiology

FPIR - Advantages

- Readouts are extremely fast
  - Almost no lag
- No veiling glare or pincushion distortion like an I.I.
  - This distortion is part of your readings on pg 410 of Bushong
- Not affected by magnetic fields
- Does not degrade with age
- Small and light
  - Maneuverable in tight spaces

FPIR - Disadvantages



https://sayingimages.com/make-it-rain-meme/

What do we use fluoroscopy for?

- Functional exam

- Various internal organ systems
  - Digestive
  - Biliary
  - Urinary
  - Reproductive
  - Vascular
  - Skeletal system repairs in the OR
  - So many more!

Watch an Upper GI Exam

- https://www.youtube.com/watch?v=xlLnOSLoME4

Tech Role

- Verify the exam
- Obtain history
- Set up room and patient
- Assist the radiologist
- Patient care
- Documentation and cleaning

Before the Exam

- Verify the exam
  - Check the requisition
  - Requested exam matches stated history and room booking
- Obtain history
  - Specific questions per site protocol
  - Communicate concerns to radiologist
- Set up room and patient
  - Correct contrast
  - All supplies
  - Console properly filled in and set
  - Patient changed and in correct position

During the Exam

- Assist the radiologist
  - Grab equipment
  - Open supplies or add to sterile tray
  - Relay information to other staff members

- Patient care
  - Translate instructions
  - Ensure comfort
  - Reduce fear
  - Provide physical assistance or stability during movement

After the Exam

- Cleaning
  - Apply bandages
  - Remove sterile tray from sight
  - Ensure room is ready to be used again
  - Restock supplies

- Documentation
  - All medications used
  - Relevant care notes
  - Images taken
  - Fluoro time used
  - Complete exam so radiologist can report
  - After care given to patient