Radiography:
Parameter/Protocol Optimization
New Technologies & Applications

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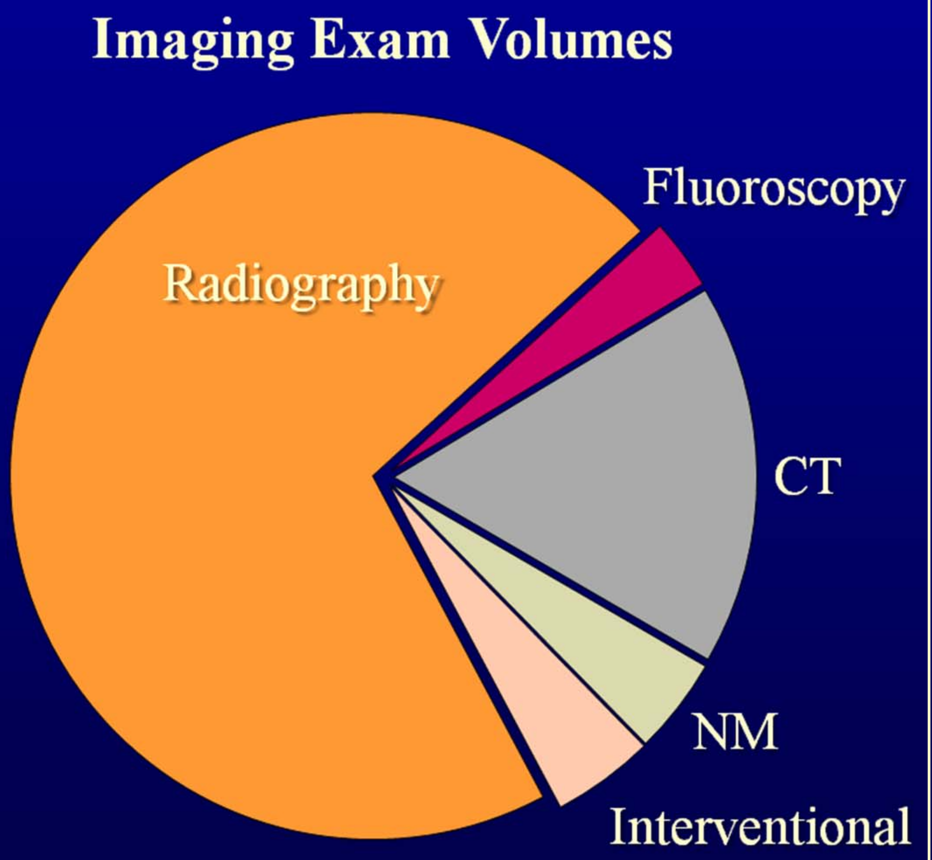
Disclosures

- No financial disclosures

Introduction

- Radiography has been the primary tool in radiology for over 100 years
- New image receptors and applications are making rapid changes to a field that has been stable for decades



Reference: NCRP Report No. 160

Learning Objectives

1. Examine selection of optimal exposure parameters for digital radiography
2. Learn about new radiographic detector technology
3. Review new radiographic imaging applications and techniques

Optimization of Digital Radiography

- Image quality generally improves with increased radiation dose
- First, assess the level of image quality needed for the diagnostic task
- Second, determine the acquisition parameters that provide that level of image quality at the lowest patient dose

Image Quality Criteria Example: L-spine

- Visualization of intervertebral joints, spinous process, transverse process, pedicles, sacro-iliac joints
- Sharp cortex and trabecular structures
- Contrast in soft tissue, psoas shadow

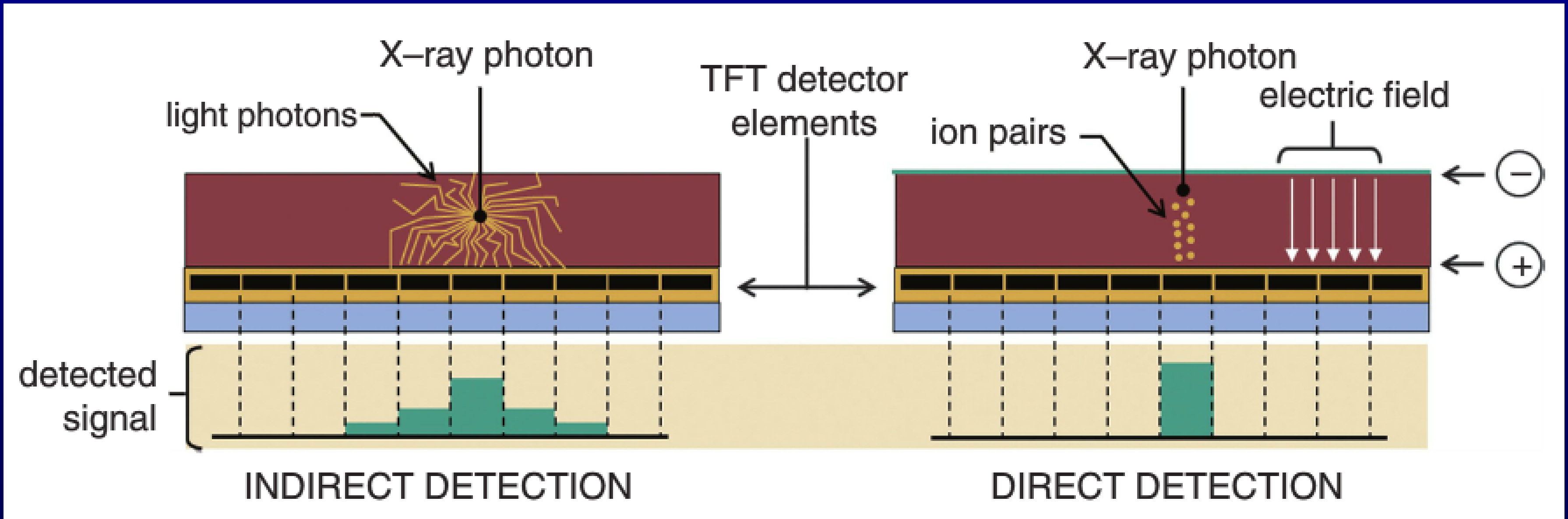
Image Quality Factors

- Spatial resolution
- Noise
- Contrast

Spatial Resolution Factors

- Geometric magnification and focal spot size
- Patient motion
- Detector resolution
  - Computed radiography (CR):
    - Blur primarily due to scattering of laser light during image plate readout
  - Flat panel detectors (FPD):
    - Indirect type (CsI, GdOS):
      - Blur primarily due to lateral light spread in scintillator layer
    - Direct type (aSe):
      - Negligible lateral spread, resolution limited by pixel pitch

FPD Spatial Resolution



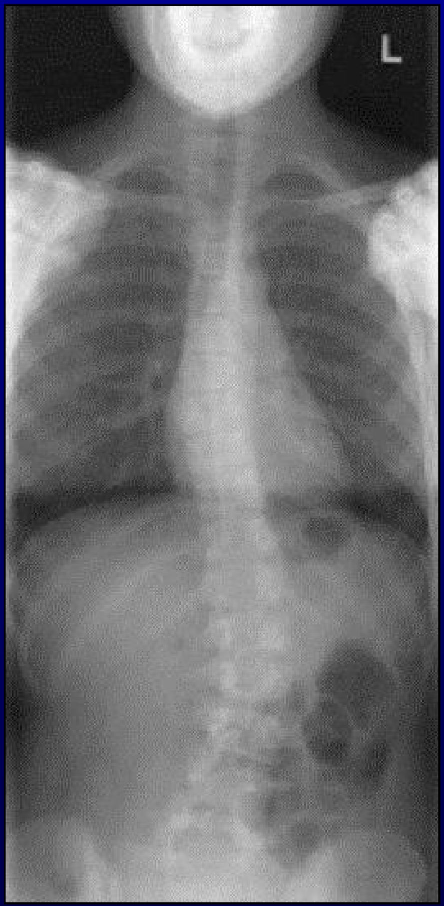
Reference: Bushberg et al, The Essential Physics of Medical Imaging

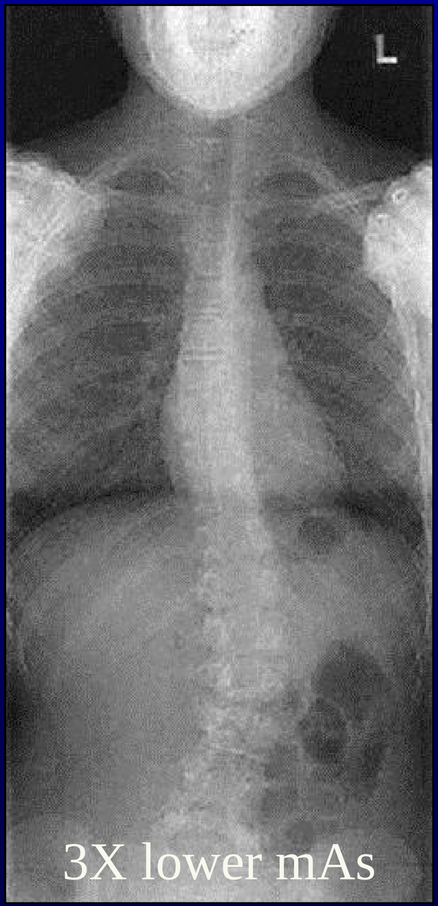
Noise Factors

- Electronic noise
- Quantization noise
- Fixed-pattern noise
  - CR image plate non-uniformity
  - FPD amplifier gain variation – largely removed by gain calibration
- Quantum mottle
  - Should be dominant factor
  - Determination of appropriate quantum mottle level for the diagnostic task is an important part of optimization

Scoliosis Radiography

- Additional noise may be tolerated in follow-up radiographs acquired to assess level of spine curvature
- Allows for reduction in patient dose





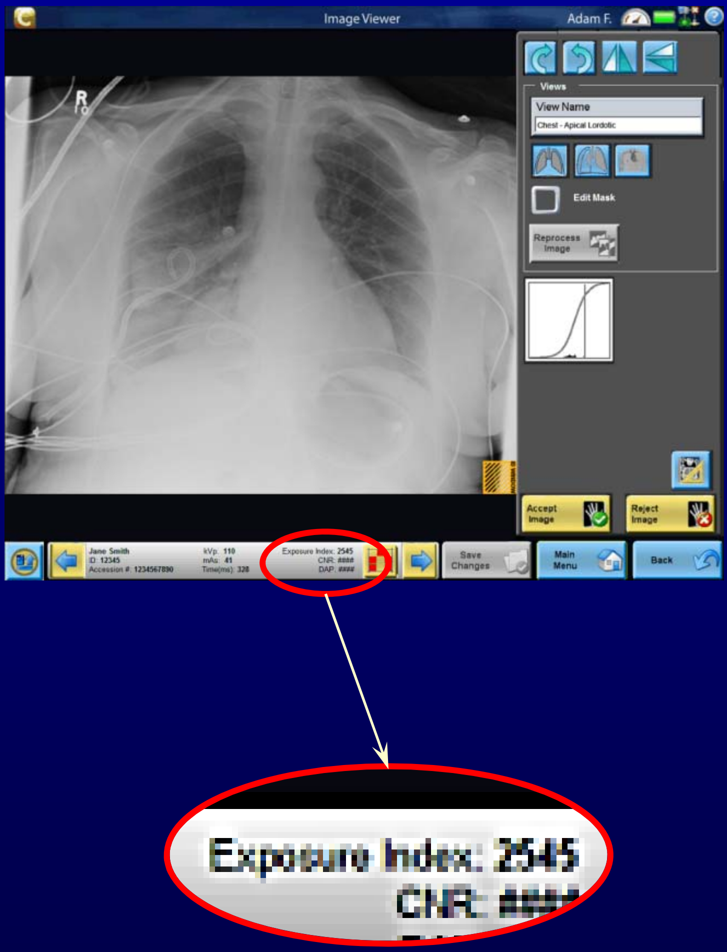
Reference: Seibert, Health Physics 2008

Dose Creep

- Tendency for technologists to increase exposure parameters over time when using digital radiography
  - Under-exposure visible as increased image noise prompting radiologist complaints
  - Over-exposure may cause gray-scale clipping (burn-out) but is generally not detectable
  - Higher kVp and mAs used to avoid potential complaints

Dose Creep Solution

- Exposure Indicator
  - Value that indicates the radiation exposure incident on the image receptor
  - Displayed to technologist to assist with determination of under- or over-exposure
- Problem:
  - Digital radiography manufacturers have defined exposure indicators differently



Manufacturer-specific Indices

Manufacturer	Exposure Indicator	Formula (X=Exposure)
Agfa	lgM (Log Median of histogram)	2X-0.3
Canon	REX (Reached Exposure Level)	α X(mR)
Carestream	EI (Exposure Index)	2X-300
Fujifilm	S (S Value)	200/X(mR)
GE	DEI (Detector Exposure Index)	2.4X(mR)
Konica	S (Sensitivity number)	200/X(mR)
Philips	EI (Exposure Index)	1000/X(µGy)
Siemens	EXI (Exposure Index)	100X(µGy)

Manufacturer-specific Indices

Manufacturer	Exposure Indicator	Under-exposed	Target	Over-exposed
Canon	REX	50	100	200
Carestream	EI	1700	2000	2300
Fujifilm, Konica	S	400	200	100
Philips	EI	200	100	50
Siemens	EXI	500	1000	2000

- Scales differ
- Some values are proportional to exposure, others inversely proportional
- Confusion likely in sites with multiple manufacturer systems

Standardized Exposure Indicator

- AAPM Report No. 116 An Exposure Indicator for Digital Radiography (2009)
- IEC concurrently wrote standard 62494
  - Documents are similar with small differences in exposure index (EI) definition
- EI proportional to detector exposure
- User defines the target EI (EI_T)
- Deviation index (DI) = 10 log (EI/EI_T) is displayed to technologist

Clinical Use of DI

Deviation Index	Action
> +3	Excessive patient radiation exposure, Repeat only if relevant anatomy is clipped or burned out, Requires immediate management follow-up
+1 to +3	Overexposure, Repeat only if relevant anatomy is clipped or burned out
-0.5 to +0.5	Target range
< -1	Underexposed, Consult radiologist for repeat
< -3	Repeat

Role of Medical Physicist

- Help to define target EI values for each body part, radiographic view, ped/adult
- Encourage purchase of digital radiographic equipment that incorporates use of the deviation index (DI) method
- Encourage purchase of PACS systems that display DI on all workstations
- Train technologists to understand DI values

Image Quality Factors

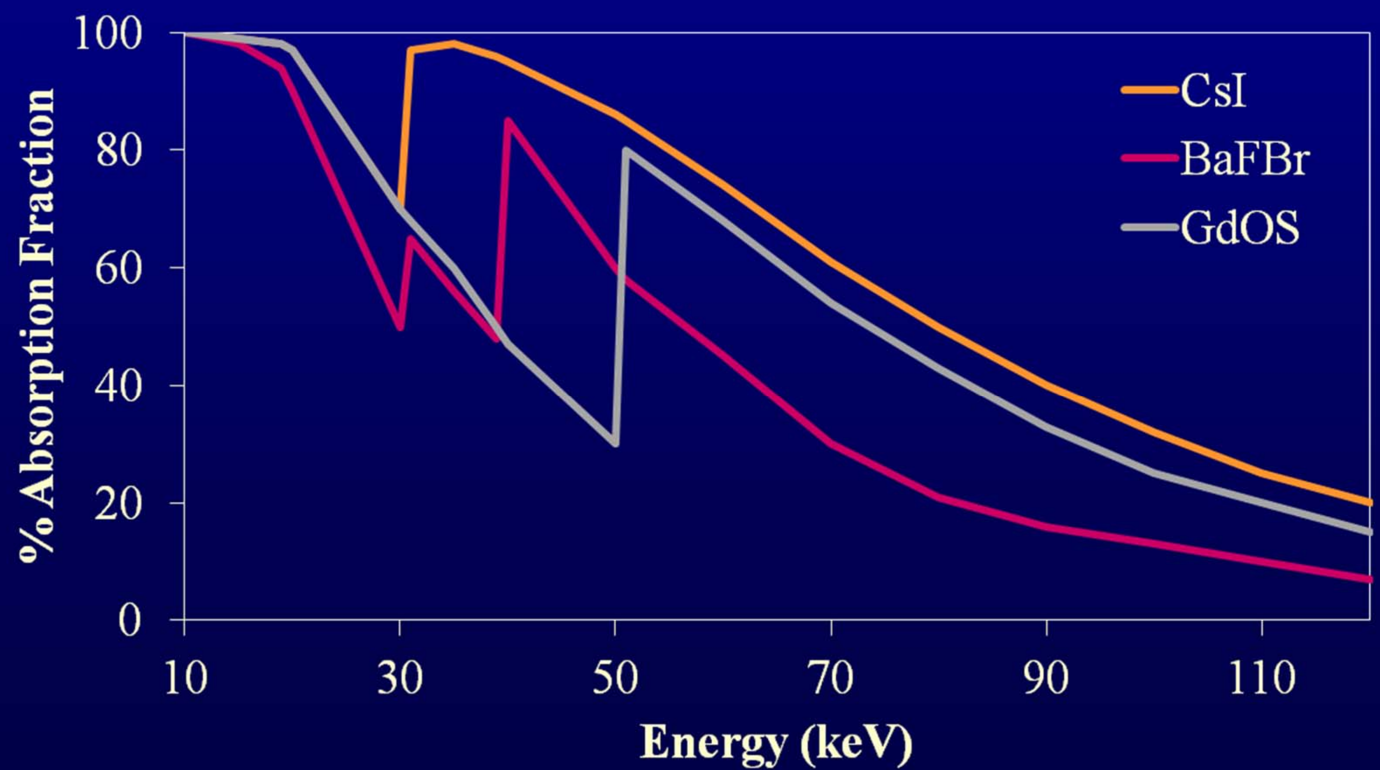
- Spatial resolution
- Noise
- Contrast

Contrast Factors

- Subject contrast
  - X-ray beam energy (kVp, filtration)
  - Tissue attenuation differences
  - Scatter (collimation, air gap, grid use)
- Detector contrast
- Display contrast
  - Determined by image processing

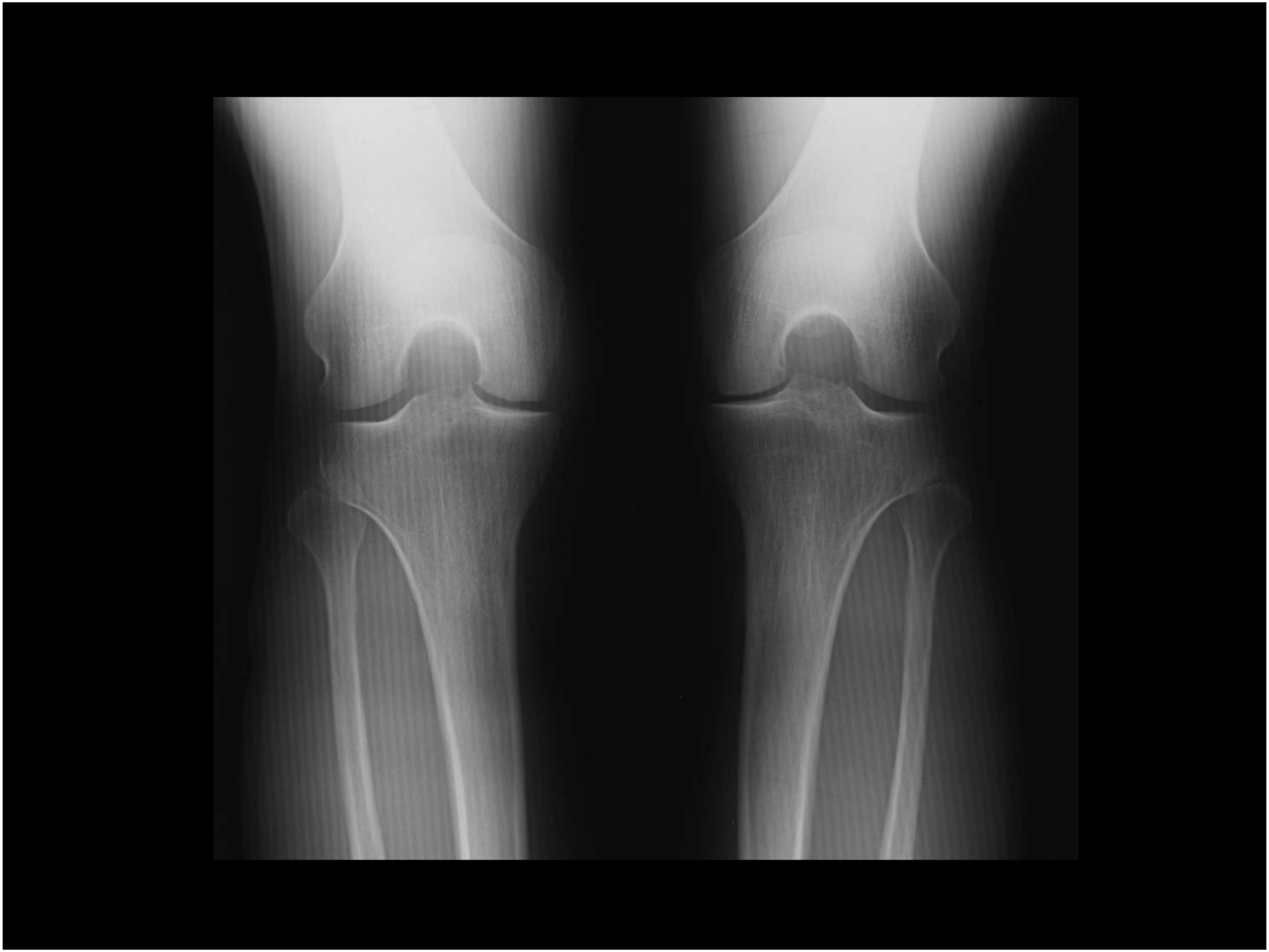
Grid Use in Digital Radiography

- Grids needed due to increased sensitivity to low energy scatter x-rays



Grid Use in Digital Radiography

- Stationary grids must be high frequency (60-80 lines/cm) to avoid aliasing artifacts
  - CR: interference between scan lines in laser scan direction and grid lines
  - FPD: interference between pixel matrix and grid lines
- Certain applications require stationary grids only
  - Portable radiography
  - Lateral projections
- Some FPD manufacturers use stationary grids in table and wall image receptors



Grid Use in Digital Radiography

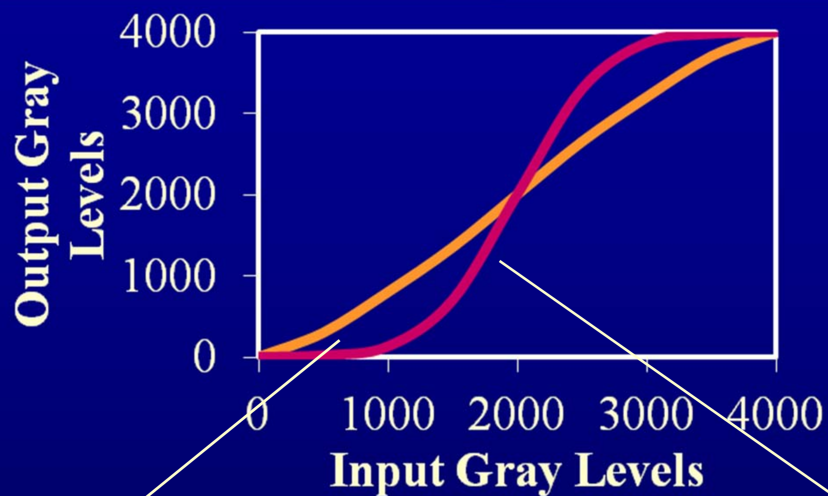
- Reciprocating grids have no frequency requirement since grid lines are blurred
- Moving grids are preferred so that lower frequency grids can be used for better scatter cleanup
- Optimal grid parameters:
  - Table and wall bucky: 15:1, 40 lines/cm
- Grid suppression software also allows use of lower frequency stationary grids

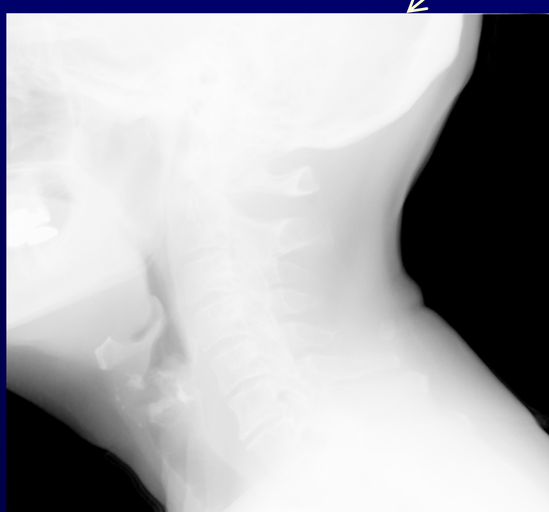
Image Processing

- Affects appearance of spatial resolution, noise and contrast
- Selection specific to body part, view, imaging task and personal preference
- Techniques include:
  - Grayscale processing
  - Edge enhancement
  - Contrast enhancement

Grayscale Processing

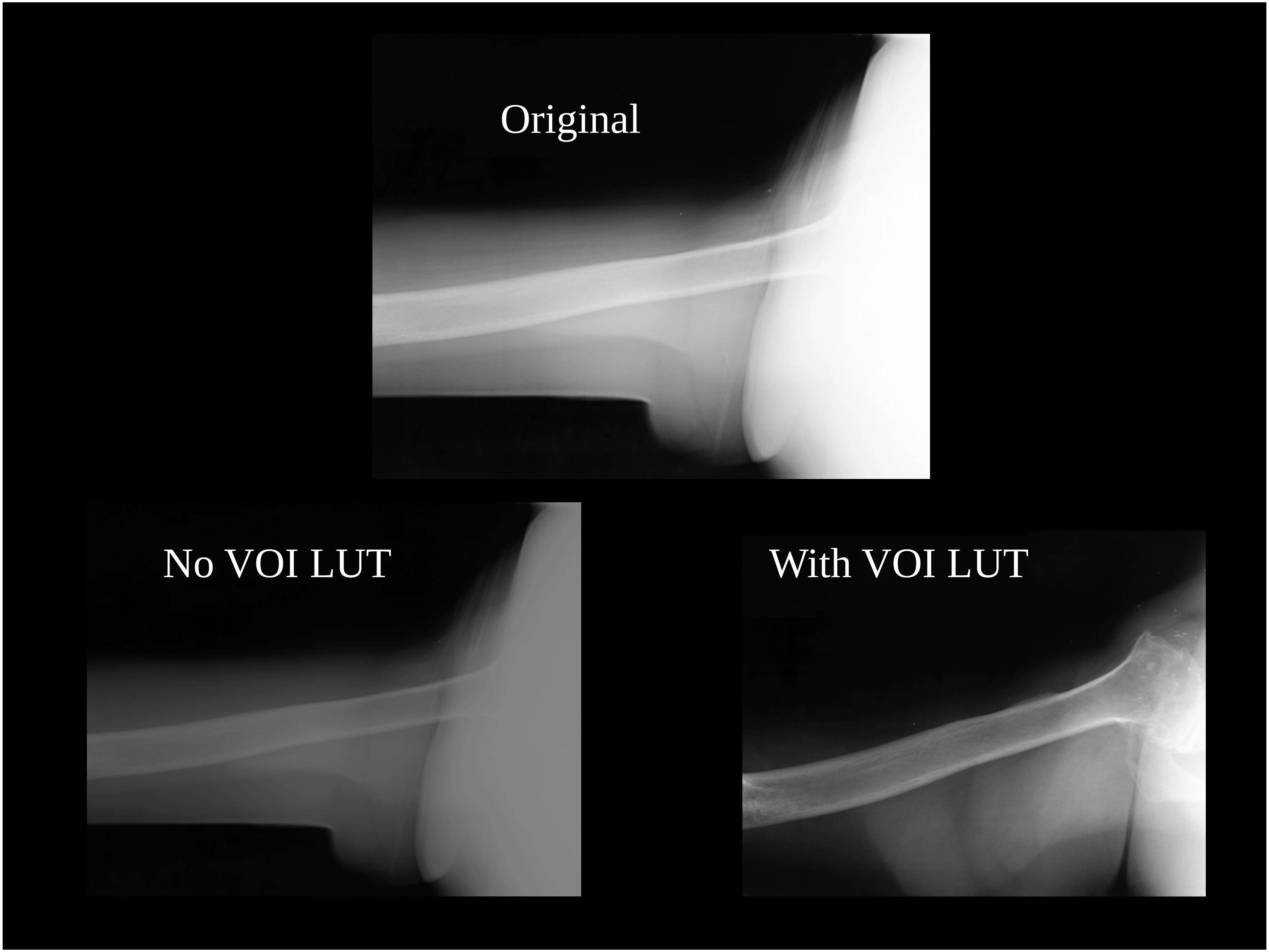
Lookup Table (LUT)





LUT

- LUT can be “burned in” at the modality workstation or stored in the DICOM header as a VOI (value of interest) LUT
- If LUT is burned in, ability to adjust contrast in PACS is limited
- With VOI LUT, user can adjust window/level to see structures in low contrast regions


Original
No VOI LUT
With VOI LUT

Edge Enhancement

- Used to improve image detail
- Excessive edge enhancement can result in amplification of image noise or cause artifacts that could confusion diagnosis
- Skeletal imaging – generally beneficial
- Chest imaging – should be used carefully


R
10F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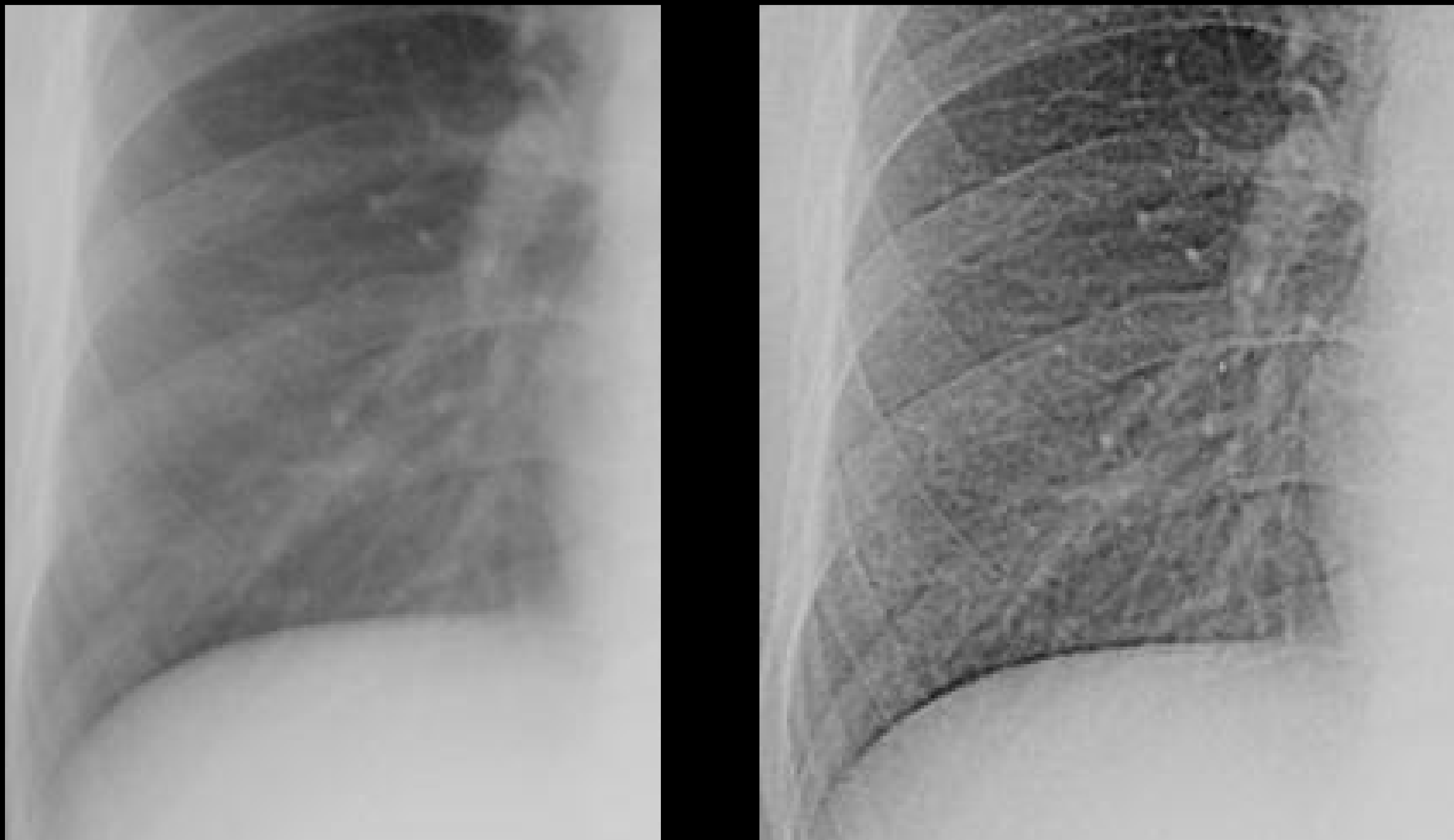
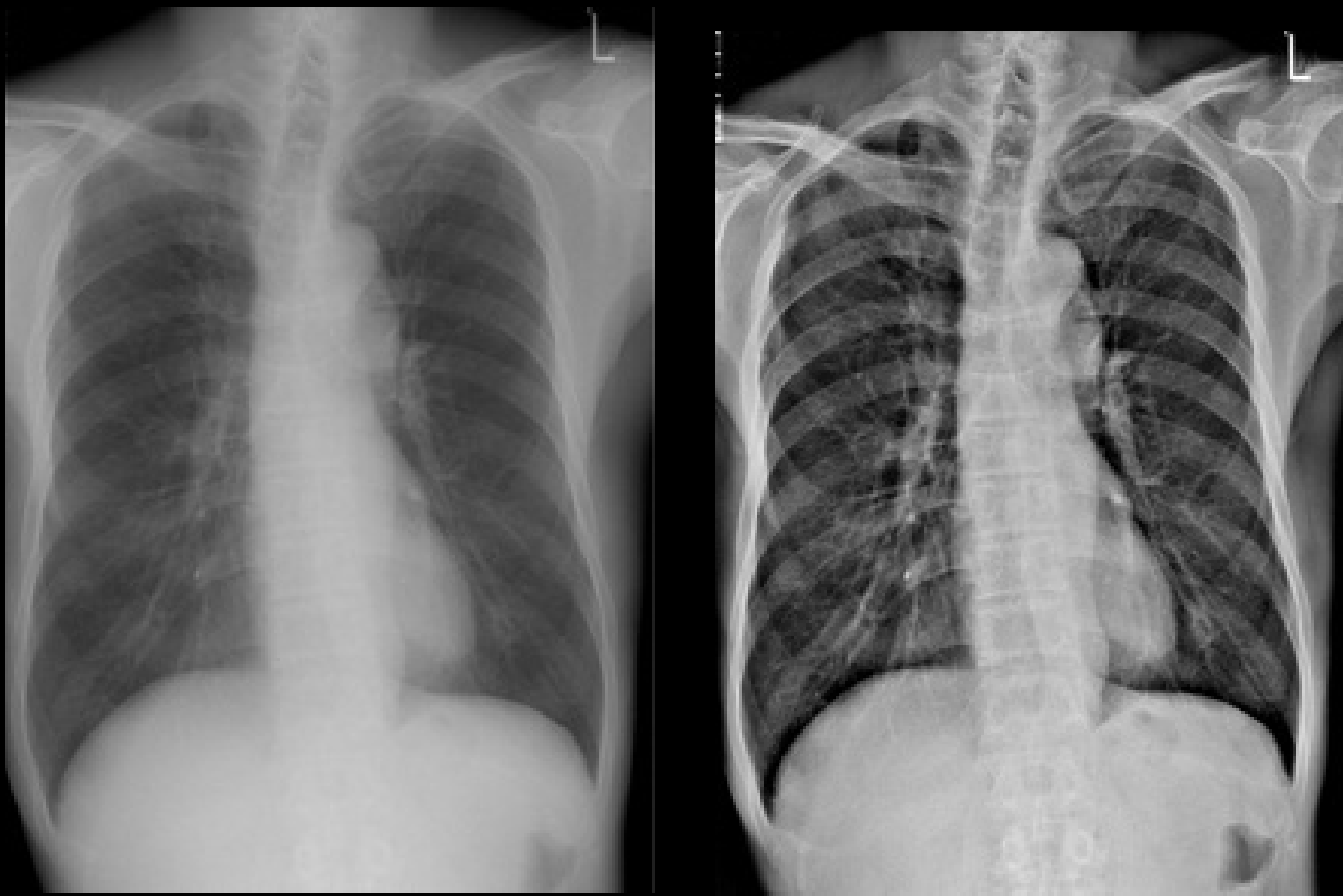


Reference: Samei et al, RSNA/AAPM Online Physics

Contrast Enhancement

- Contrast enhancement or equalization improves visualization in both dark and bright image areas
- Unsharp masking:
  - Create blurred mask image
  - Subtract from original image to create a detail image
  - Add back to original image to enhance detail contrast



Reference: Samei et al, RSNA/AAPM Online Physics

Role of Medical Physicist

- Manufacturer default settings may not be optimal
- With basic knowledge of image processing techniques and potential artifacts to avoid, you can provide valuable assistance working with the application specialist and radiologist
- If adjustments in image processing are needed:
  - Anthropomorphic phantoms can be helpful to start, but actual patient imaging needed for adequate adjustments

Image Processing Adjustment

- Apply new settings to patients of different body habitus
- Make sure image appearance is also compared with previous patient comparison images and not in isolation
- Matching image appearance is particularly challenging
  - between different manufacturers
  - between FPD and CR

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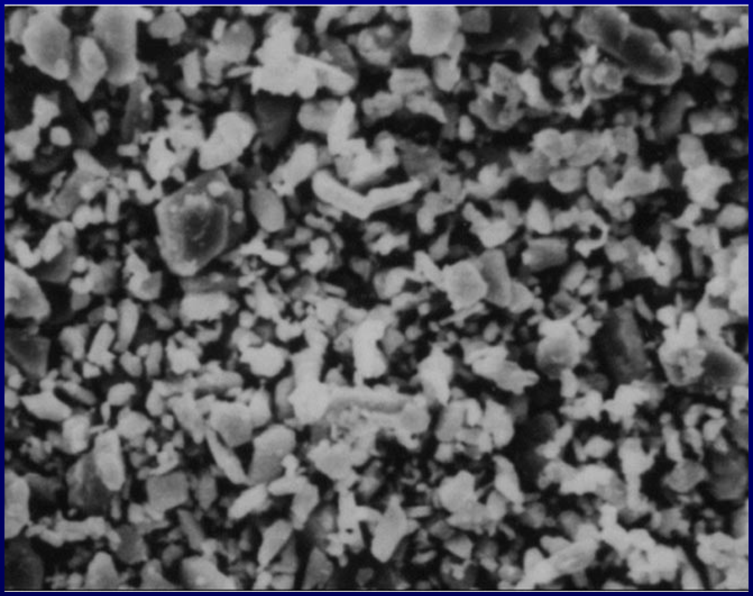
Computed Radiography

- Historical development
  - Cassette-based phosphor CR (1980s)
  - Integrated, high-throughput cassette-less CR (1990s)

CR Recent Developments: Phosphors

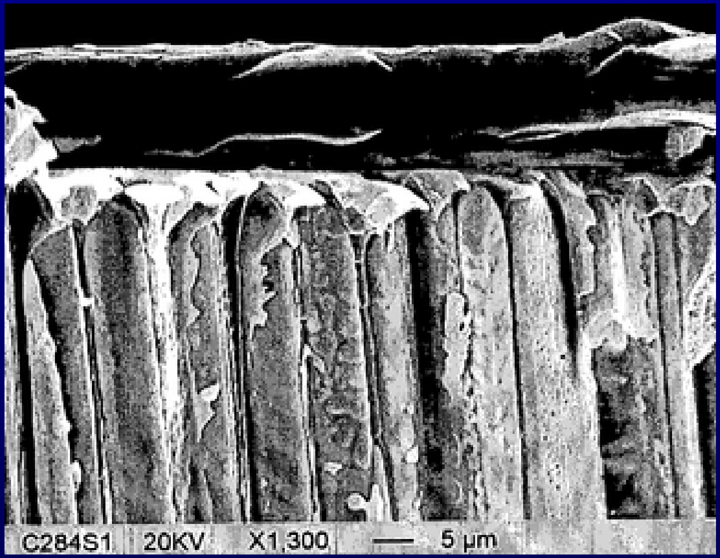
- Traditional photostimulable storage phosphors are made of a powdered material in a binder
  - Robust and easy to manufacture
  - Light scatters within the material causing light spreading and reduced spatial resolution



BaFBr

Structured CR Phosphors

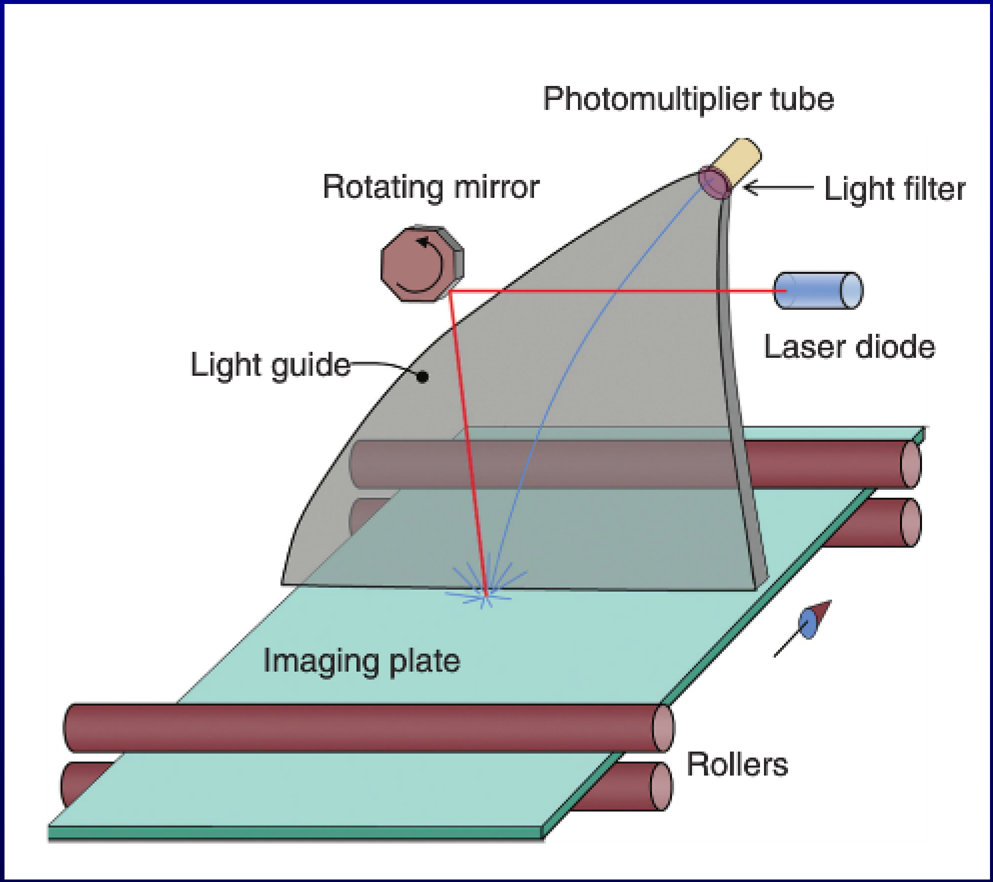
- Phosphor material deposited in a columnar needle-like structure
  - Reduced light scattering for improved spatial resolution
  - Allows for thicker layer and increased packing to improve x-ray absorption



CsBr

CR Recent Developments: Readout

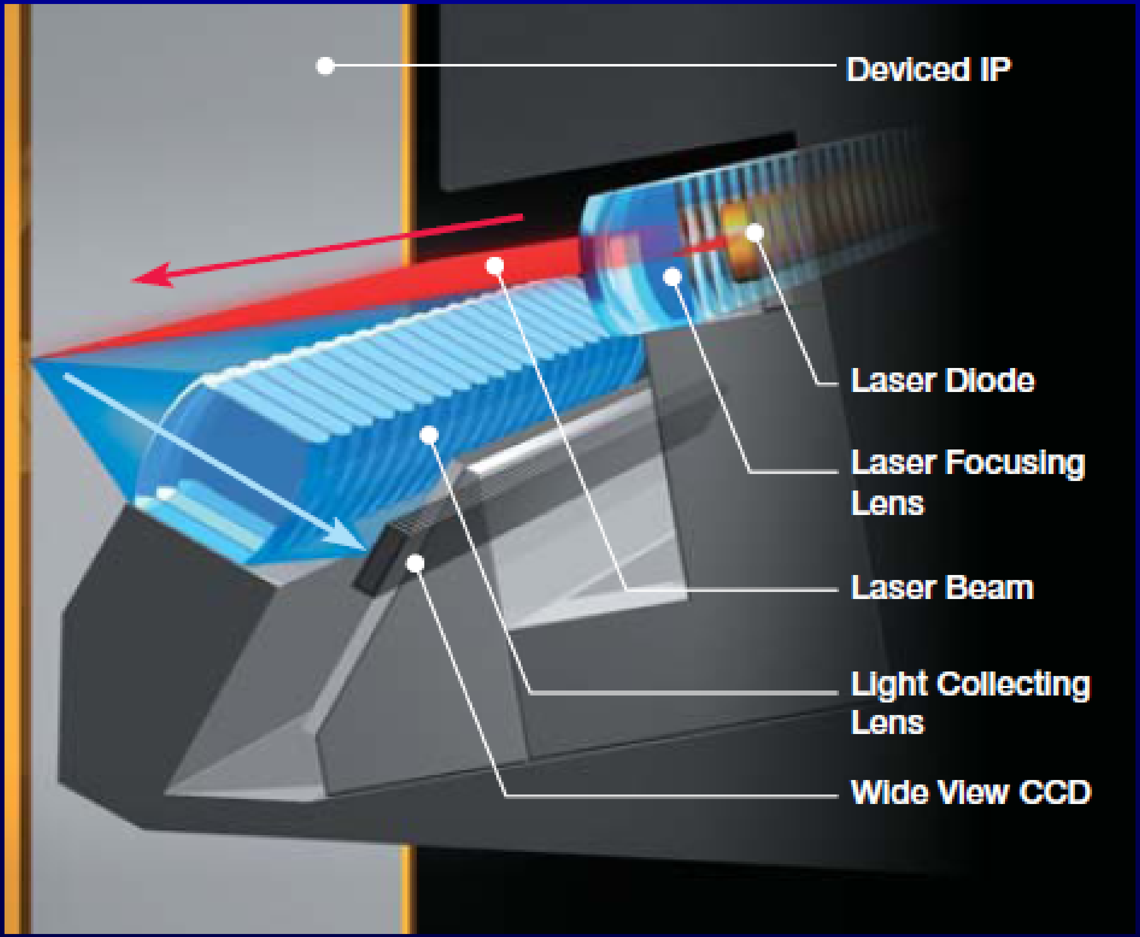
- Traditional CR readers use a flying spot of laser light to stimulate the emission of trapped energy in a photostimulable phosphor plate



Reference: Bushberg et al, The Essential Physics of Medical Imaging

Line-scan CR

- Laser light formed into a line and emitted light collected line-by-line for increased readout speed



Courtesy of Fujifilm

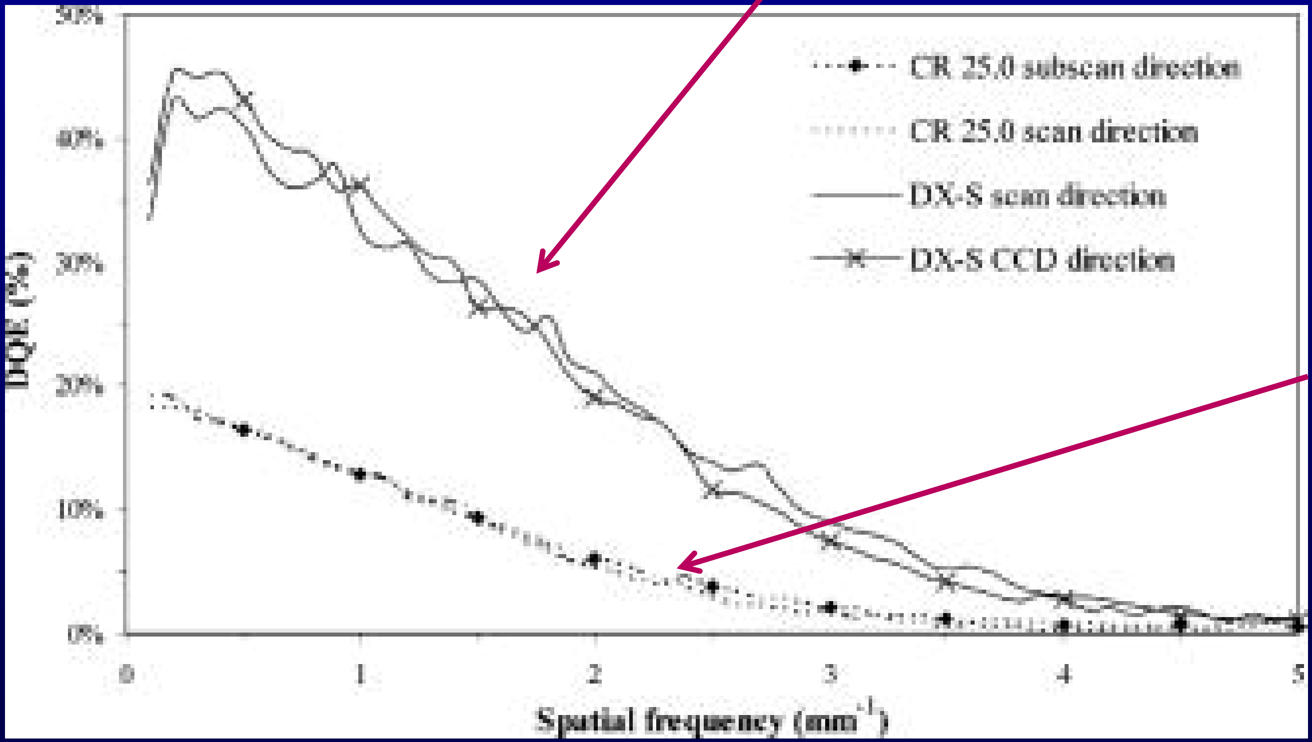
Line-scan CR

- Line-scan readout incorporated with a fixed phosphor plate to form a cassette-less image receptor
  - Fujifilm Velocity series: 9 sec readout (compare to about 1 min for a flying spot reader)

Courtesy of Fujifilm

CR Technology Comparison

Structured phosphor with line-scan CR reader

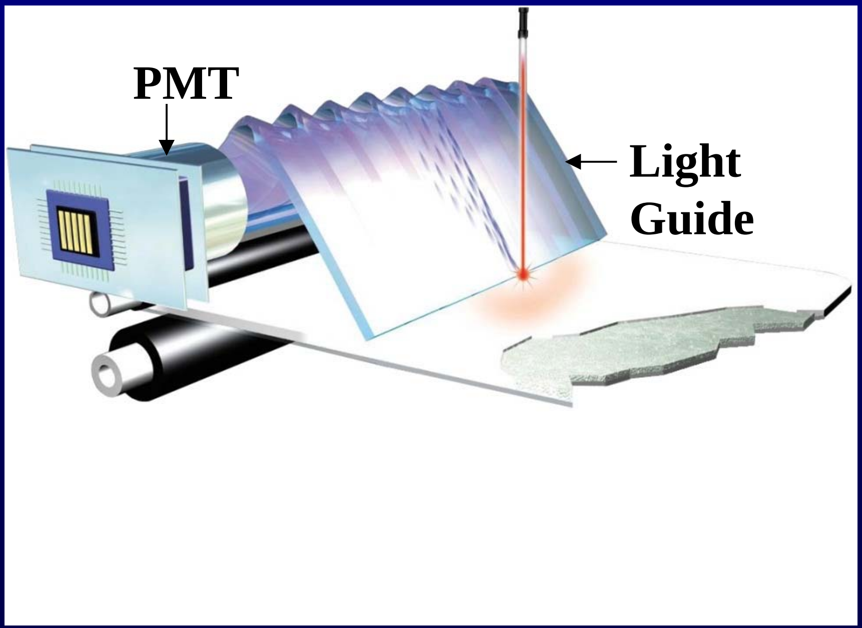


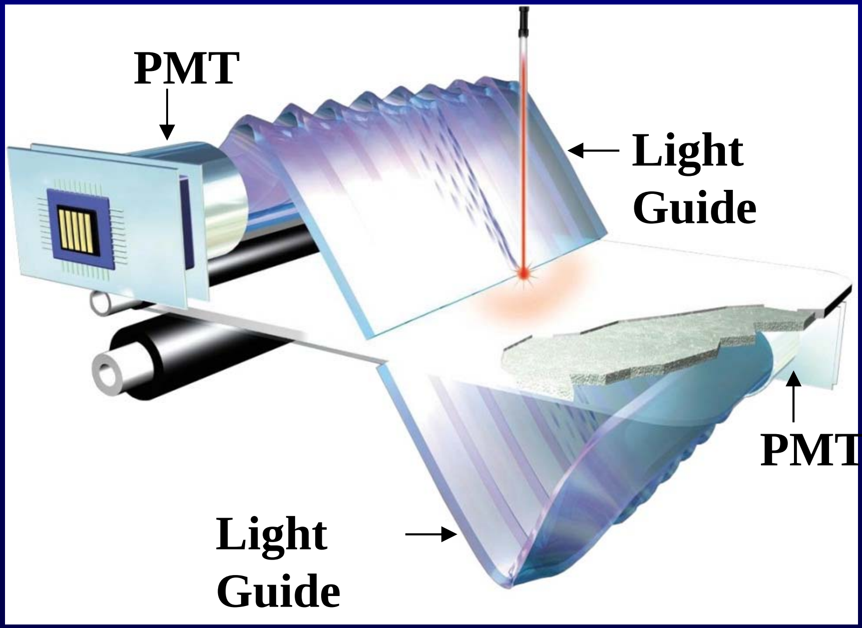
Powder phosphor with spot CR reader

Reference: MacKenzie and Honey, Med Phys 2007

CR Recent Developments: Dual-Side Reading

- Light guides above and below
- Phosphor plate has clear support layer

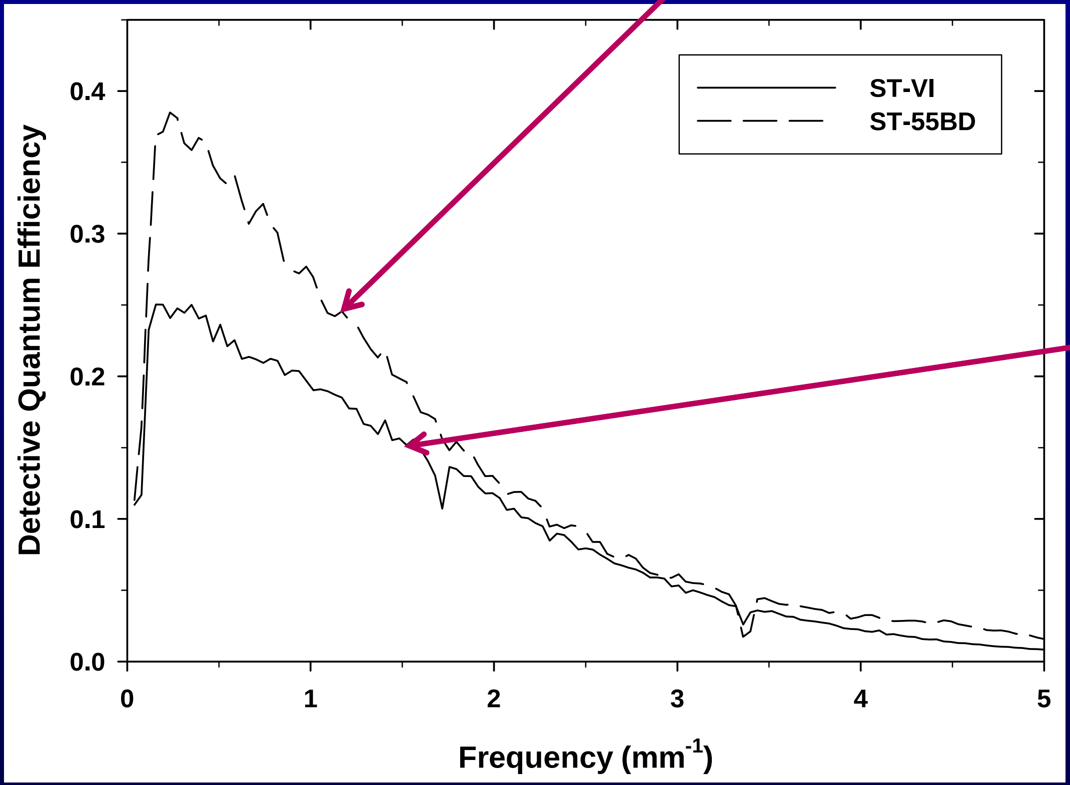




Courtesy of Fujifilm

Dual-Side Reading for CR

Dual-side Readout

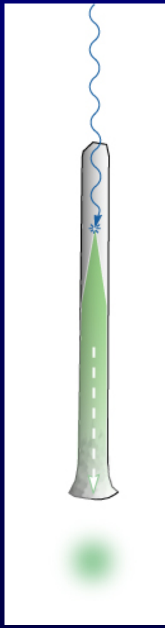


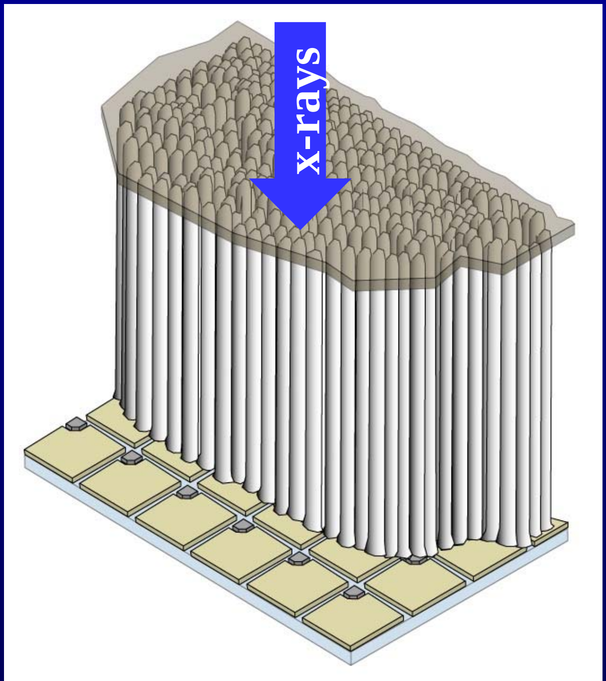
Single-side Readout

Reference: Fetterly and Schueler, Med Phys 2006

FPD Recent Developments

- Conventional CsI FPD
  - Columnar CsI crystals deposited on TFT array
  - Light detection occurs at base of crystal
  - Efficiency loss:
    - Loss of light that is emitted at the top surface
    - Flaring at base results in signal loss and blur

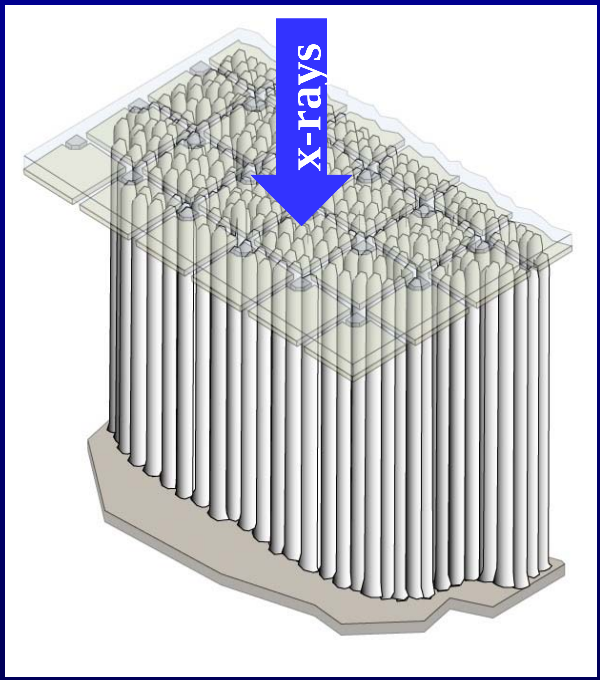




Courtesy of Fujifilm

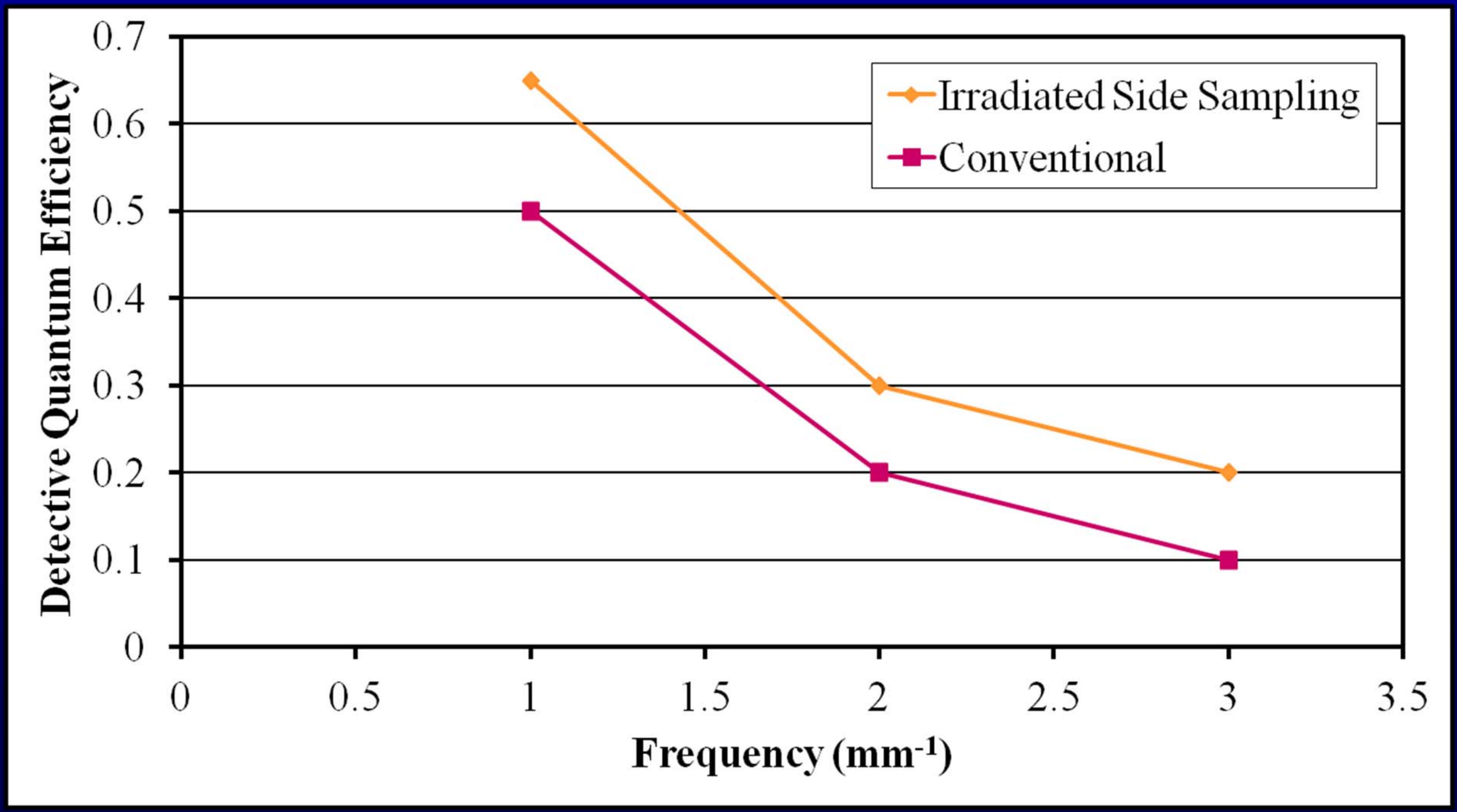
FPD Recent Developments

- Irradiated Side Sampling
  - TFT array positioned on x-ray entrance side of the CsI
  - Glass replaced with alkali substrate to reduce x-ray absorption in front of the CsI
  - Improved efficiency and spatial resolution



Courtesy of Fujifilm

Irradiated Side Sampling FPD



Reference: Rivetti et al, RSNA 2011

Learning Objectives

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2. Learn about new radiographic detector technology
3. Review new radiographic imaging applications and techniques

FPD Cassettes

- Allows for conventional system retrofit
- Replaces CR cassettes for free cassette views

Courtesy of Carestream

FPD Cassettes

- Tethered, wireless, screen-film cassette size, with handle

Courtesy of Canon, Carestream, GE

FPD Portable Radiography

- Pros compared to CR:
  - Improved DQE
    - lower noise and/or lower dose and shorter exposure times
  - Immediate image viewing
    - Streamlined image QA and transfer to PACS for improved efficiency
    - Prompt feedback for trauma and OR applications

Courtesy of GE

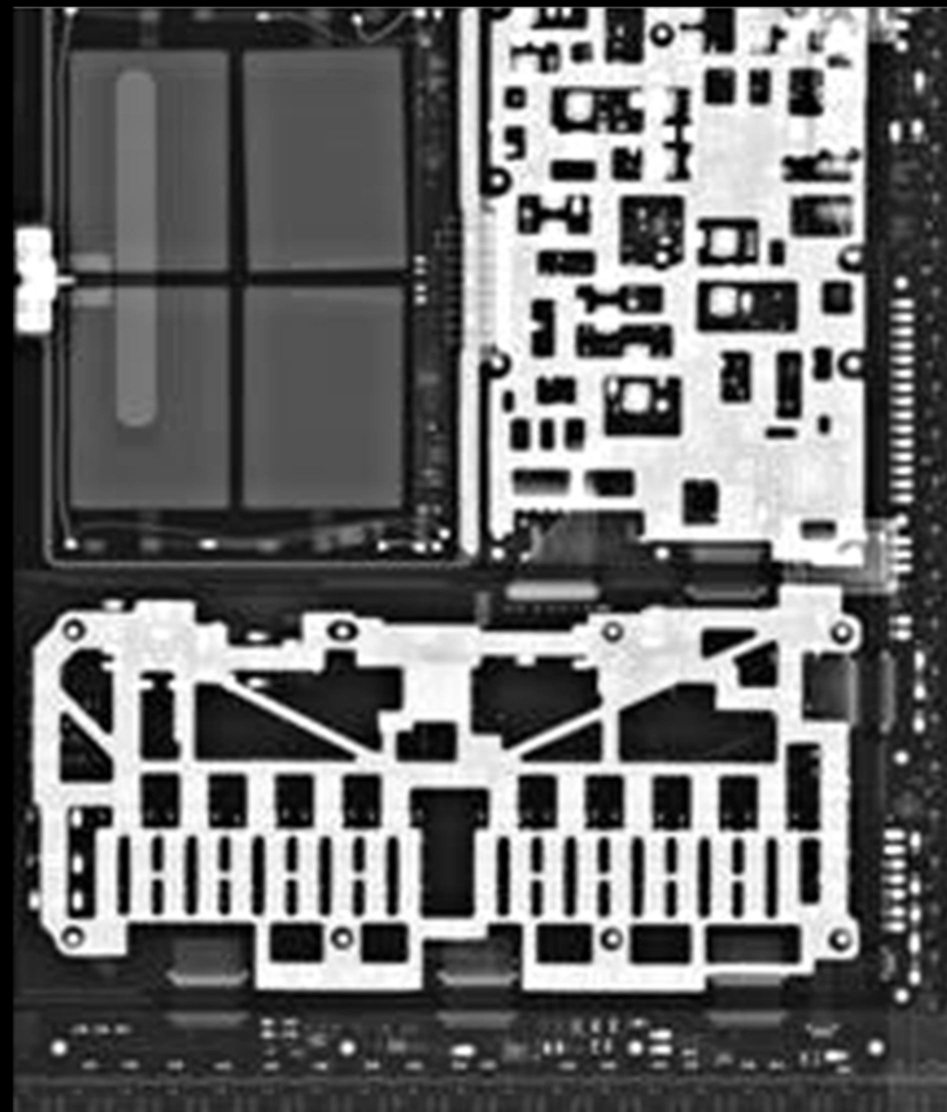
FPD Portable Radiography Issues

- Increased image receptor weight (no grid)

Type	Manufacturer/Model	Weight (lbs)
CR cassette	Fujifilm	4
FPD 14x17" cassette-sized	Carestream DRX-1, Canon CDXI-70C	7.5
FPD 14x17" with handle	Philips MobileDiagnost wDR, Siemens Mobilett Mira (Trixell)	10.4
FPD 16x16" with handle	GE Flashpad	9

FPD Portable Radiography Issues

- Detector expense
  - Sensitivity to drops or other impacts, liquids
  - Some models have drop indicators (digital or analog)
- Cable can be problematic for tethered detectors
- Be aware of backscatter artifacts
  - Reduce technique
  - Put lead behind detector



Reference: Walz-Flannigan et al, AJR 2012

Wireless Connectivity

- Isolated private connection between detector and portable for exposure signal and image data transfer
- Standard network connection from portable to hospital network for worklist and image transmission to PACS

Wireless Connectivity Issues

- Coordinate installation with hospital IT personnel
- ORs, ICUs, Emergency Departments already have many wireless devices in place
- Proximity to other wireless devices may cause dropped signal
  - Option to connect a cable to detector is helpful
- There may be facility restrictions on the selection of radio frequency power, IP addressing, channel
- Manufacturers that provide configurable and most up-to-date wireless systems are preferred

FPD Portable Radiography Issues

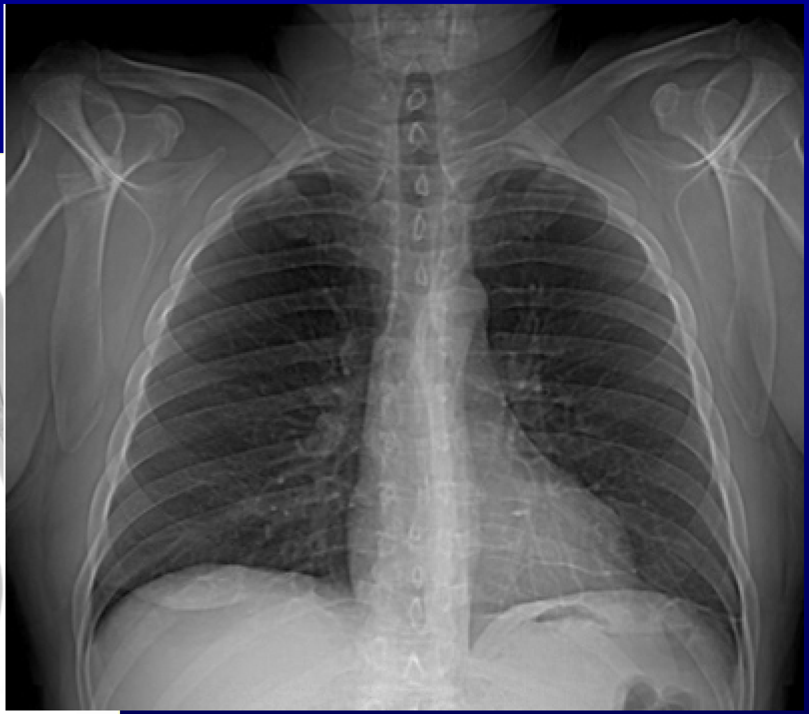
- On-board display monitors
  - Ensure adequate for technologist evaluation of positioning, motion, exposure level
    - Zoom, pan, W/L adjustment needed
  - Physician viewing?
    - Adequate display brightness?
    - Can display be calibrated?
    - Easy replaced if backlight dims?
  - Video output to external display monitor

Courtesy of Siemens

Slot Scanning Systems

- Linear detector coupled with collimated slot x-ray beam
- Typical detector utilize linear CCDs
- Excellent scatter rejection, no grid needed
- Long scan times can result in patient motion during imaging
- Historical systems:
  - Philips Thoravision, Fischer Senoscan

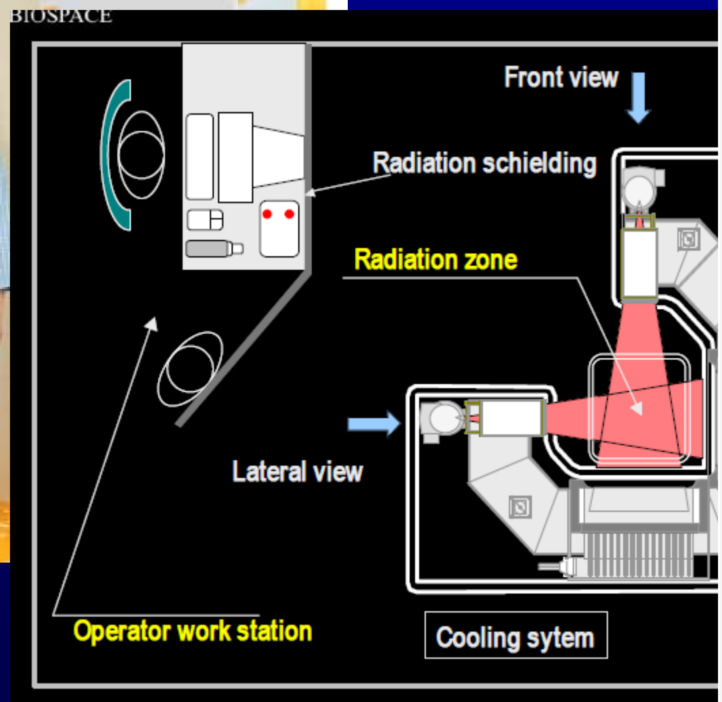
Slot Scanning Systems

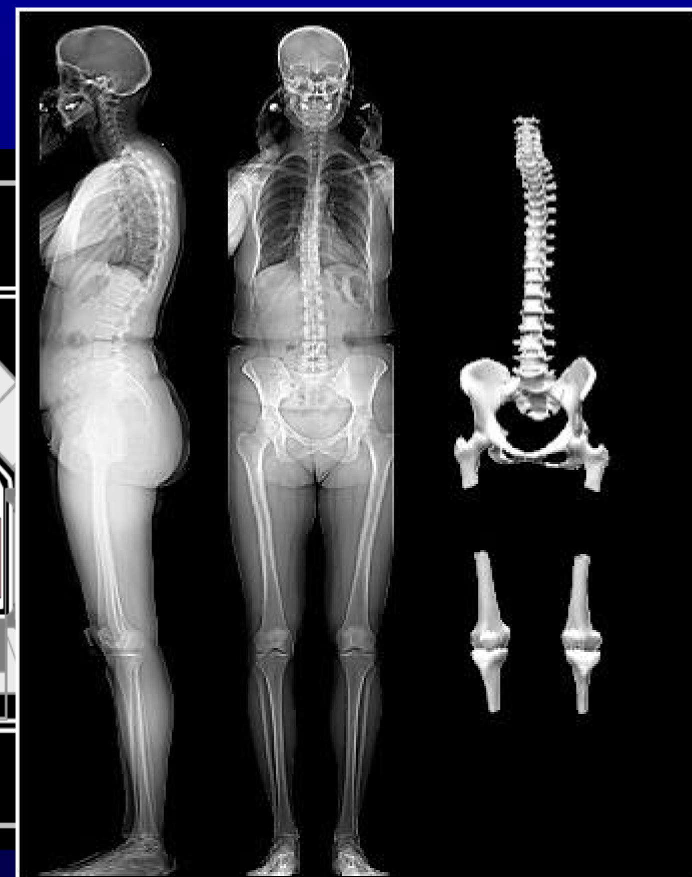


Statscan
Fastest scanning rate: 14 cm/s

Courtesy of Lodox

Slot Scanning Systems





EOS

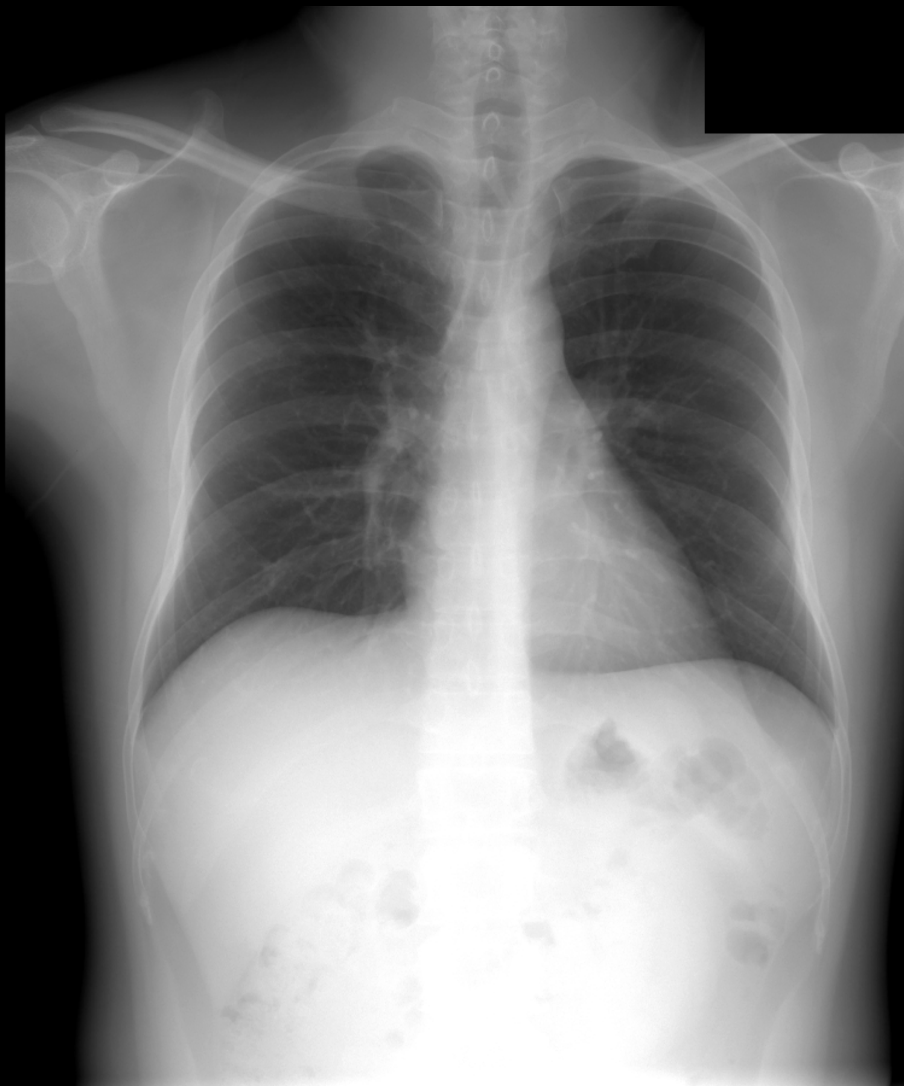
Fastest scanning rate: 15 cm/s

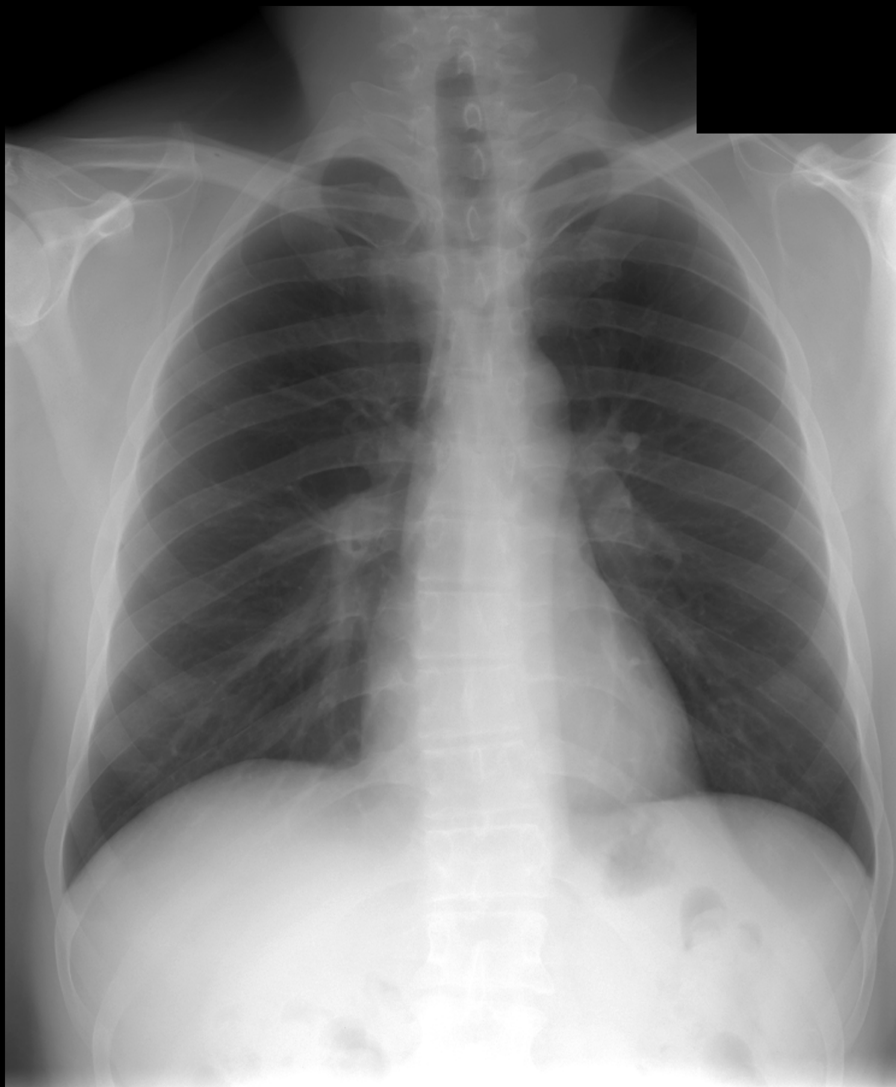
Courtesy of Biospace

Dual-Energy Radiography

- Acquisition of low kVp and high kVp image in single breath-hold
  - Requires FPD with rapid image readout
- Log image subtraction to accentuate either the bone or soft-tissue components of the image
  - $DE = \alpha + \beta(\ln I_{High} - R \times \ln I_{Low})$

    where DE = dual-energy image, I_{High} = high kVp image, I_{Low} = low kVp image, R determines bone or soft-tissue enhancement, α and β scale brightness and contrast of final image




Digital Tomosynthesis

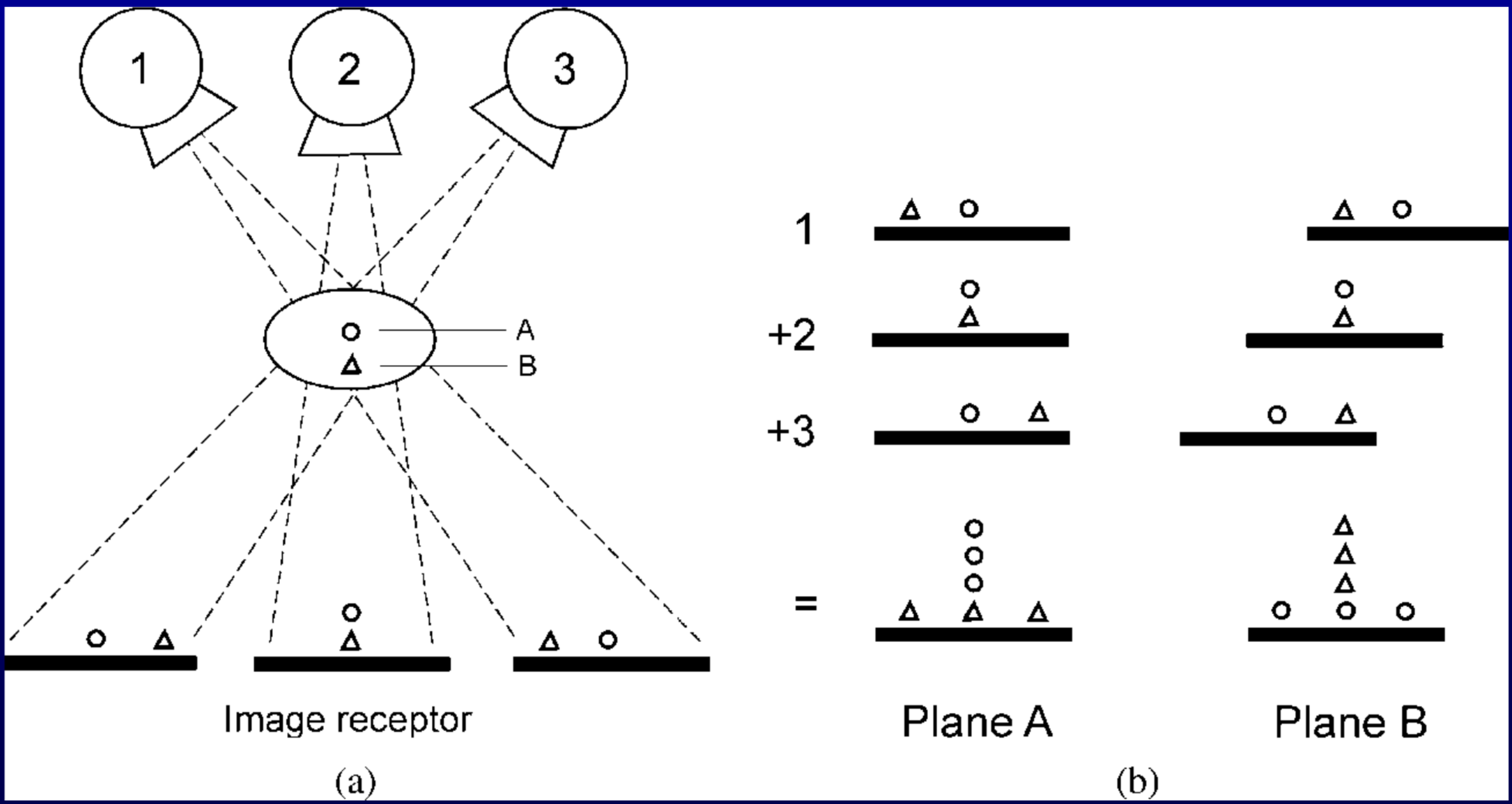
- Acquisition of a series of images while x-ray tube and detector move about patient during single breath-hold
  - Requires FPD with rapid image readout
- Similar to linear tomography except that an arbitrary number of slice planes can be rendered from one acquisition sweep
- Chest imaging is most common radiographic application

Digital Tomosynthesis

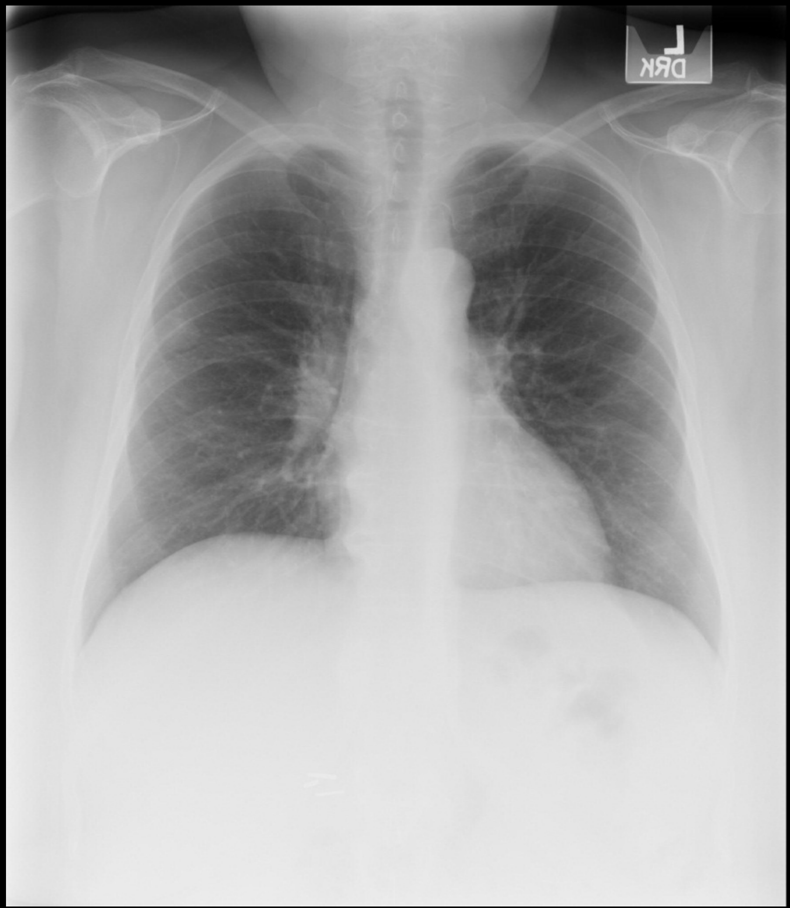
- GE VolumeRAD
  - 61 images acquired in 11 sec
  - For chest imaging, patient dose similar to a lateral chest radiograph

Courtesy of GE

Digital Tomosynthesis



Reference: Dobbins and Godfrey, Phys Med Biol 2003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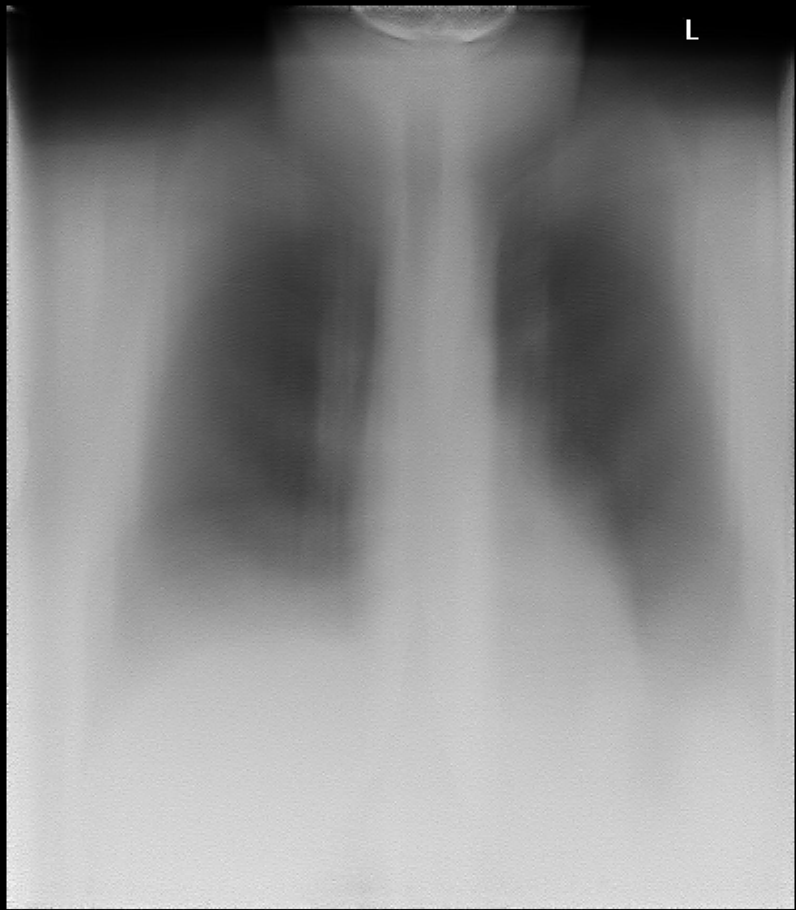
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