Acceptance and acceptability testing of fluoroscopic equipment: Image quality and perception

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Fluoroscopy is inherently dynamic

• Operators are making decisions in real time based on spatiotemporal information delivered by the fluoroscopy system

• Medical physicists face key challenges when evaluating and configuring fluoroscopy systems
  • Optimizing the system for clinical use
  • Monitoring the performance of the system relative to its intended clinical use
  • Connecting periodic testing to the clinical use of the system
Assume it matters until you’re sure it doesn’t

- LIH vs. live fluoro
- Acquisition mode used
- Measuring field used and location of test objects relative to MF
- Orientation of the gantry
- Location of the gantry relative to the patient table
- Organ program selection
- Ambient illuminance of room
- Sending images to PACS or to external storage for analysis
- Etc.
Assume it matters until you’re sure it doesn’t

- LIH vs. live fluoro
- Acquisition mode used
- Measuring field used and location of test objects relative to MF
- Orientation and location of the gantry
- Organ program selection
- Ambient illuminance of room
- Sending images to PACS or to external storage for analysis
- Etc.

- Frame averaging to create LIH
- Different FS, kV, scene time
- Change in kV, detector dose
- Added filtration, kV
- Many parameters
- Ambient light sensor, contrast sensitivity
- Resizing of images
Image analysis for periodic testing

• What is the goal?
  • Qualitative vs. quantitative

• Are your methods and tools appropriate?
  • Are you testing what you think you are testing?

• How does your test relate to the clinical performance of the system?
Viewing conditions

• Ambient lighting

• Display calibration and configuration

• Position of operator relative to the display
Ambient lighting

Specified $R_s \leq 0.01$ for this screen protector

**AAPM On-line Report No. 03 - Assessment of display performance for medical imaging systems**

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Table 4. Maximum allowable ambient illuminance, based on specular reflection.

<table>
<thead>
<tr>
<th>$L_{\text{max}} - L_{\text{min}}$ (cd/m²)</th>
<th>$C_s$</th>
<th>$R_s = 0.002$</th>
<th>$R_s = 0.004$</th>
<th>$R_s = 0.008$</th>
<th>$R_s = 0.020$</th>
<th>$R_s = 0.040$</th>
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<td>5000 – 20</td>
<td>0.010</td>
<td>349</td>
<td>175</td>
<td>87</td>
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<td>17</td>
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<tr>
<td>2500 – 10</td>
<td>0.011</td>
<td>192</td>
<td>96</td>
<td>48</td>
<td>19</td>
<td>10</td>
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<tr>
<td>1000 – 4</td>
<td>0.015</td>
<td>105</td>
<td>52</td>
<td>26</td>
<td>10</td>
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<tr>
<td>500 – 2</td>
<td>0.018</td>
<td>63</td>
<td>31</td>
<td>16</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>250 – 1</td>
<td>0.024</td>
<td>42</td>
<td>21</td>
<td>10</td>
<td>4</td>
<td>2</td>
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</table>

For a display device with a specific minimum luminance, $L_{\text{min}}$, and a specific specular reflection coefficient, $R_s$, the ambient illumination that maintains specular reflections from high-contrast objects below the visual contrast threshold ($C_s$) is tabulated.

Table 5. Maximum room lighting based on diffuse reflection.

<table>
<thead>
<tr>
<th>$L_{\text{max}} - L_{\text{min}}$ (cd/m²)</th>
<th>$R_d = 0.005$</th>
<th>$R_d = 0.010$</th>
<th>$R_d = 0.020$</th>
<th>$R_d = 0.040$</th>
<th>$R_d = 0.060$</th>
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<tr>
<td>1000 – 4</td>
<td>200</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>500 – 2</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>250 – 1</td>
<td>50</td>
<td>25</td>
<td>12</td>
<td>6</td>
<td>4</td>
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</table>

For a display device with a specific minimum luminance, $L_{\text{min}}$, and a specific diffuse reflection coefficient, $R_d$ in units of cd/m² per lux or sr⁻¹, the ambient illumination which maintains 80% contrast in dark regions is tabulated. The maximum room illuminance is calculated as $0.25 L_{\text{min}}/R_d$. 
In our labs at MD Anderson, with LED downlighting behind baffles (set to medium-low), and overhead can lights off during live fluoroscopy, we measure ~ 20 lux on the surface of our monitor, and there is no difference in visibility of the TG-18AD pattern.

With overhead can lights on low, this increases to ~ 50 lux, and visibility of the TG18-AD pattern is reduced compared to total darkness.
Ambient lighting – in practice

• Reposition, block, or remove source of specular reflection

• If available, use TG18-AD test pattern
  • Set room lighting to where the threshold for visibility is the same in total darkness and when viewed in ambient lighting ($D_v = 30\,\text{cm}$)

• Alternatively, set room lighting to achieve $L_{\text{amb}}$ according to Tables 4 and 5 from AAPM OR3
  • Can also adjust monitor if backlight is capable

• Ambient light sensors may be incorporated into these monitors
Display calibration and configuration

• There is no clear guidance for display characteristics for fluoroscopically-guided and CT-guided procedures
  • Primary or secondary?
  • How big? How big is too big?

• Modern interventional procedure suites or hybrid ORs can have a dizzying array of monitors
  • If using non-OEM monitors, verify equivalent performance
Not GSDF compliant
Does not preserve aspect ratio
Pixel pitch too large
Modern fluoroscope configuration

- Procedure room monitors supplied with fluoroscopy systems
  - Smaller monitors (19 – 27”) have pixel pitch from 0.271 mm to 0.294 mm
  - Larger monitors (58”) have pixel pitch of 0.334 mm
  - Peak luminance is typically set to be about 400 cd/m²
  - DICOM GSDF calibrated

- Console monitors supplied with fluoroscopy systems
  - Similar pixel pitch to smaller procedure room monitors
  - Peak luminance ranges from 250 to 400 cd/m²
  - DICOM GSDF calibrated

- Procedure and control room monitors for CT
  - Similar pixel pitch as other 19” monitors
  - Peak luminance ranging from 100 to 150 cd/m²
  - DICOM GSDF calibrated
Display calibration and configuration

• DICOM GSDF compliant
  • Verify

• Appropriate pixel pitch
  • 0.250 mm, no larger than 0.300 mm, for extended distance viewing

• Aspect ratio and resolution of source image maintained

• Luminance ratio of 250

ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging (2017)
Location of the operator

• Optimal viewing distance is approx. 1.33x the image diagonal
  • For “high pixel pitch” displays

• For “low pixel pitch” displays this distance is approx. 2x the image diagonal
  • minimum Distance (m) ~ 3.26 x pitch (mm)

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ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging (2017)

Mike Flynn presentation from 2014 AAPM, Medical Physics 1.0 to 2.0: Displays
Location of the operator

- Appropriate $D_v$ given pixel pitch of the display

- Position as much image detail as possible at the peak contrast sensitivity

Barten PGJ. Contrast sensitivity of the human eye and its effects on image quality.
Location of the operator

• Appropriate $D_v$ given pixel pitch of the display

• Position as much image detail as possible at the peak contrast sensitivity

• Limit the information displayed in regions of lower visual acuity

$D_v = 108$ cm

$D_v = 130$ cm

$D_v = 84$ cm
Location of the operator – in practice

• 19” XA monitor from Siemens
  • 1280 x 1024
  • Pixel pitch ~ 0.294 mm
  • $D_v = 96$ cm
  • 2x diagonal = 97 cm

• 58” Eizo LS580W
  • 3840 x 2160
  • Pixel pitch = 0.332 mm
  • $D_v = 108$ cm
  • 2x diagonal (64 cm) = 128 cm

*D$_v$ = minimum viewing distance
2x diagonal = optimal viewing distance for “low” pixel pitch display
Image processing

• Spatiotemporal image processing is integral to modern angiography systems

• Can cause strange appearance of test patterns and objects

• Requires consideration both for configuration of fluoroscopic equipment and for quality control
<table>
<thead>
<tr>
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<th>Relative contrast</th>
<th>CNR</th>
<th>SNR</th>
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<td>15.5</td>
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<td>22.1</td>
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<td>0.52</td>
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<td>22.1</td>
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<td>0.51</td>
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<td>0.68</td>
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<td>Auto6</td>
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<tr>
<td>Auto7</td>
<td>0.49</td>
<td>14.8</td>
<td>30.5</td>
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<td>Auto8</td>
<td>0.35</td>
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<td>29.9</td>
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<table>
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<tr>
<th>Setting</th>
<th>k-min.</th>
<th>k-max.</th>
<th>Usage</th>
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<tr>
<td>Auto1</td>
<td>1.25</td>
<td>2.0</td>
<td>&quot;Cardiac speed&quot;, less integration, more noise but almost no lag.</td>
</tr>
<tr>
<td>Auto2</td>
<td>1.12</td>
<td>1.6</td>
<td>&quot;Cardiac standard&quot;, good relationship between noise and lag for cardiac examinations</td>
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<tr>
<td>Auto3</td>
<td>1.38</td>
<td>2.5</td>
<td>&quot;Angio&quot; standard.</td>
</tr>
<tr>
<td>Auto4</td>
<td>1.88</td>
<td>3.0</td>
<td>&quot;Roadmap&quot; setup, very high integration but also high lag, almost no noise.</td>
</tr>
</tbody>
</table>
Image Quality

- Image quality is a convoluted output of:
  - Radiation dose
    - X-Ray tube and filters
    - Collimation
    - Imaging protocol
    - Radiation dose mode
    - Field of view setting
    - Geometric setup
  - Attenuation in the beam
    - Test patterns
      - Subjective vs. objective evaluation
    - Patients
      - Patients with anatomic/physiologic variations
  - Characteristics of the grid and detector
  - Image processing
  - Display technology and system
    - Workstations
    - Ambient lighting
Example: Radiation output characterization of an interventional fluoroscopy system

Radiation output in different dose modes for a single protocol

Flavor 1
Fitted

Flavor 2
Fitted

Flavor 3
Fitted

mGy/mA-min @ 30 cm from flat panel detector

kVp
Example: Input detector exposure rate characterization

- **IDER (uGy/sec)**
  - 0.0
  - 0.2
  - 0.4
  - 0.6
  - 0.8
  - 1.0

- **FPD – Field of View (")**
  - 17
  - 13
  - 6
  - 13
  - 13

- **Flavor 1**
- **Flavor 2**
- **Flavor 3**

- **Without Grid**
- **With Grid**

- Attenuation: 2 mm Cu
Example: Radiation output rate during acquisition sequences

![Bar chart showing radiation output rate for different body parts during acquisition sequences. The chart labels the x-axis with Protocols (Abdomen, Thorax, 2 Lower Legs, Neck) and the y-axis with Obs. mGy/min@30 cm from flat panel detector. The chart shows the highest output for Thorax, followed by Abdomen and Neck, with the lowest output for 2 Lower Legs.]
Image quality phantoms available for testing

Individual Phantoms

Integrated Phantoms

Note: Sample phantoms shown, the list is not exhaustive
Anything abnormal seen in these phantom images?
Advantages of image quality phantoms
Advantages of image quality phantoms
Edge effects with advanced image processing

• Edge images of a lead attenuator
  • Different fields of view
  • Different imaging modes
  • Different protocols

• Observations
  • Overshoot of the edge
  • Overshoot decayed more quickly with advanced image processing
    • Characteristic ringing effect

• Conclusion
  • Changes in appearance of high-frequency content in images

Marsh R and Silosky M.  https://doi.org/10.1118/1.4887960; 2014
Are vendor specific image processing features testable using standard phantoms?

Forsberg MA et al. https://doi.org/10.1117/12.2254561; 2017
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Are vendor specific image processing features testable using standard phantoms?

- Depending on the image quality phantom and quantitative metrics used for describing the performance of a given interventional fluoroscopy system, the results differ and comparisons between systems should, therefore, be interpreted with caution.

- Quantitative metrics derived from standard fluoroscopy phantoms lack the discriminatory ability to assess vendor-specific advancements in interventional fluoroscopy systems.
Case studies - highlighting image quality aspects important to physicians during the procedure
Case 1

• Patient: BMI > 40; weight > 300 lbs

• Procedure:
  • Bilateral hepatic lobe hypervascular metastases
  • Infusion of chemotherapy drug
Low Dose Mode

SID: 98 cm
kV: 120
mA: 2
FPS: 15
Frames: 39
Indicated air kerma: 0.4 mGy
Medium Dose Mode

SID: 98 cm
kV: 110
mA: 5
FPS: 15
Frames: 48
Indicated air kerma: 1.2 mGy
High Dose Mode

SID: 98 cm
kV: 95
mA: 7
FPS: 15
Frames: 53
Indicated air kerma: 2.5 mGy
Acquisition Run: SID: 98 cm, kV: 80, mAs: 45, FPS: 3, Frames: 38 Indicated air kerma: 104 mGy
Low Dose Mode

Medium Dose Mode

High Dose Mode

2.2 mGy/min

3.3 mGy/min

7.8 mGy/min
Low Dose Mode

Medium Dose Mode

High Dose Mode
Case 2

• Patient: BMI ~ 28; weight ~ 205 lbs

• Procedure:
  • Left iliopsoas abscess drainage using fluoroscopic guidance
  • Gas in the abscess as a target
Case 3

• Patient: BMI ~ 24; weight ~ 150 lbs

• Procedure:
  • Pneumothorax
  • Drainage catheter placement
Case 4

• Patient: BMI ~ 26; weight ~ 180 lbs

• Procedure:
  • Chemo/Immuno embolization
<table>
<thead>
<tr>
<th>Run no.</th>
<th>No. of Images</th>
<th>Procedure</th>
<th>Speed fr/sec</th>
<th>KV</th>
<th>mAs</th>
<th>MS</th>
<th>DAP (mGy/cm²)</th>
<th>AK (mGy)</th>
<th>Rotation</th>
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<td>LAO20</td>
<td>0</td>
<td>94</td>
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</table>

**Radiation output in different dose modes for a single protocol**

The graph shows the radiation output in different dose modes for a single protocol. It compares three flavors (1, 2, 3) with their respective fitted lines. The vertical axis represents mGy/mA-min @ 30 cm from flat panel detector, and the horizontal axis represents kVp. The graph illustrates the relationship between kVp and radiation output for each flavor.
Dose Calculation = 
2 mGy/mA-min * 
6 mA * 
(93/15/60) min = 
1.2 mGy
Dose Calculation = 2 mGy/mA-min * 6 mA * (93/15/60) min = 1.2 mGy

Dose Calculation = 4.2 mGy/mA-min * 2 mA * (118/15/60) min = 1.1 mGy
On the possibility of utilizing clinical images for image quality evaluation?

Fluoroscopic image (left) and digital subtraction angiography image (right) of a patient undergoing hepatic chemoembolization procedure. Circular ROIs (diameter: 2 cm) were used to measure signal (mean) and noise (standard deviation) in bone (orange) and liver (green) parenchyma. The signal and noise values were obtained using a circular ROI within the hepatic vessels (blue) (till 4 bifurcations; vasculature and bone landmarks in the images were used to ensure all measurements were made on the same structures in each case). The full width at half maximum (FWHM) was computed from a line profile (red) across the vessel wall (a lesser value indicates sharper edge).

Forsberg MA et al. https://doi.org/10.1117/12.2254561; 2017
On the possibility of utilizing clinical images for image quality evaluation?

Forsberg MA et al. JVIR 28(2) S194-195; 2017
Image Quality Considerations

• Characterization of system
  • Utilization of static and/or dynamic phantoms
  • How closely these phantoms mimic clinical needs

• Task based image quality assessments
  • Characterization of image processing features offered by vendors
  • Image quality assessment based on clinical images?

• The ‘E. Samei’ approach
  • Lin Y et al. Med Phys, 2012
  • Samei et al. Med Phys, 2014
Acknowledgement and Disclosure

• Acknowledgement
  • David Eschelman, MD – Co-Director, Division of Interventional Radiology

• Disclosure
  • Research products
    • Definity vials from Lantheus Medical Imaging
    • Sonazoid vials from GE Healthcare
  • Research funding
    • American Heart Association
    • National Institutes of Health – NHLBI
    • Philips Healthcare