Assuring image quality for classification of digital chest radiographs

Ehsan Samei, PhD
Carl Ravin, MD

Duke Advanced Imaging Laboratories
Department of Radiology
Duke University Medical Center
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
MTF in photography

Canon 35mm f/1.4L

Canon 50mm f/1.4

Canon 135mm f/2L

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MTF of DR systems

Spatial Frequency (mm⁻¹)

MTF

- xQi-2 / 120 kVp
- Aristos / 121 kVp
- 40G / 120 kVp
- Compact+ / 120 kVp
- Xplorer / 121 kVp
- EPEX / 122 kVp
- Thorascan / 140 kVp
Noise

• Unwanted signals that interfere with interpretation

Low resolution High resolution High res/ high noise
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

Example 1
Uncorrelated Noise

Example 2
Correlated Noise

Image Data

NPS
NPS of DR systems

- xQi-2 / 120 kVp
- E₀/3.2, E₀, 3.2E₀

- EPEX / 122 kVp
- Horizontal, Vertical

- COMPACT+ / 121 kVp
- E₀/3.2, E₀, 3.2E₀

- 40G / 120 kVp
- Horizontal, Vertical

- THORASCAN / 140 kVp
- Horizontal, Vertical

- XPLOLER / 121 kVp
- Horizontal, Vertical

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Noise and Resolution => SNR

- Higher MTF: better visibility of details
- Higher NPS: poorer visibility of details
- Visibility $\sim$ 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

\[
DQE = \frac{SNR^2}{SNR_{ideal}^2} = \frac{MTF^2}{SNR_{ideal}^2 \times NPS}
\]
DQE of DR systems

![Graph showing DQE of different DR systems.](image)
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

@\text{E}_{nl}

- 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

Spatial Frequency (mm\(^{-1}\))

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

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