Quality Assessment Procedures for Digital Radiography

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Detector Systems

- Cassette Based Digital Radiography Technology
  - Photostimulable phosphor (PSP) imaging (often called Computed Radiography or CR)
    - Agfa Fuji Kodak Konica
- "Flat Panel" Digital Radiography (DR) Technologies
  - Amorphous selenium and Thin Film Transistor (TFT) array
    - Hologic (Kodak, Lorad, Siemens)
    - Shimadzu
  - Photodiode arrays coupled with CsI
    - Canon*
    - GE*
    - Trixell (Siemens, Philips, Kodak)
  - Gd_2O_2S and TFT array
    - Canon*
  - CCD camera with CSI
    - IDC
    - Vidar

* Also market the detector in an "umbilical cord" attached cassette style system

PSP problems/artifacts

- White specks/traces
  - Unclean or cracked plates
- Vertical bands
  - Dirty light guide
- Multiple/Ghost images (non-erased detector)
- Aliasing and Moiré pattern
  - Due to grid/scan frequency mismatch
- Incorrect image processing
  - Segmentation error (incorrect positioning)
  - Wrong body part/view selected

DR problems/artifacts

- Pixel defects:
  - Inherent detector defects
- Pixel gain variation:
  - Area variations, Amplifier gain variations, etc.
- Multiple/Ghost images (residual signal)
- Aliasing and Moiré pattern
  - Due to grid/scan frequency mismatch
- Incorrect image processing
  - Segmentation error (incorrect positioning)
  - Wrong body part/view selected

Requirements

- Only two States have requirements for QA on all digital systems
  - Specific testing requirements not clearly defined
- Several European governments require QA on all radiographic systems, including digital
  - Testing requirements in some areas have been defined or are being defined now

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Standards/Recommendations

- *DIN 6868-58 (2001) and 6868-13 (2002):* Acceptance testing and constancy checks of projection radiography systems with digital image receptors
  - German standard for testing of PSP systems using a specially designed phantom to measure image quality parameters
- *IEC 62220-01 (2003):* Method for determining Detective Quantum Efficiency (DQE) of digital imaging systems
- *AAPM Task Group #10 (TG10):* Acceptance Testing and Quality Control of Photostimulable Phosphor Imaging Systems

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QA testing*

- Daily (technologist)
  - Inspect system operation and verify operational status.
- Monthly (technologist)
  - Erase all plates in the inventory
    - particularly those that are infrequently used
  - Acquire QC phantom image and implement QC measurements (vendor specific).
    - Verify performance levels, store results in database file.
  - Monitor calibration for QC workstations
    - SMPTE pattern, contrast/brightness settings

*TG 10 Report: Acceptance Testing and QC of PSP Systems

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QA testing

- Quarterly (technologist)
  - Rotating cleaning program for all cassettes
    - Inspect and clean with approved cleaner by manufacturer
  - Qualitative and quantitative QC phantom analysis,
  - Review image retake rate
    - determine causes of unacceptable PSP images
  - Review QC exposure indicator database
    - determine cause of under/overexposures

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QA testing

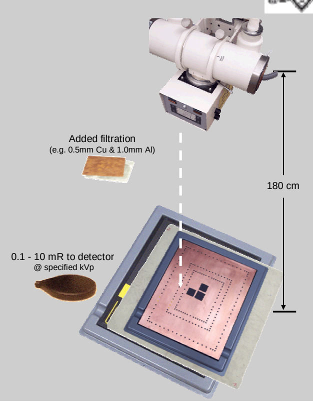
- These are suggested QC and performance evaluation tests should be used as a guideline
  - These should be done in addition to any routine QC activities recommended by the manufacturer
- Depending on the specific system characteristics and resources available, some test may be unnecessary, or frequencies may be adjusted

QA testing

- Annual/After “major” repair (Physicist)
  - Inspection/evaluation of image quality
    - spot check image processing algorithms for appropriateness.
  - Review technologist QC activities and reports
    - evaluate retake activity
    - patient exposure trends
    - QC records
    - service history of the equipment.
  - Acceptance test procedures to verify and/or re-establish baseline values.
    - Use complete inspection and verification procedures

Acceptance/Annual testing

- Parameters to test
  - Spatial resolution
  - Contrast resolution
  - Uniformity/geometric distortion
  - Dose response/signal dynamic range
  - Noise
- Experiments/testing methods
  - Direct measurements
  - Phantoms/image tools
    - Qualitative
    - Quantitative



Acceptance/Annual testing

- Dark Noise
  - Electronic noise
  - Signal in absence of radiation
- Uniformity
  - Non-uniformity due to:
    - Pixel gain, dead pixels, tiling, fiber optics, etc.
  - Uniform exposure to detector

Test	Quantity of Interest	Acceptance Tolerance
Dark Noise	Signal within 80% of image	σ_E/exposure < 1%, Image w/o artifacts
Uniformity	Signal σ within 80% of image and σ between detectors (e.g. plates)	$\sigma_E < 5\%$

*E. Samei, et al, Med. Phy. 28(3), p361-371, 2001, and TG10 Report: Acceptance Testing and QC of PSP Systems

Acceptance/Annual testing

- Laser beam function
  - Tests scan line integrity
    - Beam jitter, signal dropout, beam focus, etc.
  - Image of an edge phantom
- Limiting resolution
  - Image of a line pair phantom
  - Qualitative/Semi-quantitative evaluation

Test	Quantity of Interest	Acceptance Tolerance
Laser beam function	Jitter dimension in pixels	< 1 pixel
Limiting resolution	Maximum "discernable" spatial frequency	$R_{\parallel \text{ or } \perp}/f_{Nyquist} > 0.9$ $R_{45}/1.41 f_{Nyquist} > 0.9$

*E. Samei, et al, Med. Phy. 28(3), p361-371, 2001, and TG10 Report: Acceptance Testing and QC of PSP Systems

Acceptance/Annual testing

- Exposure indicator calibration
  - Exposure using a standardized beam condition
  - Verification of manufacturer's indicator value
  - TG #116 developing a standard method
- Linearity/auto-ranging response
  - Determines response of detector/read-out system over large exposure range

Test	Quantity of Interest	Acceptance Tolerance
Exposure indicator calibration	Expressed in terms of 1 mR exposure (E) to detector	$(E_{measured} - 1) < 10\%$
Linearity/auto-ranging	Slope of response vs. log(E)	(Slope – 1) < 10% Correlation > 0.95

*E. Samei, et al, Med. Phy. 28(3), p361-371, 2001, and TG10 Report: Acceptance Testing and QC of PSP Systems

Acceptance/Annual testing

- Noise/low contrast resolution
  - Contrast resolution should be limited by quantum statistics
  - Image of a low contrast phantom
- Spatial accuracy
  - Distance measurement accuracy
  - Image of object with known dimensions

Test	Quantity of Interest	Acceptance Tolerance
Noise/low contrast	Linear fit of system noise vs. log(E)	Correlation > 0.95
Spatial accuracy	Δ between measured and actual distances	(Δ / actual) < 2%

*E. Samei, et al, Med. Phy. 28(3), p361-371, 2001, and TG10 Report: Acceptance Testing and QC of PSP Systems

Acceptance/Annual testing

- Erasure thoroughness
  - Tests residual signal/ghost image retention
- Aliasing/grid response
  - Image of a high frequency pattern
  - Check for Moiré pattern creation
- Throughput

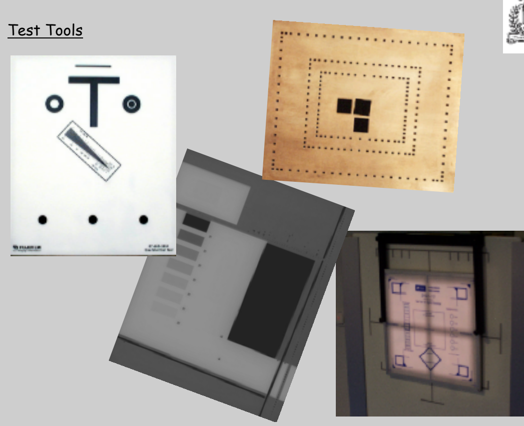
Test	Quantity of Interest	Acceptance Tolerance
Erasure thoroughness	Signal within 80% of image	σ_E/exposure < 1%, Image w/o artifacts
Aliasing/grid response	none	Absence of "ghost image"
Throughput	Δ between measured and specified throughput	(Δ / actual) < 10%

*E. Samei, et al, Med. Phy. 28(3), p361-371, 2001, and TG10 Report: Acceptance Testing and QC of PSP Systems

Phantom Image Quality Control Tools

- Original Equipment Manufacturer (OEM) Products
  - Highly automated procedure
  - Reproducible quantitative results
  - May detect sub-visible changes in image quality performance to initiate timely preventive maintenance
  - Provide data reporting in spreadsheet format and may be assessable remotely for review and/or advanced processing
- Non-OEM Phantoms are required for older systems and for Physicist to use across multiple systems and sites

Test Tools

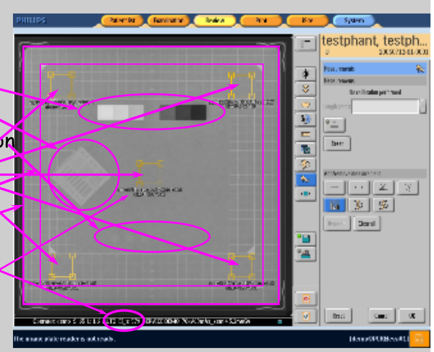


Tests Performed

- Uniformity/geometric distortion
  - Pixel size accuracy and aspect ratio
  - Laser Beam Function
- Noise
- Spatial resolution
- Contrast resolution
- Dose response/signal dynamic range
  - Exposure linearity
- Image artifacts
- Residual signal erase

Test Object Analysis*

Dynamic range
Spatial resolution
Contrast resolution
Uniformity
Geometry
Artifacts
Exposure Index



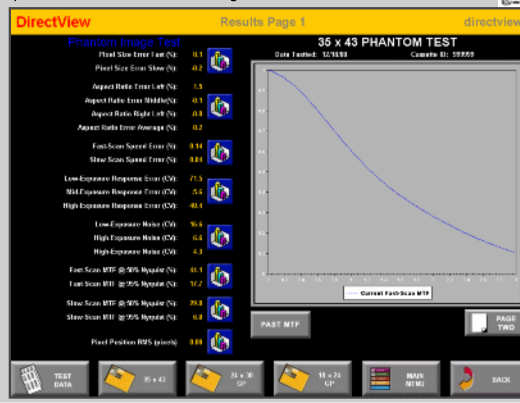
* Images provided by Philips Medical Systems

* Images provided by Eastman Kodak Company

User Interface*

* Images provided by Eastman Kodak Company

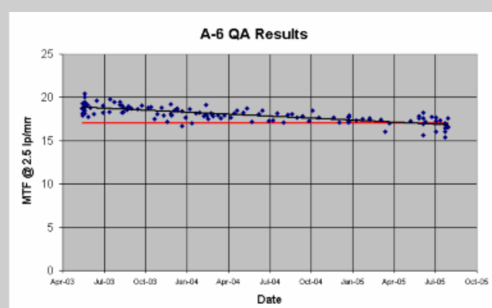
System Result Details & Tracking



Test Limits

- Pre-set by OEM
- Basis for limit may not be justified in OEM literature
  - Review literature and talk with Vendors Application and Technical experts to fully understand these
- May not be modifiable
  - This flexibility has not been formally addressed by many OEM
- If system fails a test, Service Engineer may not be educated how to correct problem

What are the test limits?



*Data provided by S. Jeff Sheppard, University of Texas M. D. Anderson Cancer Center

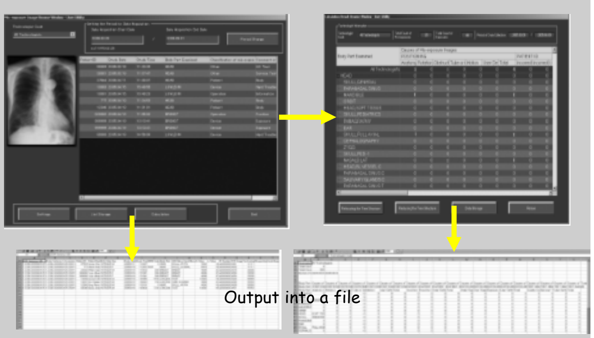
Review QC activities and reports

- Retake analysis
- Patient exposure trends
- QC records
- Service history of the equipment

Retake Analysis

- Retake rates for film and digital acquisition should be between 1% - 3%
- Root cause for any change should be investigated

Retake Analysis*



* Images provided by FujiFilm Medical Systems

Retake Analysis

- Retake rates increase initially after conversion to digital technology during the "learning curve" stage of the process
  - Should level off within 1st Quarter of use
- Retake rates also increase when physicist and radiologist work to "optimize" image processing
  - Focus on education to all staff on the proper positioning and processing to use can reduce these problems

Exposure Indicator Trends

- Different vendors call the exposure to the detector by different names
  - Agfa Medical Systems . . . . lgM number
  - Eastman Kodak Company . . . . Exposure Index (EI)
  - Imaging Dynamic Corp (IDC) . . . F-number
  - Konica and Fuji . . . . S-value
- Currently, method used to calculate the values varies by vendor
  - AAPM TG #116 is in the process of developing a Standard with vendor participation

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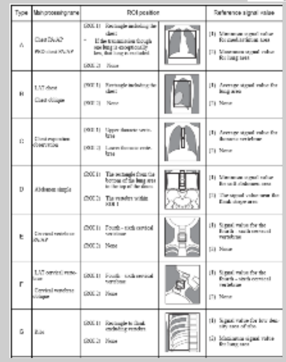
Exposure Indicator Determination

- For all vendors, Exposure Indicator is determined only for a portion of the image
- Region used depends on body part/view chosen by the operator
- Extremely important that positioning is correct and that correct body part/view are chosen
  - Effects calculation of Exposure Indicator
  - Effects image processing applied



* Images provided by Konica

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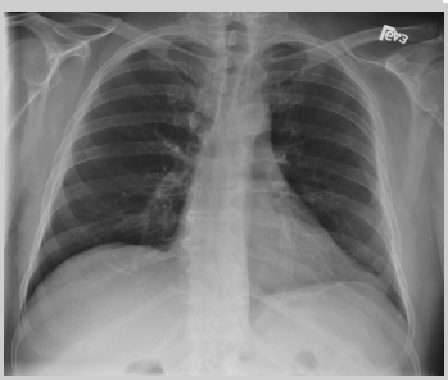
Example: correct exposure used



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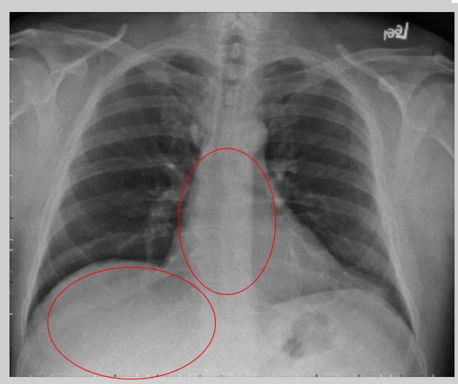
Example: Low Exposure



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Example: High Exposure

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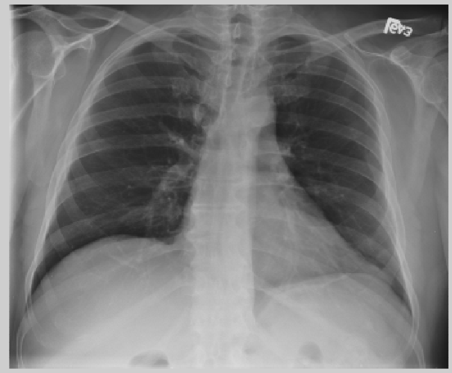
Example: correct exposure used



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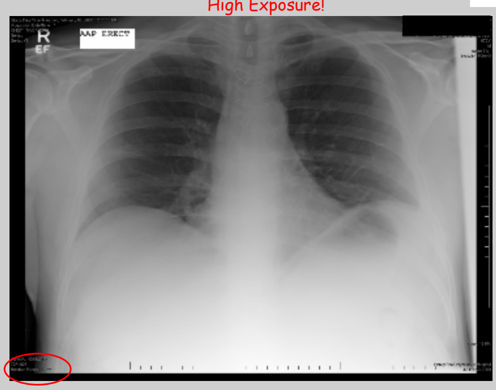
Example: High or Low?

Konica S-number < 200

High Exposure!



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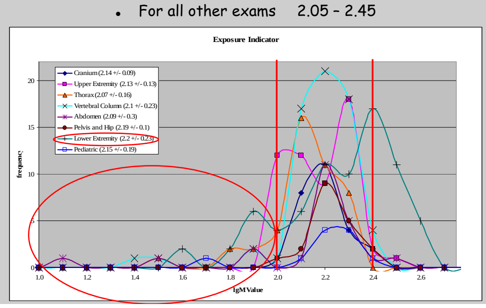
Patient Exposure Trends

Target Indicator value = 2.0 – 2.4 for all exams

- Chest 1.85 – 2.15
- Extremity 2.05 – 2.35
- For all other exams 2.05 – 2.45



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Lessons Learned

- Low exposure is easy to detect
  - noisy image
  - May require a retake
- High exposure cannot be easily detected
  - high quality, but high dose to patient
  - Should not be retaken to correct unless saturation of the detector has occurred or diagnostic information is compromised
- If body part/view incorrectly chosen when processing
  - Exposure Indicator may be incorrectly calculated
  - Processing may make contrast, noise, etc. appear poor even though exposure is in correct range

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MTF, NPS and DQE

- Modulation transfer function (MTF) quantifies the efficiency of an imaging system in transferring any given spatial frequency from an input to an output
- Noise power spectrum (NPS) is the relative strength of spatial frequencies in a uniform image
  - If only source of noise is x-ray quantum mottle, the NPS is inversely proportional to exposure to detector
- Detective Quantum Efficiency (DQE) describes the measured Signal to Noise in relation to an ideal detector
  - SNR^2 is deduced from the ratio of the MTF squared ($signal^2$) to the NPS ($noise^2$)

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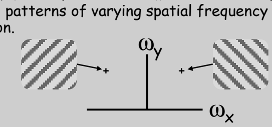
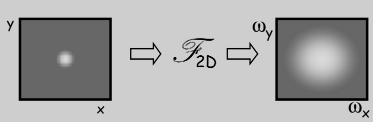
2D MTF and PSF

- The 2D MTF is defined as the modulation transfer for 2D sinusoidal patterns of varying spatial frequency and orientation.



- 2D MTF may be computed as the magnitude of the 2D Fourier transform of the systems point spread function (PSF).



- The PSF describes the systems response to x-rays normally incident to the detector at a specific point.

**** Difficult to construct a phantom that can produce an adequate PSF ****

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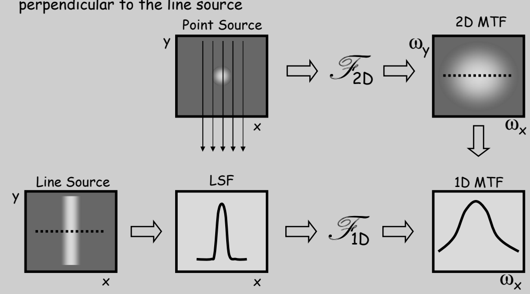
*K. Rossman, Radiology, Vol 93, 1964

Central Ordinate Theorem*

- The projection of a PSF is equal to the Line Spread Function (LSF) for a line source oriented parallel to the projection direction.
- 1D MTF is equal to the 2D MTF values along a line through the origin and perpendicular to the line source



**** Difficult to construct a phantom that can produce an adequate LSF ****

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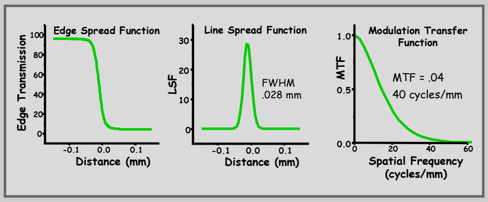
Samei, Med. Phys., V 25, N 1, 1998

Edge measures

- Edge spread function (ESF) represents the values of a 2D edge response image along a line perpendicular to the edge.
- ESF is equal to a definite integral of the differential line sources
- LSF is simply deduced as the derivative of the ESF



** Construction of an adequate edge phantom can be done **

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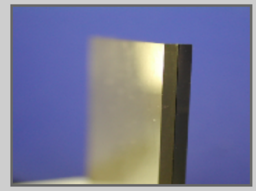
Edge Test Devices

- Edges should be made of very high Z material to minimize Fluorescent Radiation effects
  - Lead, Tungsten, Platinum-Iridium, depleted Uranium
  - For low energies, a Brass-Aluminum laminate may be adequate
- Can be fabricated in lab
  - Laminate a metal foil between two lucite plates.
  - Precision mill to final shape.
  - Lap all edges to obtain a straight edge
    (use a sub-micron grit and flat lapping stone)
- Test equipment manufacturers are developing edge tools
  - Gammex RMI



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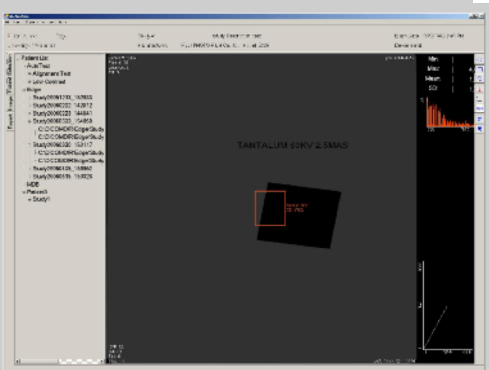
Edge Test Software



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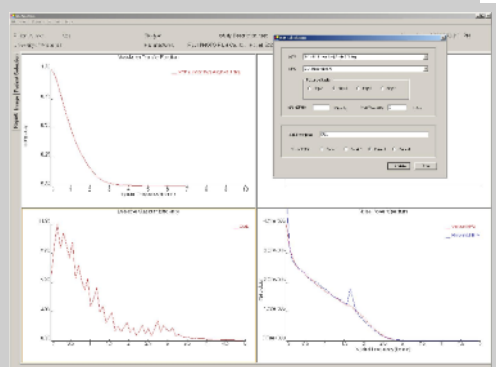
Edge Test Software



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MTF, NPS and DQE

- Results in the field may only be comparable to those acquired in the exact same manner
  - Same filtration and exposure conditions
  - Same method for determining values
    - PSF, LSF or ESF used
- May provide a more robust temporal analysis of changes in a system over time

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Digital detectors system problems/artifacts

- White specks/traces
- Vertical bands
- Pixel defects:
- Pixel gain variation:
- Multiple/Ghost images (non-erased detector)
- Aliasing and Moiré pattern
- Incorrect image processing
  - Segmentation error (incorrect positioning)
  - Wrong body part/view selected

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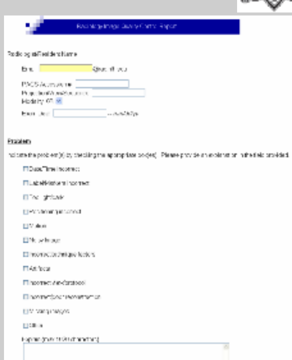
Radiologist and Technologist Review QA

- Any problems seen during day-to-day operation need to be documented and corrective action initiated
- System to document these occurrences must be easy or it will not be done
- Follow-up with person submitting Report must be done
  - Supervisors require technologist to respond with corrective action directly to Radiologist



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QA report Results

- January 2005 – July 2006
  - ~ 1 Million exams performed
  - Less than 0.1% had QA Reports
- Positioning remains the primary QA problem with Radiographic images
  - Both with film and digital
- "Other" category contains many non-acquisition related problems, such as:
  - RIS order issues
  - Jewelry/clothes left on

Problem	# Reports	% of Reports
Date/Time Incorrect	0	0%
Label/Markers Incorrect	67	8%
Too Light/Dark	85	10%
Positioning Incorrect	175	21%
Motion	23	3%
Noisy Image	73	9%
Incorrect View/Protocol	90	11%
Incorrect Technique Factors	98	12%
Artifacts	91	11%
Incorrect Poor Reconstruction	55	7%
Missing Images	46	6%
Other	224	27%

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