Physics of Computed Radiography

Overview
Acceptance Testing
Quality Control

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AAPM 1999 Annual Meeting, Nashville

Computed Radiography (CR)

...is the generic term applied to an imaging system comprised of:

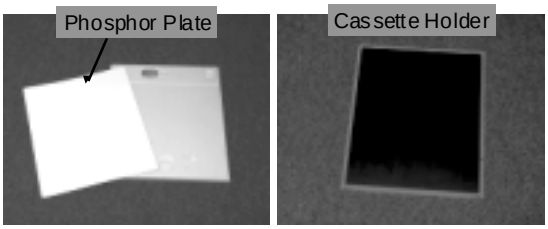
Photostimulable Storage Phosphor
to acquire the x-ray projection image

CR Reader
to extract the electronic latent image

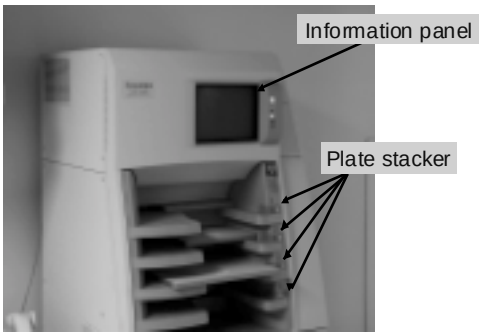
Digital electronics
to convert the signals to digital form

CR Detector

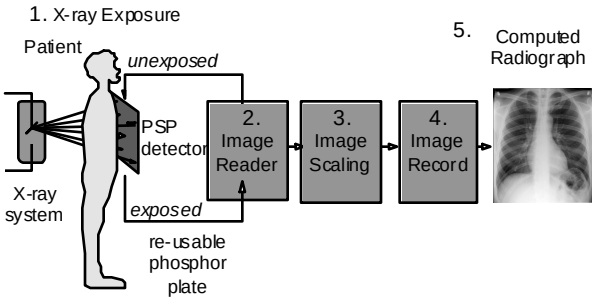
- Photostimulable Storage Phosphor (PSP)
- BaFBr compound, Eu activated



Computed Radiography "reader"



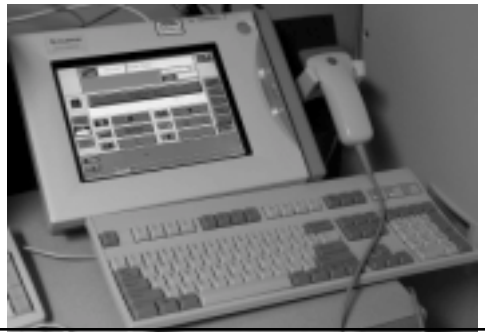
CR Image acquisition



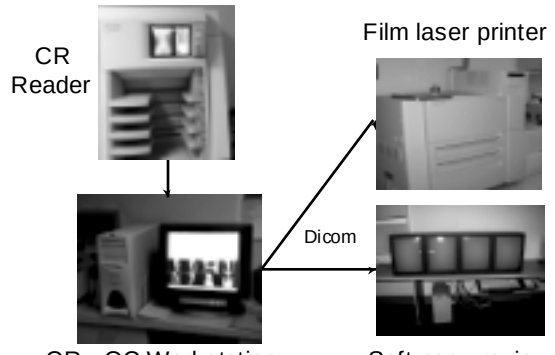
RIS interface CR reader interface

Download patient demographic data; select image processing algorithms

ID terminal: select anatomy-specific exam



Bar-code reader: identify exposed cassette



CR Networking

- DICOM
  - Digital Imaging COmmunications in Medicine
  - Provides open architecture solutions for modality interfaces, storage/retrieval, and print functions
- Technologist QC Workstation
- Modality Worklist Input
- Processed image output

CR vendors

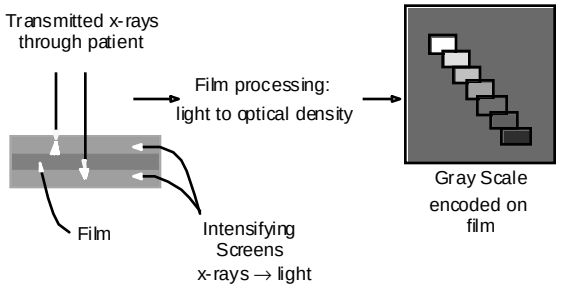
- Fuji …….. (GE, Siemens, Philips, others)
- Agfa …..… (Toshiba)
- Kodak
- Konica
- Lumisys
- Others

CR Trends

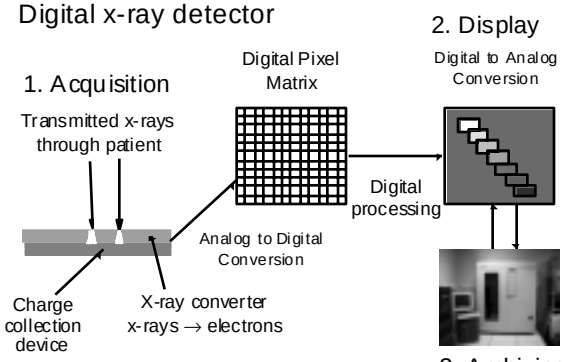
- Lower system costs
- Smaller footprint
- High throughput systems
- Low throughput systems “Table-top” units
- Integrated QC workstations for images
- DICOM output

Conventional film/screen detector

1. Acquisition, Display, Archiving

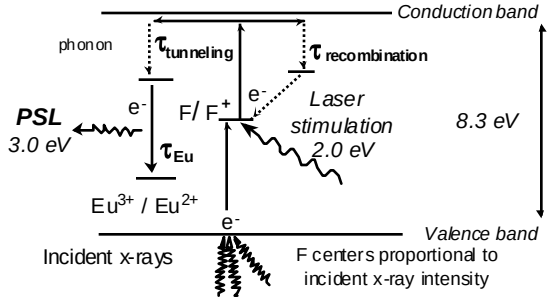


Digital x-ray detector

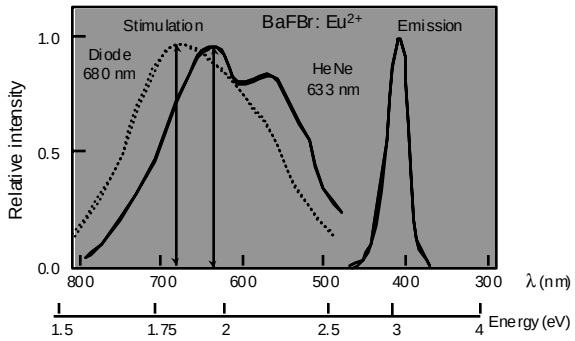


PSP Latent Image Formation

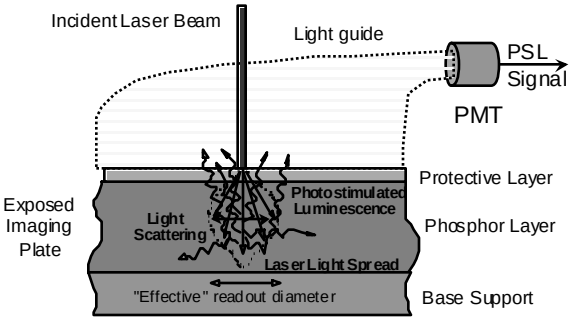
Electrons trapped in proportion to x-rays absorbed



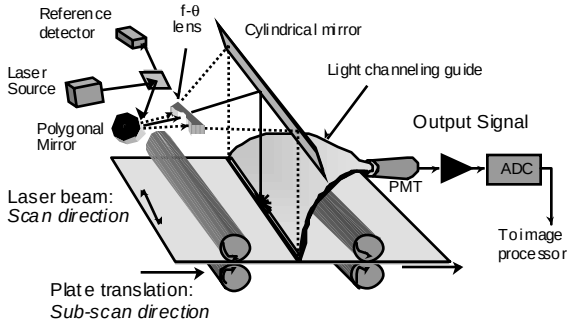
Stimulation and Emission Spectra

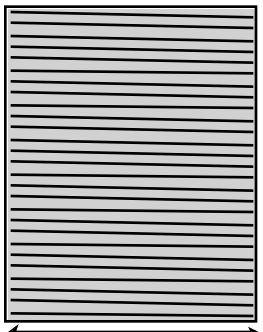


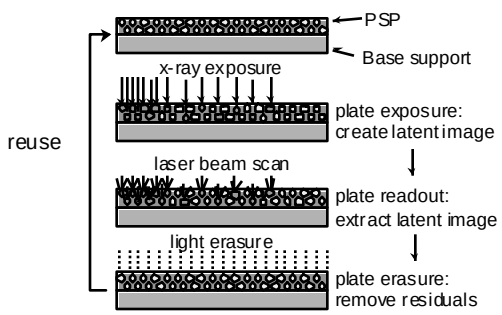
Photostimulated Luminescence



CR: Latent Image Readout

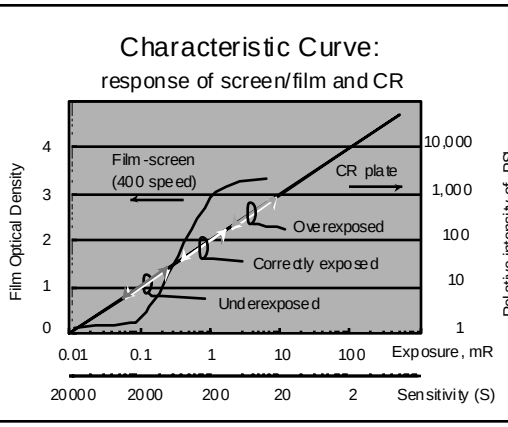






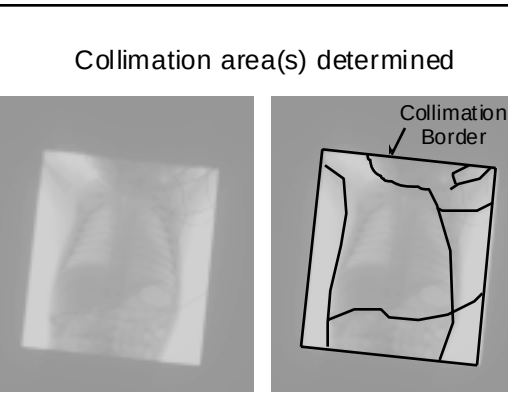
CR Image Manipulation

- Image pre-processing
  - Find the pertinent image information
  - Scale the data to appropriate range
- Contrast enhancement
  - Anatomy specific grayscale manipulation
- Spatial frequency enhancement



Finding the Image Location

- Image recognition phase
  - collimation (Agfa)
  - EDR (Fuji)
  - segmentation (Kodak)
- Finding collimation borders and edges



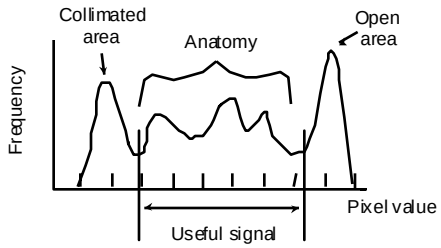
Processing the Image

- Contrast enhancement
  - MUSICA (Agfa)
  - Gradation (Fuji)
  - Tonescaling (Kodak)
- Define dynamic range (histogram analysis)
- Transform to *anatomy specific* contrast

Histogram analysis

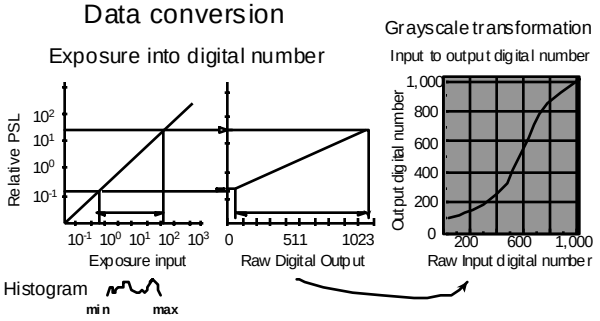
- Frequency distribution of pixel values within a defined area in the image
- Shape is anatomy specific
- Sets minimum and maximum "useful" pixel values

Histogram Distribution



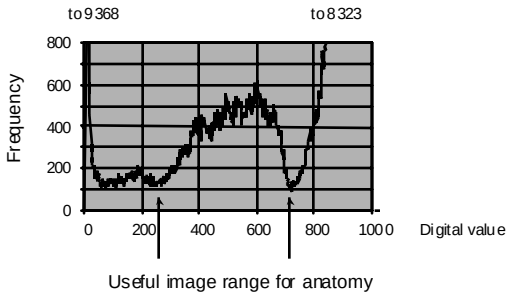
The shape is dependent on radiographic study, positioning and technique

Data conversion

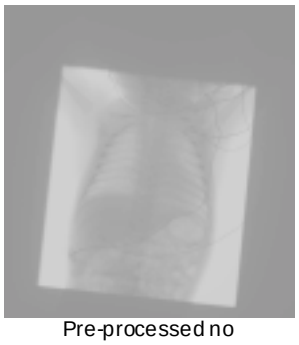


1. Find the signal
2. Scale to range
3. Create film look-alike

Histogram: pediatric image



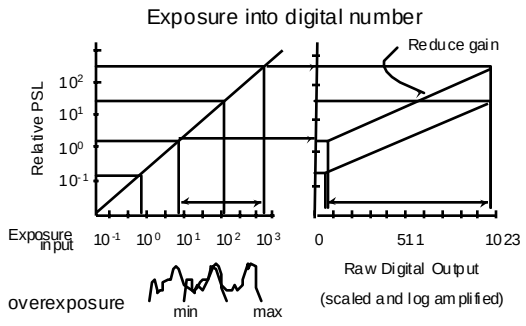
Useful image range for anatomy



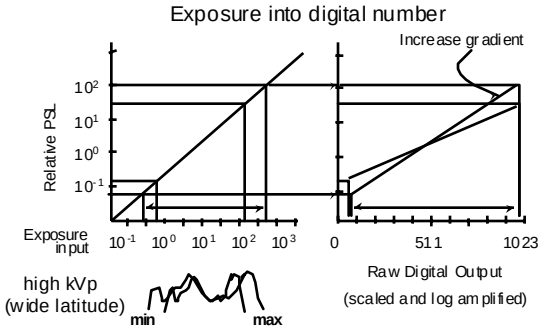
Pre-processed no window/level

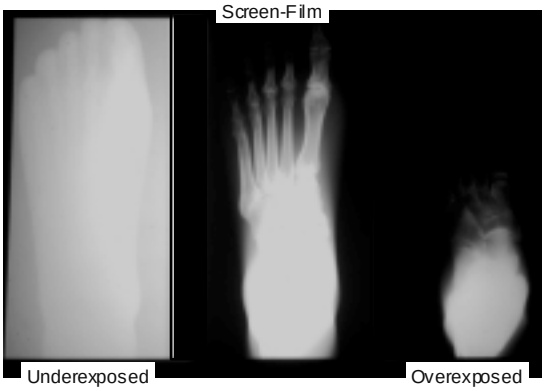
Contrast enhanced

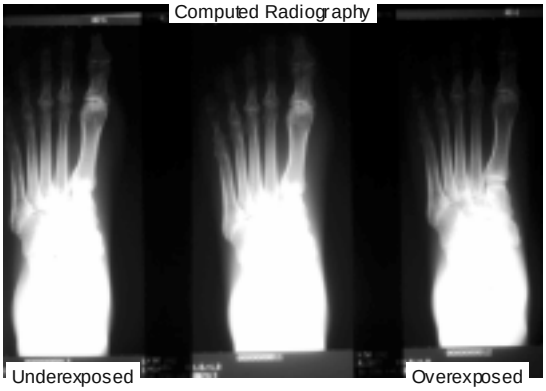
Data conversion for overexposure

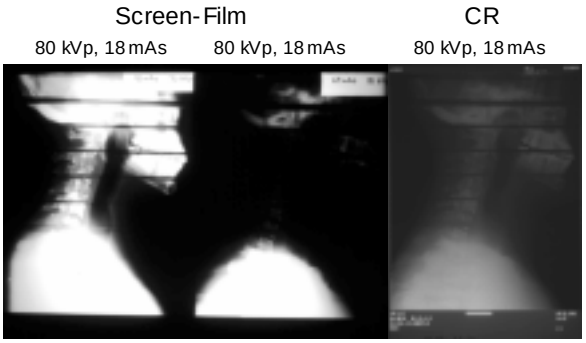


Data conversion for wide latitude

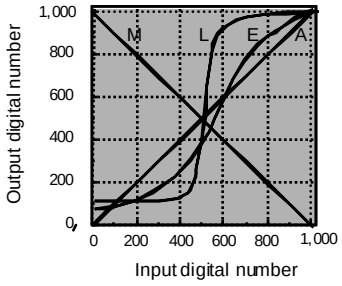






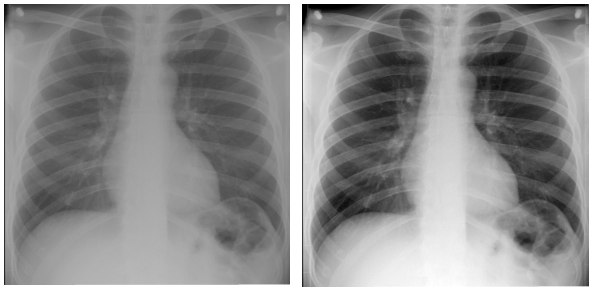


Look-up-table transformation



Fuji System
Example LUTs

CR: Contrast Enhancement



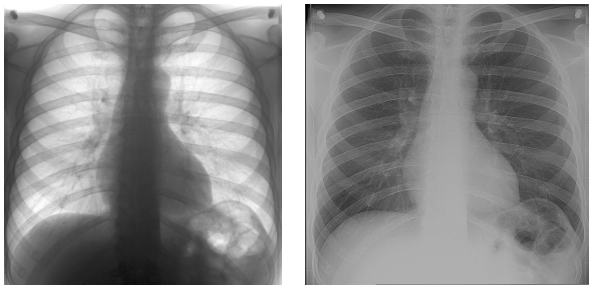
"Raw data" "Contrast Enhanced"

Spatial Frequency Processing

- "Edge Enhancement"

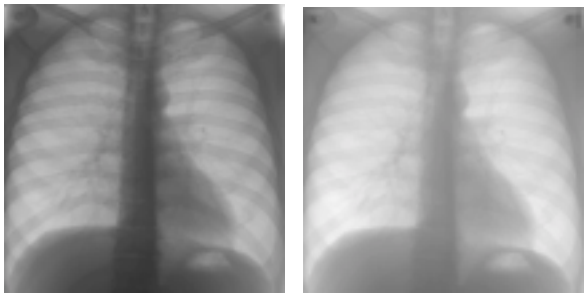
Spatial frequency

CR: Image manipulation



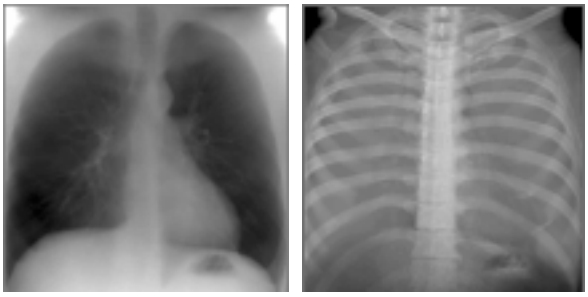
"Black Bone" "Edge Enhanced"

CR: Dual Energy Imaging



Low Energy Image High Energy Image

CR: Dual Energy Imaging



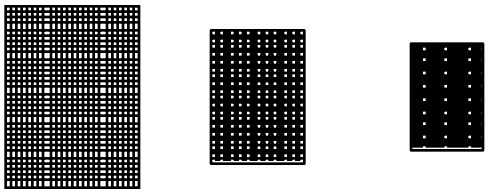
"Tissue only" Image "Bone only" Image

Image Performance Measures

- Spatial resolution
  - Dependent on IP size
  - Less than corresponding speed screen-film
- Contrast sensitivity
  - Dependent on exposure and *SNR*
- Exposure
  - *Variable speed* detector

CR: Spatial Resolution

- Phosphor plate sizes: impact on resolution



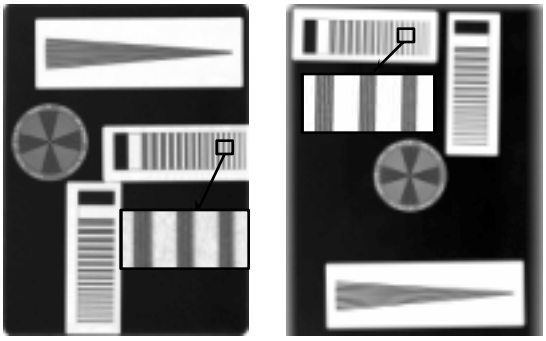
35x43 (14x17) 0.2 mm pixels

24x30 (10x12) 0.14 mm pixels

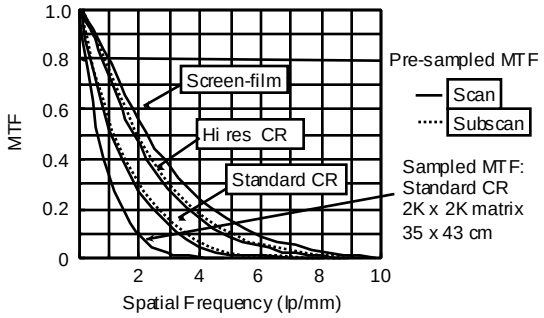
18x24 (8x10) 0.1 mm pixels

High Contrast (Spatial) Resolution

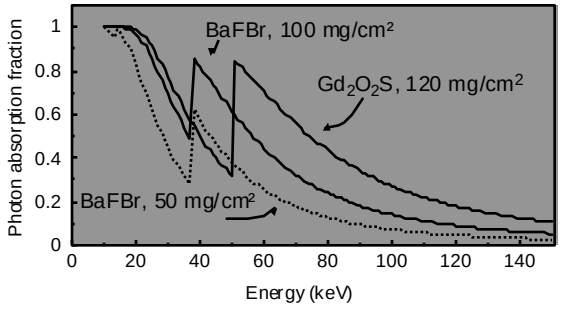
18 x 24 cm 35 x 43 cm



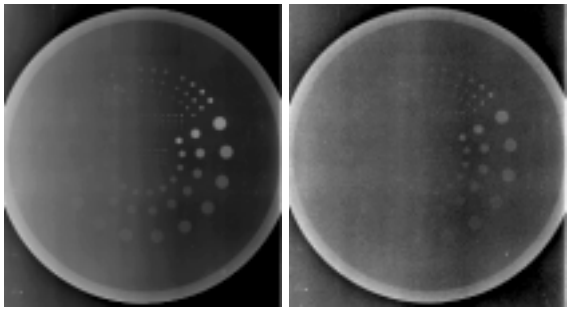
MTF Curves



X-ray Absorption Efficiency

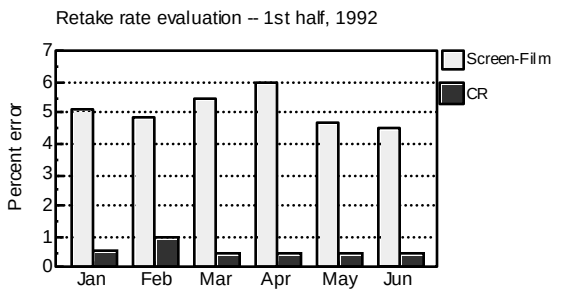


Low Contrast Response: Leeds TO-16

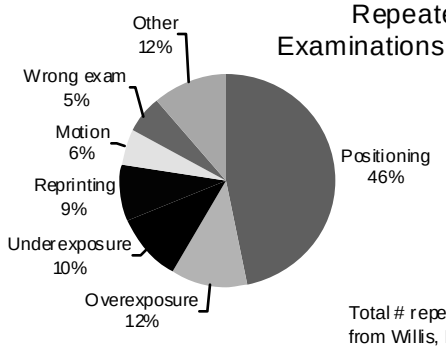


3.5 mR 70 kVp 0.5 mR

Image retake rates

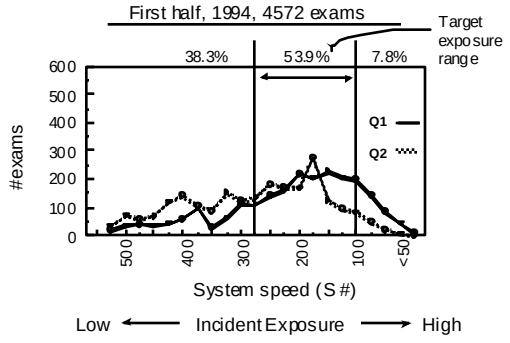


Repeated Examinations with CR

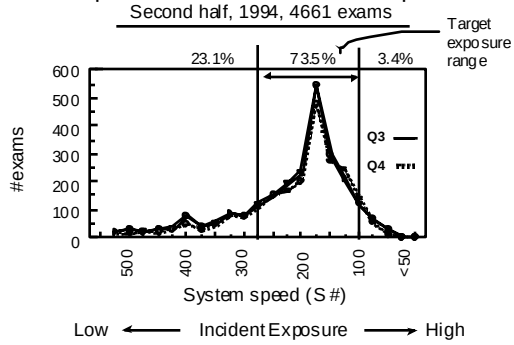


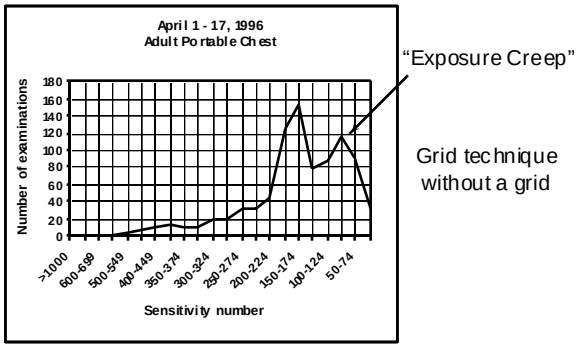
Total # repeats = 1043
from Willis, RSNA 1996

Adult portable chest calculated exposures



Adult portable chest calculated exposures





Guidelines for QC based on Exposure, typical adult exam

System speed		Indication
• >1000	<0.2 mR	• Underexposed: repeat
• 600 - 1000	0.3-0.2 mR	• Underexposed: QC exception
• 300 - 600	1.0-0.3 mR	• Underexposed: QC review
• 150 - 300	1.3-1.0 mR	• Acceptable range
• 75 -150	1.3-2.7 mR	• Overexposed: QC review
• 50 - 74	4.0-2.7 mR	• Overexposed: QC exception
• <50	>4.0 mR	• Overexposed: repeat

Radiation Dose for CR

- Variable Speed Detector
- Optimal dose *2X higher* than 400 speed screen/film
  - Lower absorption efficiency
  - Quantum and electronic noise
  - Readout inefficiencies of latent image
- Anti-scatter grids needed

New issues for the Medical Physicist: Digital Projection Imaging

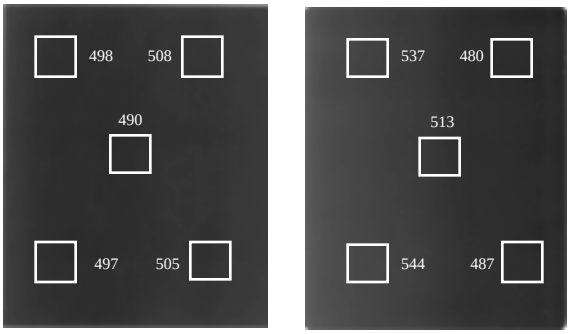
- Differences between screen-film and PSP detectors
- Testing digital systems: vendor specific details
- Indirect (CR) vs. direct (Flat-panel) detectors
- Exposure levels and SNR measurements
- QC phantoms
- Soft-copy displays and workstations

Recommended acceptance tests

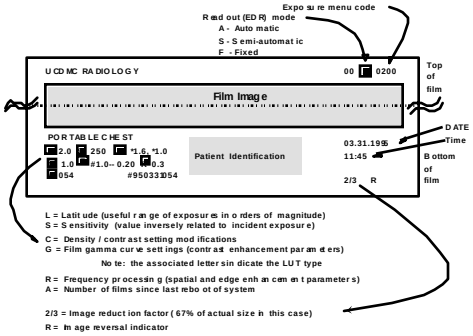
(Task Group #10 -- AAPM)

- Physical Inspection - Inventory
- Evaluation of image processing parameters
- Imaging Plate Uniformity and Dark Noise
- Signal Response
  - Linearity and Slope
  - Calibration and Beam Quality
- Laser Beam Function

Uniformity



Demographics on Fuji CR output



CR Parameter Settings

Fuji CR reader system

Anatomical region	GA	GT	GC	GS	RN	RT	RE
General chest (LAT)	1.0	B	1.6	-0.2	4.0	R	0.2
General chest (PA)	0.6	D	1.6	-0.5	4.0	R	0.2
Port Chest GRID	0.8	F	1.8	-0.05	4.0	T	0.2
Port Chest NO GRID	1.0	D	1.6	-0.15	4.0	R	0.5
Peds chest NICU/PICU	1.1	D	1.6	-0.2	3.0	R	0.5
Finger	0.9	O	0.6	0.3	5.0	T	0.5
Wrist	0.8	O	0.6	0.2	5.0	T	0.5
Forearm	0.8	O	0.6	0.3	5.0	T	0.5
Plaster cast (arm)	0.8	O	0.6	0.4	5.0	T	0.5
Elbow	0.8	O	0.6	0.4	7.0	T	1.0
Upper Ribs*	0.8	O	1.6	0.0	5.0	R	1.0
Pelvis*	0.9	O	0.6	0.2	6.0	T	1.0
Pelvis portable	0.9	O	0.6	0.2	4.0	T	0.5
Tib/Fib	0.9	N	0.6	0.25	5.0	F	0.5
Foot	0.8	O	0.6	0.3	5.0	T	0.5
Foot*	1.2	N	0.6	-0.05	7.0	T	0.5
Os Calcis	0.8	O	0.6	0.4	5.0	F	1.0
Foot cast	0.8	O	0.6	0.5	5.0	F	0.5
C-spine	1.1	F	0.6	0.5	5.0	P	0.5
T-spine	0.8	F	1.8	-0.05	4.0	T	0.2
Swimmers	1.2	J	0.9	0.3	5.0	T	0.5
Lumbar spine	1.0	N	0.9	0.4	5.0	T	1.0
Breast specimen	2.5	D	0.6	0.35	9.0	P	1.0

Date: 7/10/98 | Location: UCDMC, ACC, 3

Medical Physicist: Anthony Seibert, Ph.D. | System Identification: CR unit 3

UC Davis Medical Center

CR Reader and Screens

Signal Response: Calibration and Beam Quality

Note: Use mAs values to provide an approximate exposure of 1 mR to the IP.

				Exposure Conditions			
IP Type:	ST 14x17	Menu = TEST		Focal spot	Time delay	SID (cm)	SMD (cm)
IP SN:		SubMenu = Ave 2.0		1.2 mm	~2 min	140	130
		L = 2, EDR = semi					

kVp Dependency

kVp	Filtration	mAs	mR-meter	mR-P	S	S (1 mR)	OD	NA
60	1 Al/0.5 Cu	15.00	1.06	0.91	121.00	110.59	1.41	NA
80	1 Al/0.5 Cu	4.5	1.06	0.91	108.00	98.71	1.38	NA
115	1 Al/0.5 Cu	1.13	1.14	0.98	115.00	113.04	1.45	NA
				Maximum Difference		14.33	0.07	NA

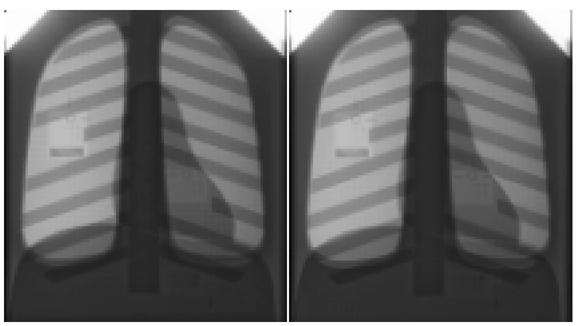
Filtration Dependency

kVp	Filtration	mAs	mR-meter	mR-P	S	S (1 mR)	OD	NA
80	none	0.50	0.96	0.83	187.00	154.79	1.40	NA
80	1 Al/0.5 Cu	4.50	1.06	0.91	108.00	98.71	1.38	NA
80	1 Al/2.5 Cu	60.00	0.99	0.85	124.00	105.85	1.40	NA
				Maximum Difference		56.08	0.02	NA

Recommended acceptance tests

(Task Group #10 -- AAPM)

- High Contrast Resolution
- Noise / Low-Contrast Response
- Distortion
- Erasure Thoroughness
- Anti-aliasing
- Positioning and collimation errors
- Throughput



10 mAs   20 mAs

Date: 7/10/98 | Location: UCDMC, ACC, 3

Medical Physicist: Anthony Seibert, Ph.D. | System Identification: CR unit 3

UC Davis Medical Center

CR Reader and Screens

Inspection Results Summary

		Acceptable
1.	Physical Inspection - Inventory	Yes
2.	Imaging Plate Uniformity and Dark Noise	Yes
3.	Signal Response: Linearity and Slope	Yes
4.	Signal Response: Calibration and Beam Quality	Yes
5.	Laser Beam Function	Yes
6.	High-Contrast Resolution	Yes
7.	Noise /Low-Contrast Response	Yes
8.	Distortion	Yes
9.	Erasure Thoroughness	Yes*
10.	Anti-Aliasing	Yes
11.	Positioning and Collimation Errors	Yes
12.	Throughput	Yes

Comments:

Spreadsheet from Ehsan Samei, Ph.D., Medical University of South Carolina

Quality Control

Three levels of system performance for quality control and system maintenance

1. Routine: Technologist level
   - no radiation measurements
2. Full inspection: Physicist level
   - radiation measurements; non-invasive adjustments
3. System adjustment: Vendor service level
   - hardware and software maintenance

Periodic Quality Control

- Daily (technologist)
  – General inspection
  – Film processor / Laser printer
  – Erase imaging plates
  – Verify digital interfaces and network transmission
- Weekly (technologist)
  – Verify CRT calibration
  – Test phantom images
  – System cleanliness

Periodic Quality Control

- Monthly (Technologist)
  - Film processor maintenance (if any)
  - Inspect and clean image receptors
  - Review film retake rate
  - QC review for "out-of-tolerance" issues

Periodic Quality Control

- Semi-Annually / Annually (Physicist)
  - Evaluate image quality
  - Acceptance tests to re-establish baseline values
  - Review
    - patient exposure trends
    - retake activity
    - QC records
    - Service history

CR: Specifications

- Phosphor plate throughput
- Spatial resolution
- Contrast resolution and dynamic range
- RIS-HIS-DICOM interfaces / compliance
- Peripheral equipment; QC phantoms
- Service issues; plate longevity; warranties

CR: Clinical Considerations

- Sensitivity to scatter
- Multiple images per phosphor plate?
- Patient demographic data
- Image quality control
- Input to PACS

Computed Radiography Experience

- Flexibility is a double-edged sword
  - reduced retakes *but* higher under/over exposures
  - variable speed (need to tailor exposure to exam)
  - more difficult to *correctly* use
- Provides guidelines for new digital detectors
- Indicates the need for *continuous* training

Summary

- CR is currently the only *readily available* technology for direct digital acquisition of projection radiographs
- Experience with CR will provide a framework for future digital detector implementation and QC
- *Filmless* radiology requires a lot more than just digital acquisition devices -- a massive investment in PACS and knowledgeable support personnel, including MEDICAL PHYSICIST INPUT is necessary