AAPM COMP 2011

Radiography: 2D and 3D Metrics of Performance Towards Quality Index

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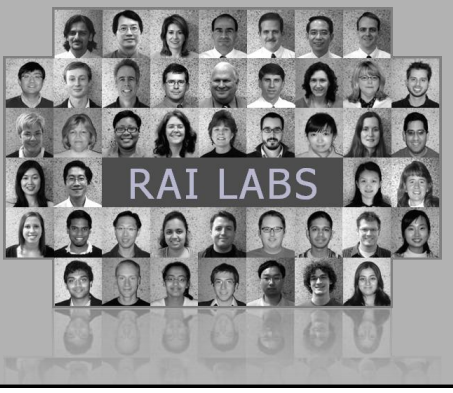


Learning objectives

1. To understand methods for 2D and 3D resolution measurements.
2. To understand the basics for DQE and eDQE measurement techniques.
3. To relate physical metrics of performance to clinical image quality.

Outlook

- Medical imaging
  - ➔ clinically meaningful information
- Quality of information
  - ➔ image quality
- Image quality
  - ➔ universally-appreciated universally-illusive

What is image quality?

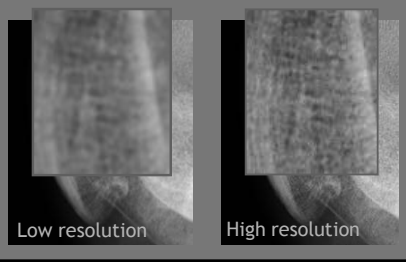
- Image esthetics
  - Subjective and qualitative
  - Not necessarily reflective of diagnostic performance
- Diagnostic accuracy
  - Expensive
  - Impractical given the extent and variability of technologies

Physical metrics of image quality

- Convenient and practical
- Effective to the extent they can be related to diagnostic performance
- Applicable under qualified conditions:
  - Detector vs system
  - Incorporation of scattered radiation
  - Incorporation of anatomical attributes
  - Incorporation of task attributes
  - System-based vs image-based metrics

Resolution

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



Resolution

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

$$MTF = \mathcal{F}\{LSF(x)\}$$

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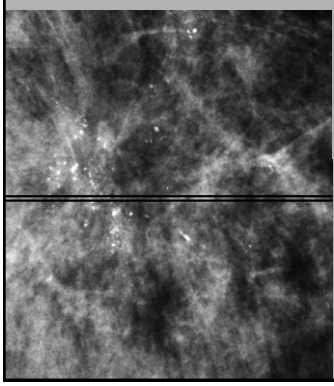
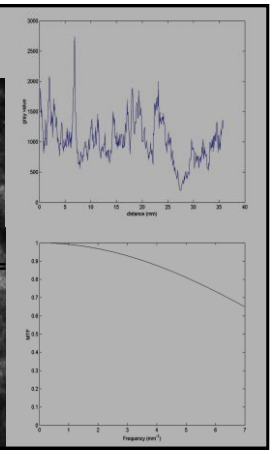
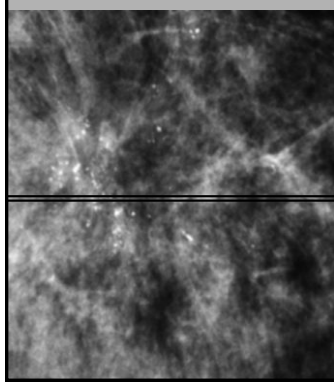
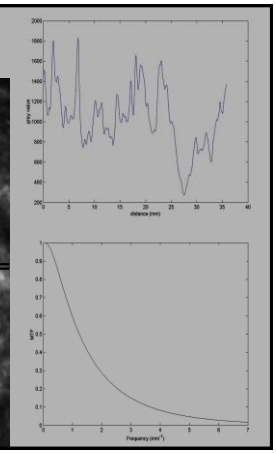
High MTF





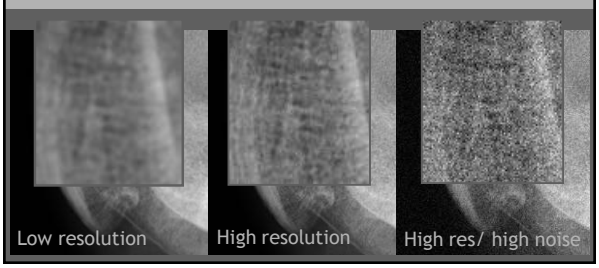
Low MTF





Noise

- Unwanted signals that interfere with interpretation



Noise

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

$$ACF(x) = \frac{1}{L}\int_L \Delta i(x+x')\Delta i(x')dx'$$

$$NPS(f) = \Im\{ACF(x)\}$$

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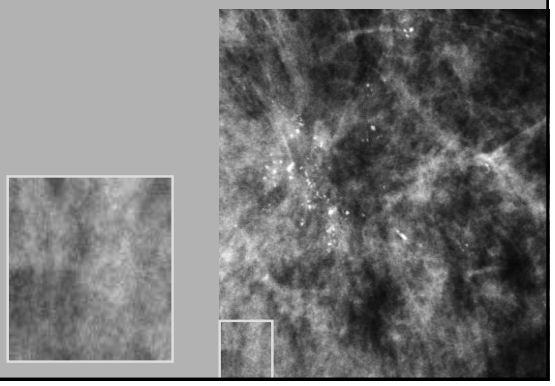
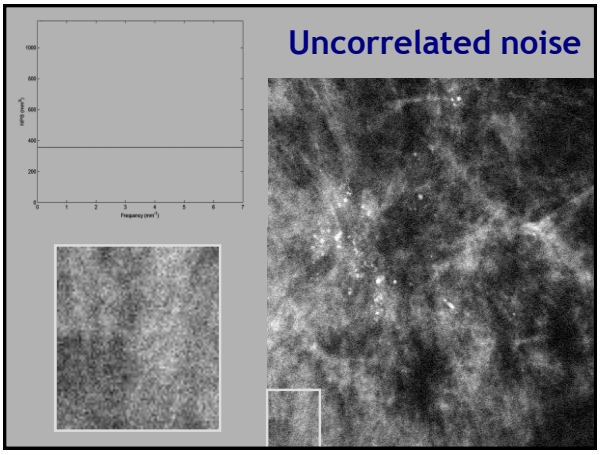
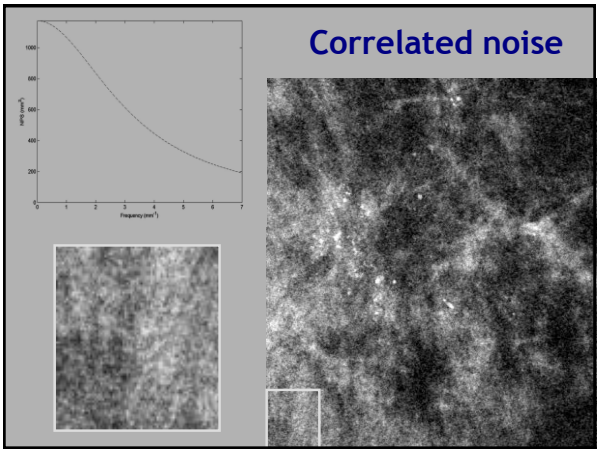
Image without noise



Uncorrelated noise



Correlated noise



Noise and Resolution => SNR

- Threshold contrast and diameter ~ 1/SNR (Rose model)
- Higher the SNR =>

Features w/ smaller C and D can be detected

$$NEQ(f) = SNR_{actual}^2 = \frac{MTF(f)^2}{NNPS(f)}$$

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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**

$$DQE(f) = \frac{SNR^2_{actual}}{SNR^2_{ideal}} = \frac{MTF(f)^2}{NNPS(f) \times E_0 \times q}$$

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Measurement method

- Beam quality and magnitude
  - kVp
  - Filtration
  - Exposure
- Access to linear or linearized data

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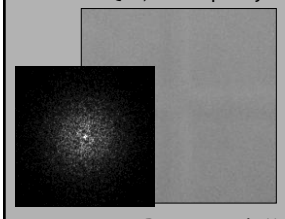
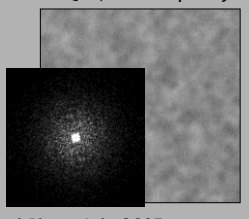
Al purity

- IEC recommendation: >99.9% purity

RQA5, 99.0% purity



RQA5, 99.99% purity



Ranger et al, Med Phys, July 2005

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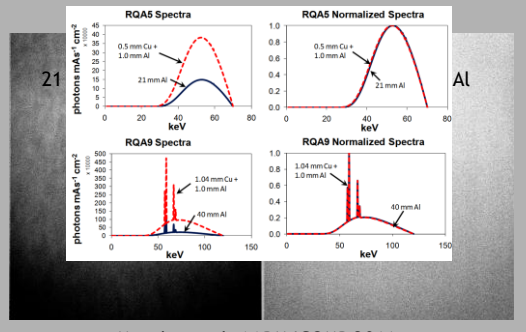
Aluminum versus Copper



Murphy et al, AAPM/COMP 2011

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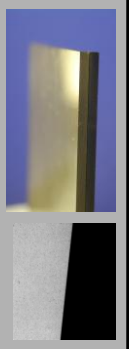
MTF methodology: Edge

- Edge test device
- ESF deduced from image data
- MTF from ESF via differentiation and Fourier trans.
- High precision, particularly at low frequencies
- Simple and quick alignment
- Established method (endorsed by the IEC)



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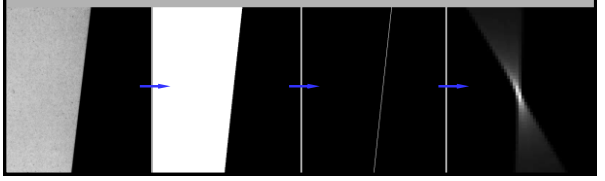
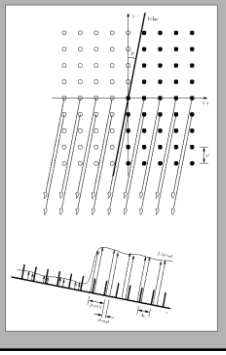
Edge image processing

1. Finding the edge angle
   - Least square fits
   - Differentiation and Hough or Radon transform



Edge image processing

2. 2D projection to obtain ESF
3. ESF differentiation and smoothing to obtain LSF
4. Fourier transformation of LSF to get the presampled MTF
5. Normalization of the MTF at 0 frequency
6. Rebinning the MTF (0.05 mm^{-1} per IEC)



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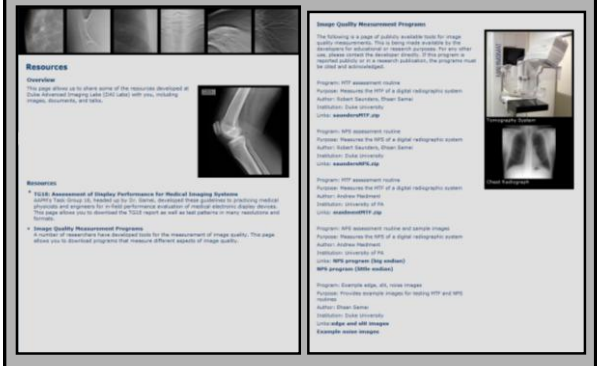
railabs.org/resources



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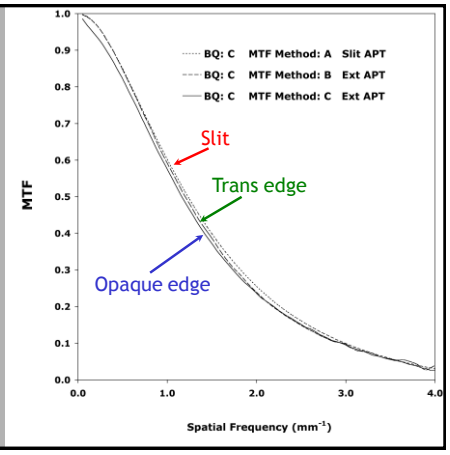
Effect of method (GE XQ/i)

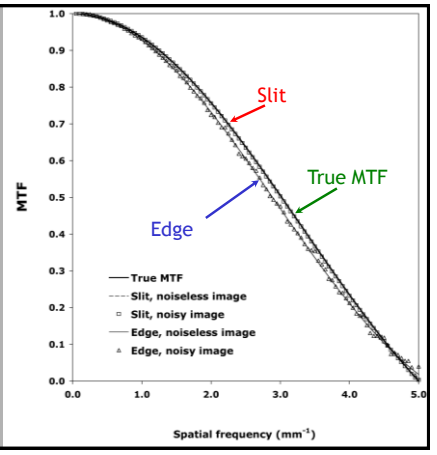
Diffs
<6% overall
<8% single f



Effect of method (ideal)

Diffs
<0.3% for slit

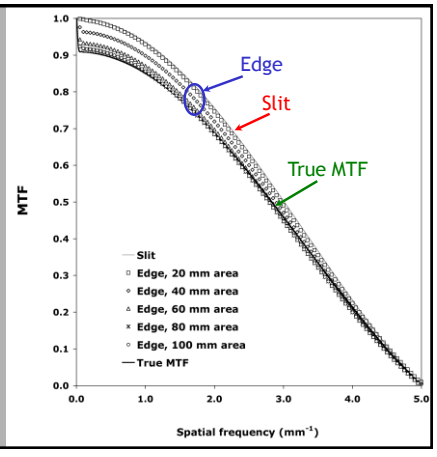
<5.2% for edge



Effect of method (w/ glare)

Diffs
<10% for slit

<2% for edge



DQE methodology

$$DQE(f) = \frac{SNR^2_{actual}}{SNR^2_{ideal}} = \frac{MTF(f)^2}{NNPS(f) \times E_0 \times q}$$

MTF	=>	Measured
NNPS	=>	Measured
E_0	=>	Measured
q (SNR^2_{ideal}/E_0)	=>	Estimated

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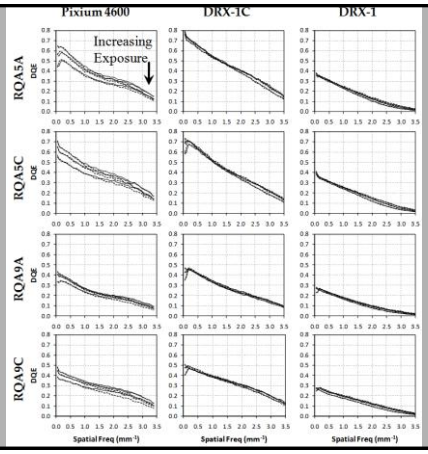

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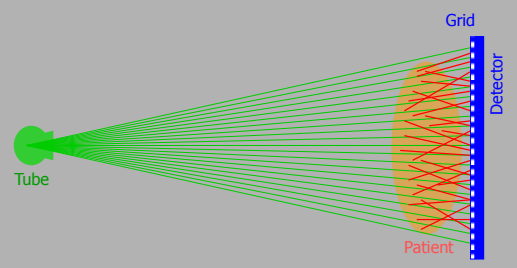
Adding magnification, scatter, grid



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Adding magnification, scatter, grid

$$DQE(f) = \frac{SNR^2_{actual}}{SNR^2_{ideal}} = \frac{MTF(f)^2}{NNPS(f) \times E_0 \times q}$$

$$eDQE(f_m) = \frac{eMTF(f_m)^2 \times (1 - SF)^2}{eNNPS(f_m) \times TF_{nb} \times E_0 \times q}$$

Samei et al, Med Phys, 2009

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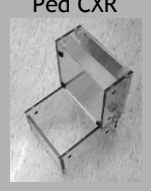
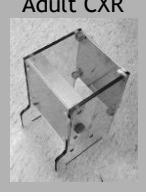
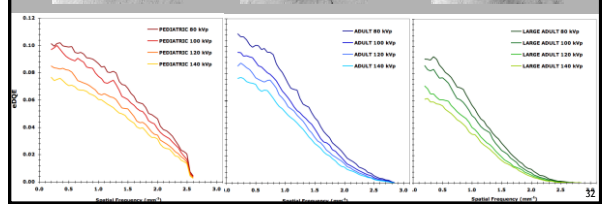
eDQE

Ped CXR | Adult CXR | XL Adult CXR

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From DQE to IQ

Resolution and contrast transfer × Attributes of image feature of interest

Image noise: magnitude and texture

$$d'^2 = \int eDQE(f_m).W(f)^2\, df$$

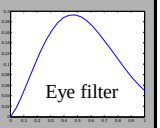
Model observers

Fisher-Hotelling observer (FH)

$$\left(d'_{FH}\right)^2 = \iint \frac{MTF^2(u,v)W^2_{Task}(u,v)}{NPS(u,v)}\,du\,dv$$

Non-prewhitening observer (NPW)

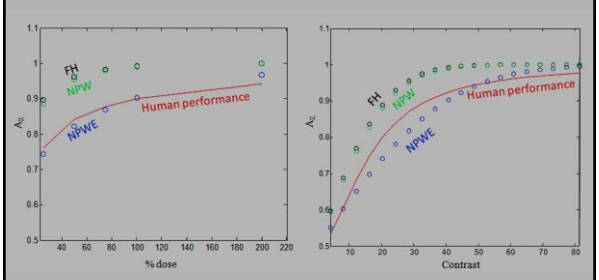
$$\left(d'_{NPW}\right)^2 = \frac{\left[\iint MTF^2(u,v)W^2_{Task}(u,v)\,du\,dv\right]^2}{\iint MTF^2(u,v)W^2_{Task}(u,v)NPS(u,v)\,du\,dv}$$



NPW observer with eye filter (NPWE)

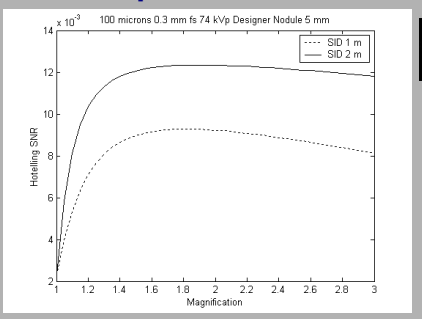
$$\left(d'_{NPWE}\right)^2 = \frac{\left[\iint MTF^2(u,v)W^2_{Task}(u,v)E^2(u,v)\,du\,dv\right]^2}{\iint MTF^2(u,v)W^2_{Task}(u,v)NPS(u,v)E^4(u,v) + MTF^2(u,v)W^2_{Task}(u,v)N_t\,du\,dv}$$

Validation of model observers



Richard, Li, Samei, SPIE 2011

eDQE applied to acquisition optimization



Boyce et al, Med Phys, 2005

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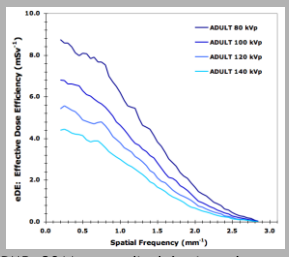
From DQE to IQ and dose: Effective Dose Efficiency (eDE)

$$eDE(f_m) = eDQE(f_m) \times q \times \frac{E_S}{ED} \times \left(\frac{SSD}{SID}\right)^2$$



Samei et al, PMB, 2011 medicalphysicsweb.org, July 29, 2011

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Summary

- MTF can be robustly measured using edge method
- DQE provides a meaningful measure of detector performance correlated with human performance
- DQE can be readily extended to system performance (via eDQE)
- DQE can readily be normalized by dose (eDE) for acquisition optimization

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