Assuring image quality for classification of digital chest radiographs

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Advantages of digital radiography

- Improved dynamic range
  - Toleration for over-/under-exposure
- Image post-processing
  - Improved visualization
- Digital format
  - Enabling quantification and digital analysis
  - Electronic archival and distribution

Digital radiography in classification of pneumoconiosis?

Notable advantages in providing accessible, standardized image data for visual interpretation or automated classification

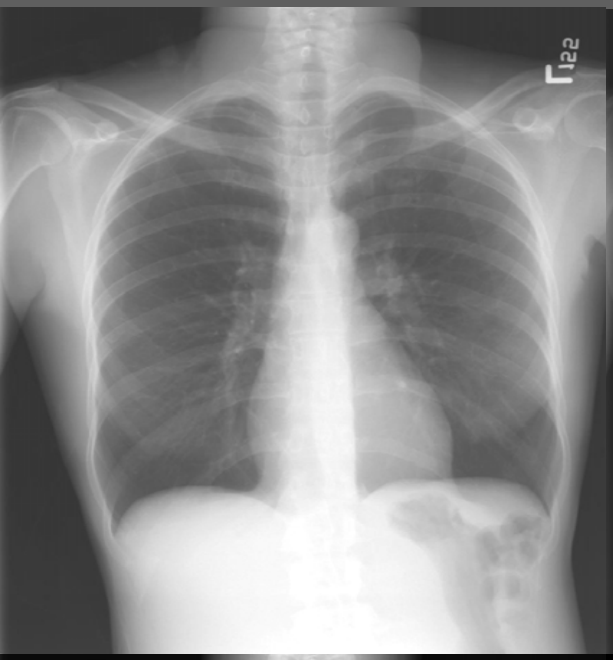
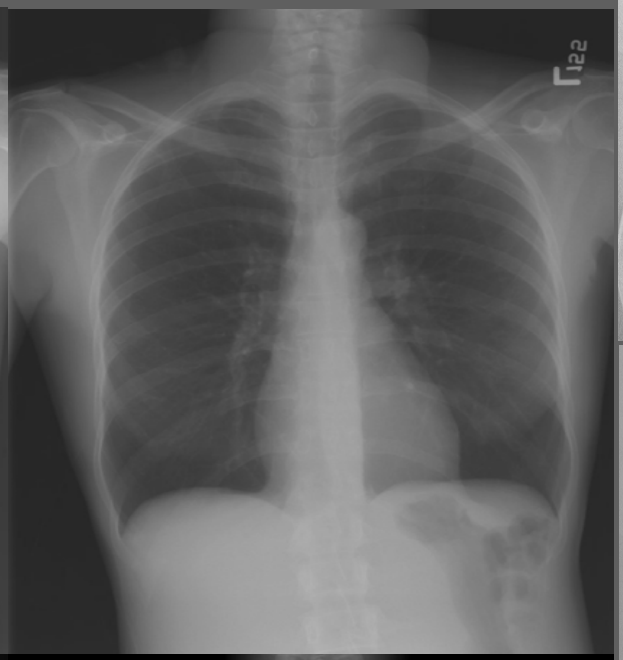
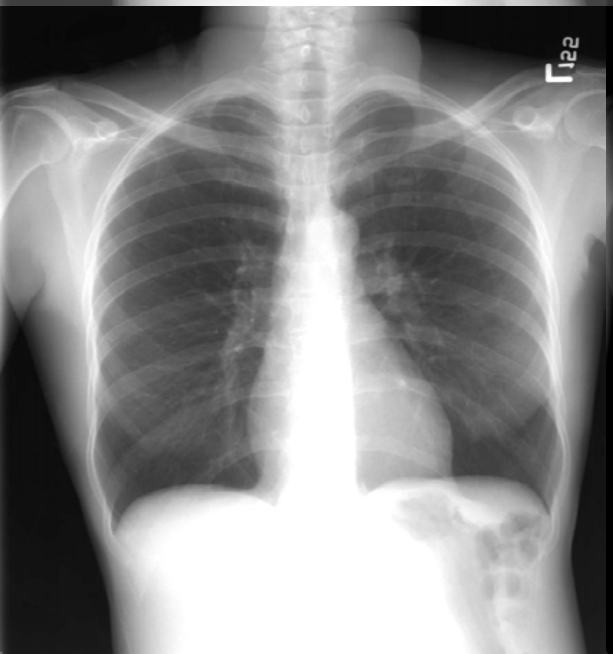
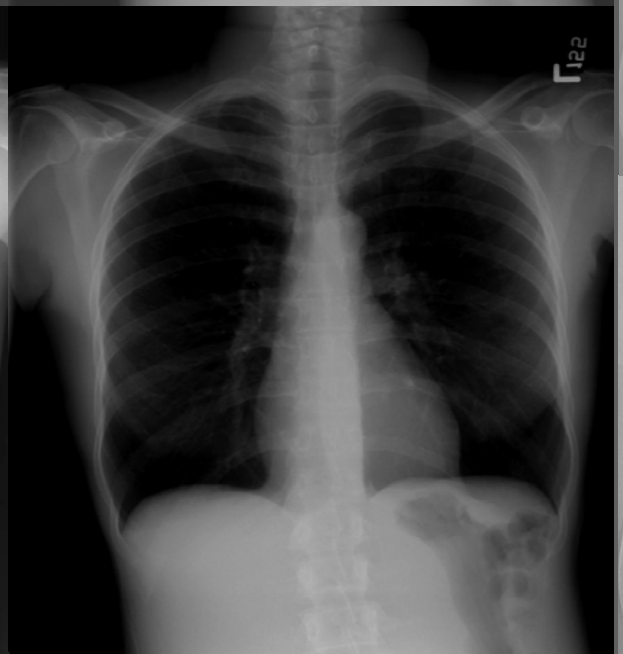
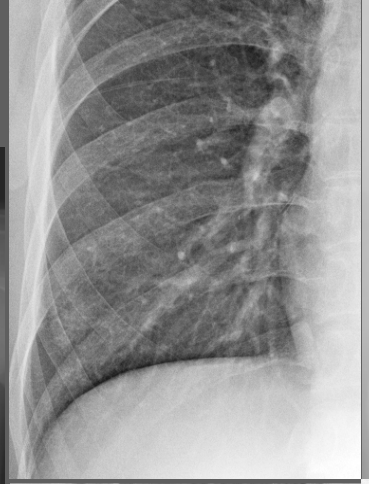
Disadvantages of digital radiography

- Improved dynamic range
  - Over-/under-exposing the patient
- Image post-processing
  - Lack of utility for the physicians
  - Loss of reading efficiency
  - Ad hoc image appearance
- Digital format
  - Lost patient data
  - Security issues

Advantages of digital radiography

- Improved dynamic range
  - Toleration for over-/under-exposure
- Image post-processing
  - Improved visualization
- Digital format
  - Enabling quantification and digital analysis
  - Electronic archival and distribution

Variable appearance




Digital radiography in classification of pneumoconiosis?

Potential advantages are not automatic; Realization requires understanding nuances associated with the features, proper implementation and QC

Digital radiography

Potential

Poor implementation

Why QC?

- "Fluidity" of DR image quality: To enable standardized processing and appearance
  - Image post-processing
- "Quantify-ability" of DR image: To enable automated quantification
  - image format
  - exposure dependency
  - image quality attributes
- To enable optimum implementation of DR

Quantitative metrics of DR image quality

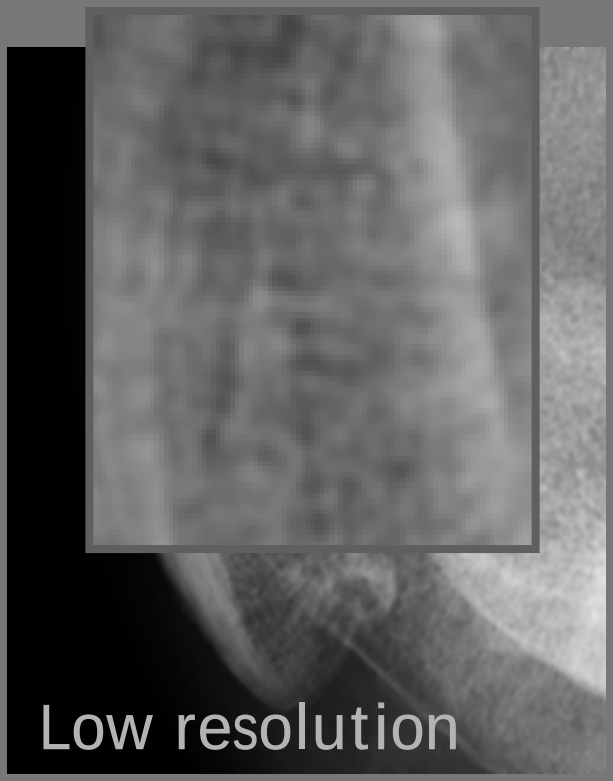
Resolution

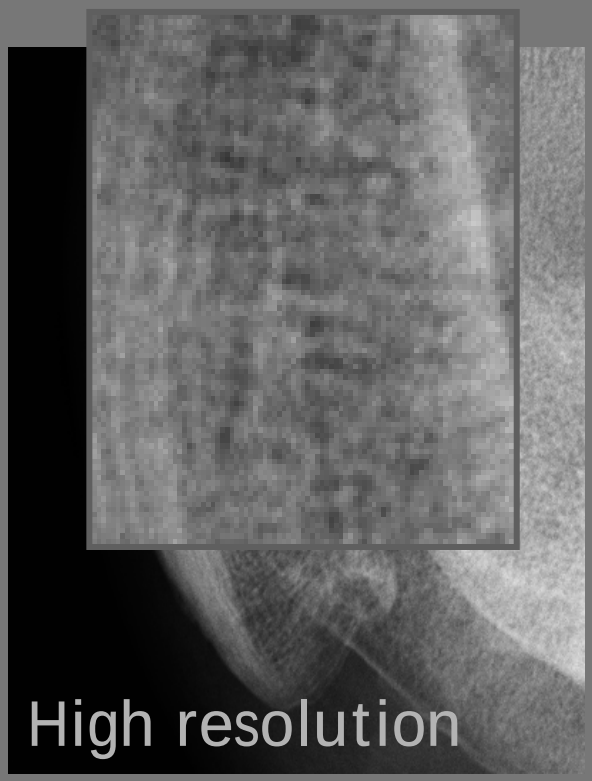
Noise

Singal-to-noise efficiency

Resolution

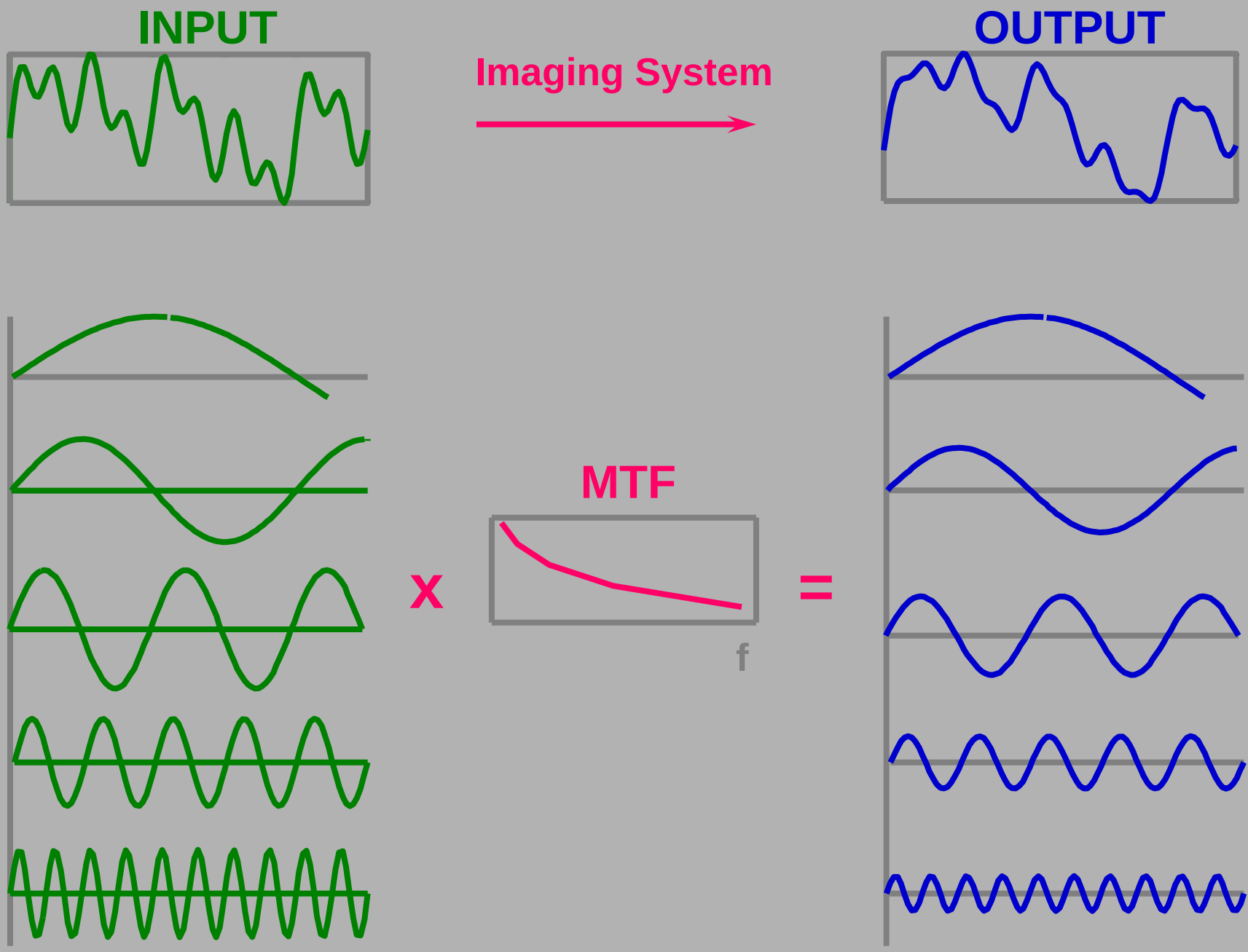
- Ability to resolve distinct features of an image from each other





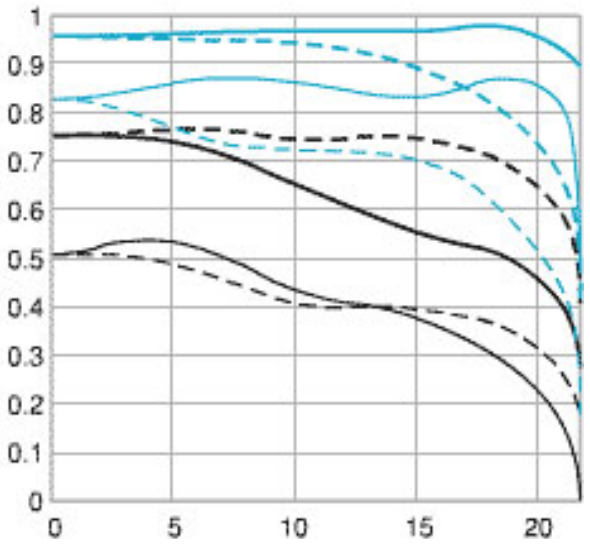
Resolution in terms of MTF

- Best characterized by the modulation transfer function (MTF):
  - **The efficiency of an imaging system in reproducing subject contrast at various spatial frequencies**

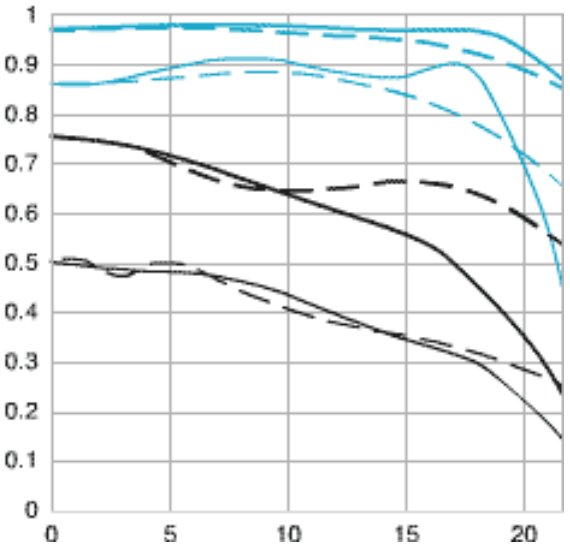

INPUT
Imaging System
OUTPUT
MTF
f
x
=

MTF in photography

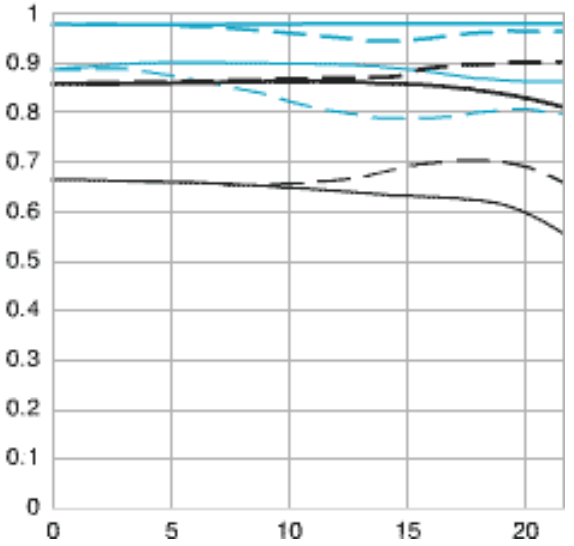
Canon 35mm f/1.4L

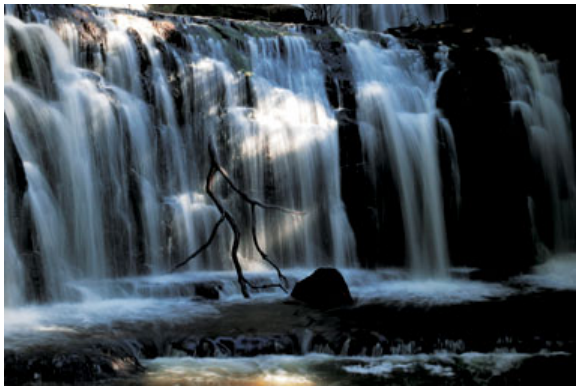


Canon 50mm f/1.4

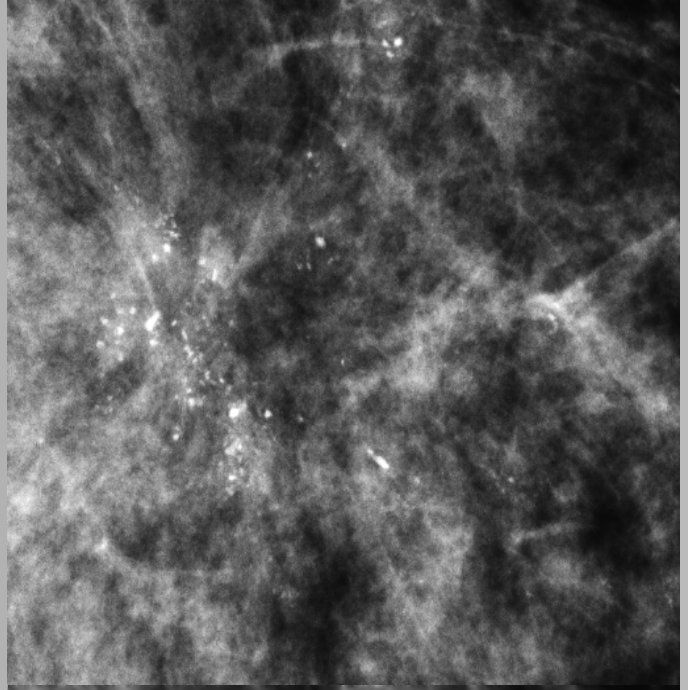


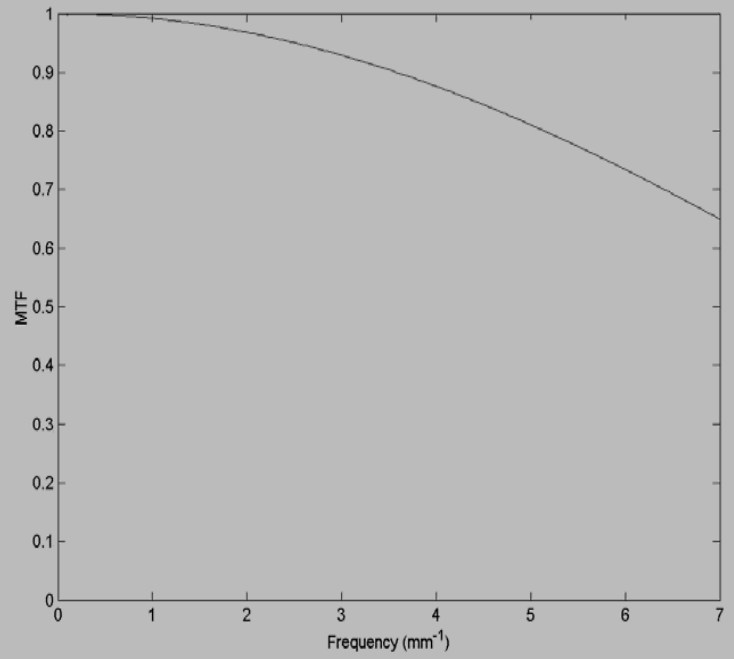
Canon 135mm f/2L



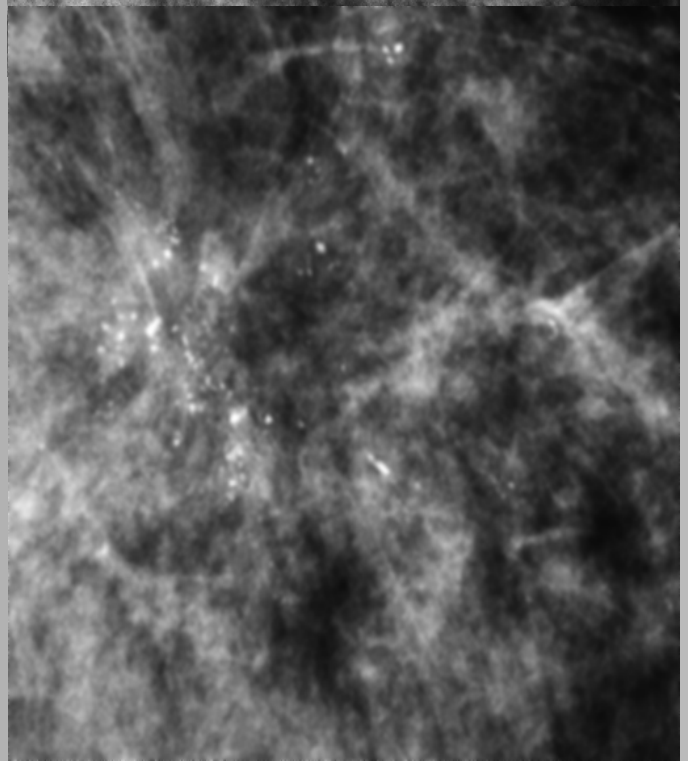


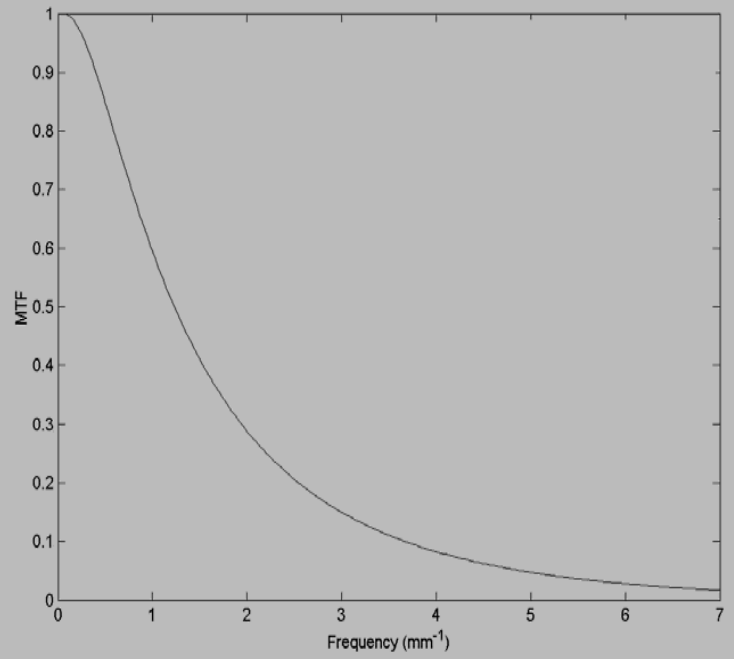
High MTF



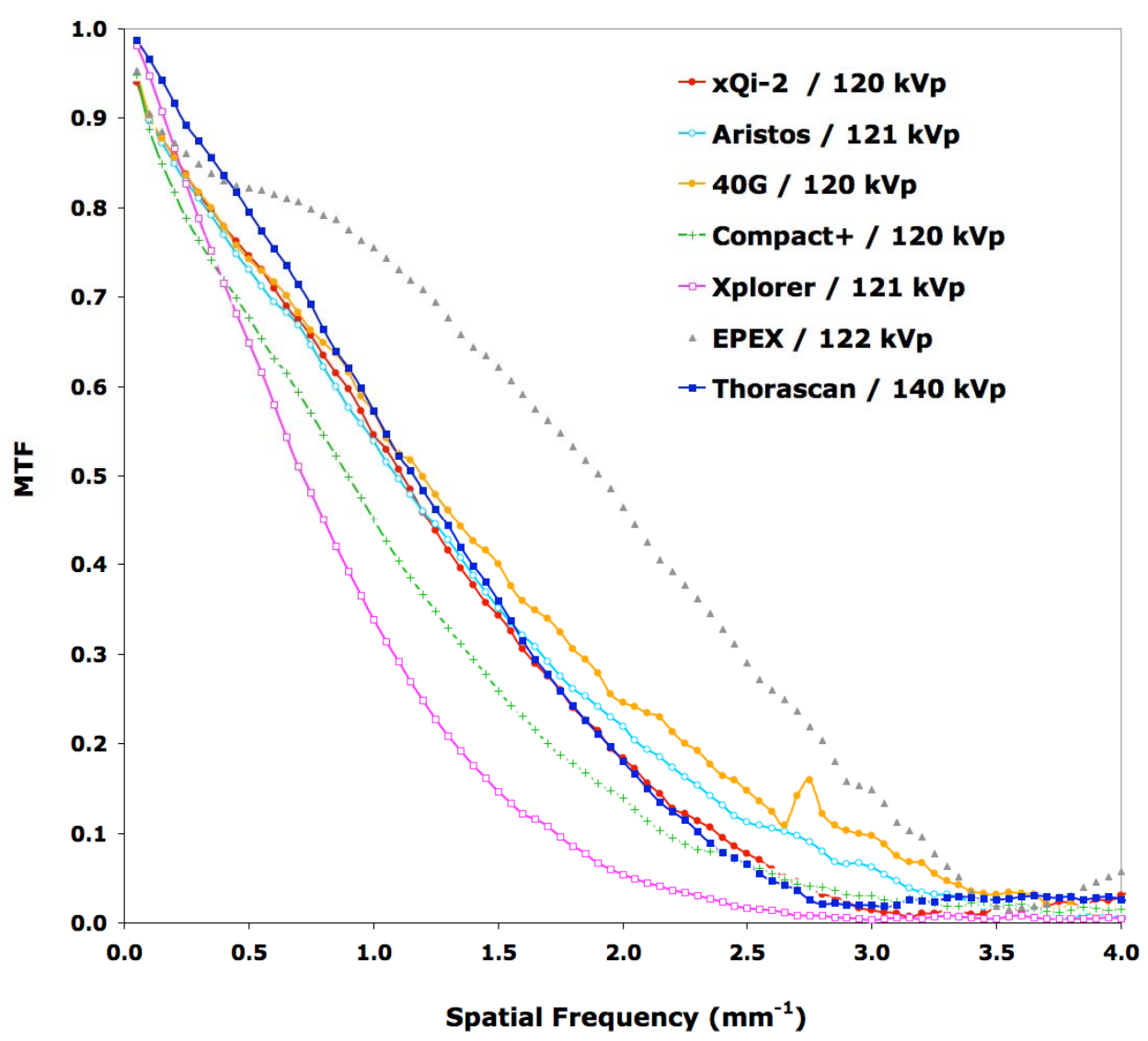


Low MTF



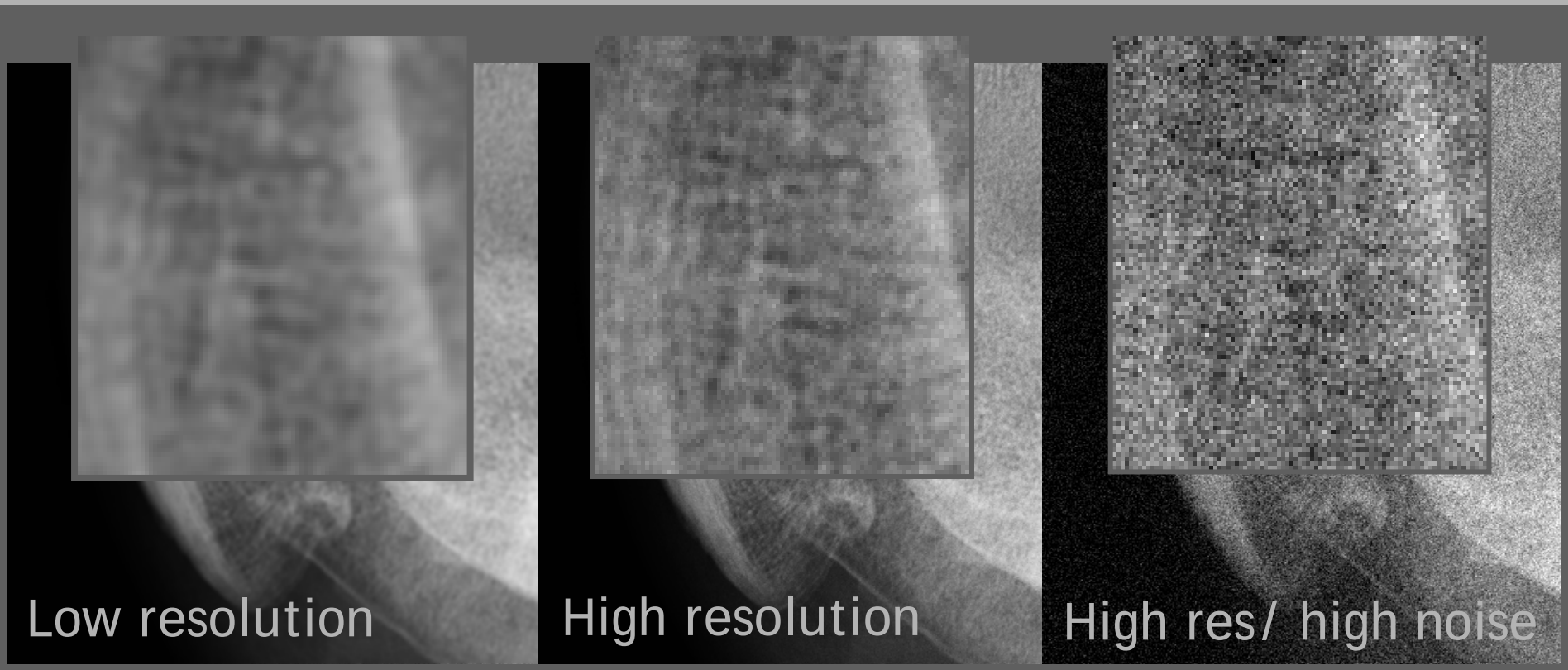


MTF of DR systems



Noise

- Unwanted signals that interfere with interpretation



Noise in terms of NPS

- Best characterized by the noise power spectrum (NPS):
  - **The variance of noise in an image in terms of the spatial frequencies**

NPS

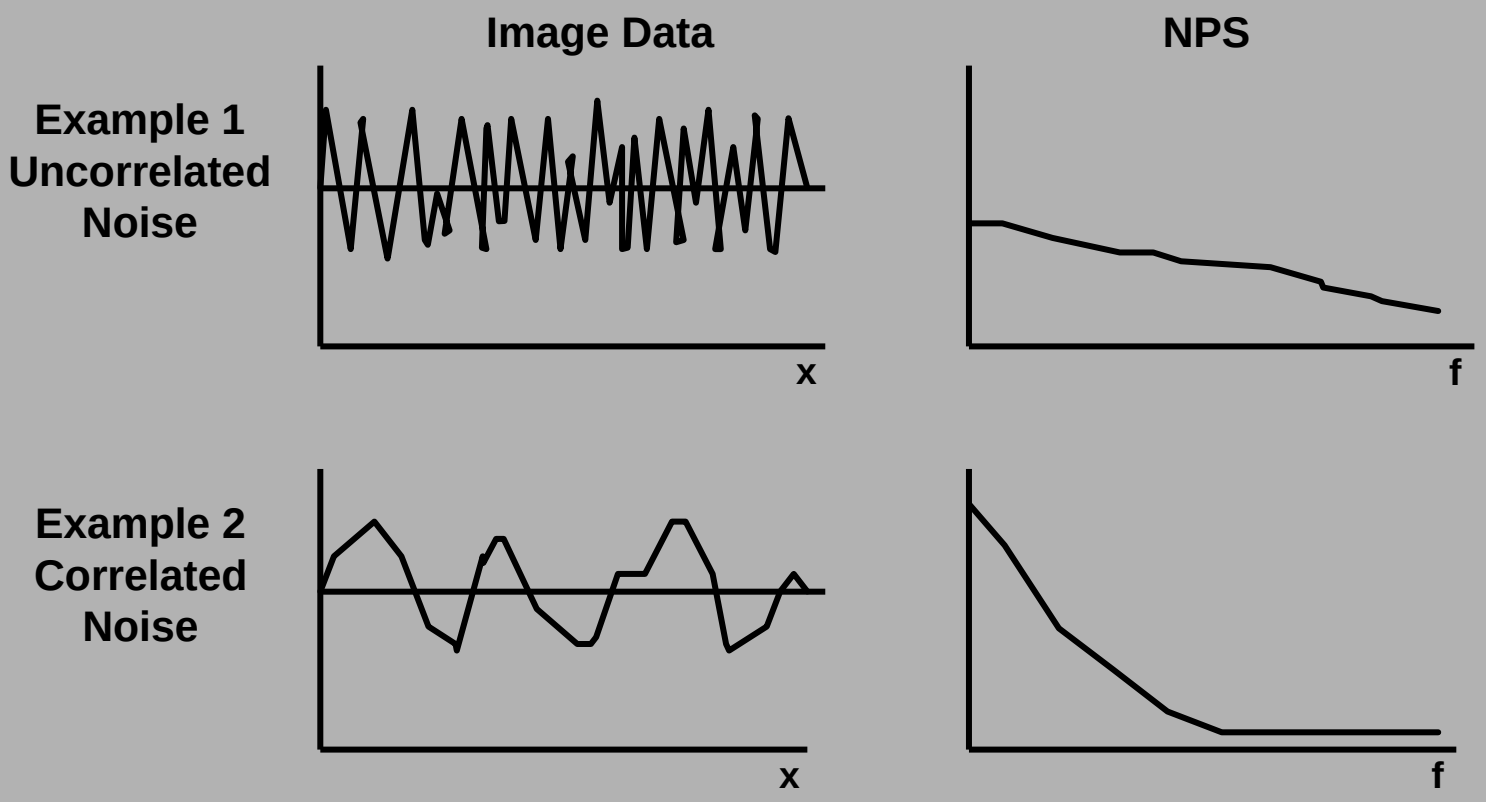
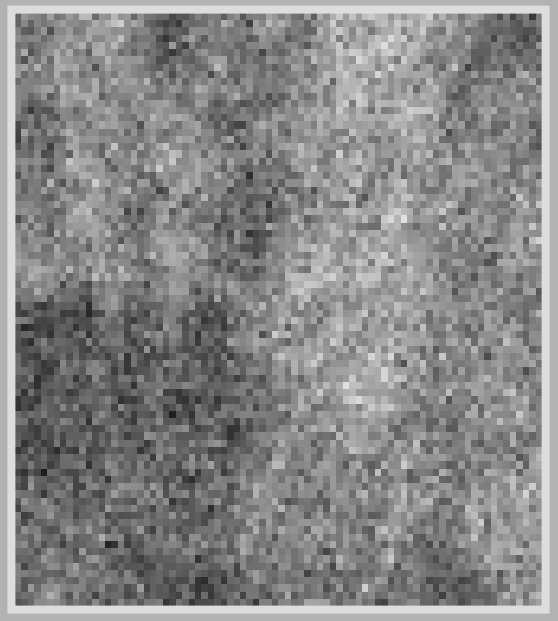
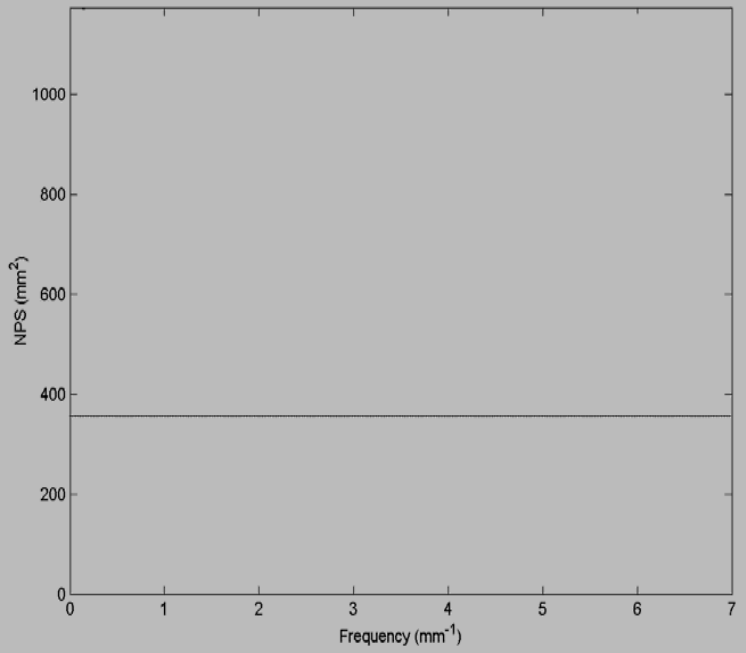


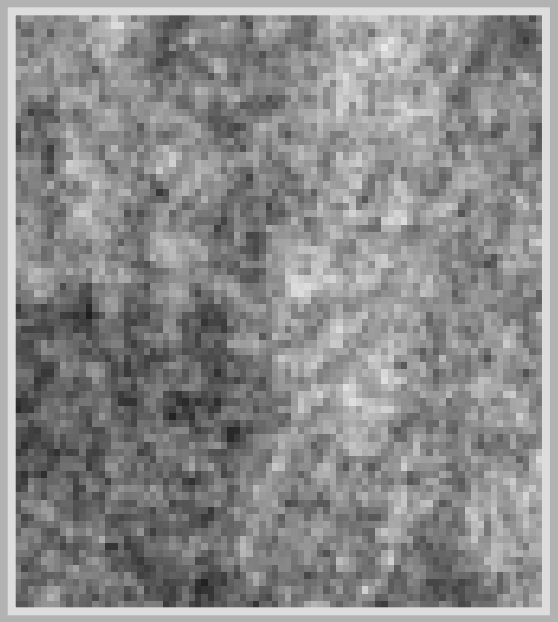
Image Data
NPS
Example 1
Uncorrelated
Noise
x
f
Example 2
Correlated
Noise
x
f

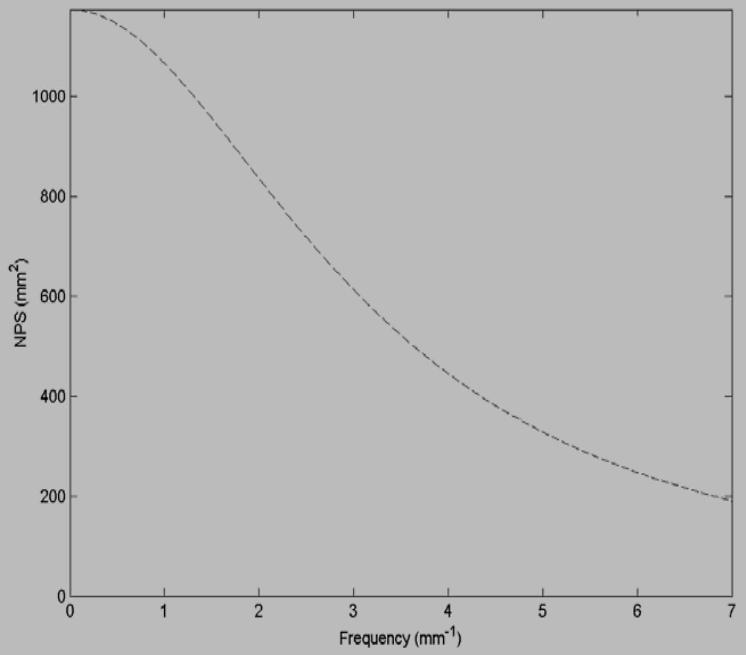
Uncorrelated noise



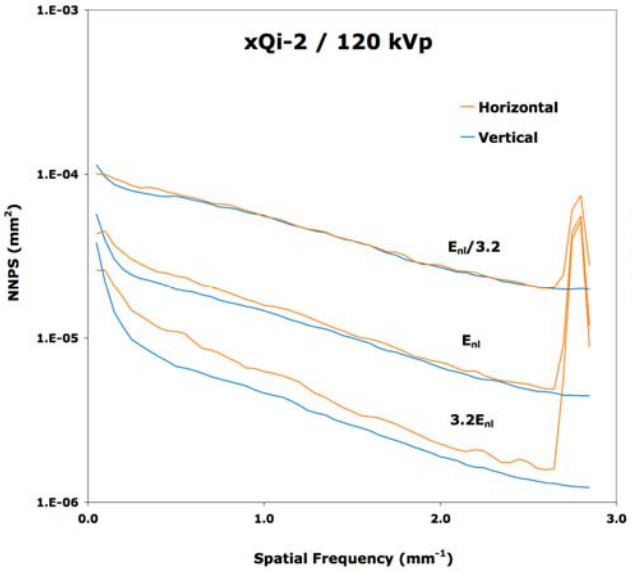


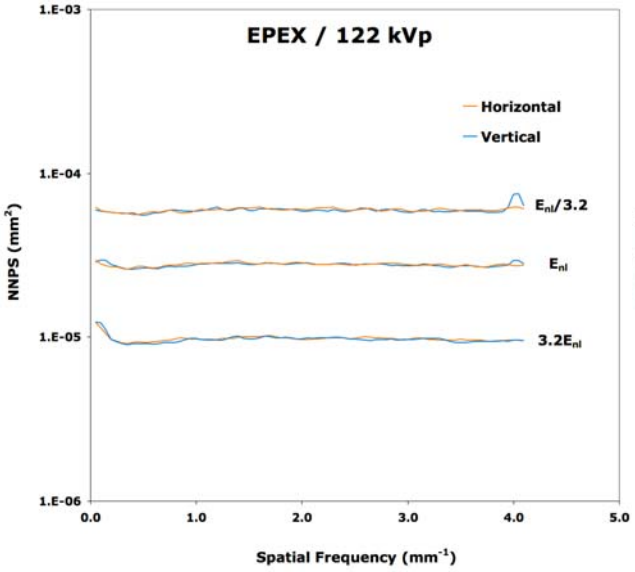
Correlated noise

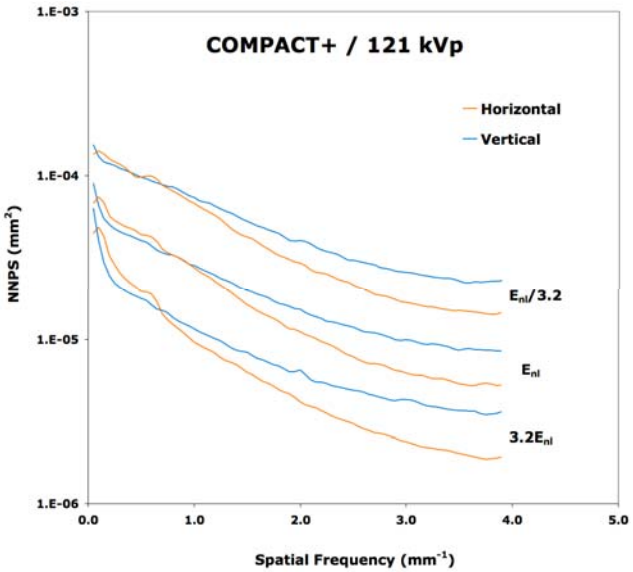


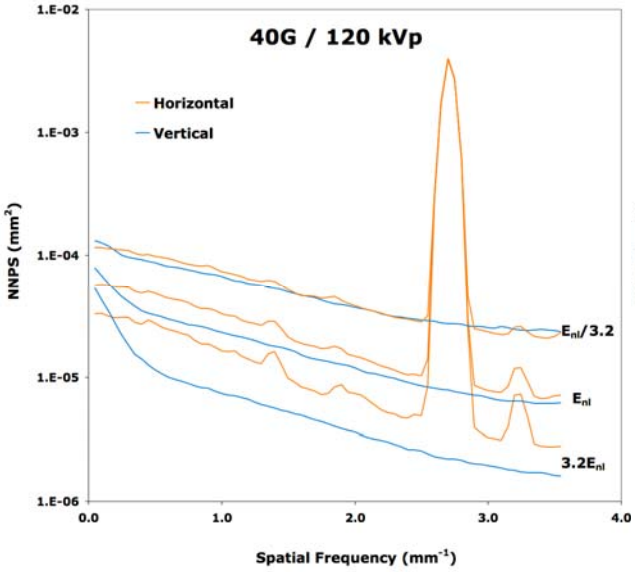


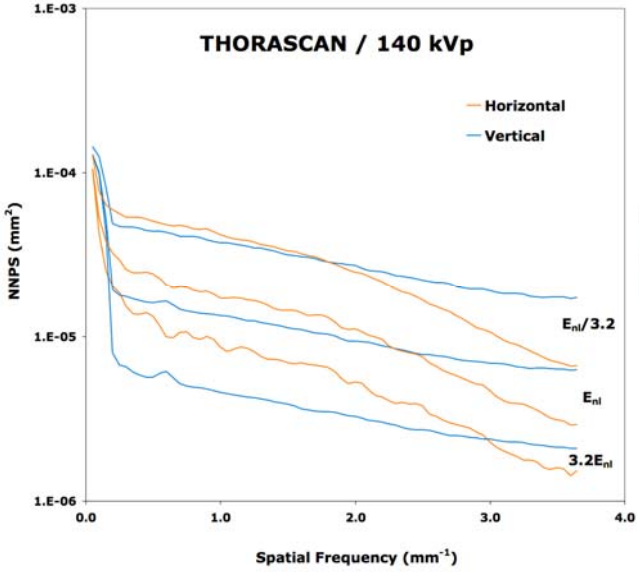
NPS of DR systems

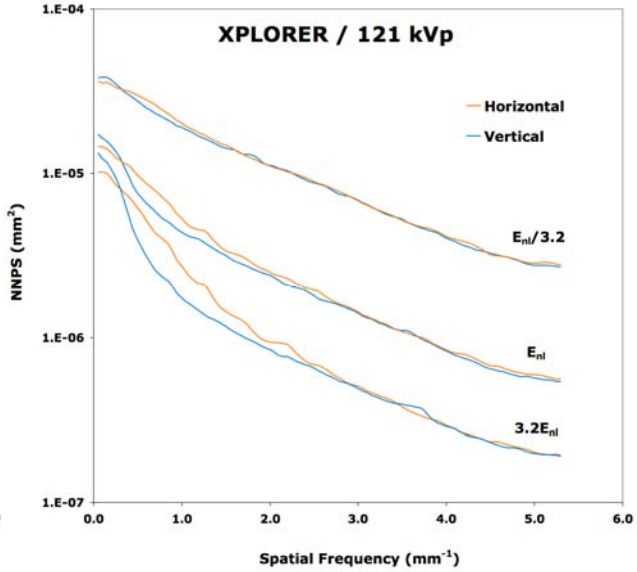












Noise and Resolution => SNR

- Higher MTF: better visibility of details
- Higher NPS: poorer visibility of details
- Visibility ~ MTF and NPS => SNR

$$SNR^2 = \frac{MTF^2}{NPS}$$

- Rose model: Higher the SNR =>

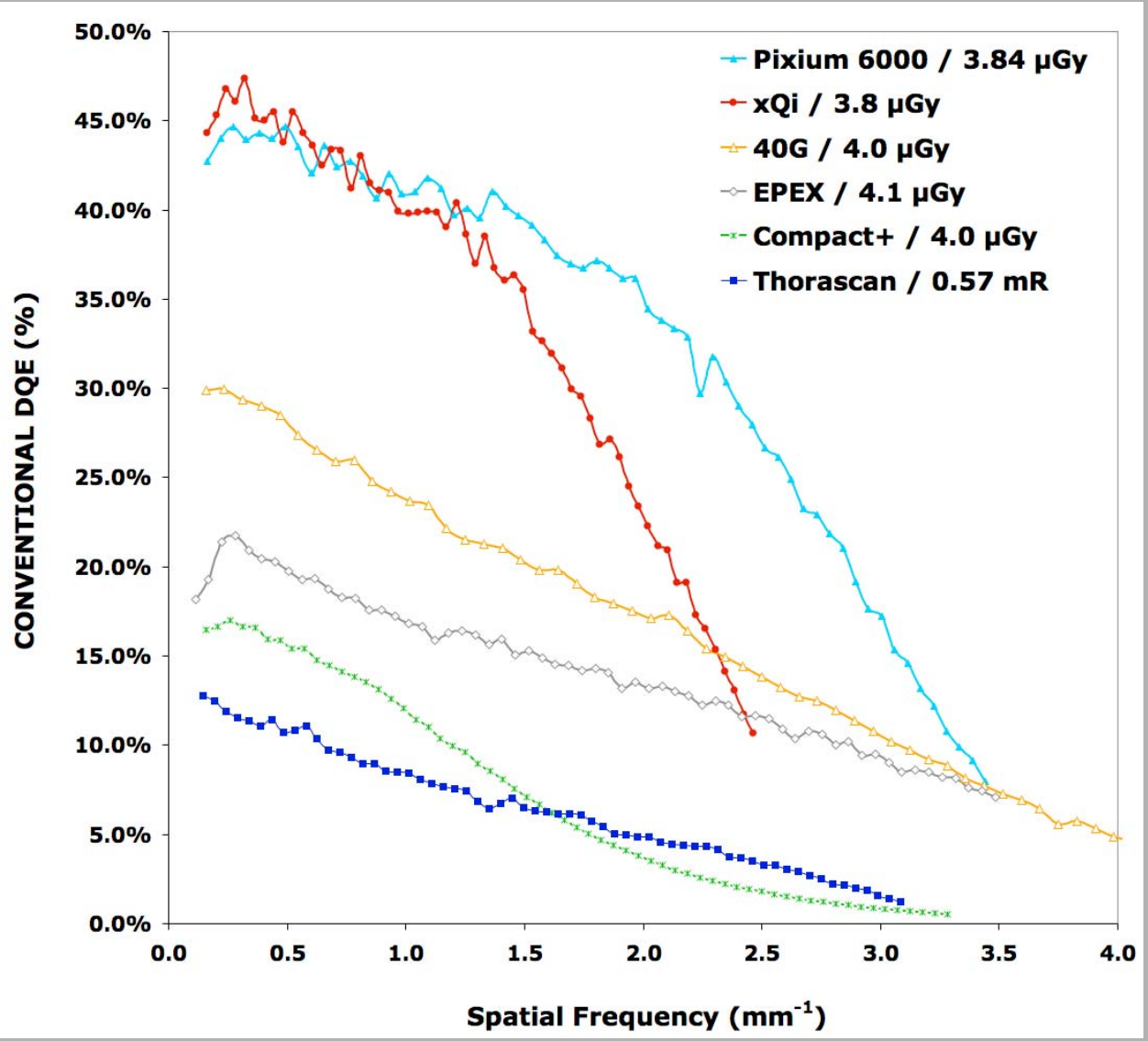
  Features w/ smaller C and D can be detected

SNR efficiency

- Best characterized by the detective quantum efficiency (DQE):
  - **Efficiency of a detector to utilize the maximum possible SNR provided by the finite number of x-ray photons forming the image**

$$DQE = \frac{SNR^2}{SNR^2_{ideal}} = \frac{MTF^2}{SNR^2_{ideal} \times NPS}$$

DQE of DR systems

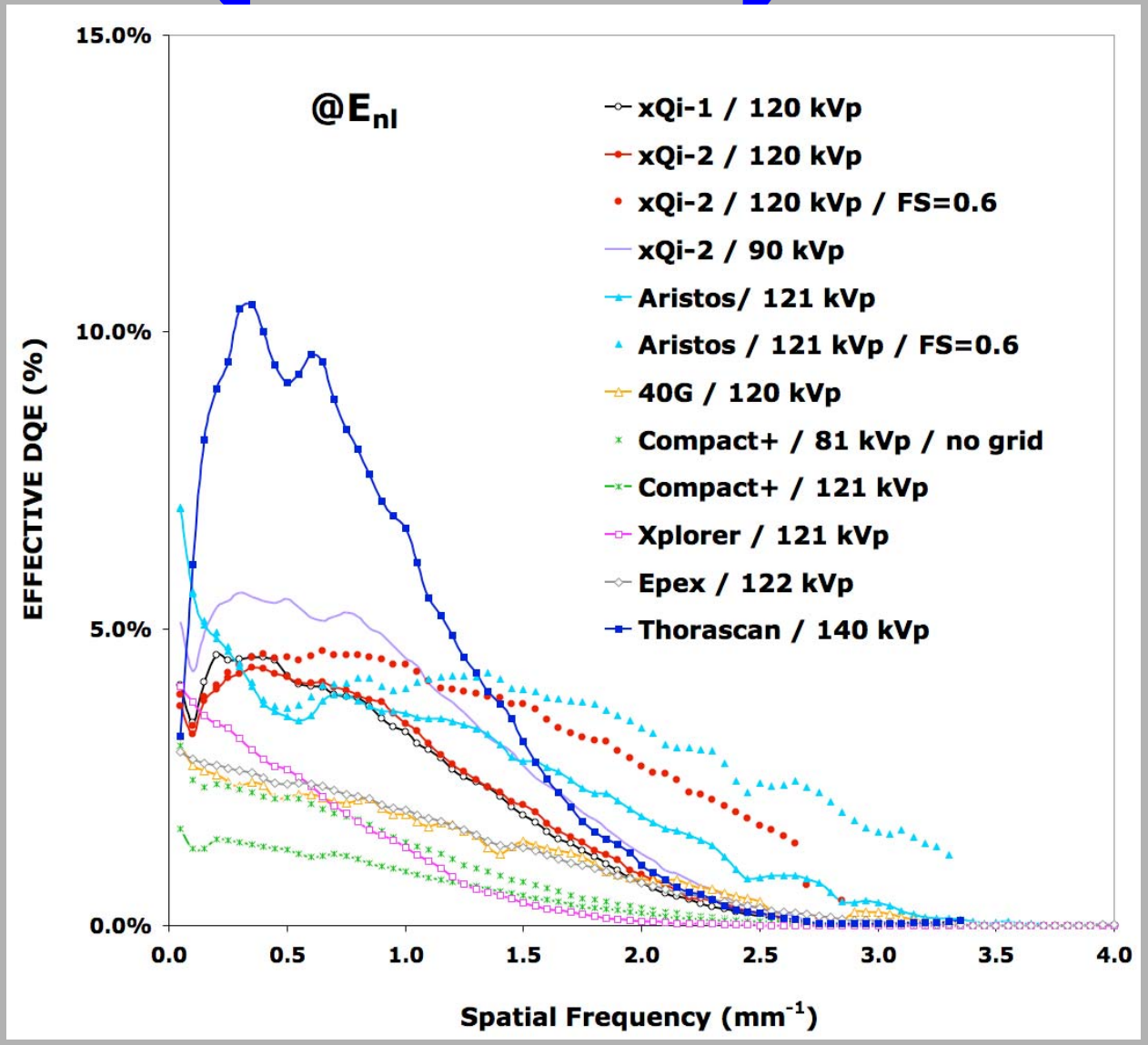


SNR efficiency in the presence of scatter, magnification, grid, and focal spot blur

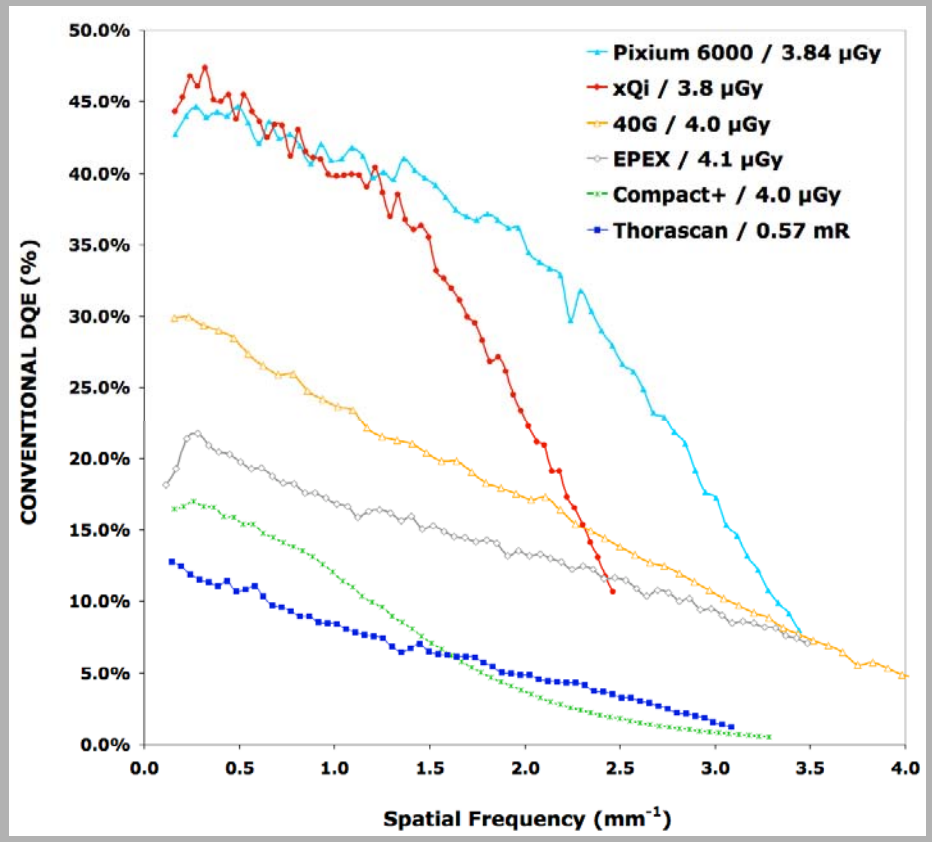
- Best characterized by the *effective* detective quantum efficiency (eDQE):
  - **Efficiency of a *system* to utilize the maximum possible SNR provided by the finite number of x-ray photons forming the image**

Samei et al, *Radiology*, April 2005

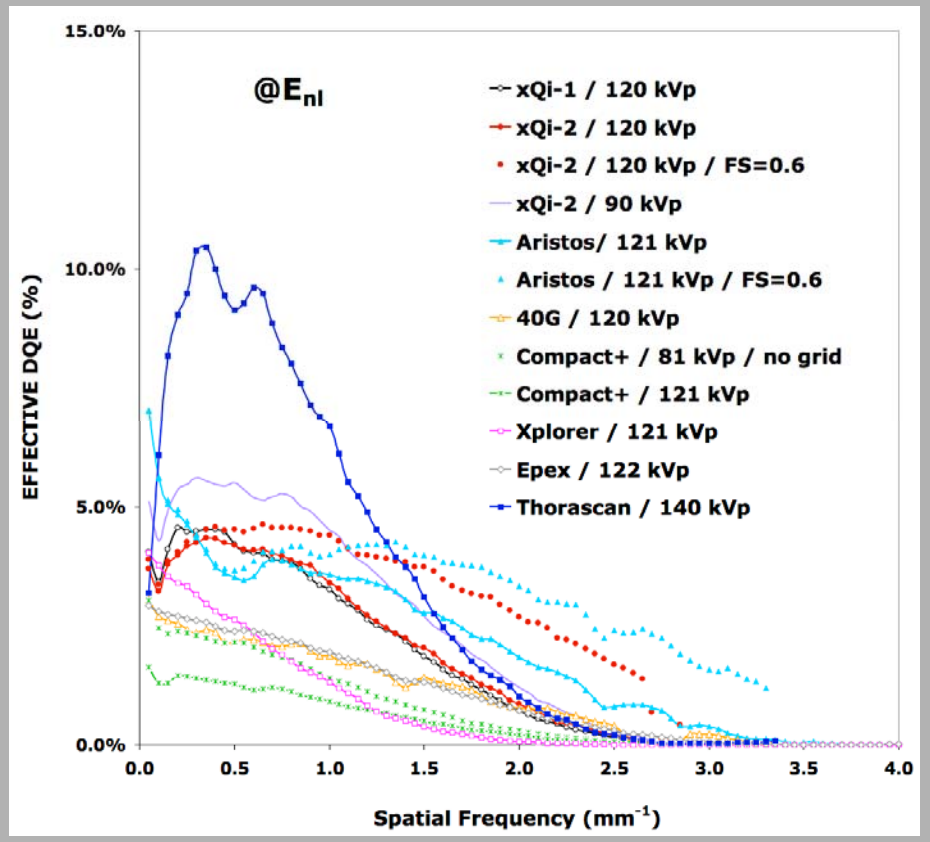
eDQE of DR systems



DQE


CONVENTIONAL DQE (%)
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Spatial Frequency (mm-1)
Pixium 6000 / 3.84 µGy
xQi / 3.8 µGy
40G / 4.0 µGy
EPEX / 4.1 µGy
Compact+ / 4.0 µGy
Thorascan / 0.57 mR

eDQE

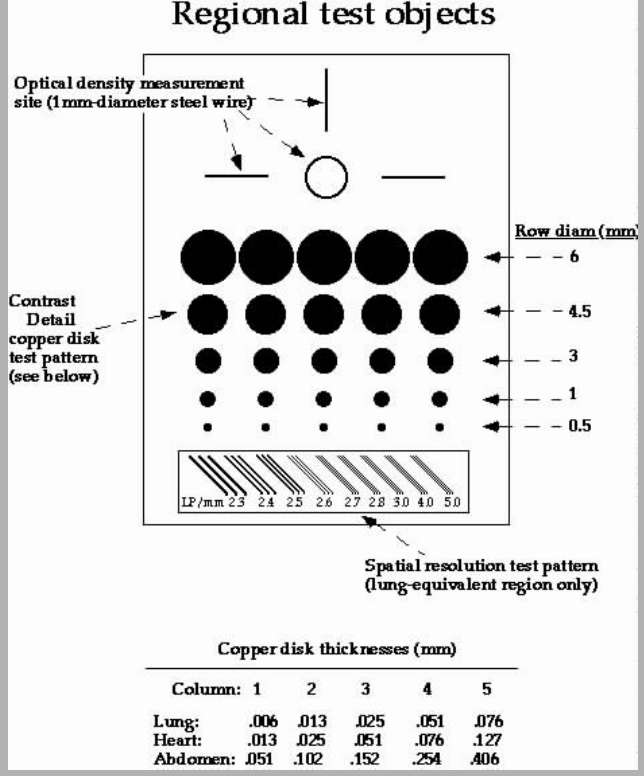

EFFECTIVE DQE (%)
15.0%
10.0%
5.0%
0.0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Spatial Frequency (mm-1)
@Enl
xQi-1 / 120 kVp
xQi-2 / 120 kVp
xQi-2 / 120 kVp / FS=0.6
xQi-2 / 90 kVp
Aristos/ 121 kVp
Aristos / 121 kVp / FS=0.6
40G / 120 kVp
Compact+ / 81 kVp / no grid
Compact+ / 121 kVp
Xplorer / 121 kVp
Epex / 122 kVp
Thorascan / 140 kVp

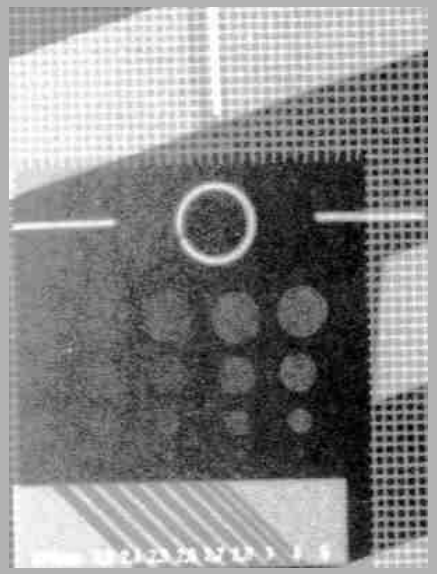
QC program for DR

1. *Acceptance testing*:
   - Upon installation
   - basic performance attributes (MTF, NPS, DQE, eDQE)
   - Baseline QC performance attributes
2. *System calibration*
3. *Preventative maintenance*
4. *Periodic assessments*

Metric	Performance attribute
MTF	Resolution properties of the image/detector/system
NPS	Noise properties of the image/detector/system
DQE	SNR transfer properties of the detector
eDQE	SNR transfer properties of the system
Dark noise	Noise in the absence of signal
Uniformity	Signal uniformity in the absence of an object
Exposure Indicator	Accuracy of exposure indication by the system
Linearity	Exposure response behavior of the system
High-contrast resolution	Ability of the system to represent high-contrast patterns
Low-contrast resolution	Ability of the system to represent low-contrast patterns
Distortion	Geometrical accuracy of images
Artifact	Non-uniform artifactual features in the images
Ghosting	Appearance of shadows of prior images on subsequent images
Throughput	Speed by which a system can sequentially capture images
Normal exposure	Target exposure values for clinical use reflecting system speed

QC phantoms
(eg, Duke Phantom)





Requirements for Classification of Pneumoconiosis

1. Robust **quality control program**
2. Standardized image acquisition **protocols** (kVp, filtration settings, target exposure levels)
3. Consistent **exposure index** (AAPM TG116)
4. Availability of **raw image data** in "for-processing" format

Requirements for Classification of Pneumoconiosis (cont.)

5. Consistent **processing and display** for consistent visualization across cases and systems
6. Consistent **analysis** for automated quantification of pneumoconiosis
7. Archival of both **raw and processed** image data for further assessment or analysis

Conclusions

- DR provides an unprecedented opportunity to provide a standardized classification of pneumoconiosis. It can do so through its quantitative nature and its tractable performance characteristics.
- QC is essential to ensure robustness and integrity of digital image data and to enable a reliable classification scheme.

Conclusions (cont.)

- QC program components:
  - *Acceptance testing, System calibration, Preventative maintenance, Periodic assessments*
- A robust QC program along with standardized acquisition and processing protocols would enable visual and automated classification of pneumoconiosis from digital chest images.

Recommendations

1. **QC program**: All NIOSH affiliated facilities should enact and maintain rigorous PM and QC programs.
2. **Protocols**: All NIOSH affiliated facilities should follow predefined acquisition and processing protocols.
3. **Web server**: NIOSH should consider a central web server for affiliated facilities.

Recommendations (cont.)

4. **Communication**: All affiliated facilities should register their imaging devices including uploading their inherent performance metrics.
5. **Processing**: The uploaded raw, "for-processing" image data may be consistently processed and analyzed for visual or automated classification.
6. **Accreditation**: NIOSH should consider a process by which it could accredit its affiliated facilities to ensure adherence to its minimum performance and operational requirements.

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Thank you for your attention

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