Protocol Conversion and Optimization When Converting from CR to DR

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(*Recently Retired*)

Conflict of Interest Disclosure

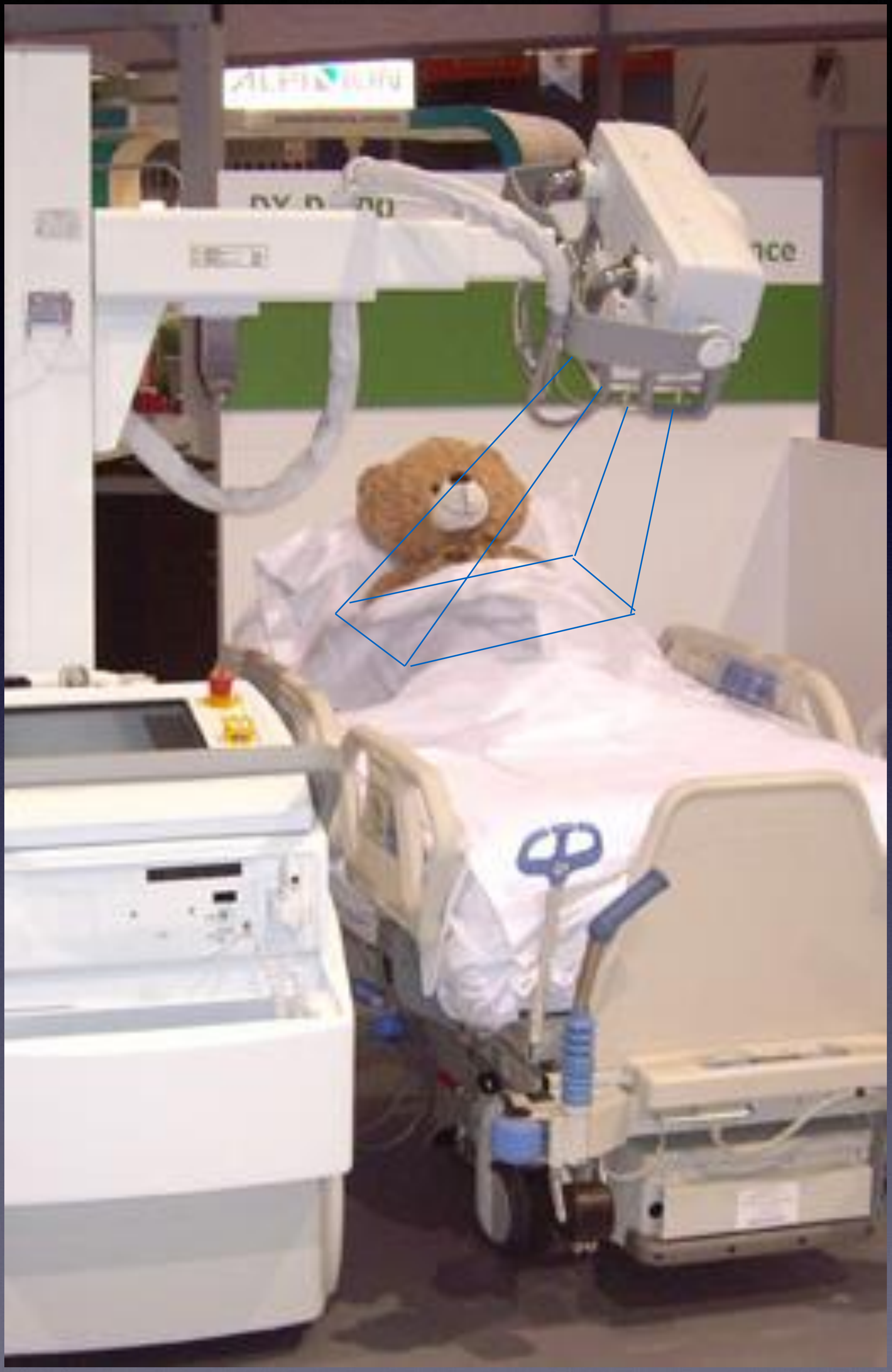
- Meetings such as this conflict with enjoying hobbies and projects that I neglected before retirement!

Assumption:

You already have an imaging operation where projection radiographs are being acquired using CR integrated into a large-scale PACS

Don't Panic!

The fundamental physics of projection radiography apply to CR and DR

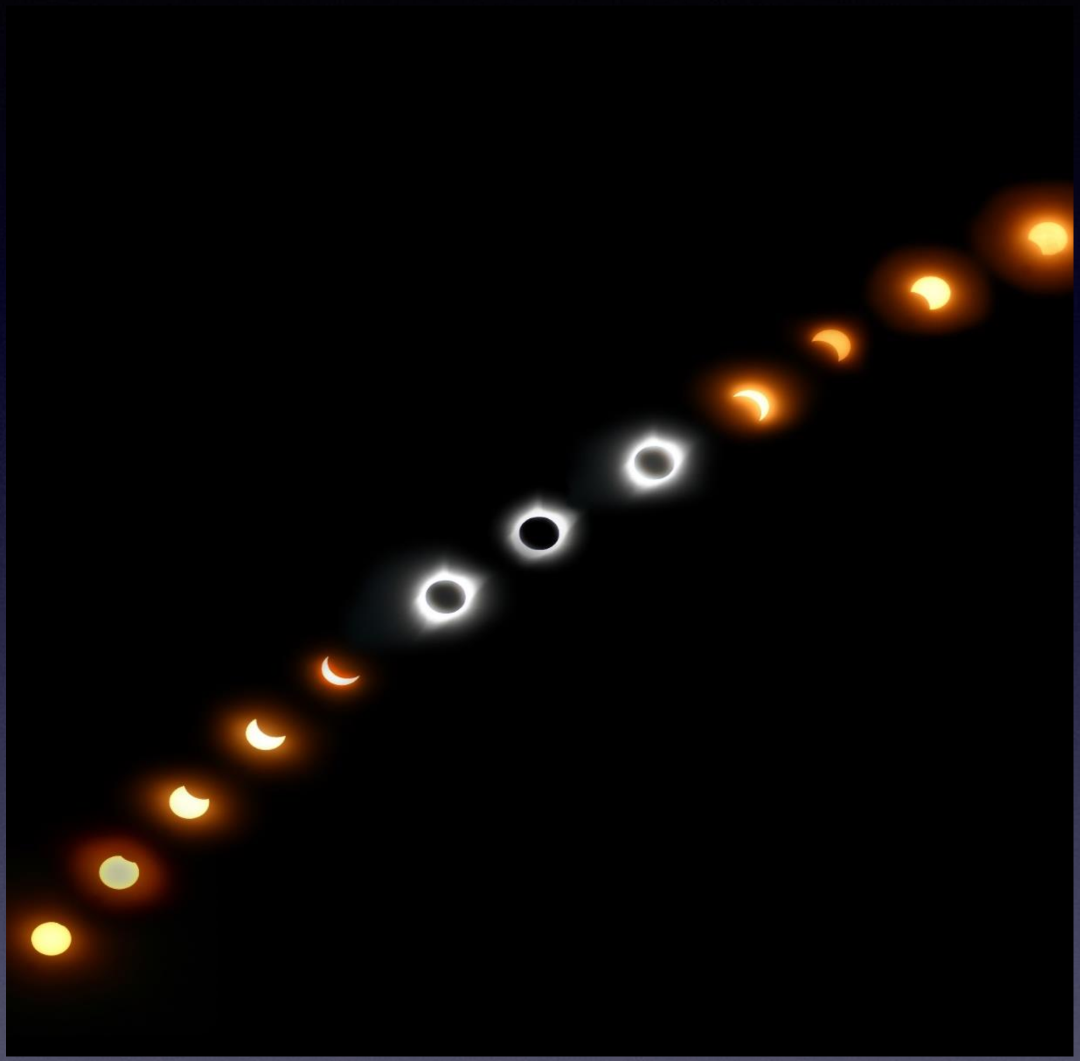


Converting from CR to DR is not that different from converting from SF to CR

- *Images will look different*
- *Radiographic technique likely not optimal*
- *Exposure factor feedback likely different*
- *Different QC*
- *Different artifacts*

Thank you for your time and attention!

- *April Fools!!!*

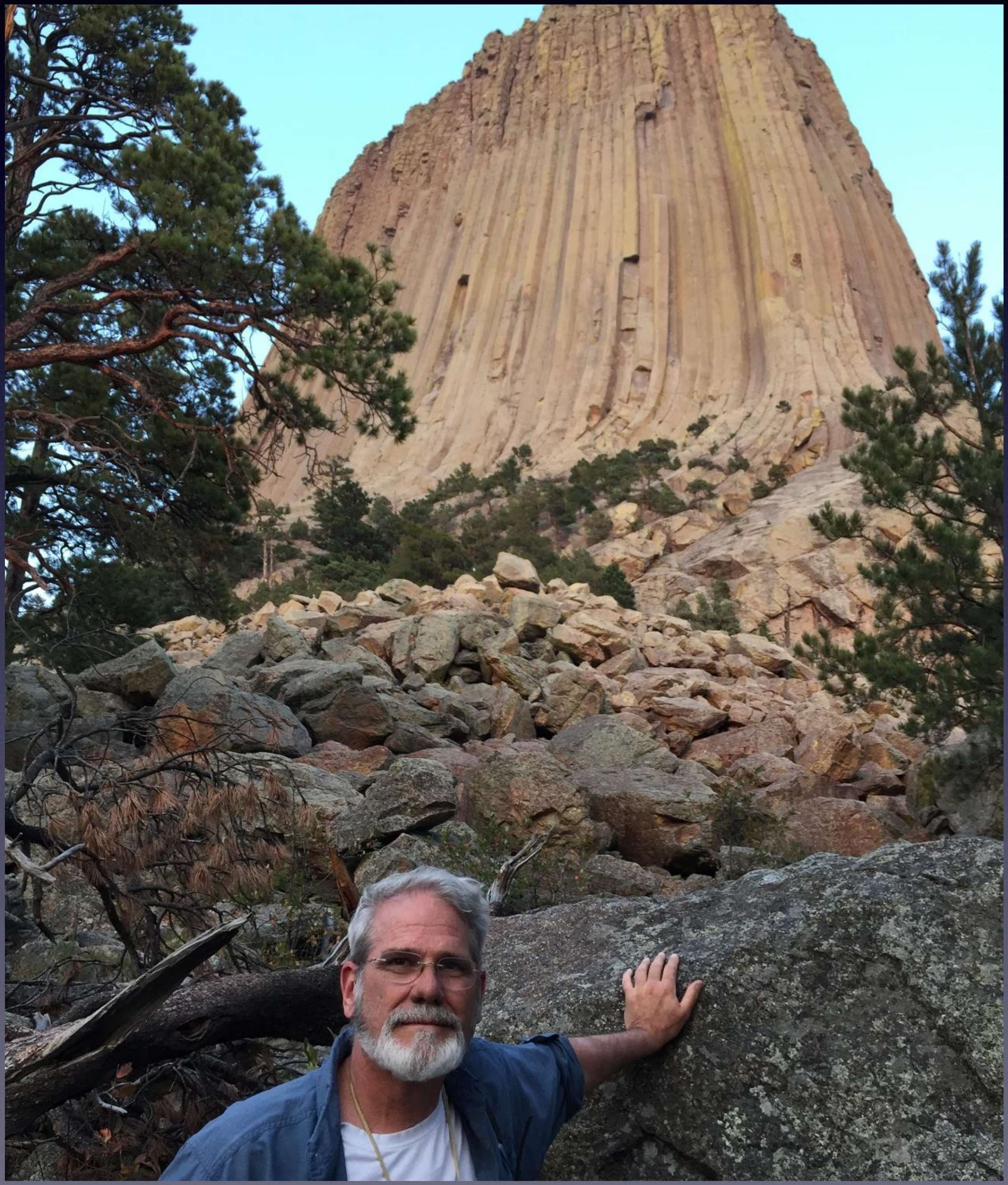


Seriously, conversion and optimization is a three step process

- Understand the sources of variability in DR imaging
  - *Do everything possible to establish consistent presentation of DR images*
- Modify presentation under controlled conditions that don't interfere with clinical operations
  - *Start with a single exam and a handful of clinical images*
- Monitor DR performance and technologist practice
  - *Never-ending story*

DR images will look different

- Even if you continue with the same vendor, consistent presentation of images is not guaranteed
- Digital image processing may not be identical
- Custom processing settings may not yield same rendering
- DR detectors and image processing can vary *even from the same vendor*



Each vendor provides default settings for digital image processing

- Only agreement is that end users don't like them and customization is laborious
- Do they include all examinations and views in your protocol book?
- Are you using the vendor's radiographic techniques?

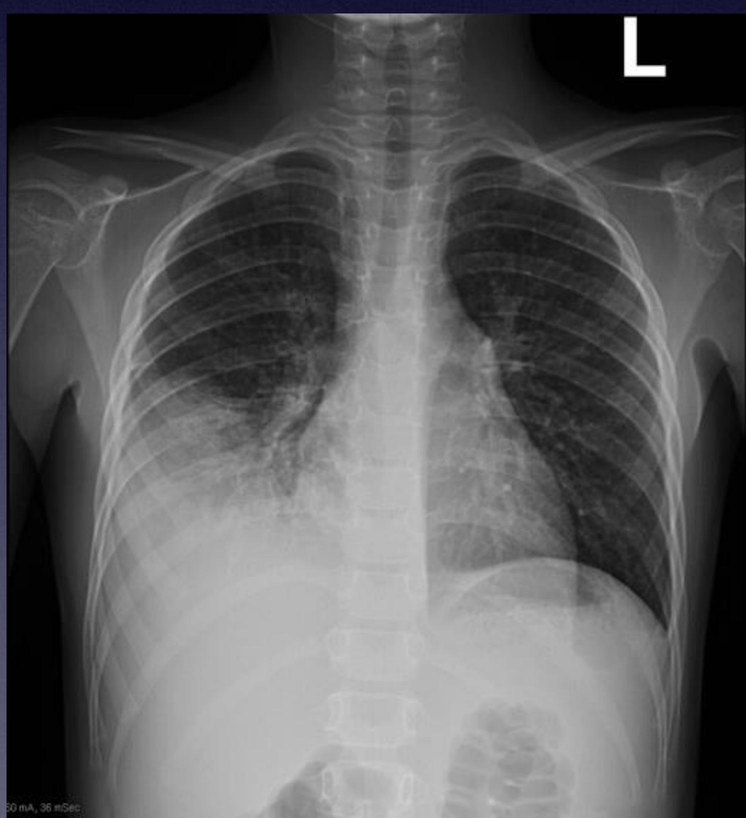
Consistency *vs.* Optimization

- Vender default digital image processing settings are unlikely to be optimal in any given clinical setting, *unless Vendor default acquisition protocols are also used!*

- Image quality and dose differences caused by vendor-specific image processing of neonatal radiographs, William F. Sensakovic, M. Cody O'Dell, Haley Letter, Nathan Kohler, Biywo Rop, Jane Cook, Gregory Logsdon and Laura Varich, *Pediatric Radiology*, Vol 46, pp 1606-1613, 2016.

There is no consensus on the correct appearance for any digital image.

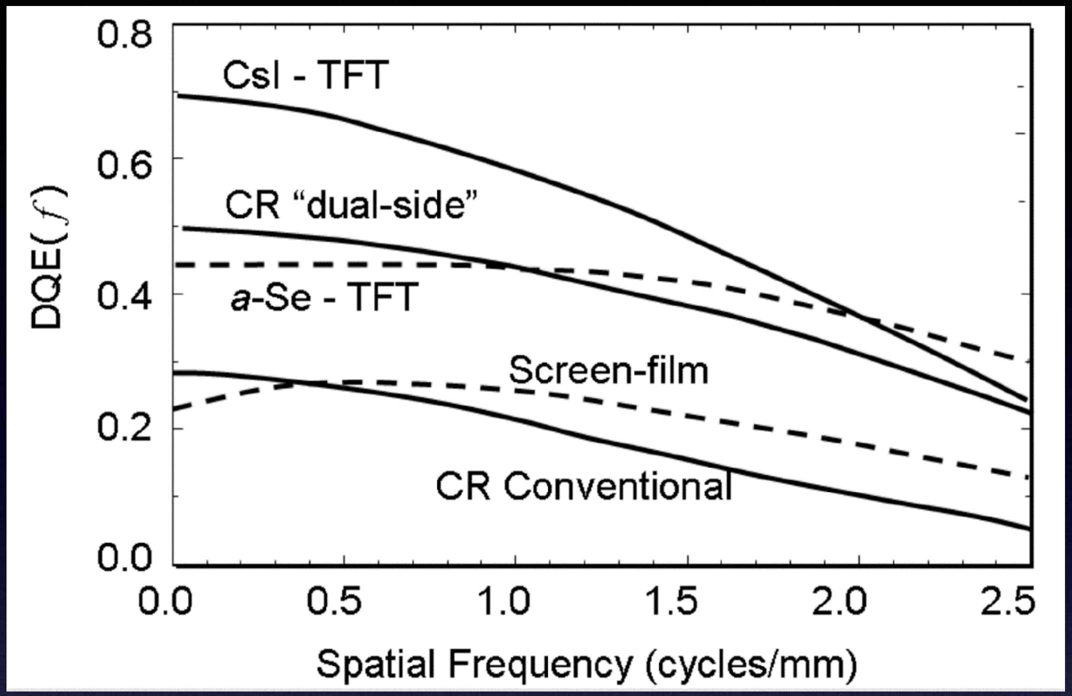
Adult processing *vs.* pediatric processing



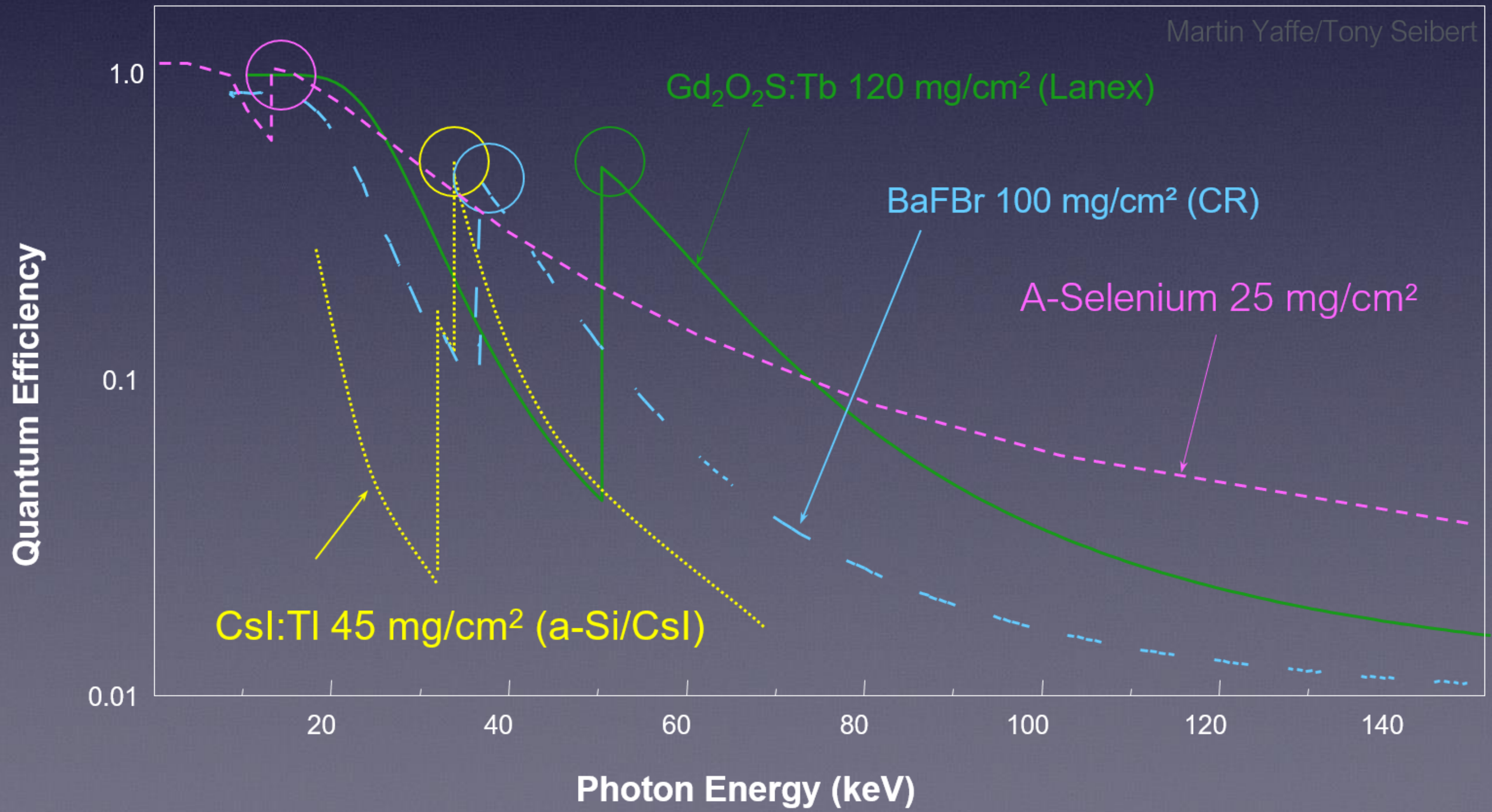
- *Processing controlled by numerous adjustable parameters*
    - Some under operator control
    - Some known only to manufacturer
- *Appropriate amount depends*
    - View
    - Patient thickness
    - Technique
- *No standards for nomenclature*

Radiographic technique likely not optimal

- DQE of CR detectors is generally 1/2 that of DR - less mAs needed for same noise statistics
- K edge of CR detector may be different from X-Ray conversion layer of DR detector - for GdOS higher kVp appropriate; for CsI probably same kVp
- *Caveat: too low a kVp may produce excessive contrast at excess patient dose, esp. using AEC*



J Anthony Seibert Pediatr Radiol 2004



K-edges of Conventional Screens

Brand Name	*Composition*	*K edge (keV)*	*Speed Class*
Cronex Par Speed/Hi Plus	$CaWO_4$	70	100/250 (CRONEX 4)
Lanex Fine/ Medium/ Regular	Gd_2O_2S:Tb	50	100/250/400 (ORTHO G)
Quanta V	Gd_2O_2S:Tb + LaOBr:Tm	50 & 39	320/400 (CRONEX4/8)
Quanta III	LaOBr:Tm	39	800 (CRONEX 4)
Xomatic Fine	$BaPbSO_4$	37	32 (XRP)
Xomatic Regular	$BaSrSO_4$:Eu	37	200 (XRP)
Quanta Detail/ Fast Detail	$YTaO_4$:Tm $YTaO_4$:Nb	17	100/400 (CRONEX 4)
GAF Rarex B Midspeed	Y_2O_2S:Tb	17	

How can we exploit DR's dose efficiency?

- Digital image processing of the same DR image by different vendors' methods using default image processing settings significantly affects perceived image quality.

- This is important because *Acquisition protocols* can be modified to exploit the difference in perceived image quality to optimize dose.

- Image quality and dose differences caused by vendor-specific image processing of neonatal radiographs, William F. Sensakovic, M. Cody O'Dell, Haley Letter, Nathan Kohler, Biywo Rop, Jane Cook, Gregory Logsdon and Laura Varich, *Pediatric Radiology*, Vol 46, pp 1606-1613, 2016.

Following the vendor’s default radiographic technique can be problematic

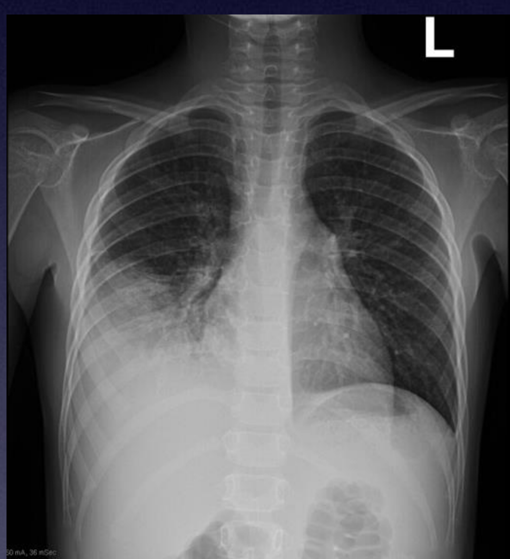
- kVp can vary widely
- Beam quality at the same kVp can vary widely (1st and 2nd HVL)
- Did vendor use same SID? Same collimation? Same grid?
- Did vendor provide sample clinical images?

There is no consensus on the correct appearance for any digital image

Interval change?

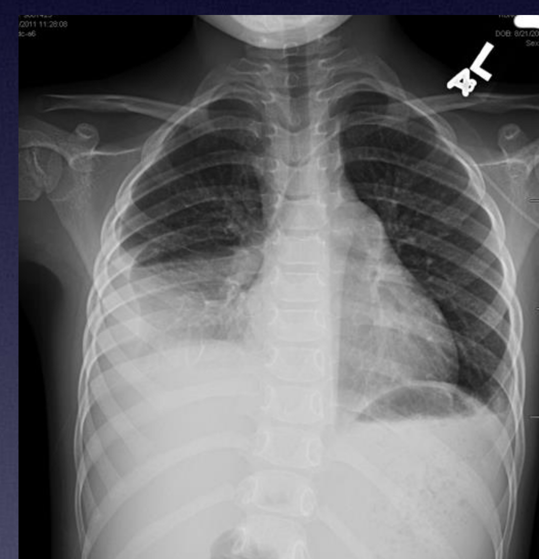
Same female 8 y/o Chronic Myeloid Leukemia patient

10/7, 10/10, 10/14



AP 110 kVp
5.8 mAs

AP 120 kVp
3.1 mAs



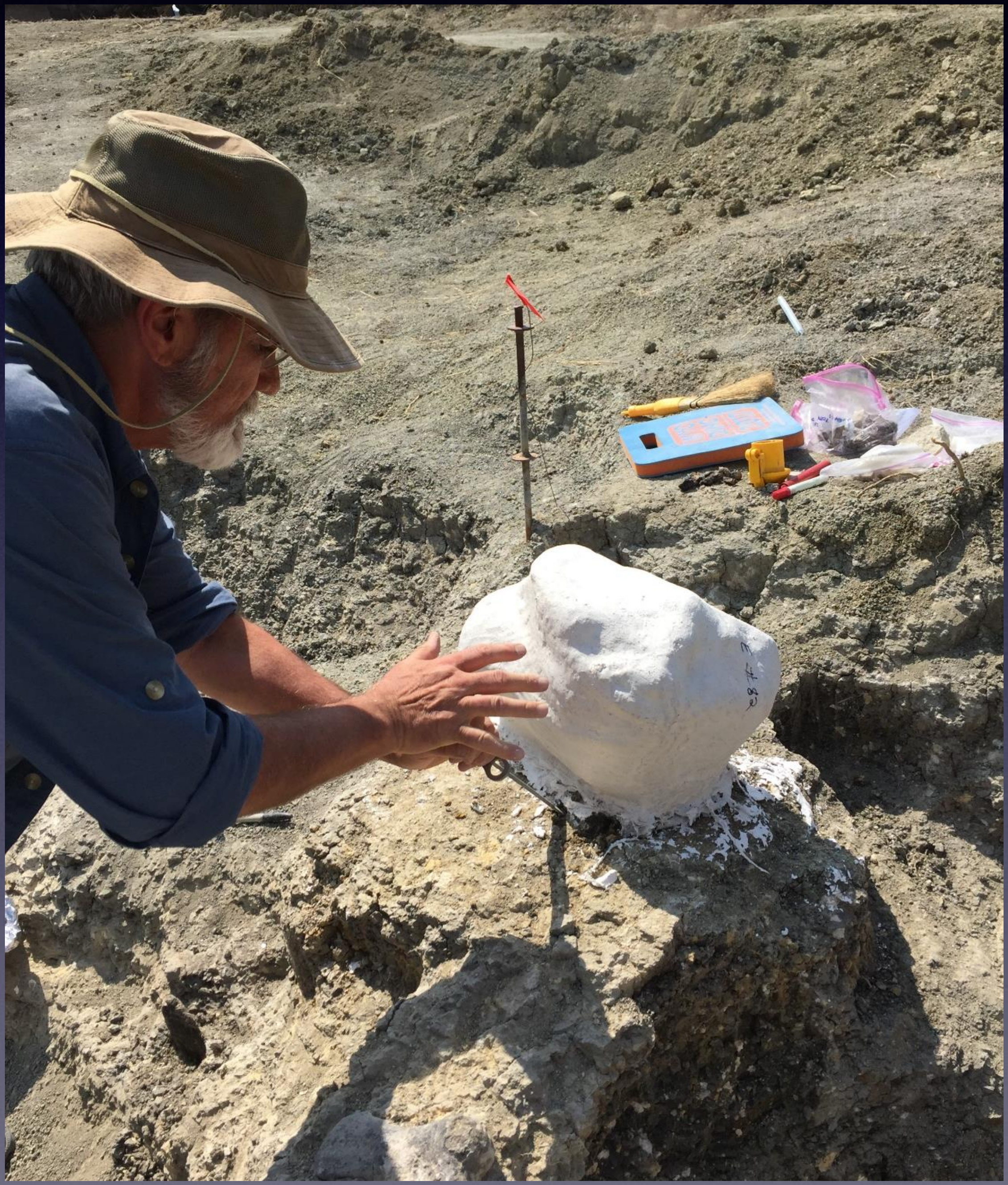
PA 100 kVp
17.3 mAs

Technique chart calls for PA 115 kVp 2.5 mAs (180 cm SID w/ non-removable grid)

- *Processing controlled by numerous adjustable parameters*
    - Some under operator control
    - Some known only to manufacturer
- *Appropriate amount depends*
    - View
    - Patient thickness
    - Technique
- *No standards for nomenclature*

Exposure factor feedback likely different

- Traditional exposure indicator units are common practice in CR
- DR systems being installed today typically provide IEC exposure indicators - the deviation index based on the target exposure index



No standards exist for the amount of radiation necessary to produce an acceptable CR or DR image

- Auto-ranging allows CR and DR to make nice-looking images at both low and high exposures
- Higher exposures tend to make images look less noisy and foster “dose creep”
- Exposure factor control is all about balancing the need for radiation to reach the detector with the need to limit dose to the patient
- *Only enough SNR is needed to visualize important clinical features*
- Exposure indicators were developed to provide operator feedback on how much radiation reached the detector

Traditional exposure indicators

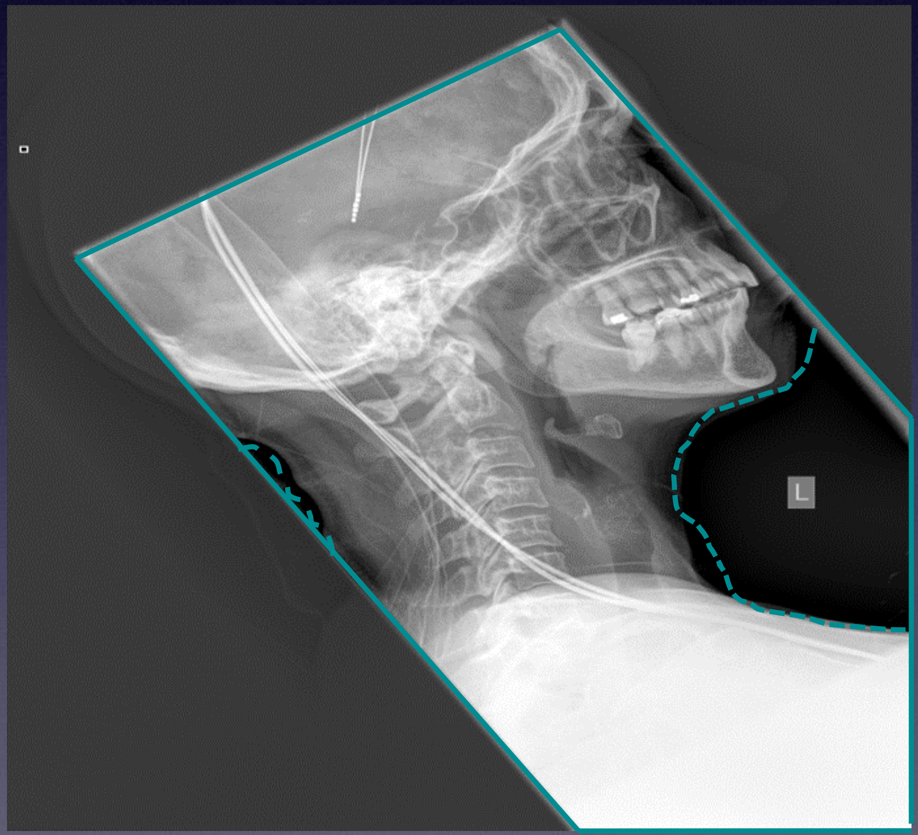
Agfa	Fuji	Kodak/CSH	Konica/Minolta	GE	Philips	Canon	Swissray	IDC
lgM	S#	EI	S#	DEI	EI_S	REX	DI	F#

The variety and inconsistency of traditional Exposure Indicators created a problem for technologists who worked with different CR and DR systems.

- The American Association of Physicists in Medicine (AAPM) Task Group 116 published a report on exposure indicators in July 2009.
- Basic concept included an exposure index that is proportional to the Air KERMA (exposure) at the detector, and a deviation index that tells how close we came to reaching a target exposure value.
- *Specific target values have yet to be established …*
- The International Electrotechnical Commission (IEC) published a standard for Exposure Index definitions in August 2008.
- The medical equipment manufacturers have been implementing this standard into their new CR and DR systems, including their associated QC systems.
- PACS systems are following with DICOM compliance.
- AAPM TG members were representatives to the IEC work group, so that the IEC standard is compliant with the AAPM report.

Digital image processing must first find the “Values of Interest” (VOI).

Detecting the Values of Interest (VOI)



Courtesy Eric Gingold, Thomas Jefferson University Hospital

- *Exposure recognition*
  - Detect collimator boundaries or anatomy within FOV
- *WW/WL Adjustment via Histogram Analysis produces:*
  - Exposure compensation
  - Latitude compensation
  - Contrast maximized for VOI
  - Exposure indicator

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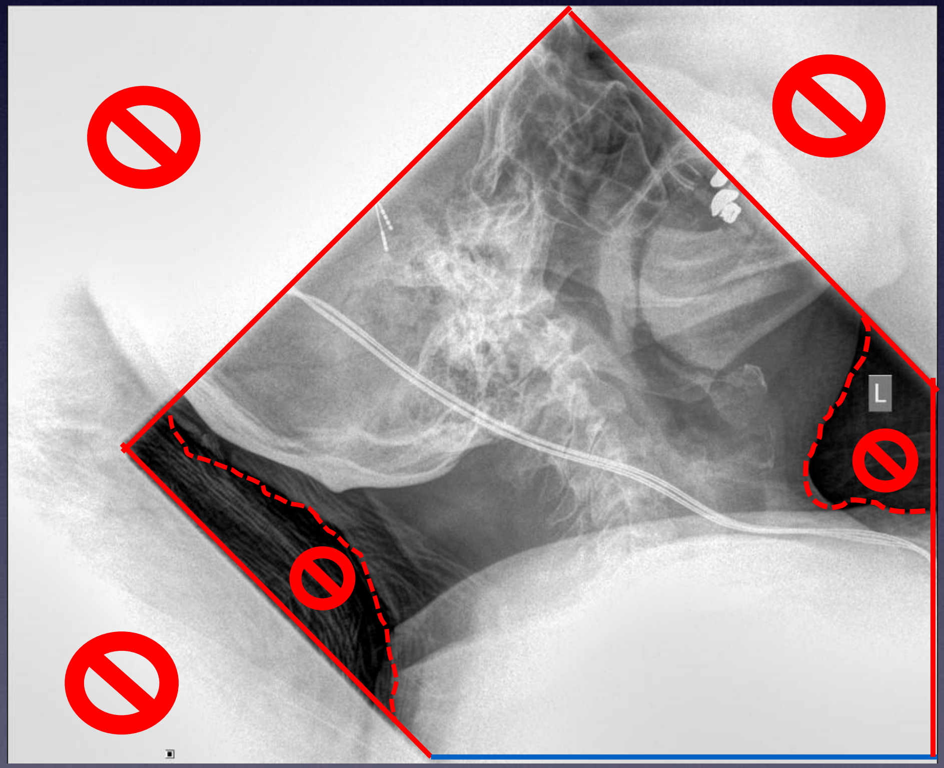
Failing to Detect the Values of Interest (VOI)



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New exposure index has caveats

- By definition it reports detector exposure of standard beam
- It depends on detector calibration
- It depends on detection of the field of view, the determined values of interest
- The deviation index depends on the target exposure index: *what was the target and why?*

TG 116 provided some guidance on how DI could be used (Table 2.)

- The guidance was not well-thought out.
  - *"too strict and did not accurately reflect clinical practice"*
  - *generated controversy in the community*
  - *spawned another AAPM Task Group*

TG 232 was to establish "practical" DI recommendations

- Investigation of the state of practice
  - *To establish achievable goals (reference levels)*
  - *To establish action levels in DR*
  - *To update Table 2*
- *Report published: Jaydev Dave et al. 2018 Med Phys 45(11)*

The objective data is there for you to establish your own local standards for target values and action levels

Just like the traditional Exposure Indicators,
the new Exposure Index and Deviation Index are subject to interferences
(and must be properly calibrated and configured)

DI = - 0.4

Beware segmentation errors!

DI = - 18.2

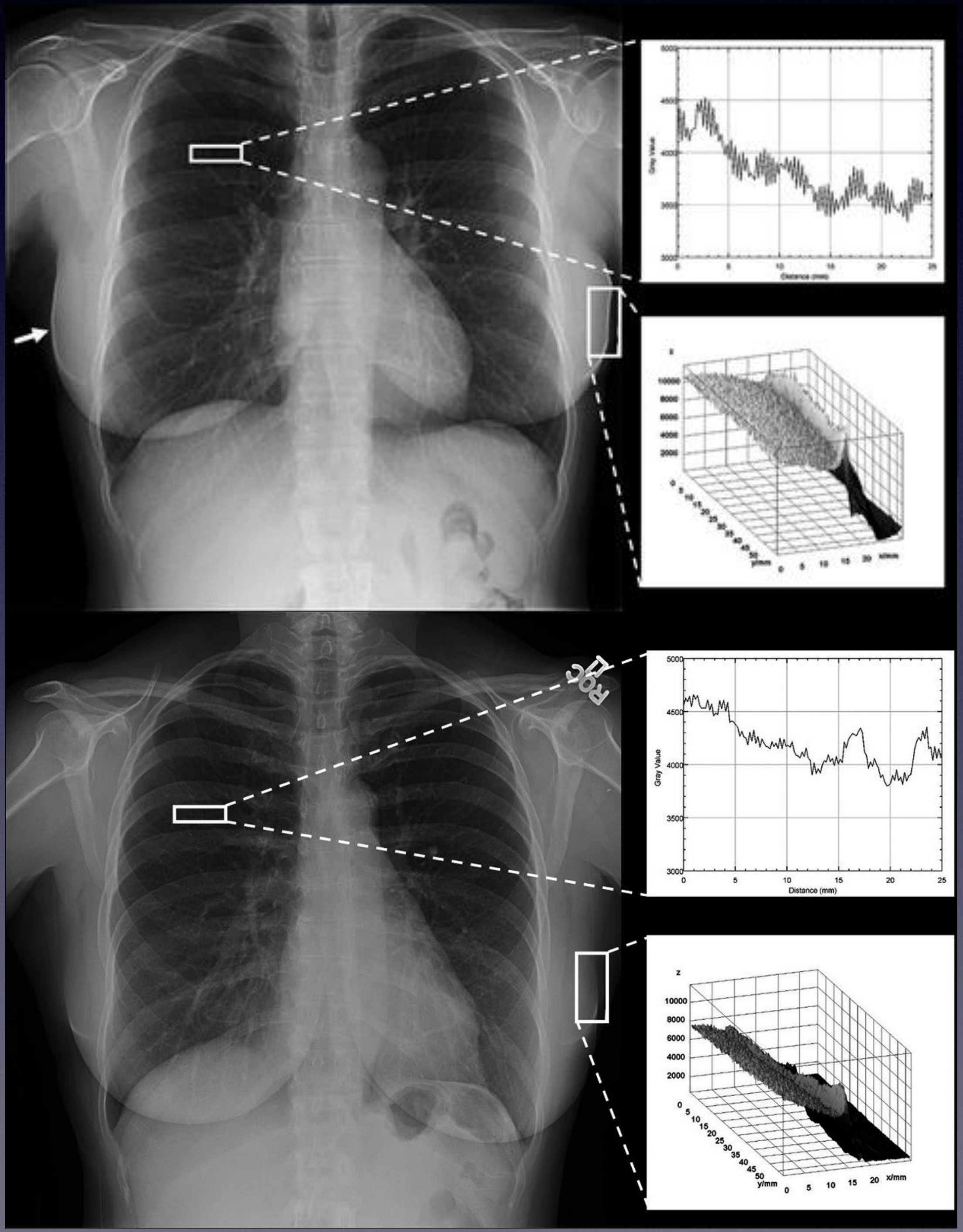
Different QC

- CR practitioners are familiar with QC activities necessary for consistent imaging results

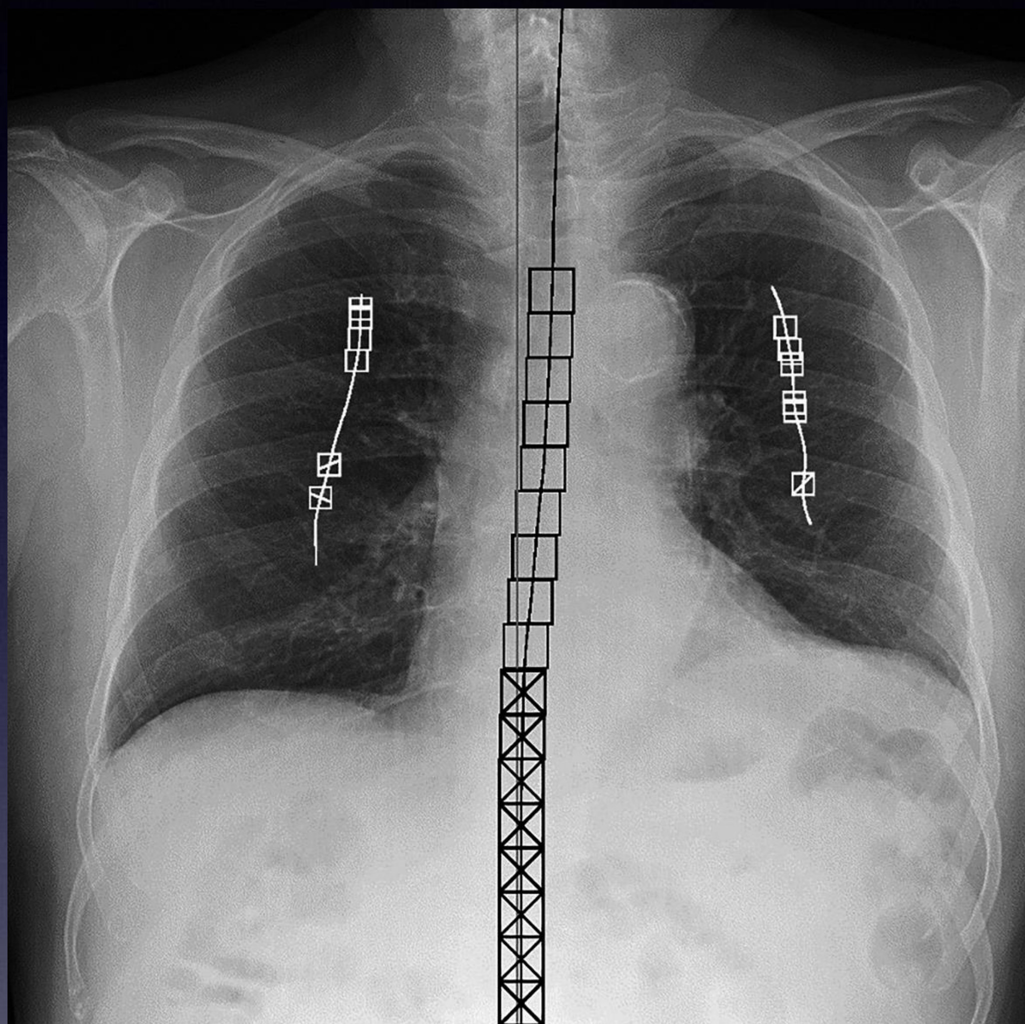
- DR QC is less well-known, less established - what are the sensitive measurements that distinguish between normal and abnormal performance?

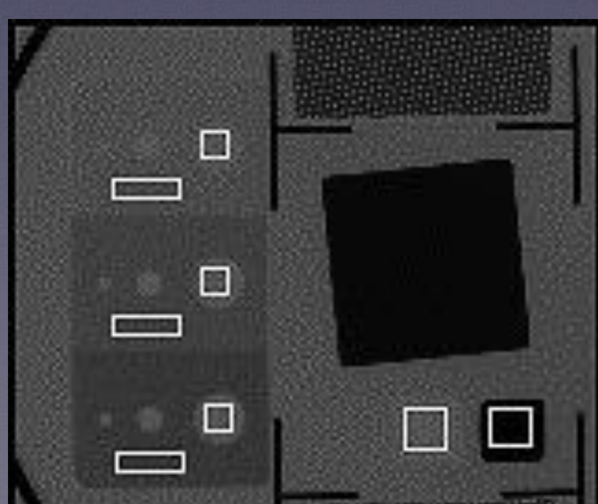
What should we monitor?

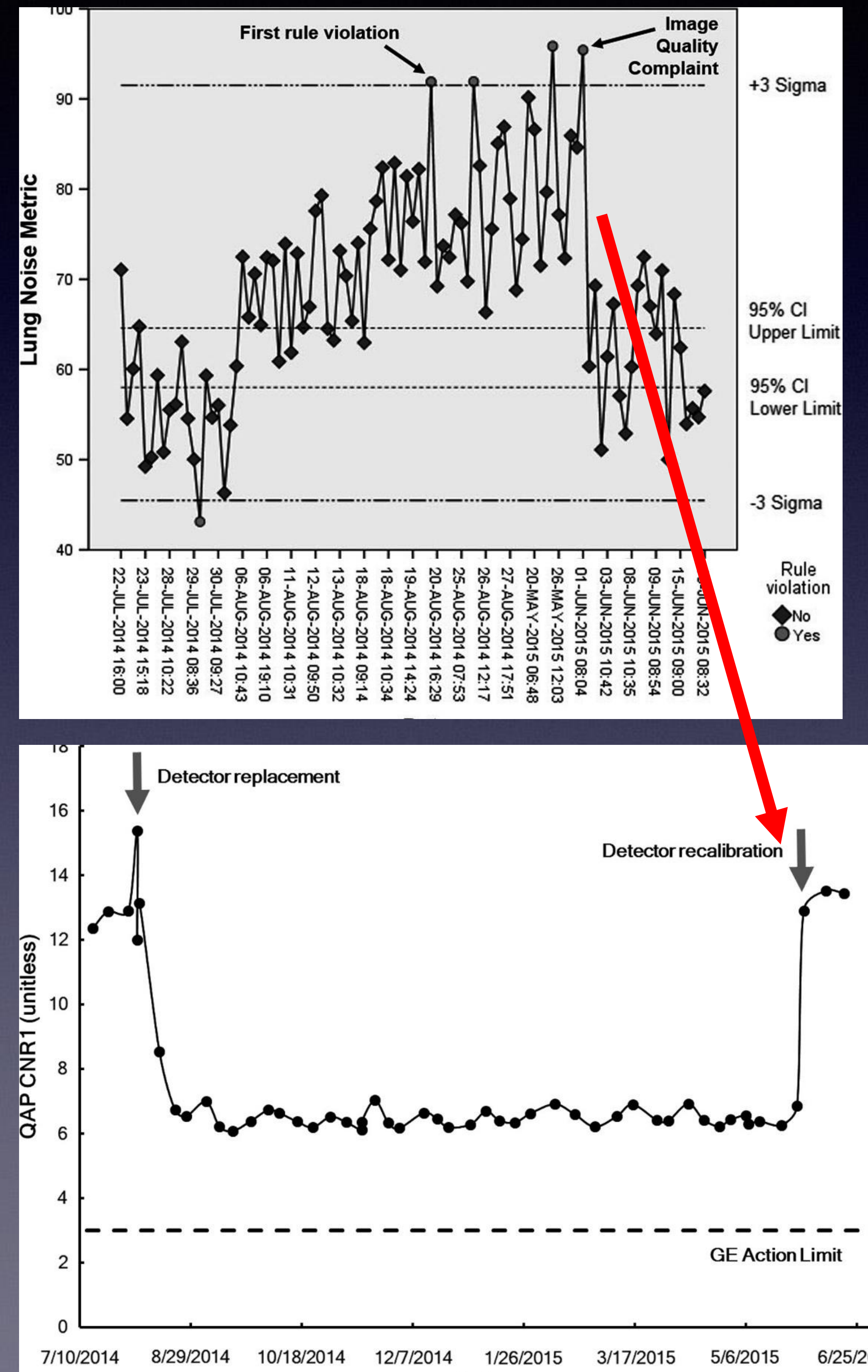
- Vendor automated or semi-automated QC can be helpful especially if you follow longitudinal results
- A simple flat field exposure can reveal problems
- Gain and offset calibration is the primary countermeasure for many problems
- Detector problems manifest in clinical images in noise, inappropriate contrast, and artifacts
- Measurements on clinical images provide the most timely indication of performance decrement



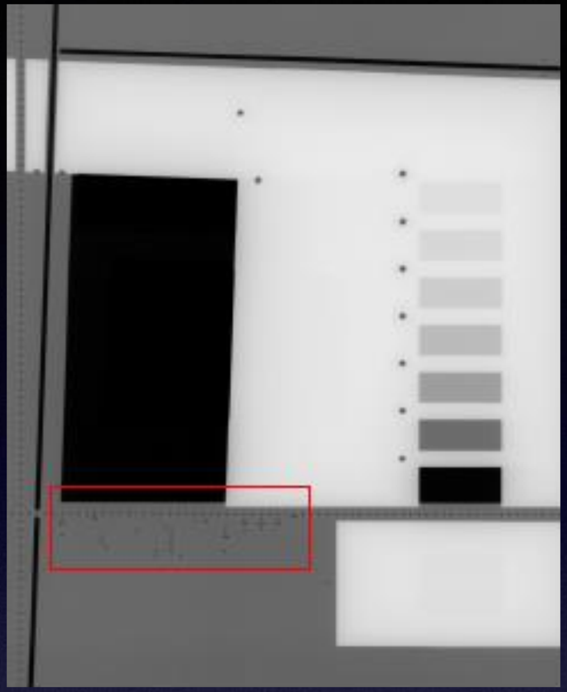
Clinical measurements *vs.* Automated QC

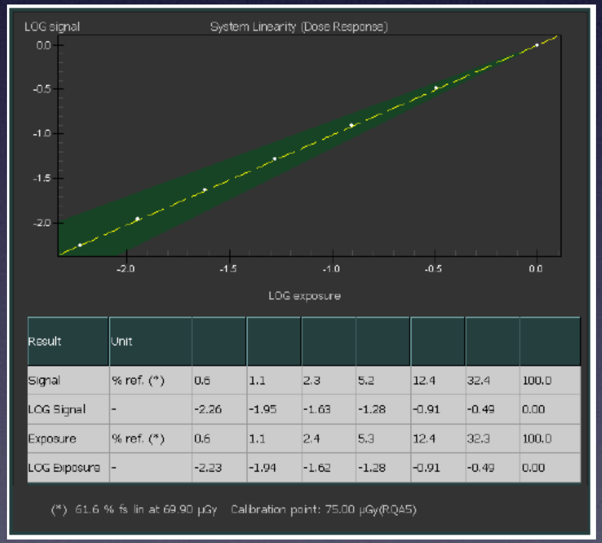


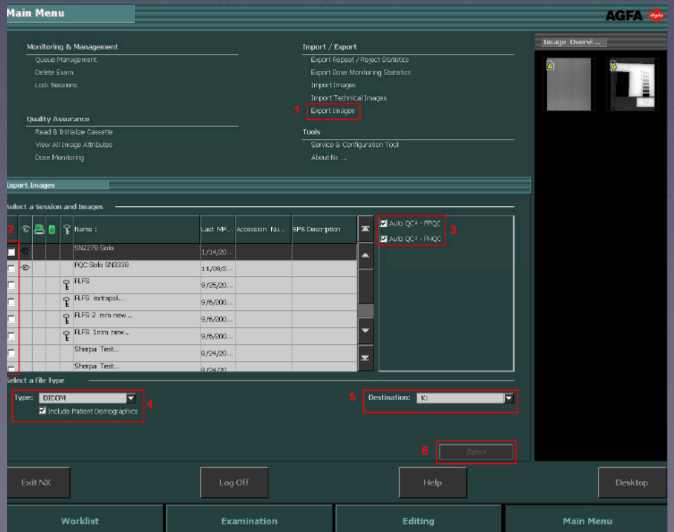


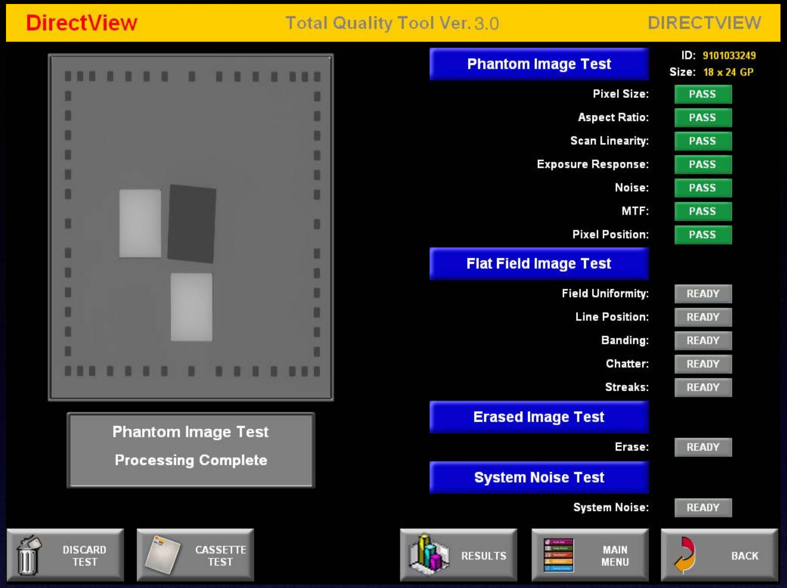


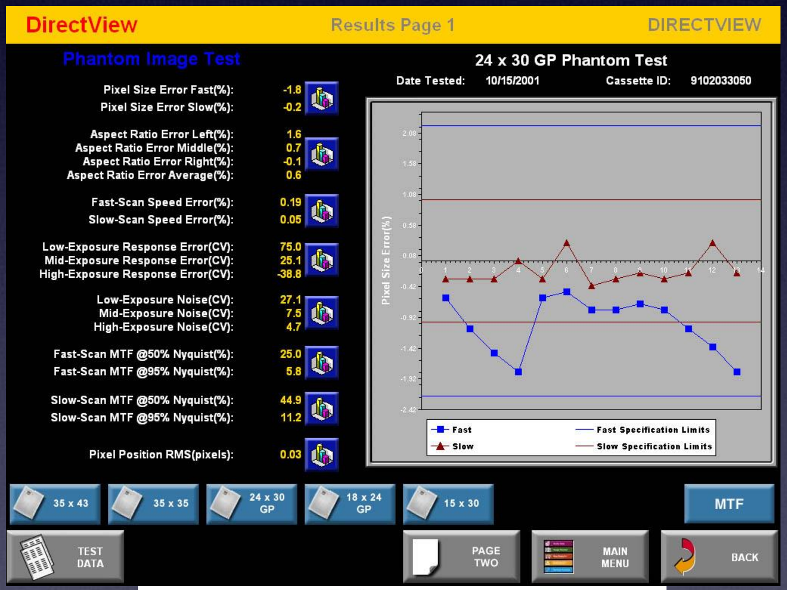
Automated evaluations of the image receptor

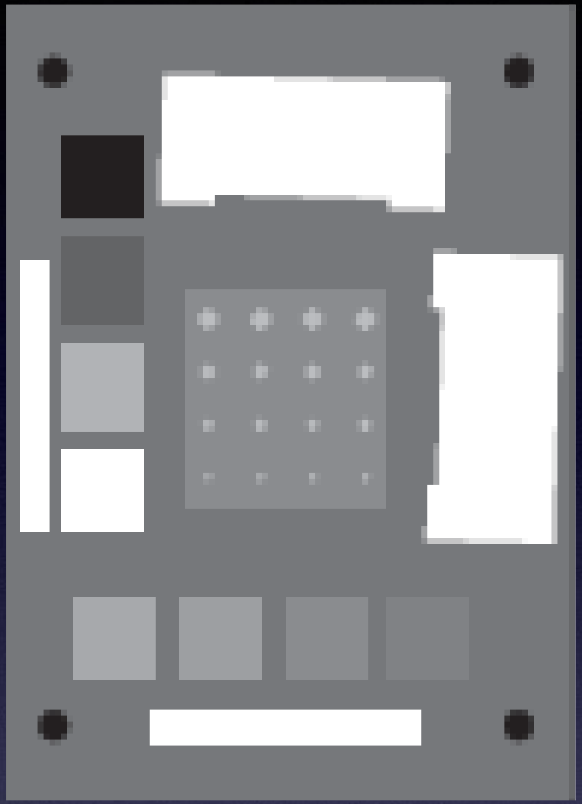


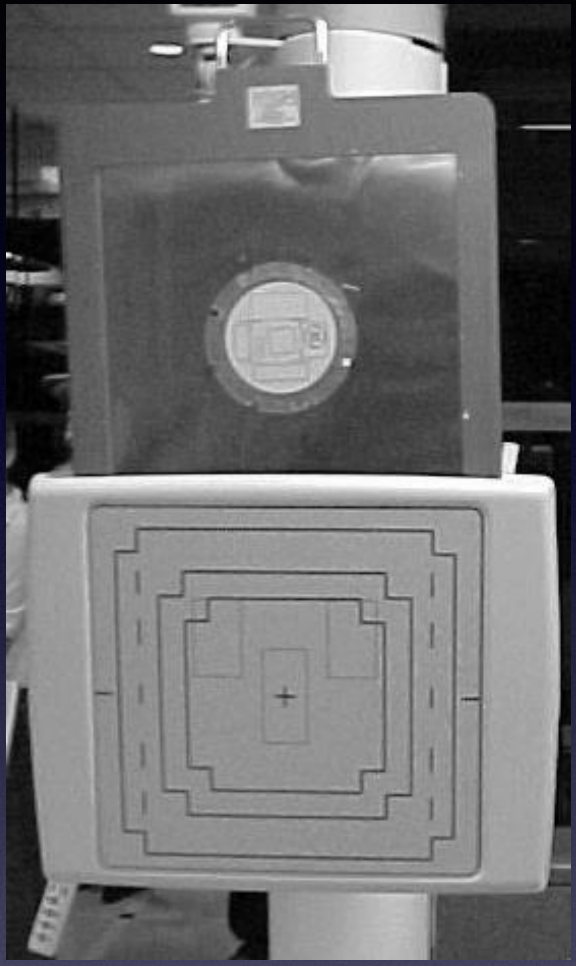


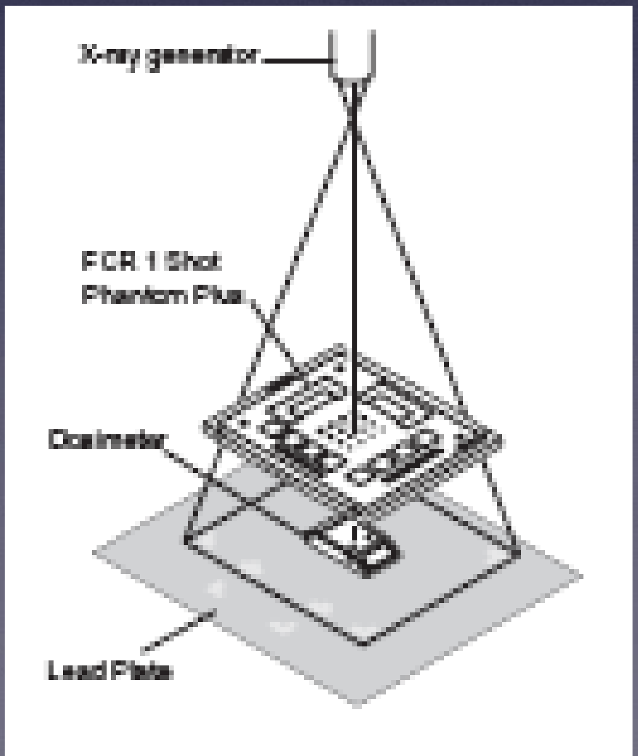








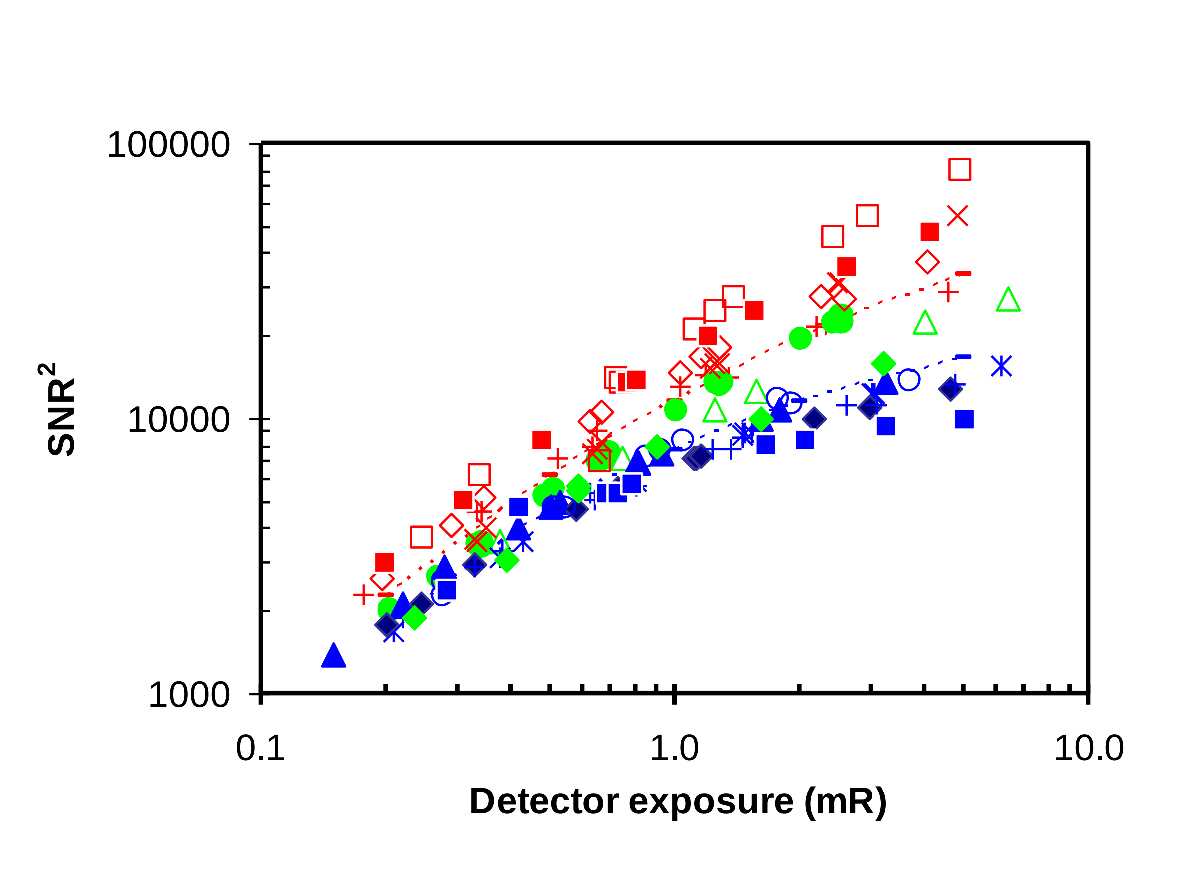




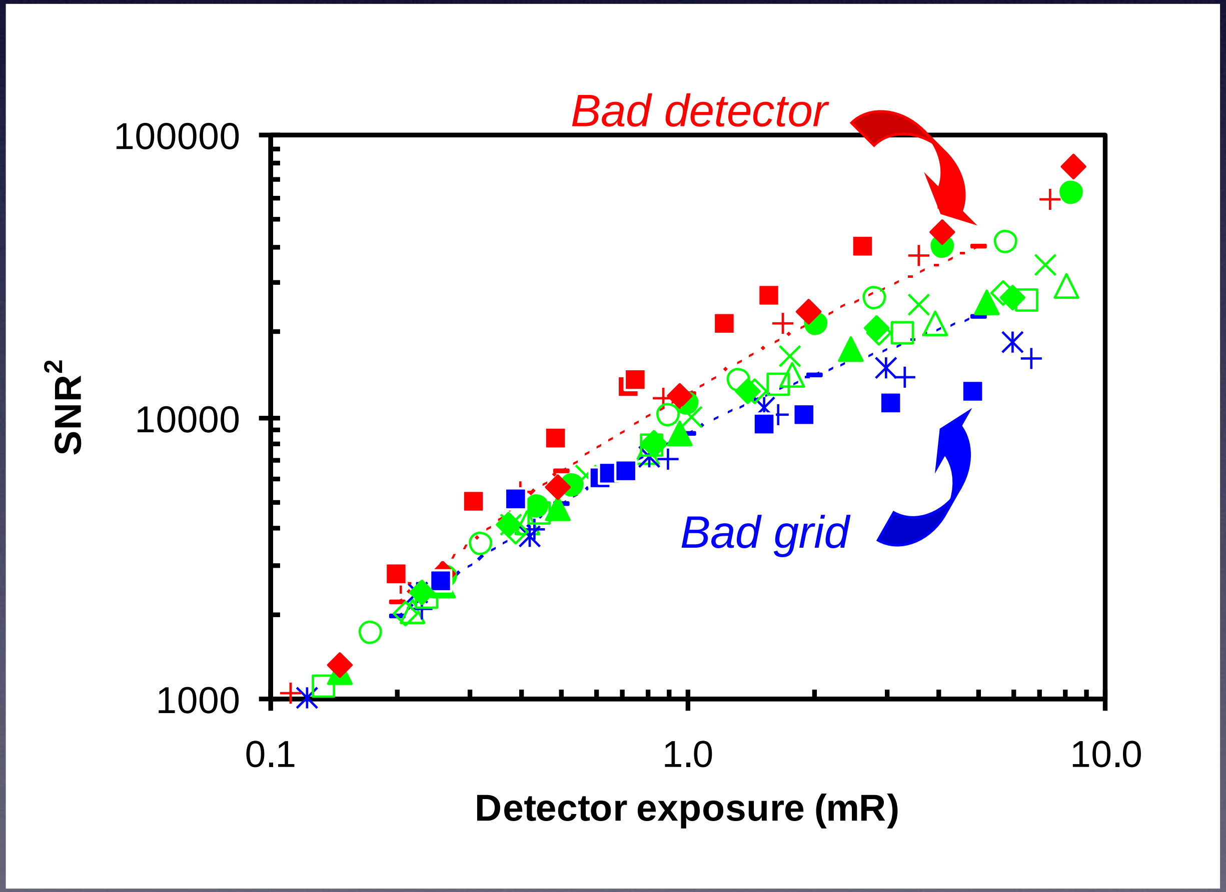
Variation in Exposure-dependent SNR is improved by gain and offset calibration

Fourteen GE DR systems, LucAl Chest phantom at 125 kVp

SNR from central ROI of "for processing" image



Before calibration



After calibration

Performance data on large numbers of DR systems under simulated clinical conditions are needed to establish action limits

Different artifacts

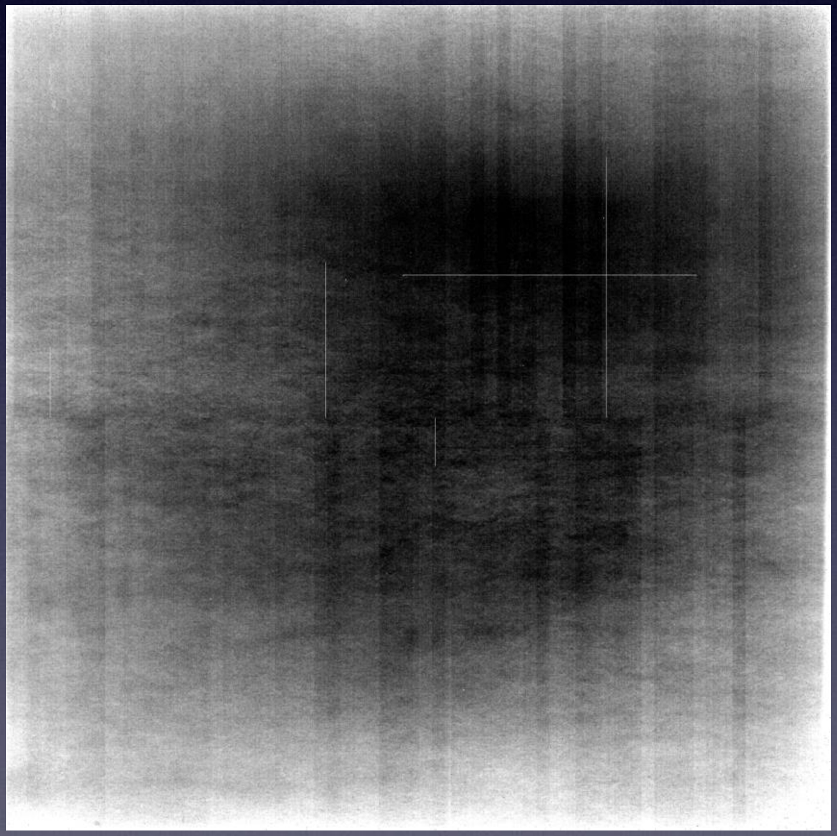
- Algorithms for VOI determination are likely different for DR, thus automatic FOV determination failures are different

- Gain and offset calibration is 2D in DR but only 1D in CR, thus detector element failures and drift in analog components manifest differently

- Backscatter in DR can reveal electronic and structural components

Both CR and DR must be corrected for non-uniformity.

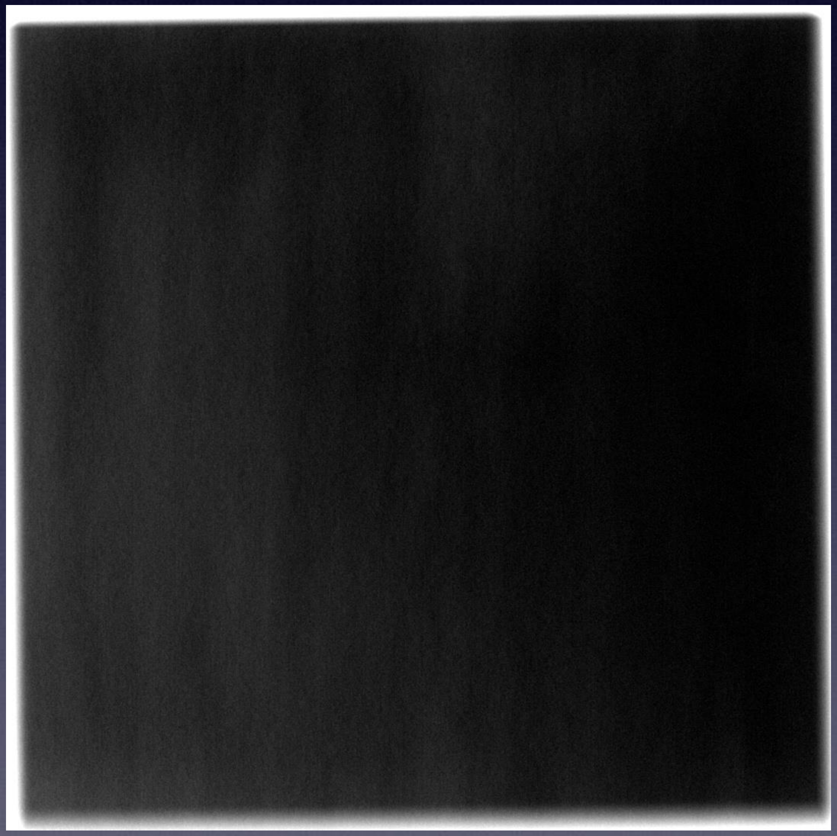
Uncorrected DR image



- In DR, corrections must be applied for differences in gain and offset among individual detector elements (dels) and amplifiers as well as corrections for nonfunctional ("dead") dels .

Both CR and DR must be corrected for non-uniformity.

Corrected DR image



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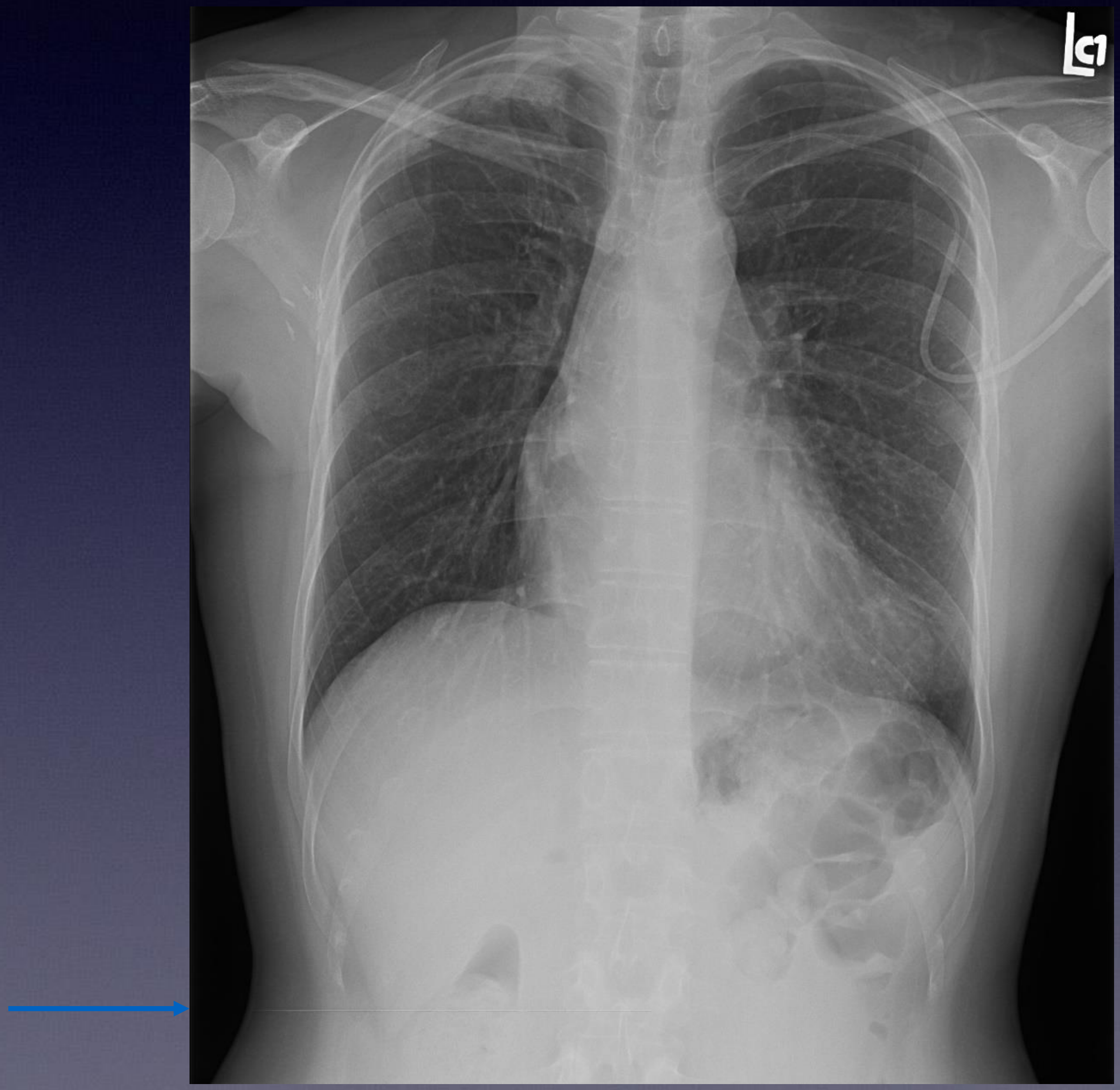
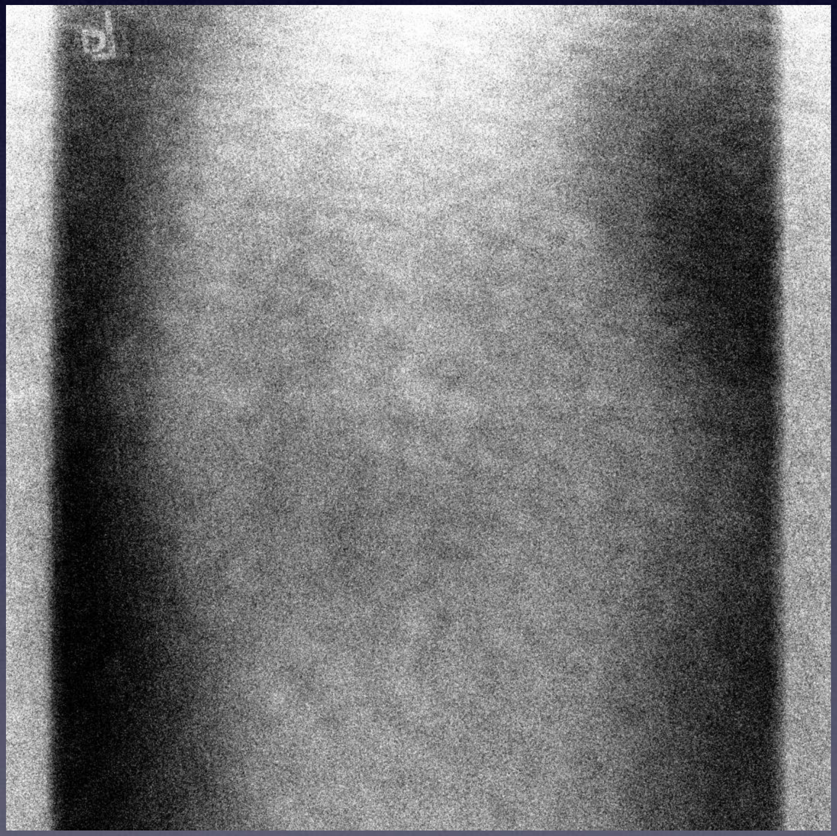


- In DR, corrections must be applied for differences in gain and offset among individual detector elements (dels) and amplifiers as well as corrections for nonfunctional ("dead") dels .
- These corrections are applied in two dimensions.
- Like CR, the correction is only as good as the uniformity of the x-ray field during calibration and the present condition of the detector.

Both CR and DR must be corrected for non-uniformity.

Corrected DR image



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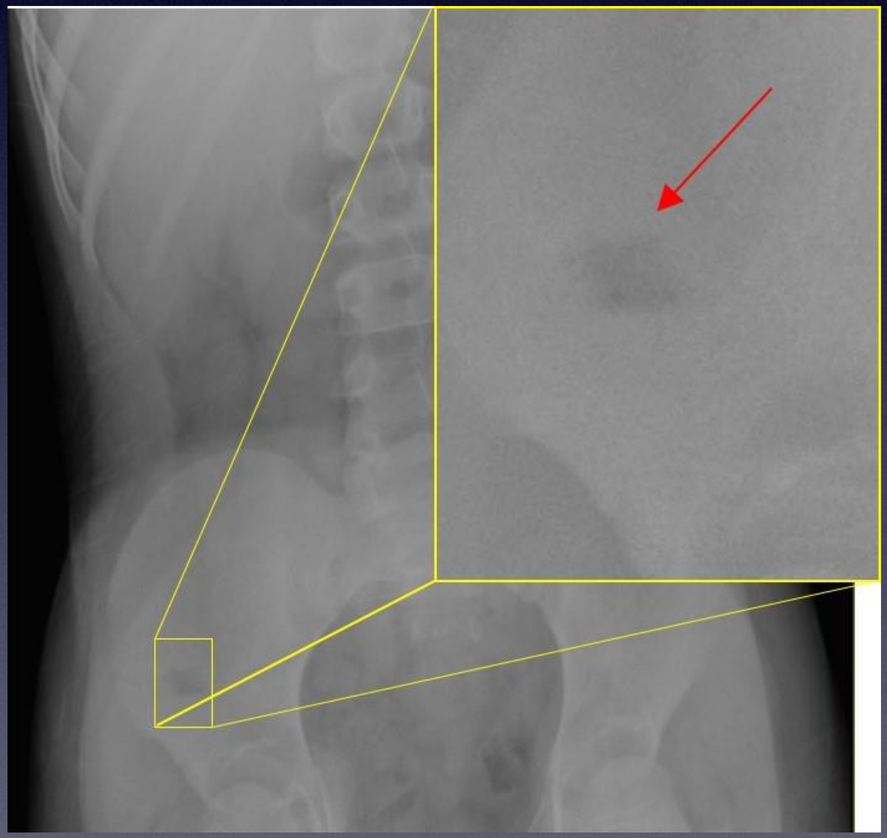
Both CR and DR must be corrected for non-uniformity.

Pediatric KUB cassette-based DR
70 kVp 5 mAs



Courtesy Laurence Parr, Naval Medical Center Portsmouth, VA

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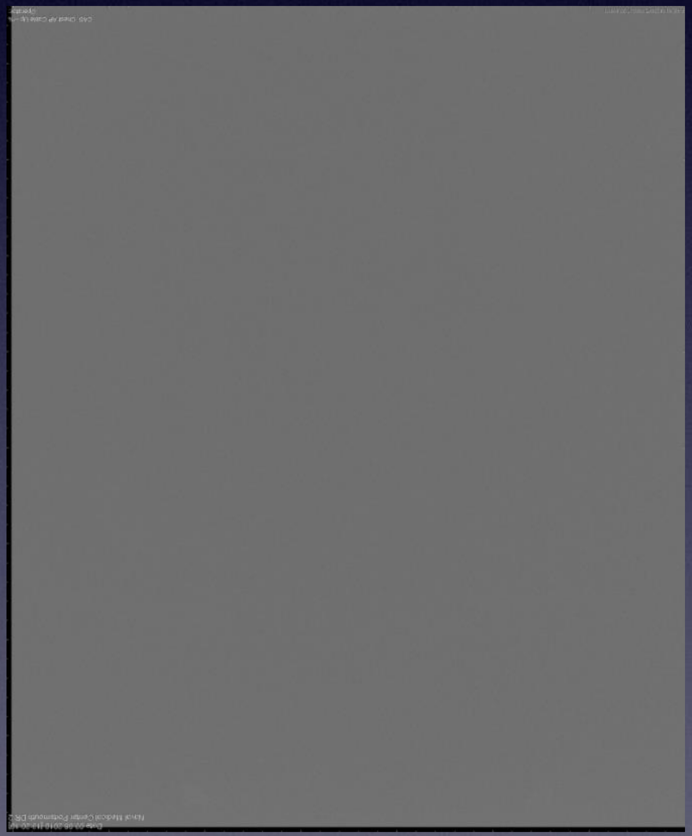
Both CR and DR must be corrected for non-uniformity.

Calibration DR image



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Both CR and DR must be corrected for non-uniformity.

Uniform DR image
detector rotated 180° relative to x-ray tube

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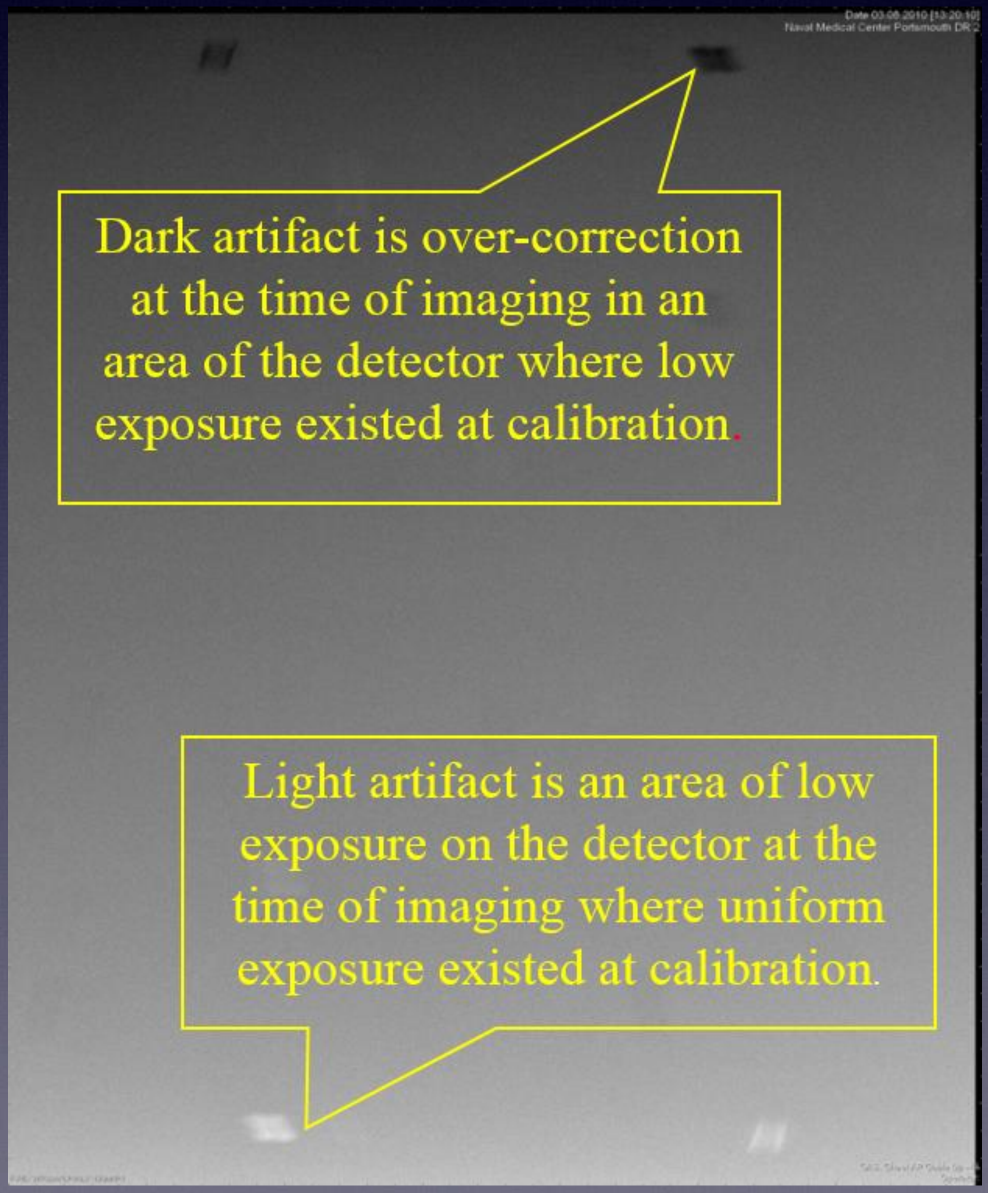
Both CR and DR must be corrected for non-uniformity.

Inverse pinhole images of the focal spot!



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- These corrections are applied in two dimensions.
- Like CR, the correction is only as good as the uniformity of the x-ray field during calibration and the present condition of the detector.

The radiologist interprets the image based on its appearance on a PACS display.

- What the radiologist sees is limited by all the previous stages of image acquisition and processing *plus* new limitations imposed by the PACS, the display station, and the ambient illumination conditions.
    - The display may not be calibrated in accordance with the DICOM Part 14 Grayscale Display Function (GSDF)
    - Even when the display is properly GSDF calibrated, the PACS may not display the image so that it looks the same as it did to the technologist.
    - The PACS may not display all of the information that is necessary to understand how the image was acquired.

Was the proper examination selected?

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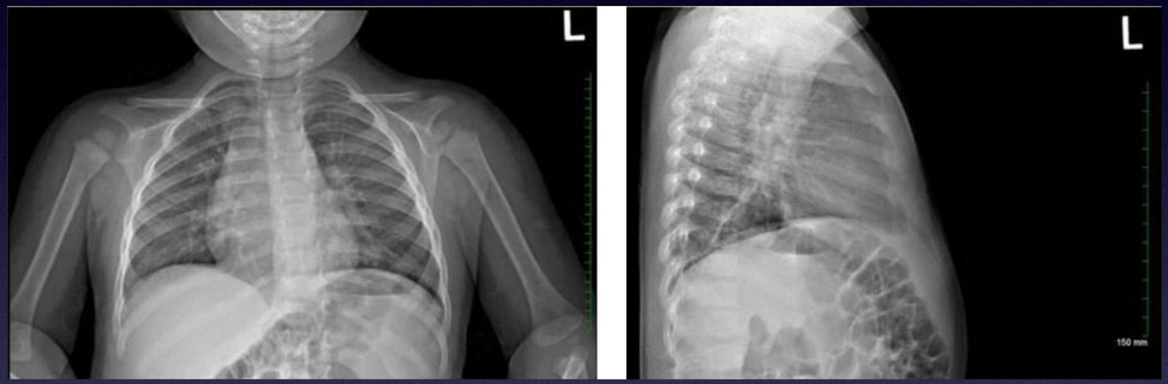
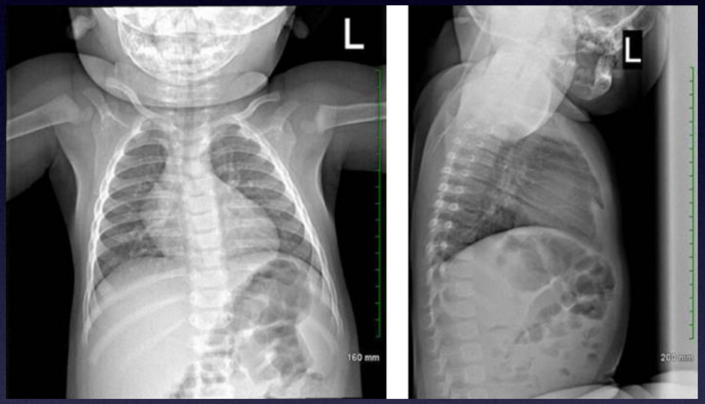
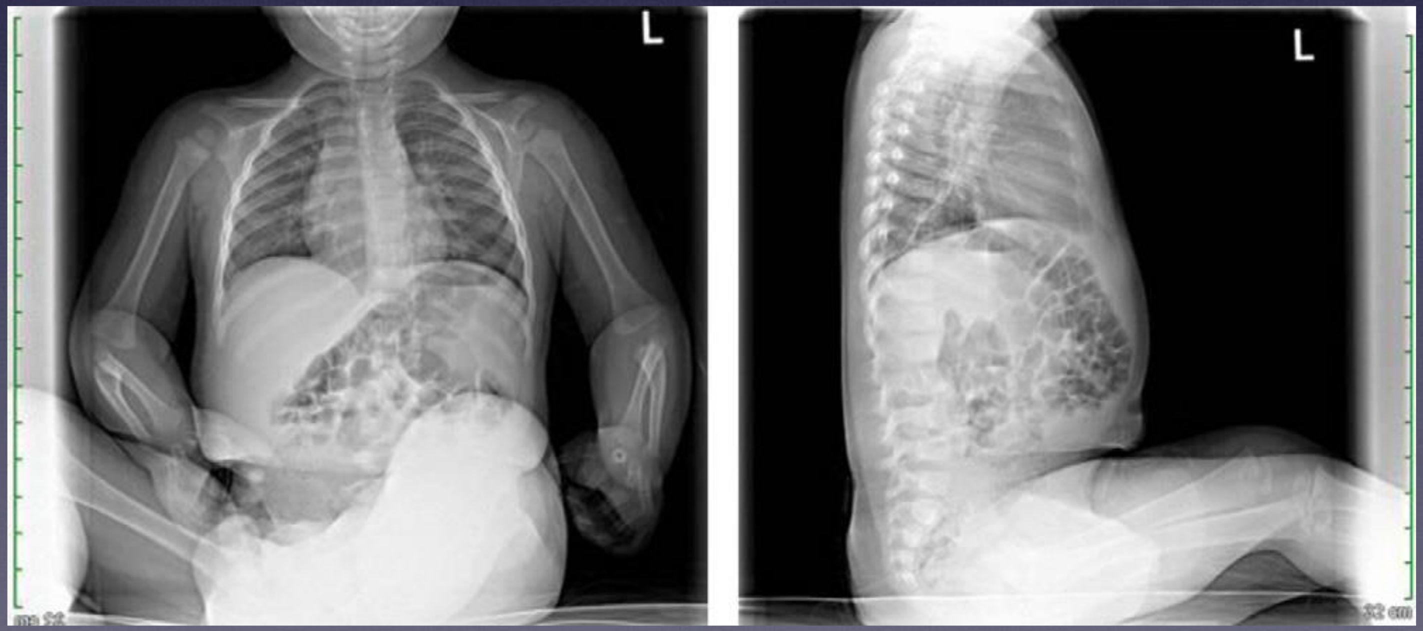
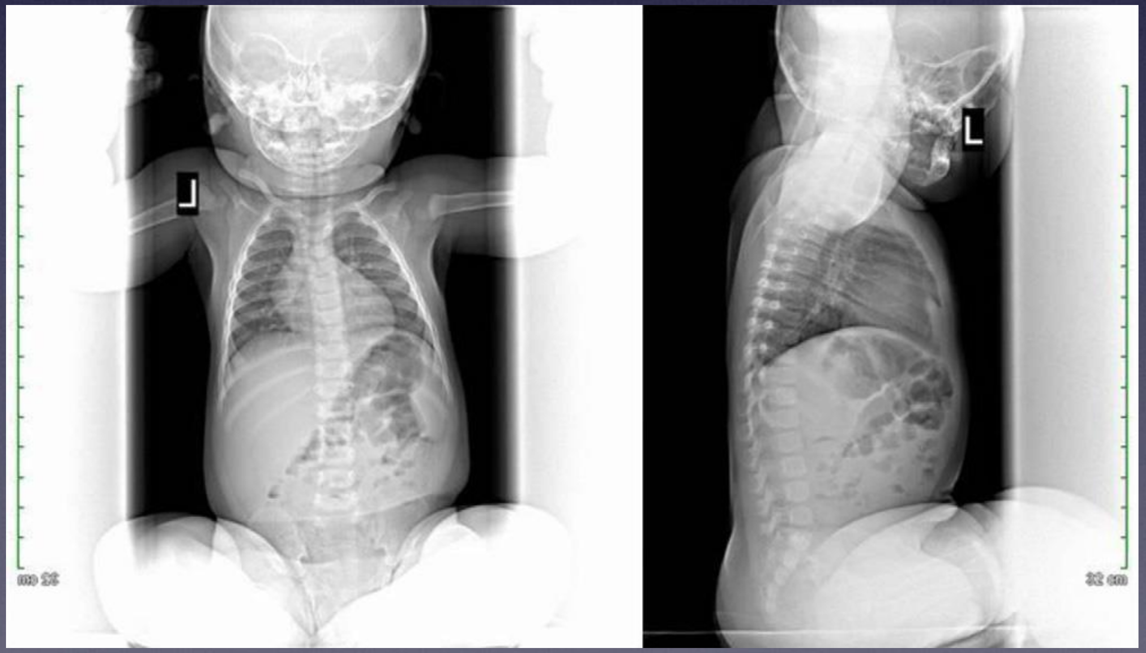
Where was the actual radiation field?

Does digital masking complicate radiologist oversight of technologist practice?





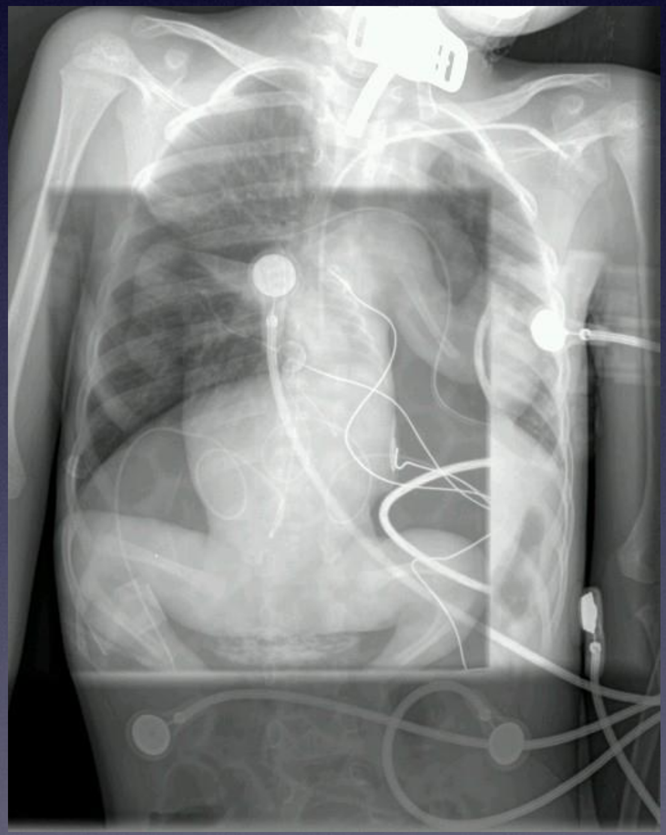


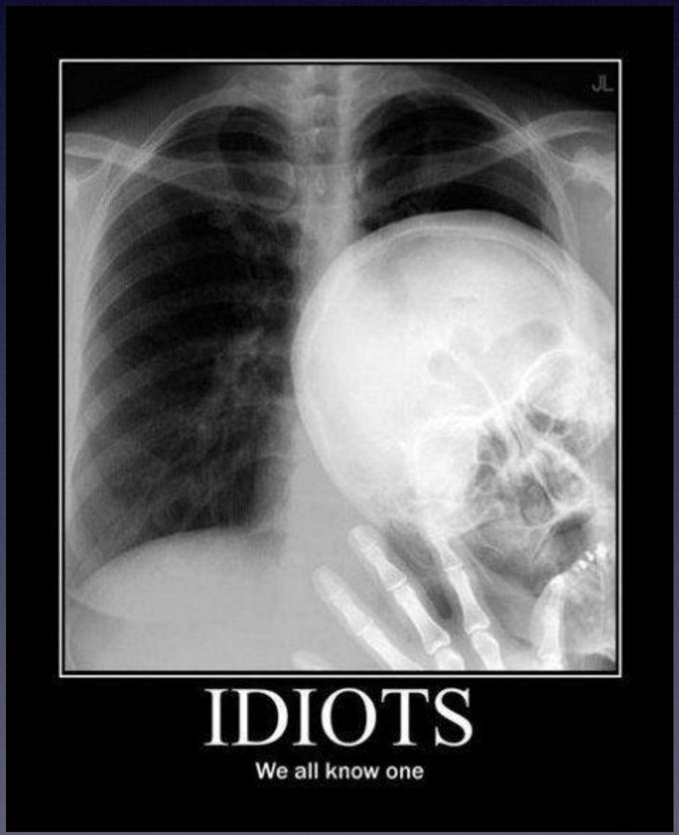


Shields and Bushong (2012) Beware the Mask. JACR. vol. 10 pp 149-152

"A common mistake that people make when trying to design something completely foolproof is to underestimate the ingenuity of complete fools."

Double exposure in CR





Unnecessary jewelry

Other considerations

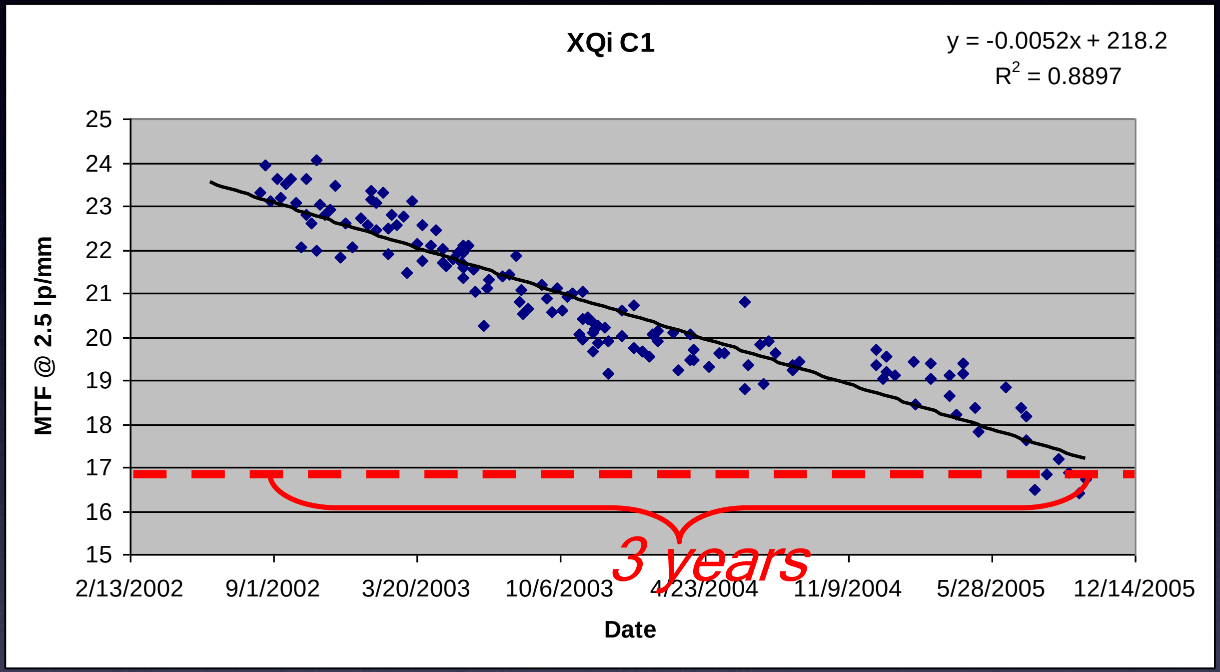
- Durability of DR detectors
- Grids
- DX versus CR object

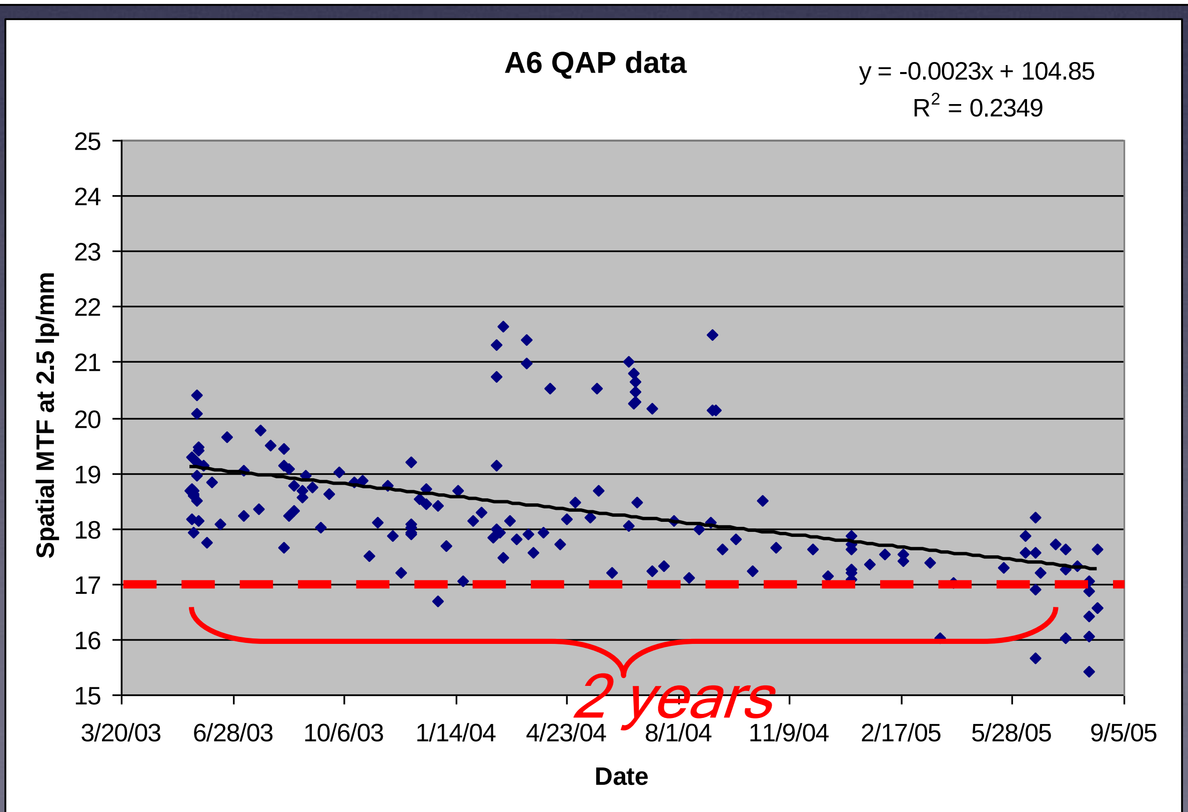
DR detectors are not indestructible

- Consequence of damaged DR detector far greater than a single CR cassette or imaging plate
- DR detectors can experience shock even in wall or table Buckey
- Technologist training, behavior enforcement, *insurance* are key!

What is the expected life of a DR detector?

- Because systems are relatively new, manufacturers are uncertain about longitudinal data
- Lower limit for test is MTF @ 2.5 lp/mm = 17%
- CsI(Tl) is hygroscopic – columnar structure is degraded
- Both systems depicted required detector replacement





Grids

- DR detector does not distinguish between on-focus and off-focus radiation - *it's all signal*
- Grids from CR or from DR vendor may not have appropriate grid rate, transmission, or scatter rejection
- Example: mid-range grid produced poor images at both short and long SID
- Same issues with grid alignment and orientation, damage to grids

DX versus CR object

- DR systems should be configured to output DICOM DX object to PACS
    - *More functionality*
    - *More mandatory vs. private tags*
- Consider reconfiguring any remaining CR systems to output DX object as well

Summary and Conclusions

- Proactive and reactive effort by the medical physicist is required to ensure consistent DR images for the radiologist at reasonable doses to the patient
- Optimization of DR imaging is an ongoing process requiring engagement of radiologists, technologists, and service engineers.
- “The price of freedom is eternal vigilance.”

“So long, and thanks for all the fish.”

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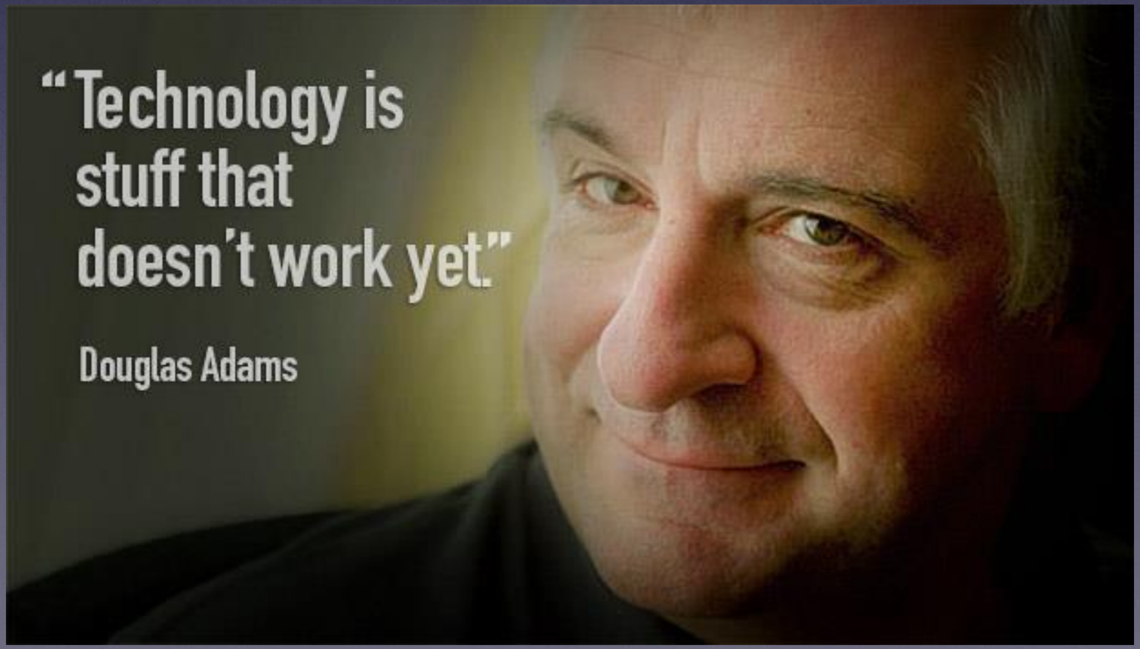

"So long, and thanks for all the fish."

- Willis et al 2011 Med Phys 38(7) – Gain and Offset calibration
- Li et al 2016 JACMP 17(5) – TG150 tests
- Carver et al 2018 JACMP 19(5) – Case Study
- Willis et al 2018 Med Phys 45(10) – Automated QC