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

Kilani MS et al. Embolization of peripheral high-flow arteriovenous malformations with Onyx. *Diagn Interv Imaging* **98**:217-226 (2017)

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

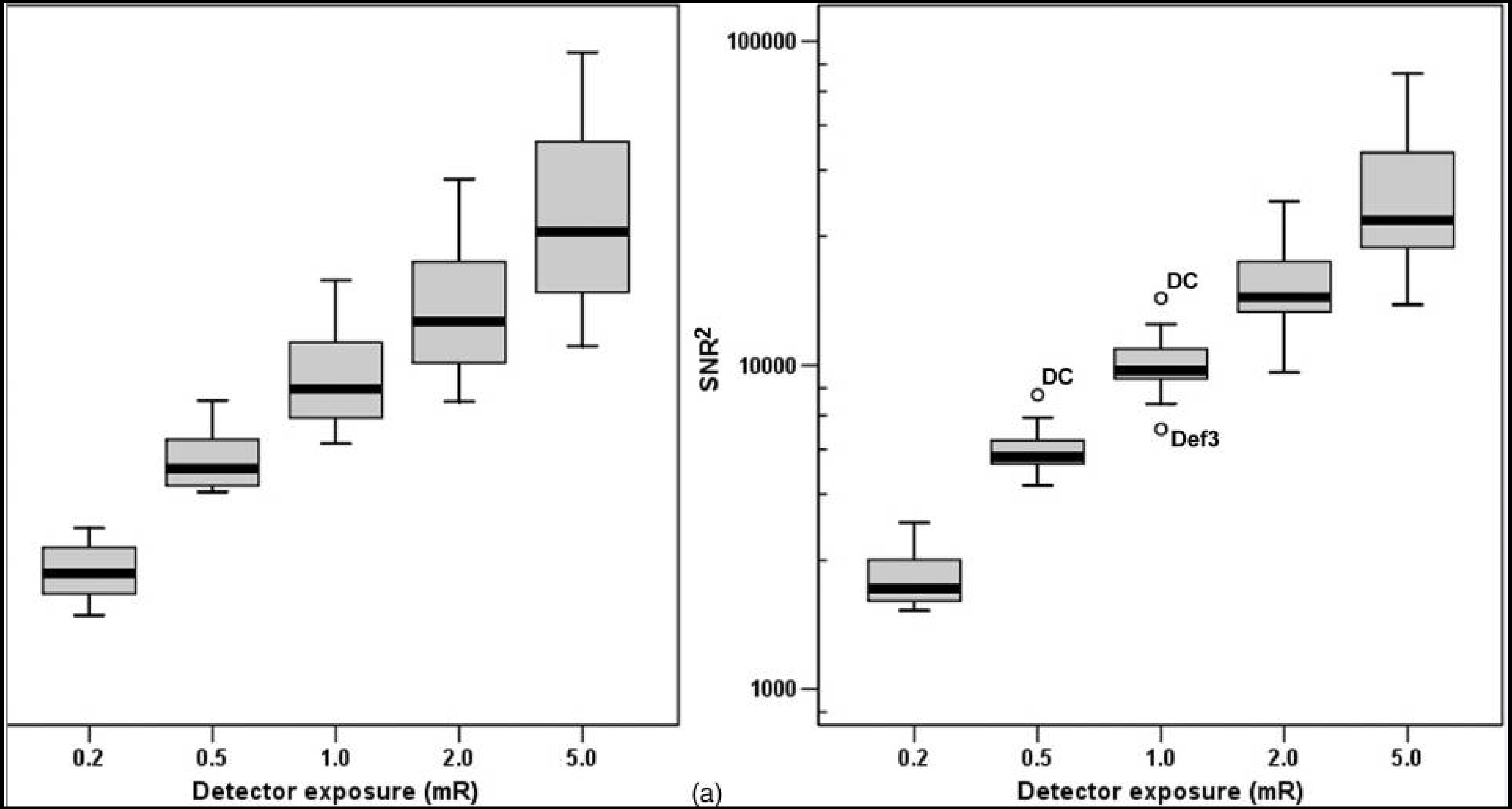
- Added filtration, kV
- Many parameters
- Ambient light sensor, contrast sensitivity
- Resizing of images

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?

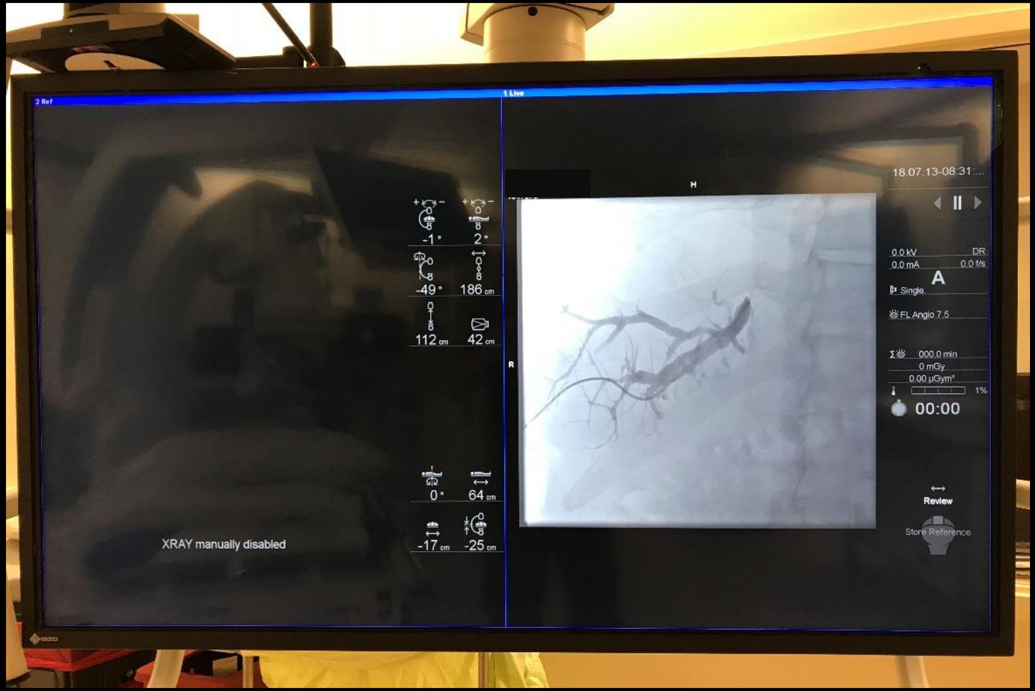


Willis CE, Vinogradskiy YY, Lofton BK, White RA. Gain and offset calibration reduces variation in exposure-dependent SNR among systems with identical digital flat-panel detectors. *Med Phys* **38**:4422-4429 (2011).

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

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

$L_{max} - L_{min}$ (cd/m^2)	C_t	Maximum Room Illuminance (lux)				
		R_s = 0.002	R_s = 0.004	R_s = 0.008	R_s = 0.020	R_s = 0.040
5000 – 20	0.010	349	175	87	35	17
2500 – 10	0.011	192	96	48	19	10
1000 – 4	0.015	105	52	26	10	5
500 – 2	0.018	63	31	16	6	3
250 – 1	0.024	42	21	10	4	2

For a display device with a specific minimum luminance, L_{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_t) is tabulated.

Table 5. Maximum room lighting based on diffuse reflection.

$L_{max} - L_{min}$ (cd/m^2)	Maximum Room Illuminance (lux)				
	R_d = 0.005	R_d = 0.010	R_d = 0.020	R_d = 0.040	R_d = 0.060
5000 – 20	1000	500	250	125	83
2500 – 10	500	250	125	62	42
1000 – 4	200	100	50	25	17
500 – 2	100	50	25	12	8
250 – 1	50	25	12	6	4

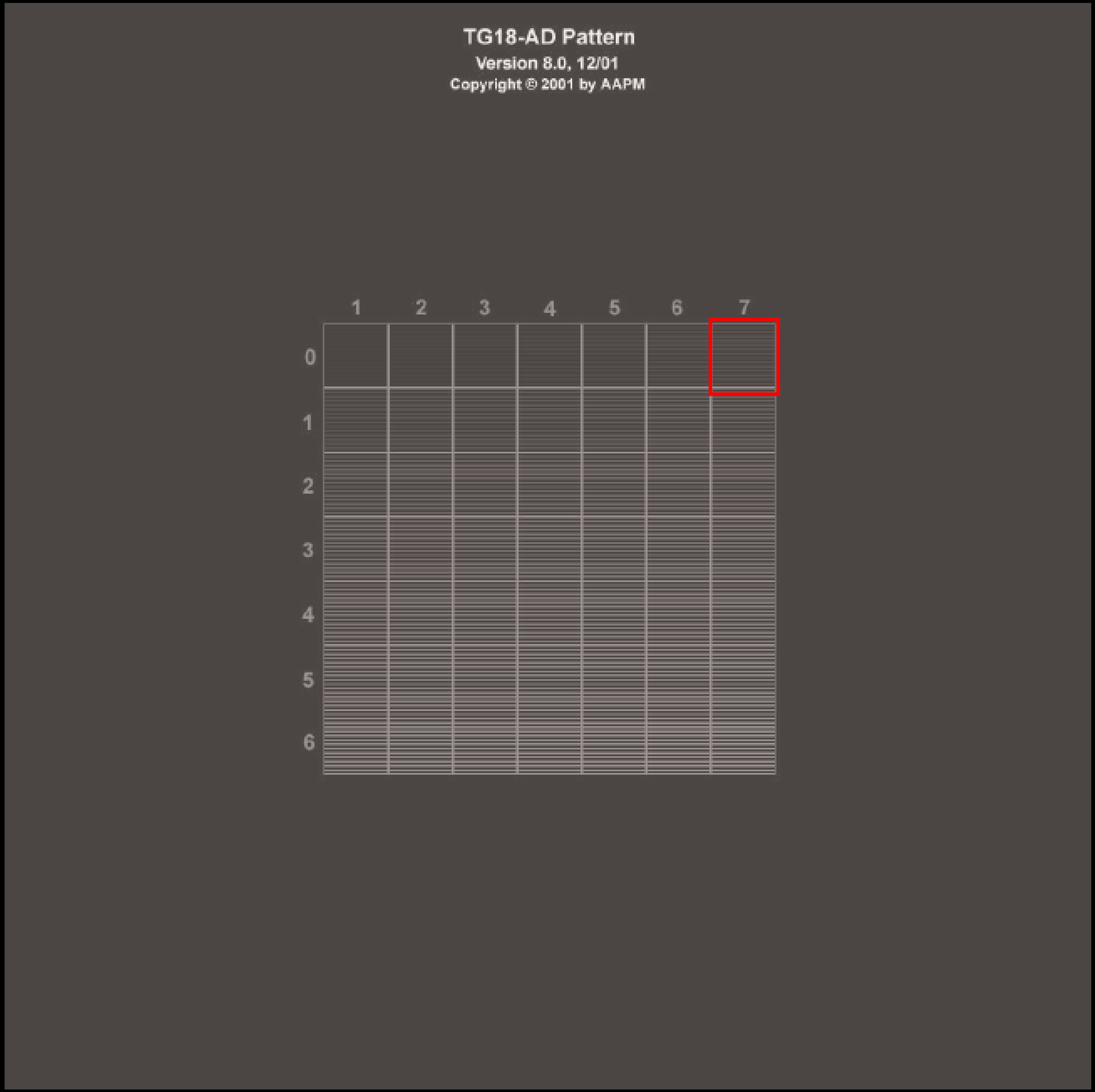
For a display device with a specific minimum luminance, L_{min}, and a specific diffuse reflection coefficient, R_d, in units of cd/m^2 per lux or sr^{-1}, the ambient illumination which maintains 80% contrast in dark regions is tabulated. The maximum room illuminance is calculated as $0.25\ L_{min} / R_d$.

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


1 Live
18.07.13-05:30:...
0.0 kV
FL
0.0 mA
0.0 f/s
A
Single.
FL Angio 7.5
000.0 min
0 mGy
0.00 µGym²
1%
00:00
Review
Store Reference
XRAY manually disabled
-1 °
0 °
-64 °
220 cm
120 cm
42 cm
0 °
62 cm
-10 cm
-28 cm

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 cm)
- Alternatively, set room lighting to achieve L_{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

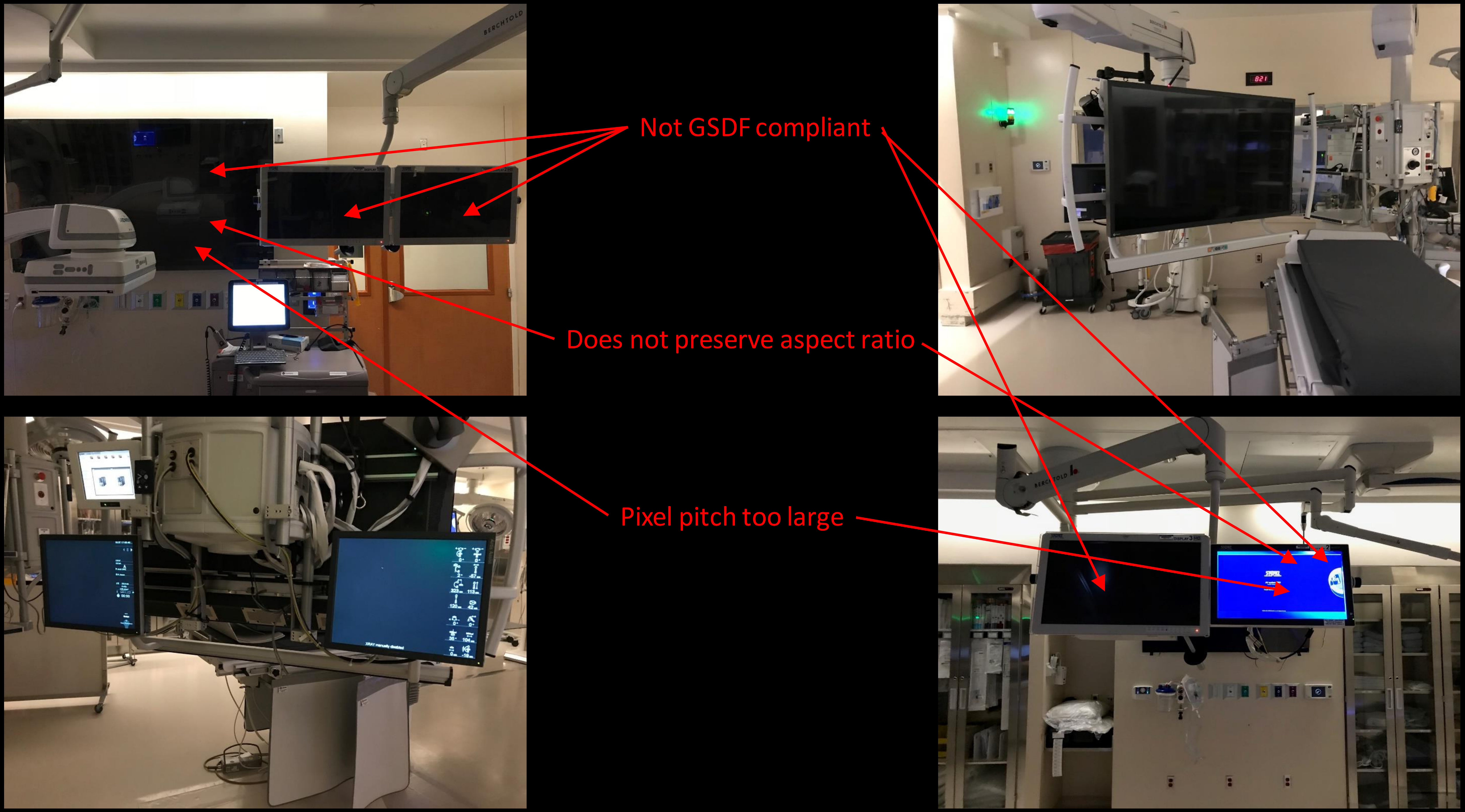
Display calibration and configuration

- 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

I.1.1 Preliminary Communications

Prior to purchase, it is important to include specifications of the size of the active area, the resolution or number of scan lines, color/spectral luminance, monochrome vs. color display, dynamic range, and magnetic shielding. These requirements will vary depending upon the intended use of the system, such as fluoroscopy, CT, US, MRI, digital spot imaging, etc. A service and/or calibration schedule including the services to be provided, tests to be performed, and the service/calibration intervals will need to be agreed upon prior to purchase.

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


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/m^2
  - 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/m^2
  - 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/m^2
  - 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)

Screen size	Viewing distance range for 1080p HDTVs
40"	5.0-8.3 feet
43"	5.4-9 feet
50"	6.3-10.4 feet
55"	6.9-11.5 feet
60"	7.5-12.5 feet
65"	8.1-13.5 feet
70"	8.75-14.6 feet
75"	9.4-15.6 feet
80"	10.0-16.7 feet
85"	10.6-17.7 feet

For HDTVs, we suggest a viewing distance between 1-1/2 and 2-1/2 times the screen diagonal.

Screen size	Viewing distance range for 4K Ultra HD TVs
40"	3.3-5.0 feet
43"	3.6-5.4 feet
50"	4.2-6.3 feet
55"	4.6-6.9 feet
60"	5.0-7.5 feet
65"	5.4-8.1 feet
70"	5.8-8.75 feet
75"	6.3-9.4 feet
80"	6.7-10.0 feet
85"	7.1-10.6 feet

To see the extra detail of 4K TVs, you should sit closer — we suggest from 1 to 1-1/2 times the screen diagonal.

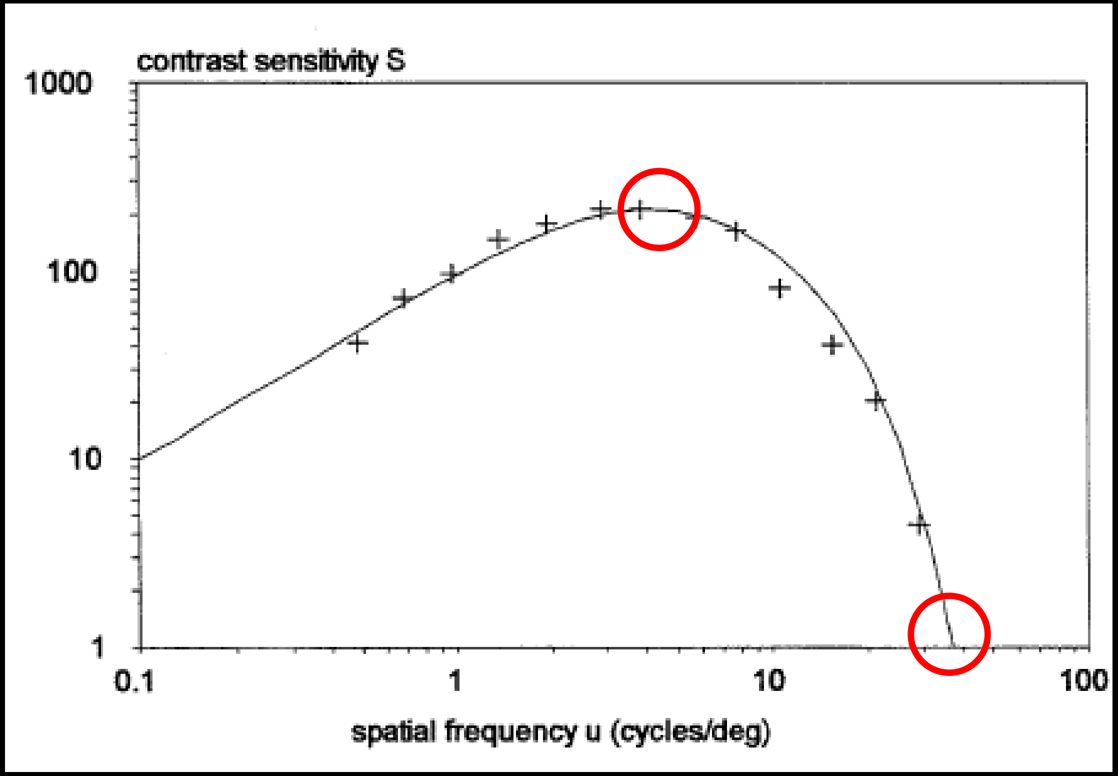
www.crutchfield.com

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

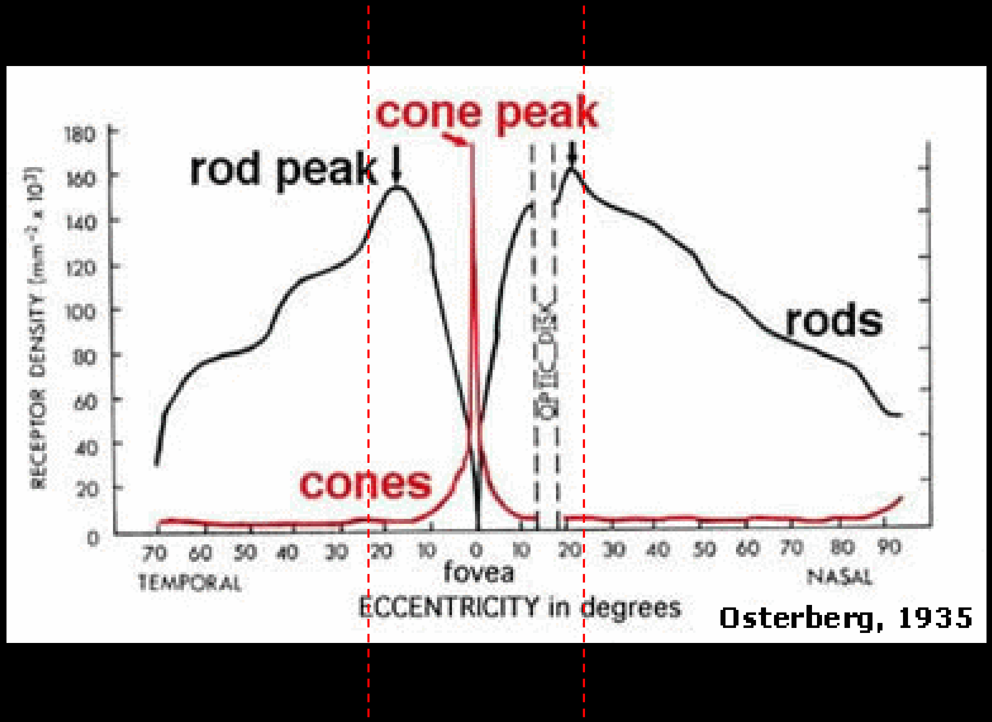
- Appropriate D_v given pixel pitch of the display
- Position as much image detail as possible at the peak contrast sensitivity



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



Osterberg G. Topography of the layer of rods and cones in the human retina. *Acta Opthal* **6(Suppl)**:1-103 (1935).

D_v = 108 cm

D_v = 130 cm

D_v = 84 cm

Location of the operator – in practice

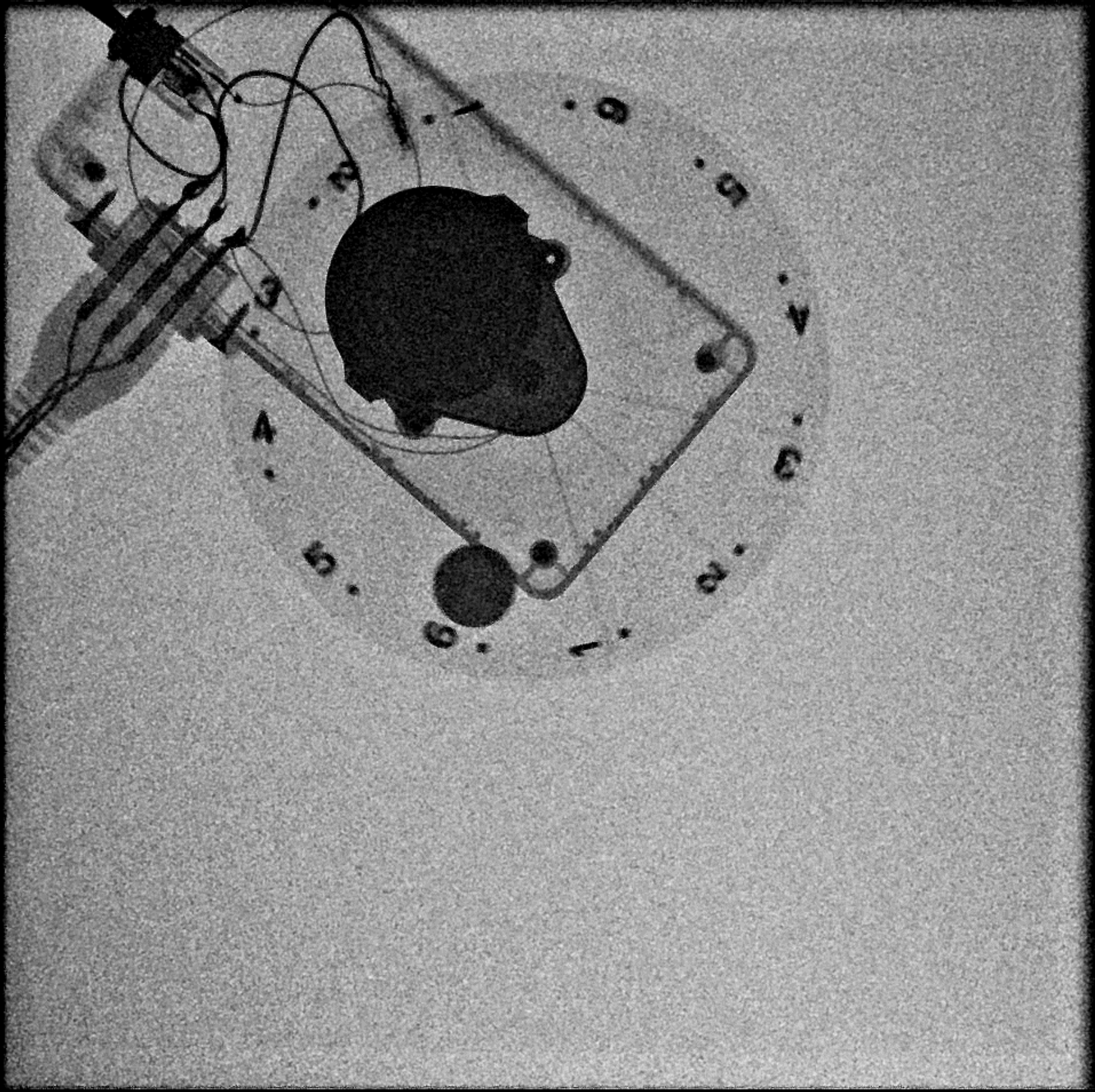
- 19” XA monitor from Siemens
  - 1280 x 1024
  - Pixel pitch ~ 0.294 mm
  - D_v = 96 cm
  - 2x diagonal = 97 cm

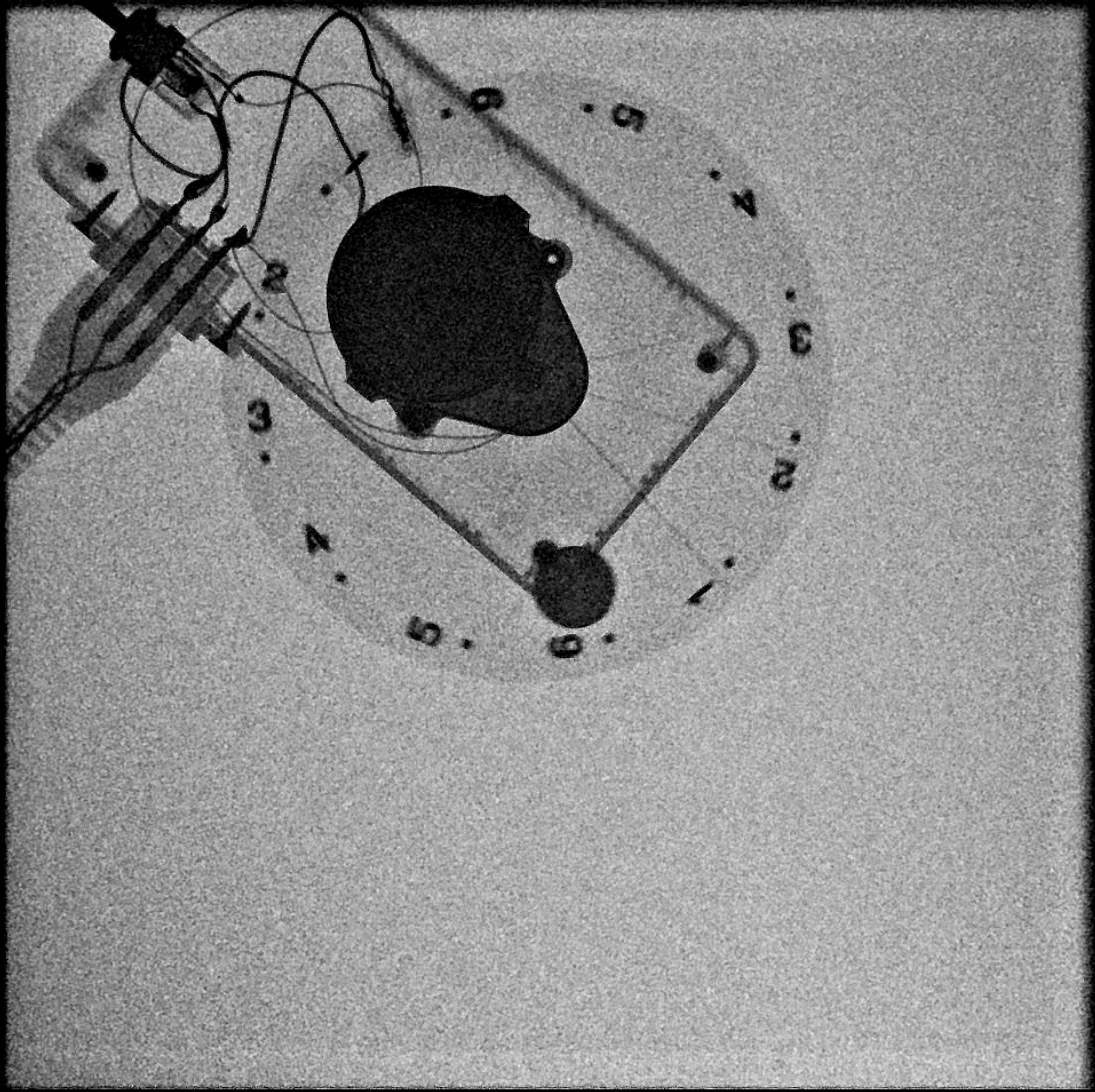
- 58” Eizo LS580W
  - 3840 x 2160
  - Pixel pitch = 0.332 mm
  - D_v = 108 cm
  - 2x diagonal (64 cm) = 128 cm

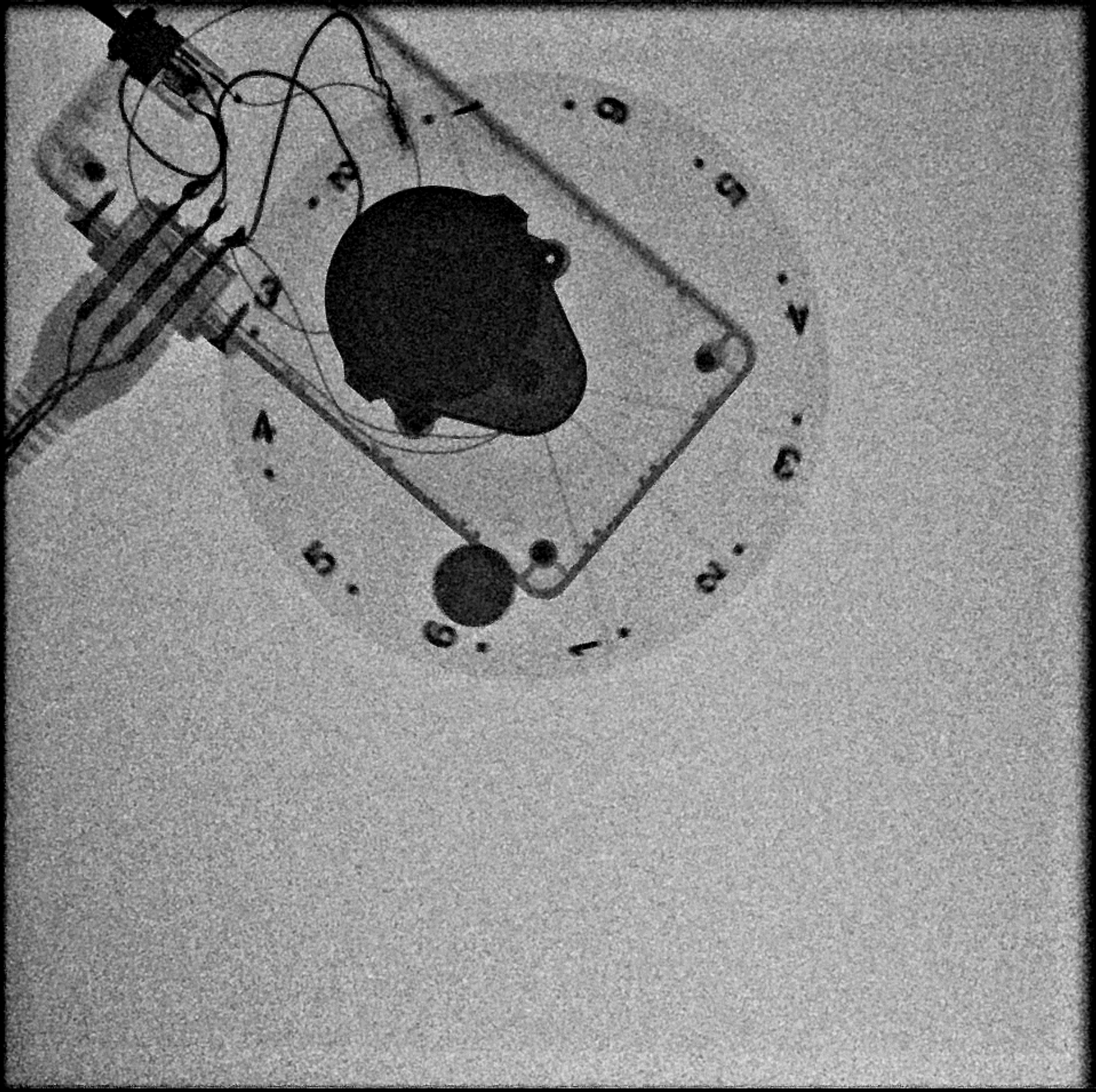
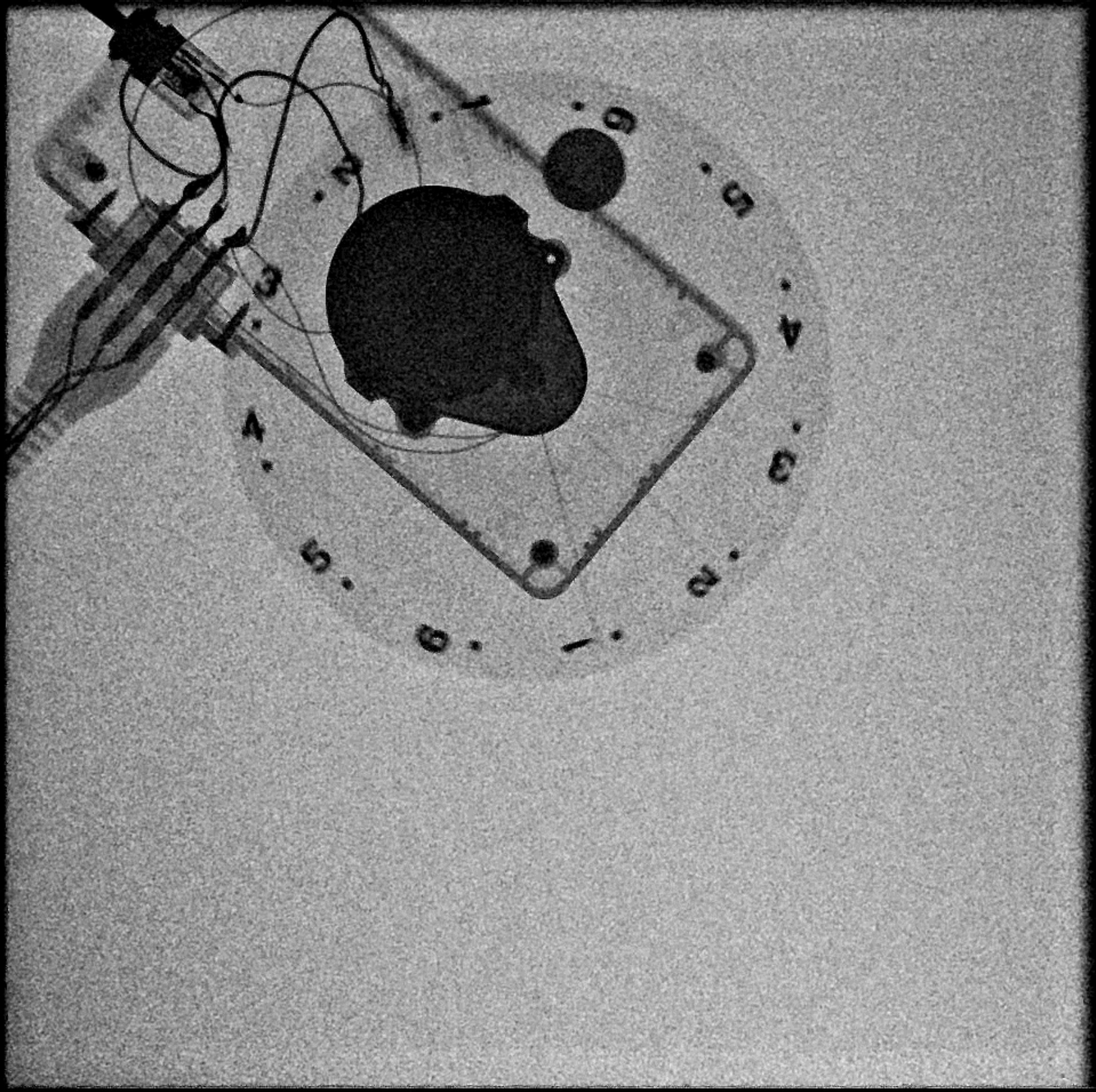
*D_v = minimum viewing distance
2x diagonal = optimal viewing distance for “low” pixel pitch display

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





Setting	Relative contrast	CNR	SNR
Off	0.69	10.6	15.5
Auto1	0.51	4.5	22.1
Auto2	0.52	11.4	22.1
Auto3	0.51	12.8	25.0
Auto4	0.68	17.0	24.8
Auto5	0.57	12.8	22.3
Auto6	0.62	17.7	28.3
Auto7	0.49	14.8	30.5
Auto8	0.35	10.3	29.9

Setting	Relative contrast	CNR	SNR
Off	0.69	10.6	15.5
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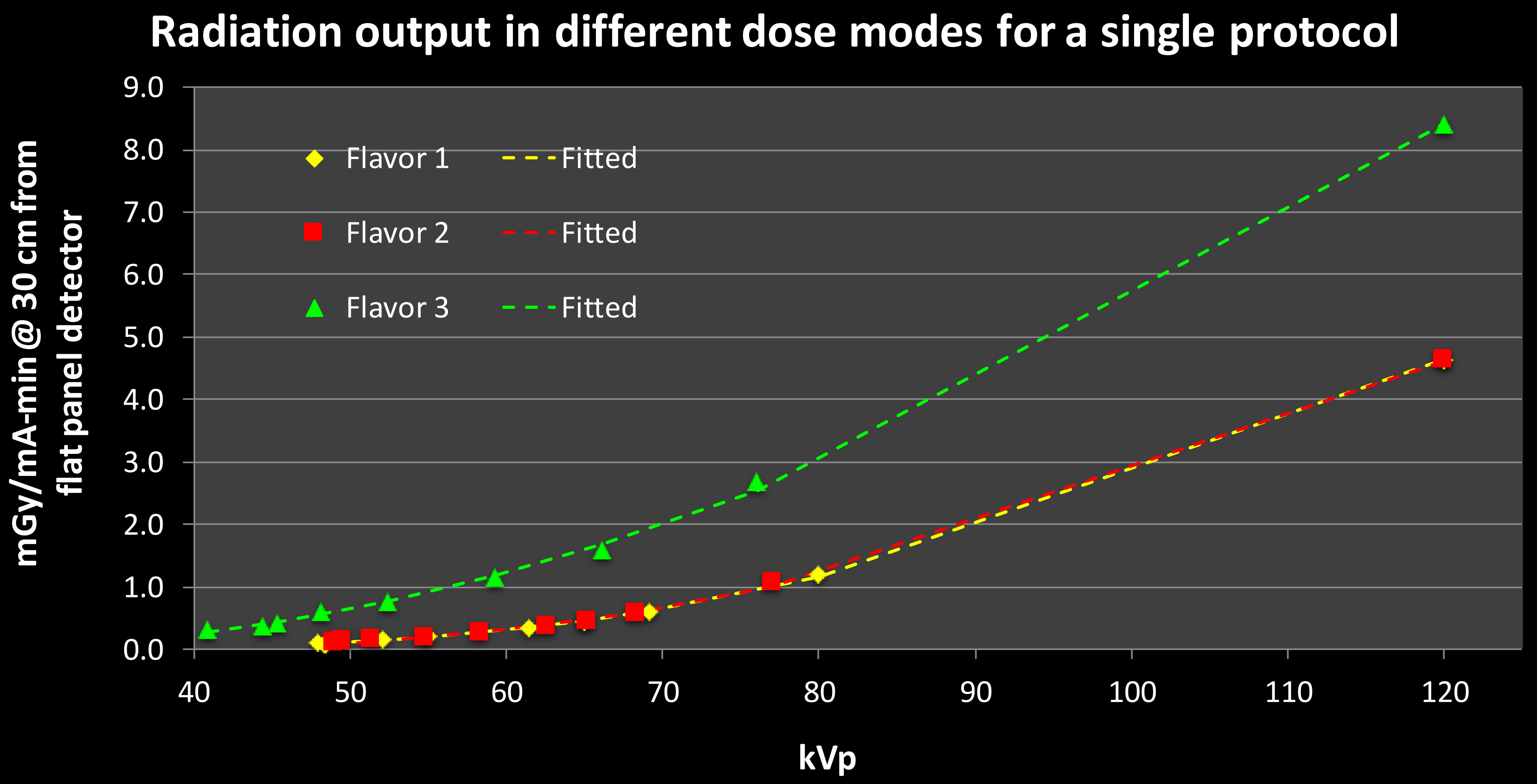
Auto7	0.49	14.8	30.5
Auto8	0.35	10.3	29.9

Setting	k-min.	k-max.	Usage
Auto1	1.25	2.0	"Cardiac speed", less integration, more noise but almost no lag.
Auto2	1.12	1.6	"Cardiac standard", good relationship between noise and lag for cardiac examinations
Auto3	1.38	2.5	"Angio" standard.
Auto4	1.88	3.0	"Roadmap" setup, very high integration but also high lag, almost no noise.

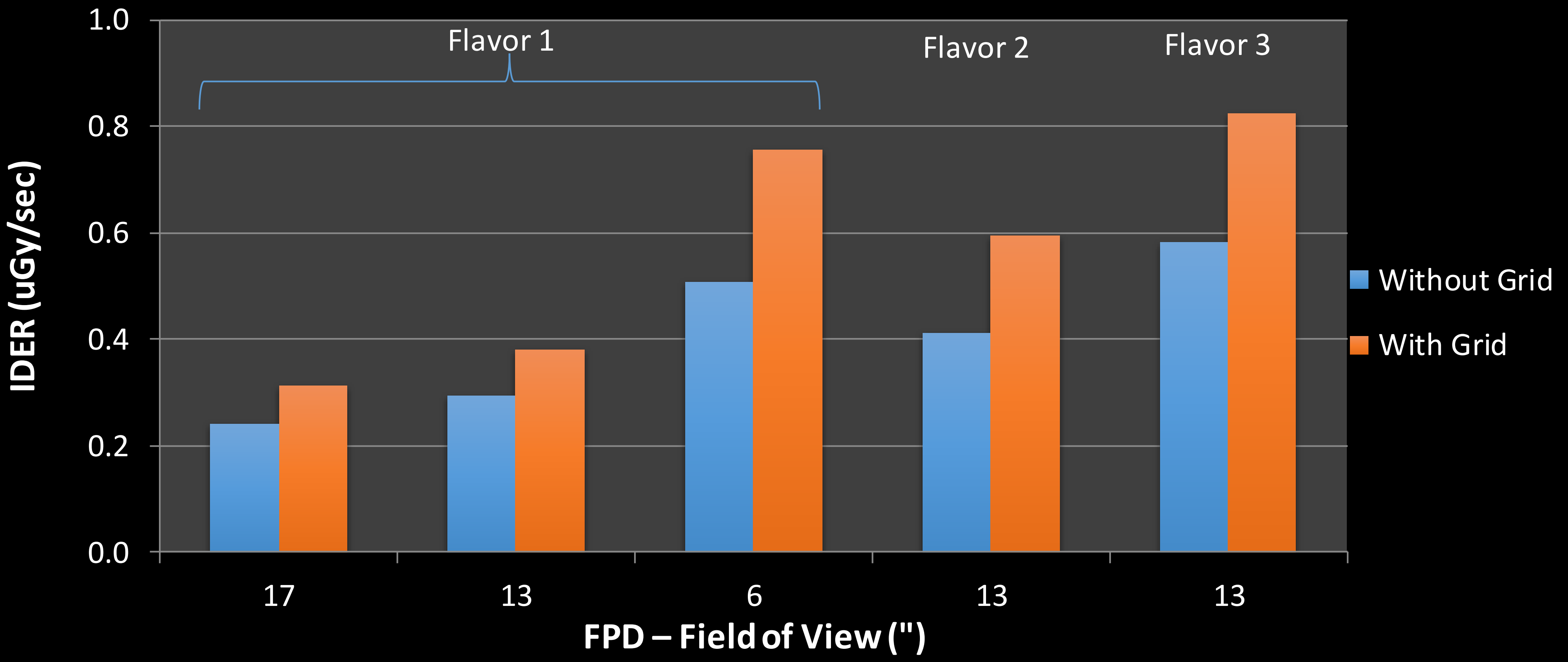
Image Quality

- 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



Example: Input detector exposure rate characterization



Example: Radiation output rate during acquisition sequences

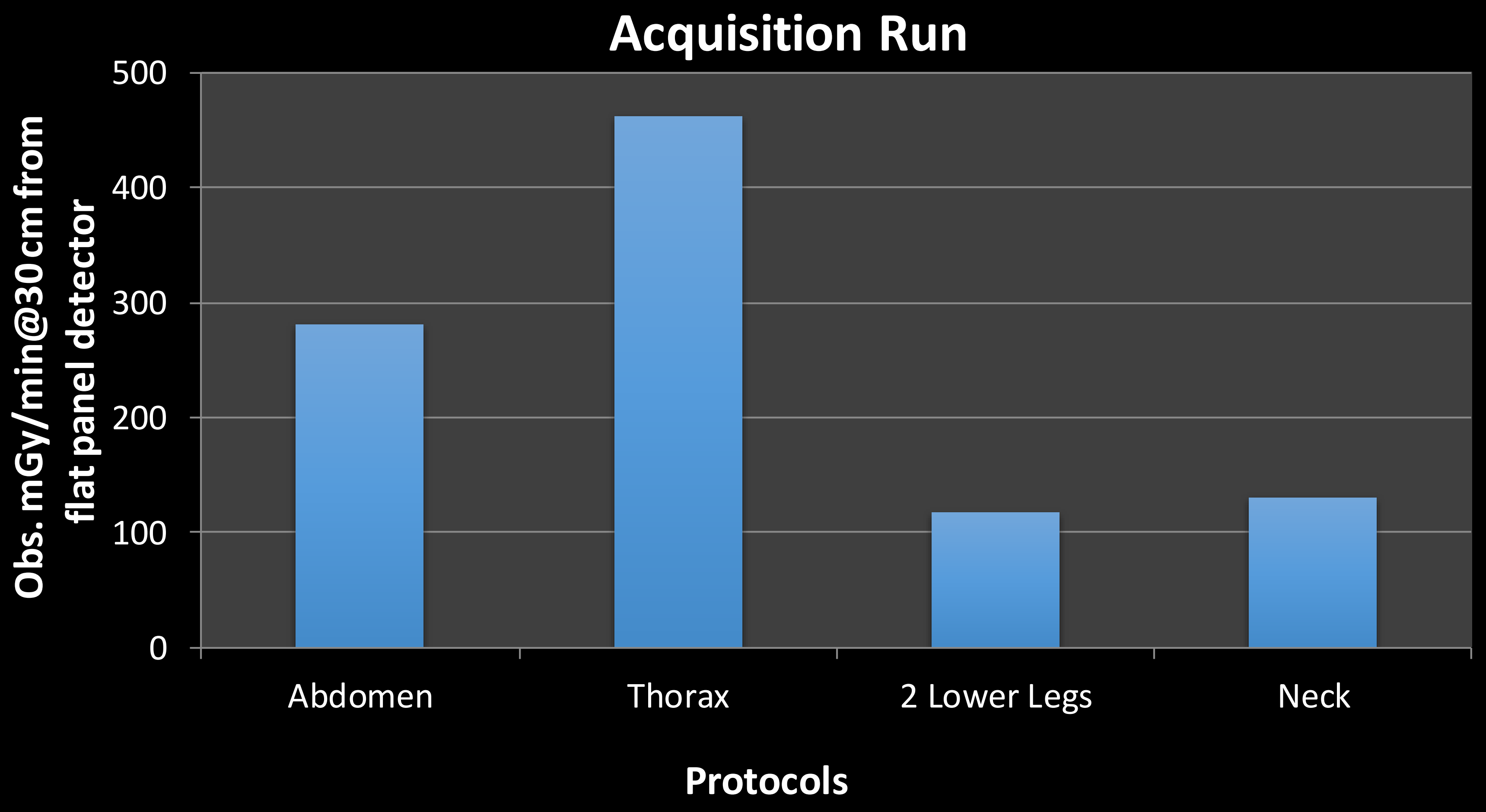
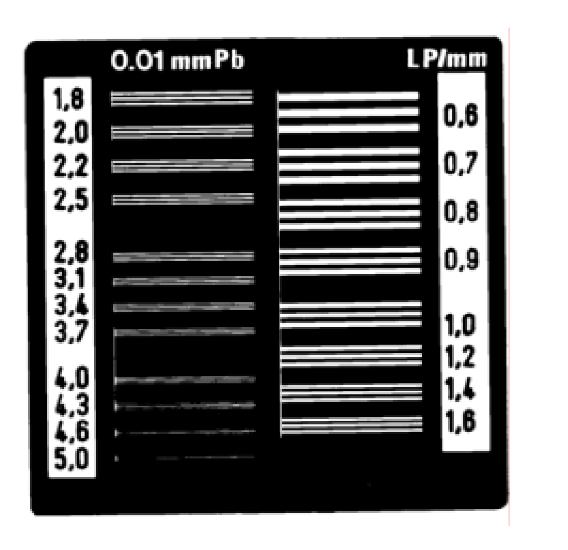
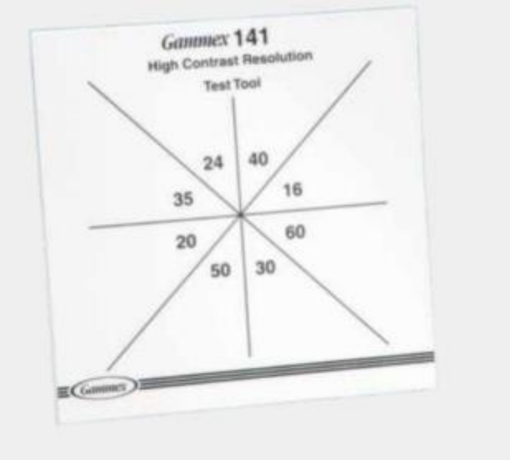


Image quality phantoms available for testing

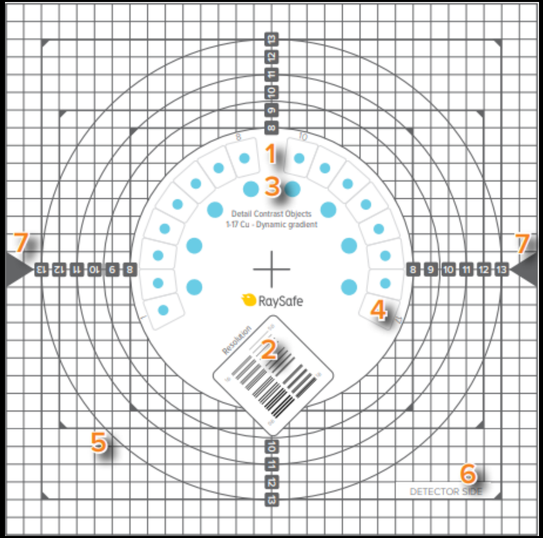


Nuclear Associates / Fluke

Sun Nuclear



Radiography Fluoroscopy Phantom - CIRS



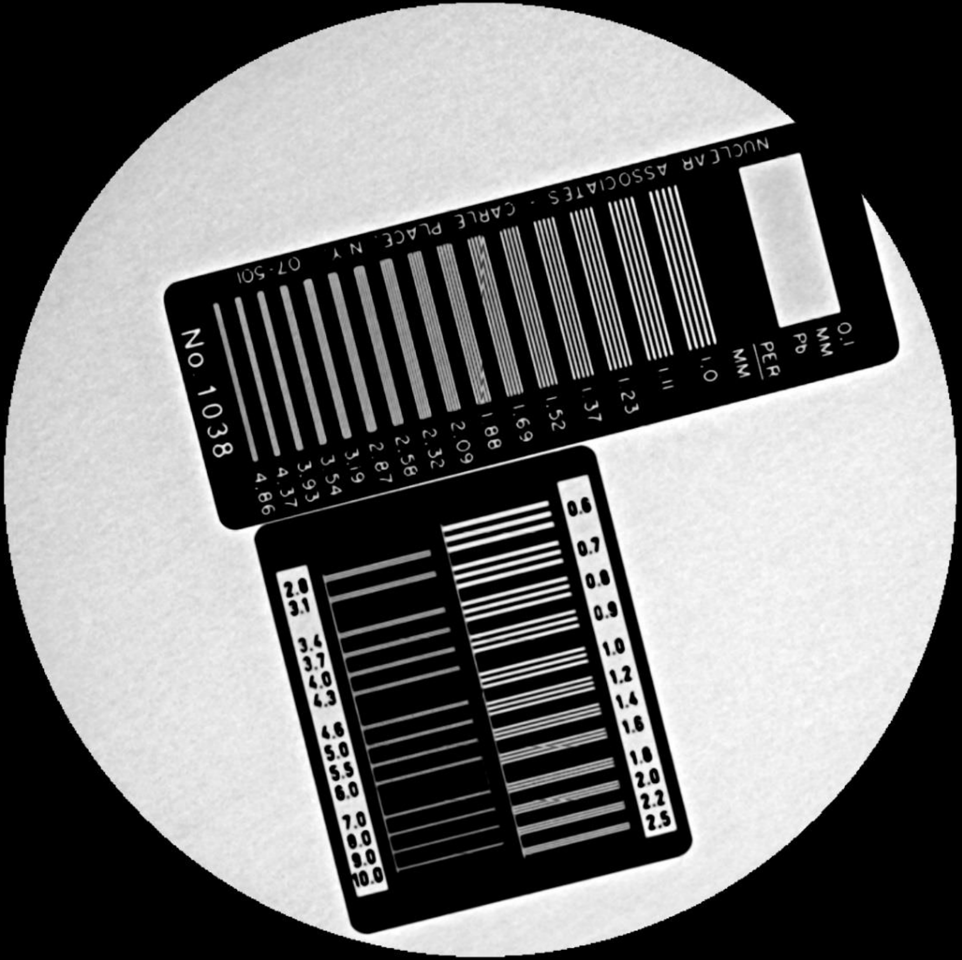
Raysafe P Fluoro Phantom

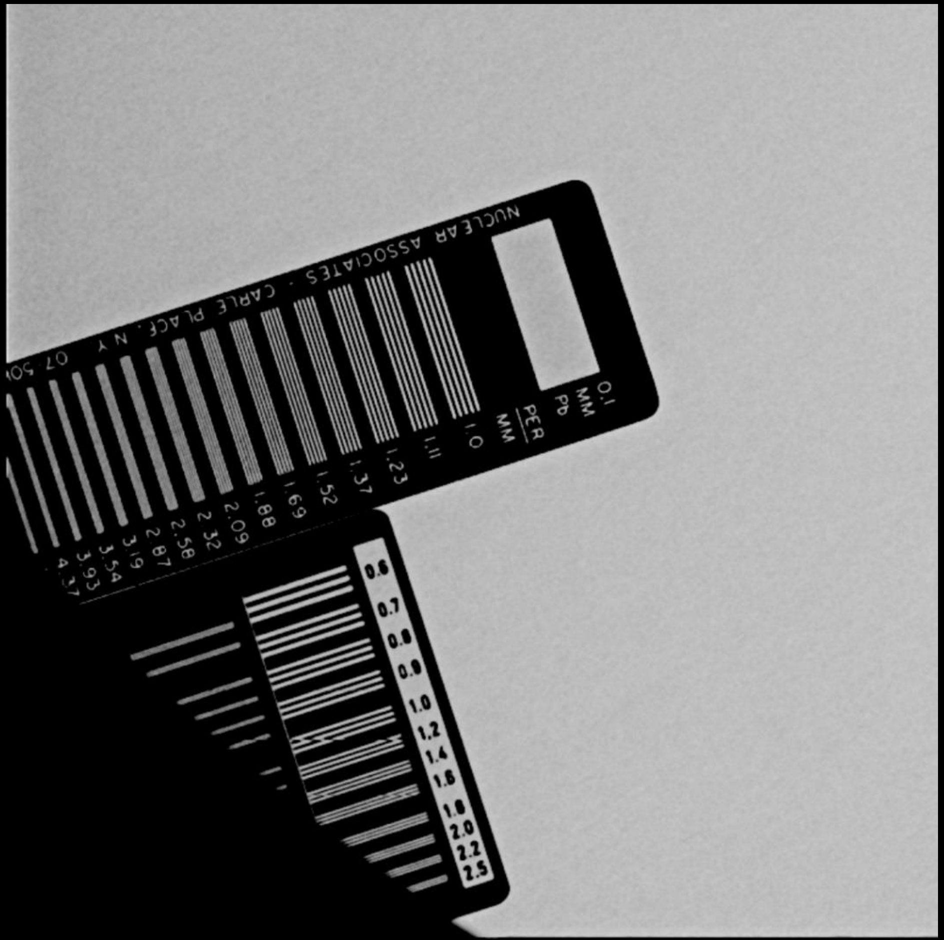
Individual Phantoms

Integrated Phantoms

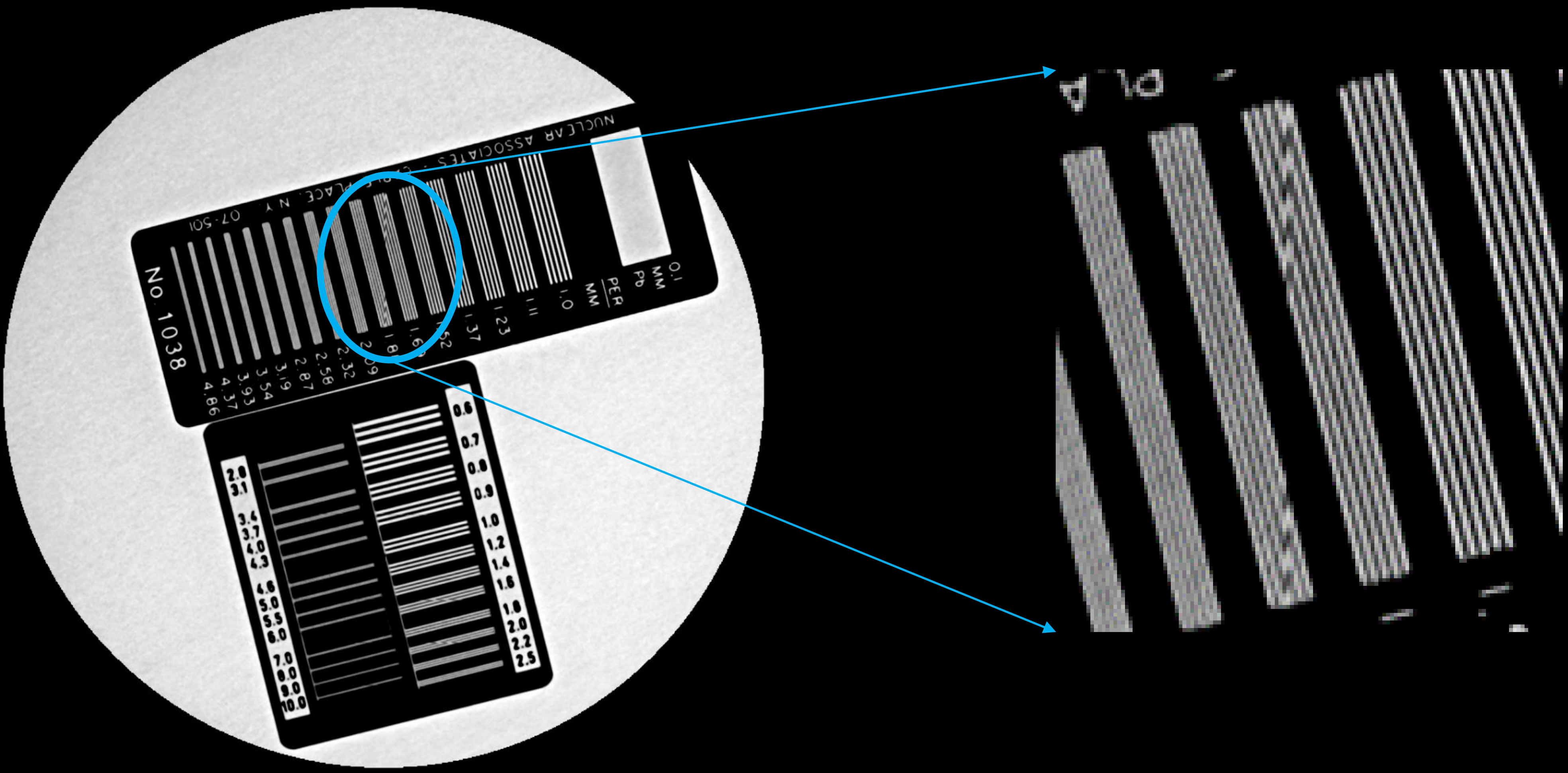
Note: Sample phantoms shown, the list is not exhaustive

Anything abnormal seen in these phantom images?

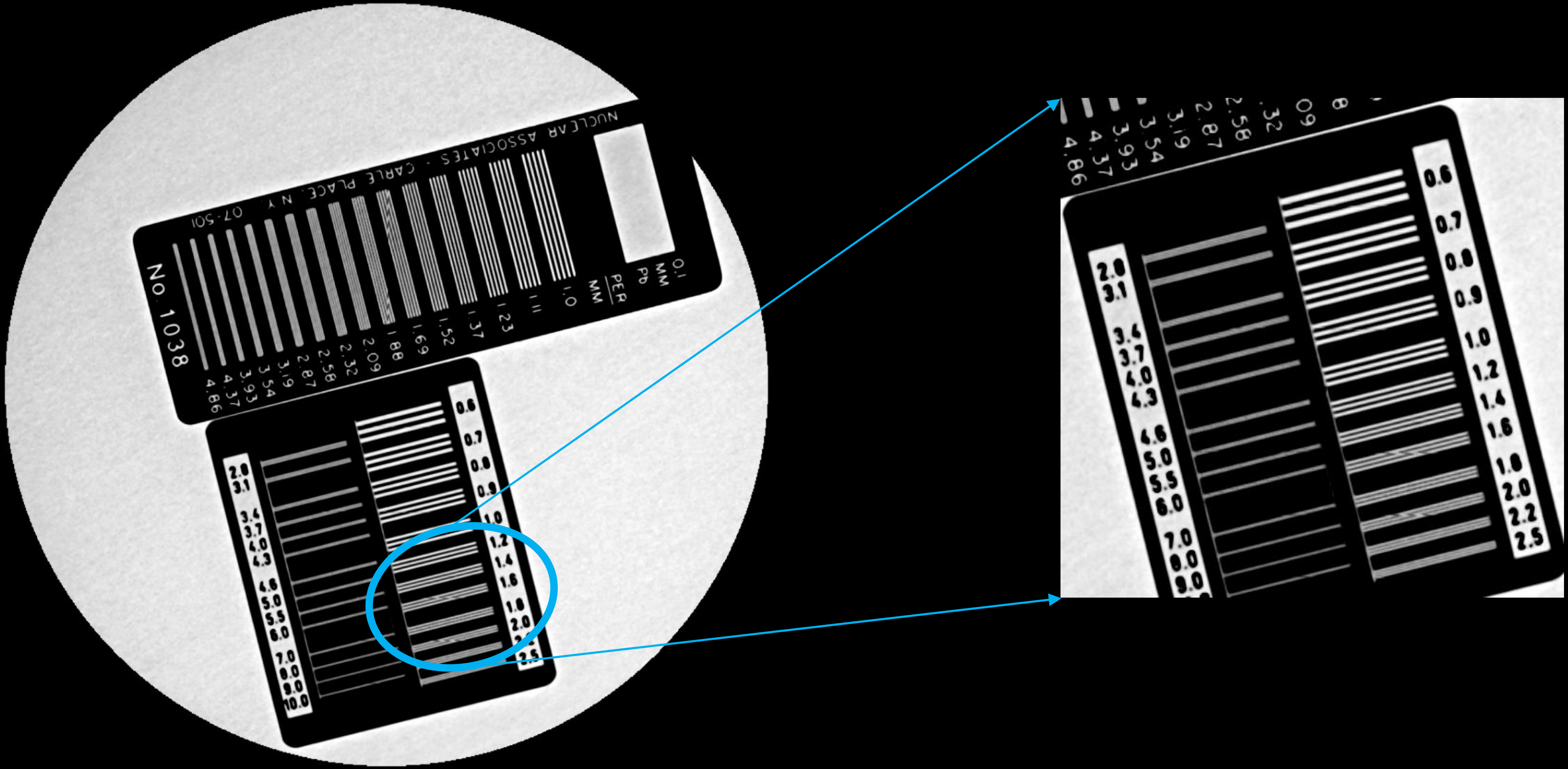




Advantages of image quality phantoms



Advantages of image quality phantoms

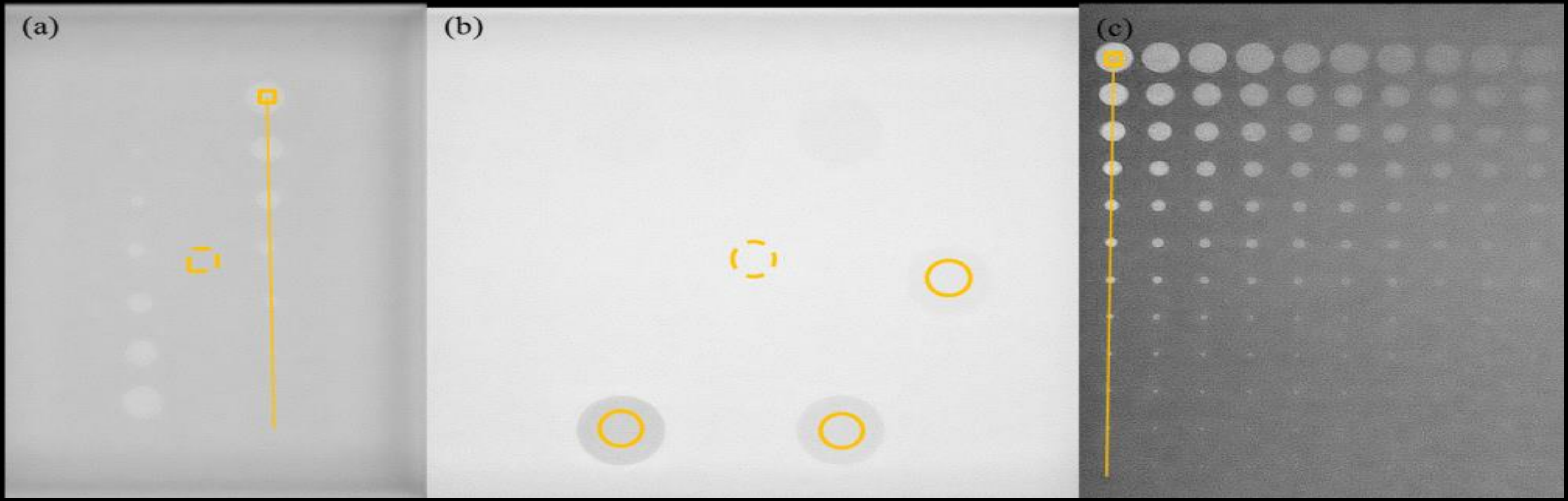


Edge effects with advanced image processing

- 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

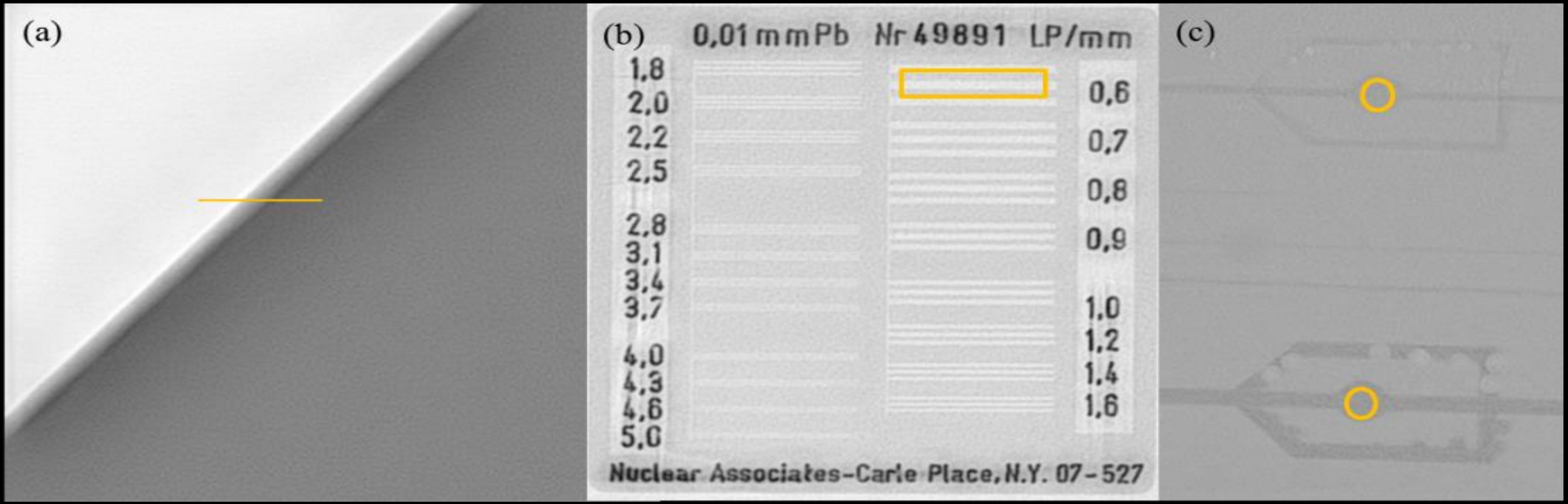
Marsh R and Silosky M. https://doi.org/10.1118/1.4887960; 2014

Are vendor specific image processing features testable using standard phantoms?



Forsberg MA et al. https://doi.org/10.1117/12.2254561; 2017

Are vendor specific image processing features testable using standard phantoms?



Forsberg MA et al. [*https://doi.org/10.1117/12.2254561*](https://doi.org/10.1117/12.2254561)*; 2017*

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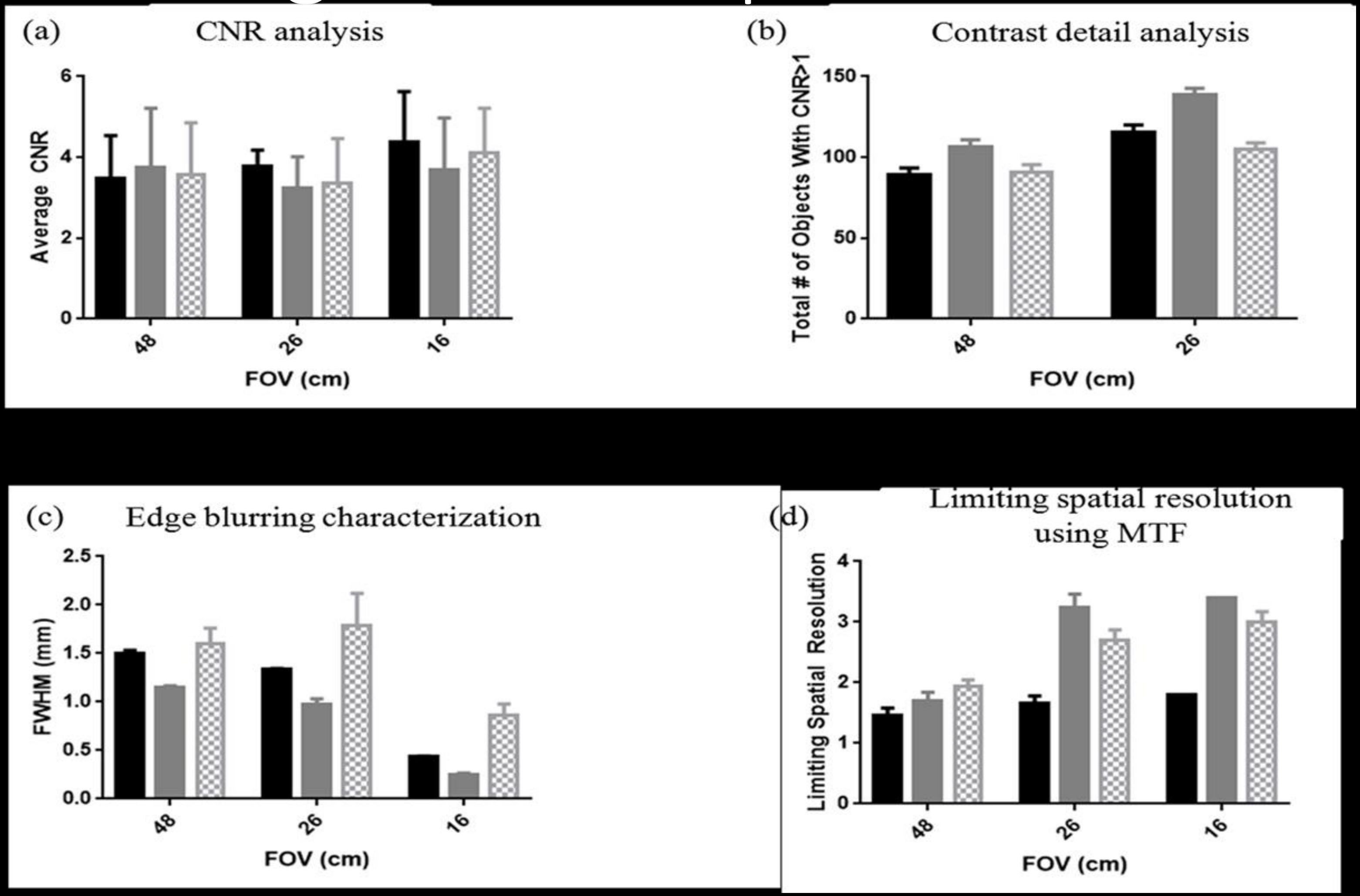


Forsberg MA et al. https://doi.org/10.1117/12.2254561; 2017

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

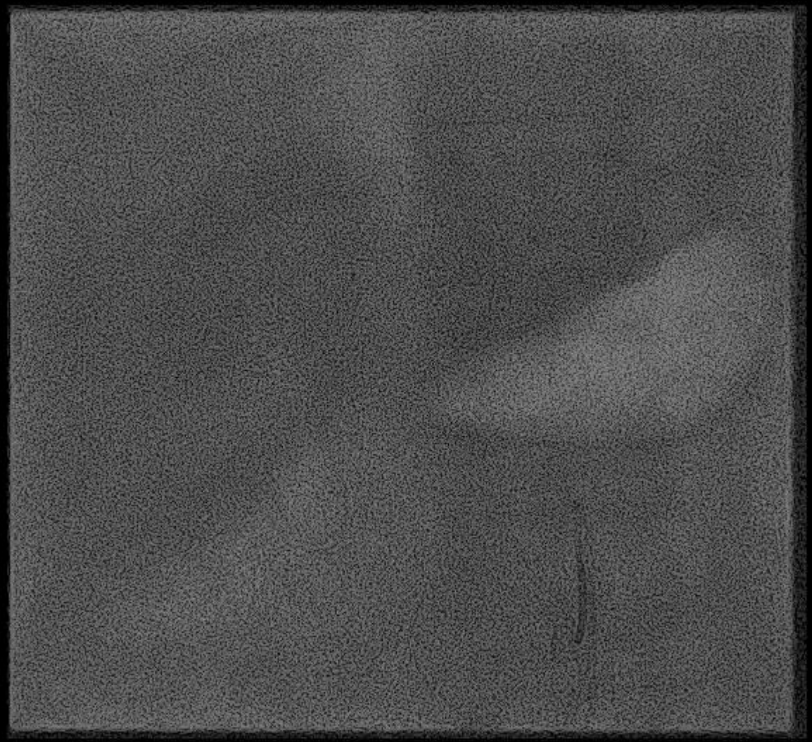
Case studies -
highlighting image quality aspects important to physicians during the procedure

Case 1

- Patient: BMI > 40; weight > 300 lbs
- Procedure:
  - Bilateral hepatic lobe hypervascular metastases
  - Infusion of chemotherapy drug

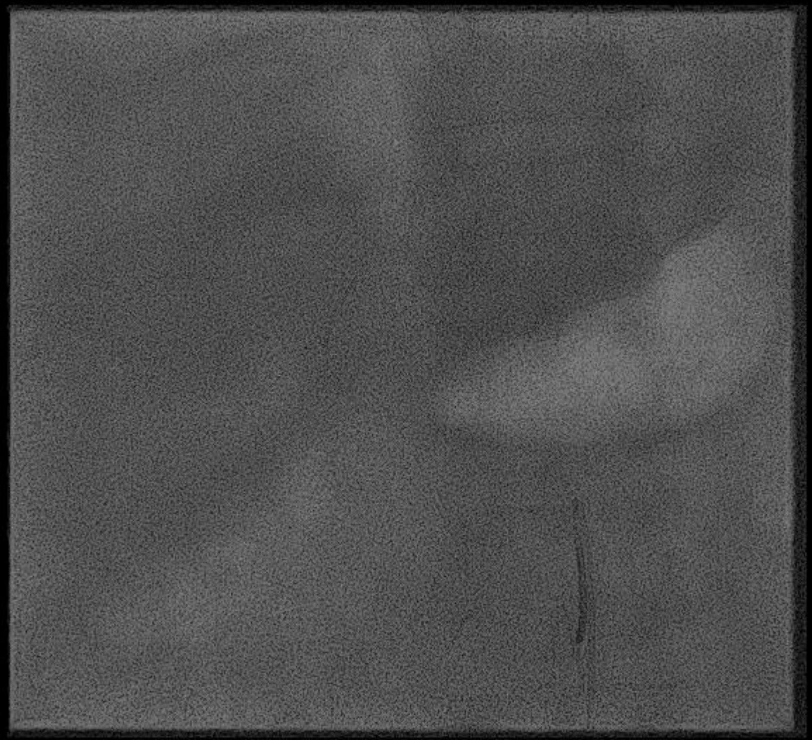
Low Dose Mode

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



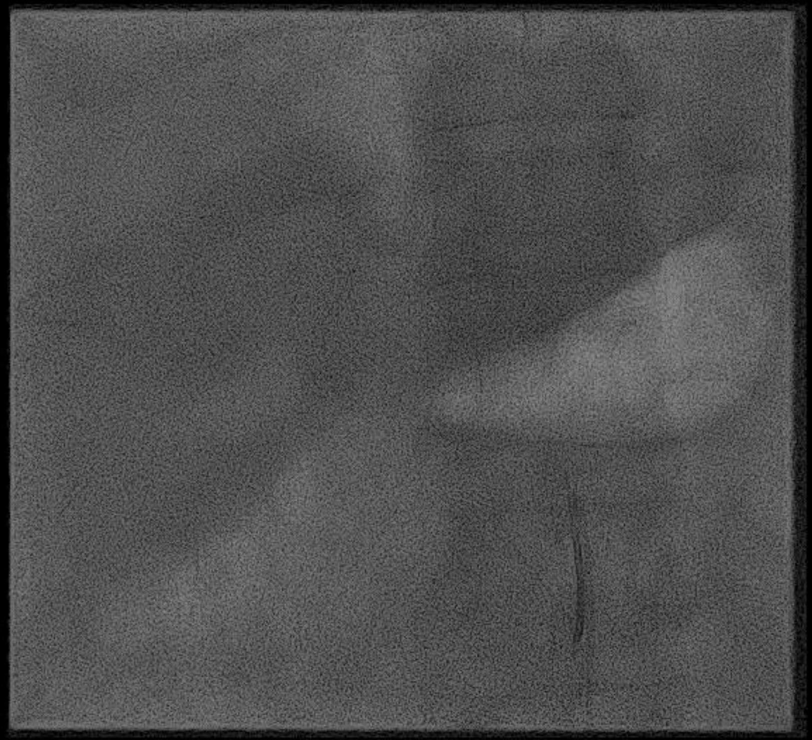
Medium Dose Mode

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



High Dose Mode

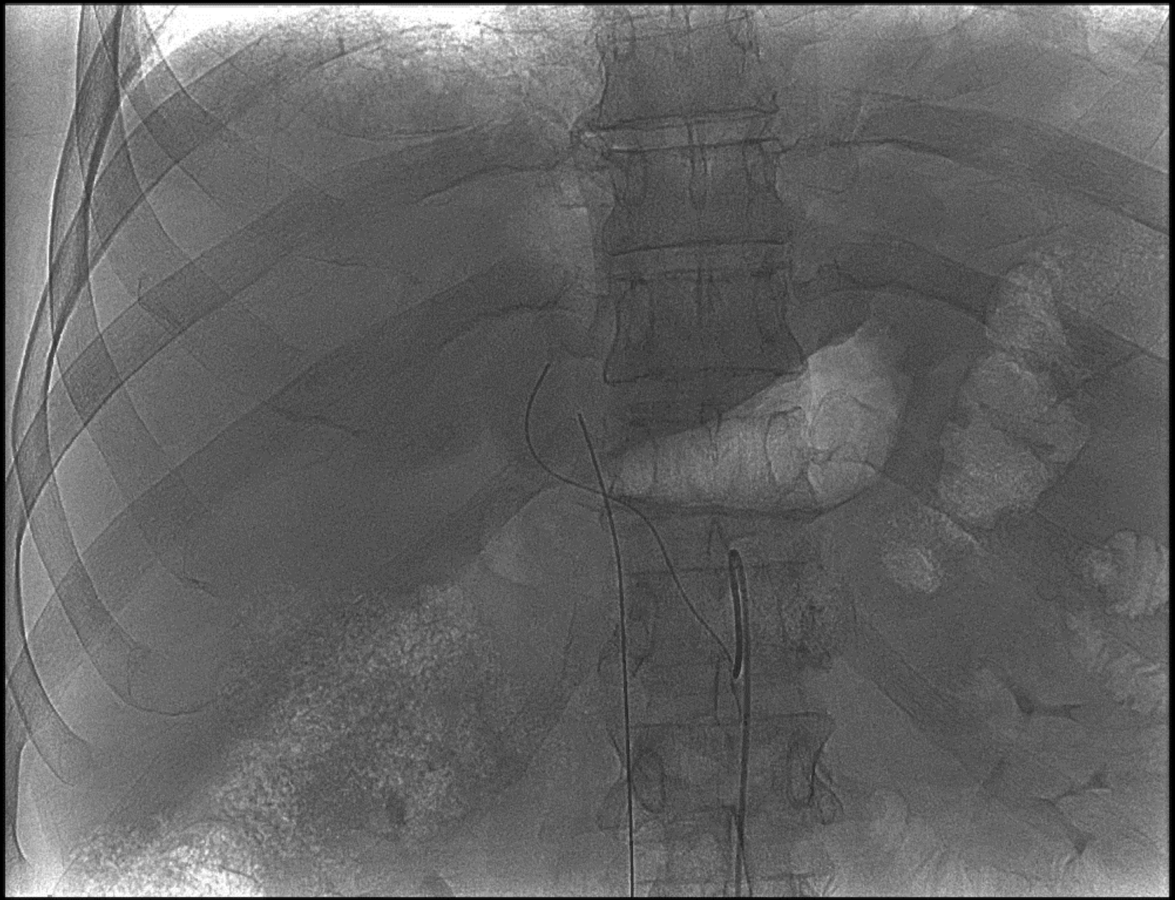
SID: 98 cm
kV: 95
mA: 7
FPS: 15
Frames: 53
Indicated air kerma: 2.5 mGy



Low Dose Mode

Medium Dose Mode

High Dose Mode



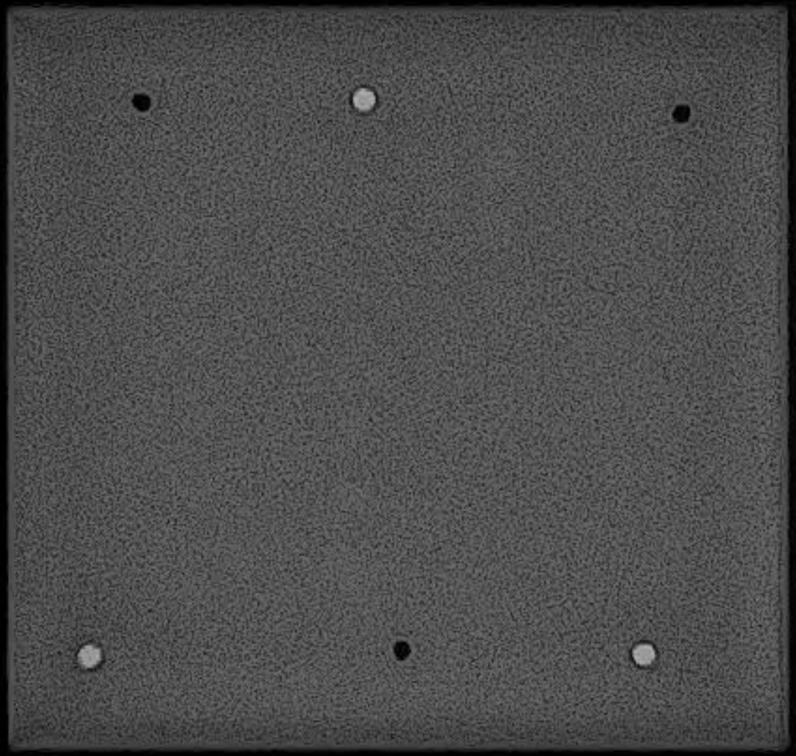
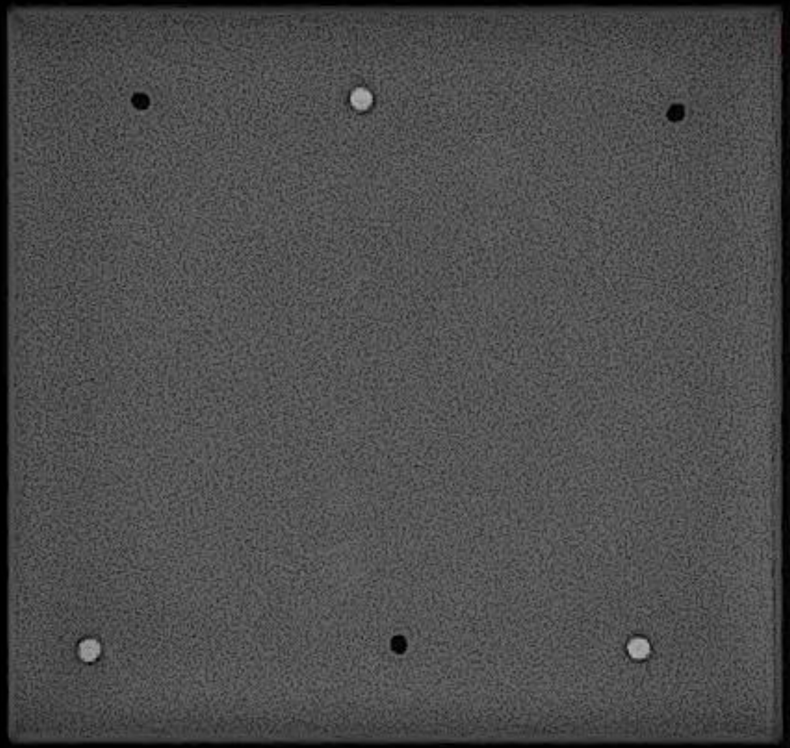
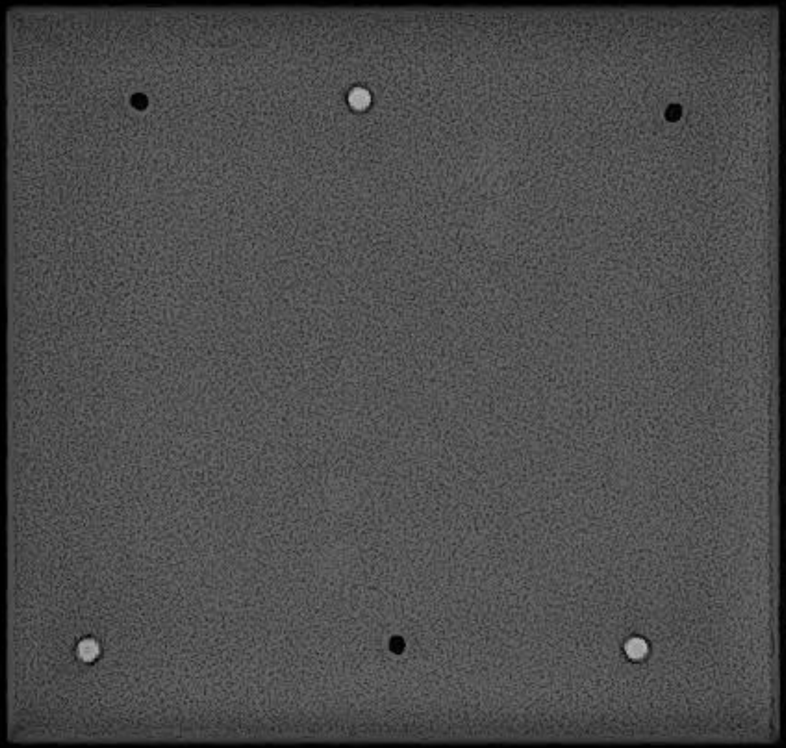
Acquisition Run: SID: 98 cm, kV: 80, mAs: 45, FPS: 3, Frames: 38 Indicated air kerma: 104 mGy



Low Dose Mode

Medium Dose Mode

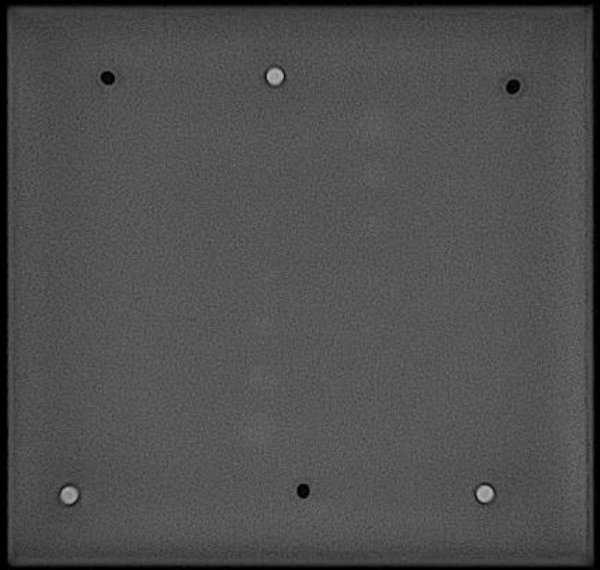
High Dose Mode

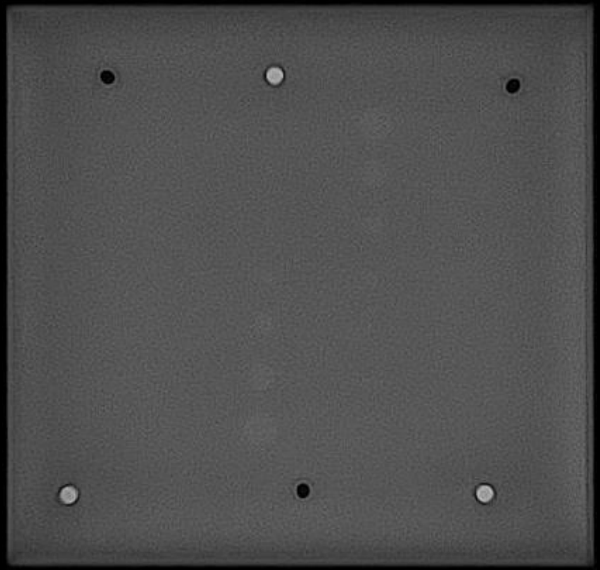
Low Dose Mode

Medium Dose Mode

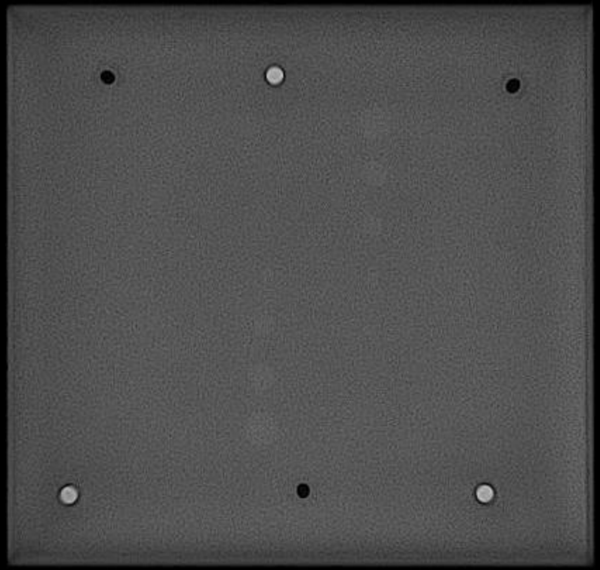
High Dose Mode



2.2 mGy/min

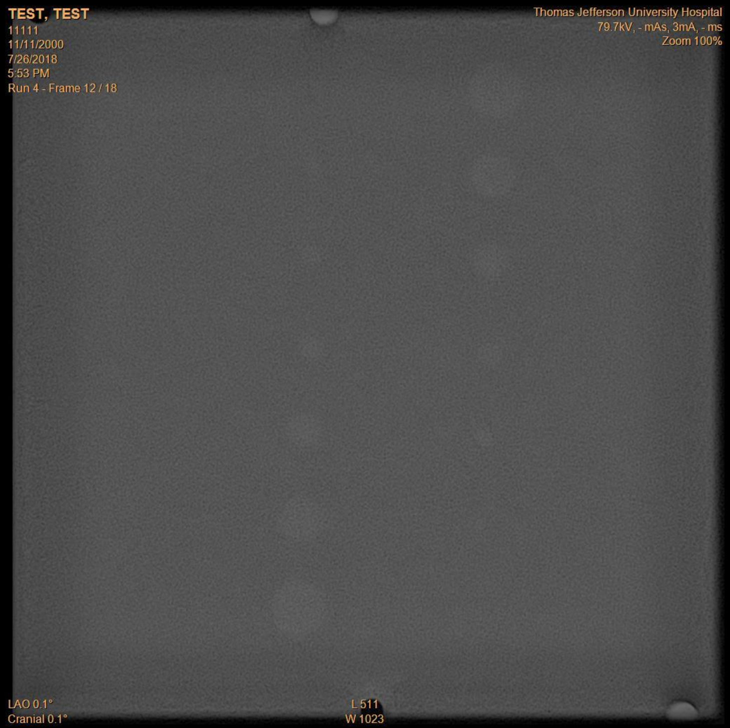


3.3 mGy/min



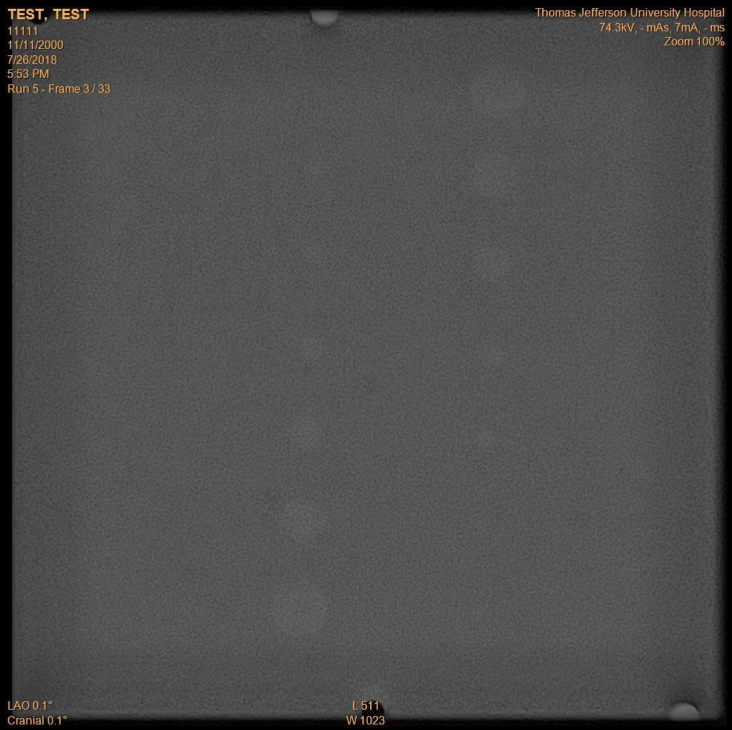
7.8 mGy/min

Low Dose Mode



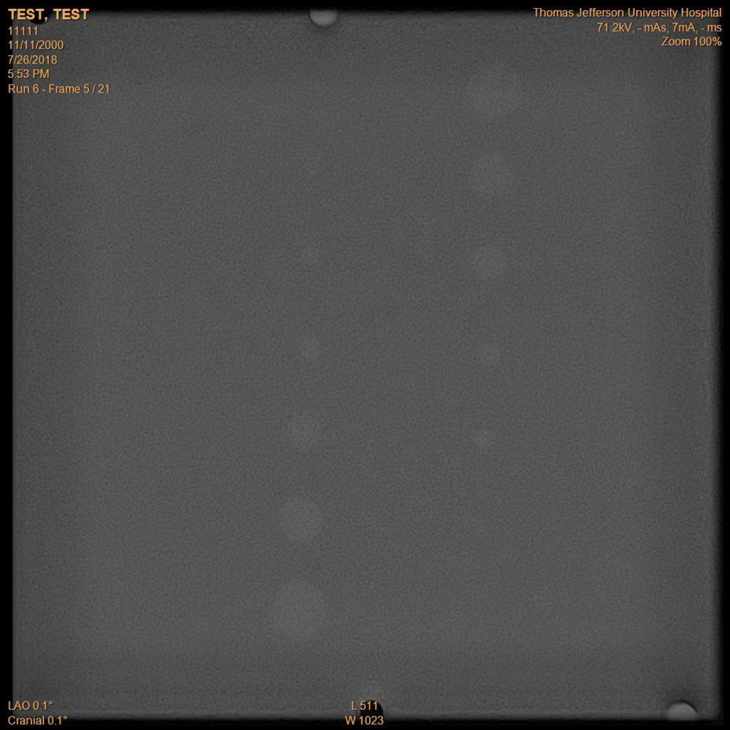
4.2 mGy/min

Medium Dose Mode

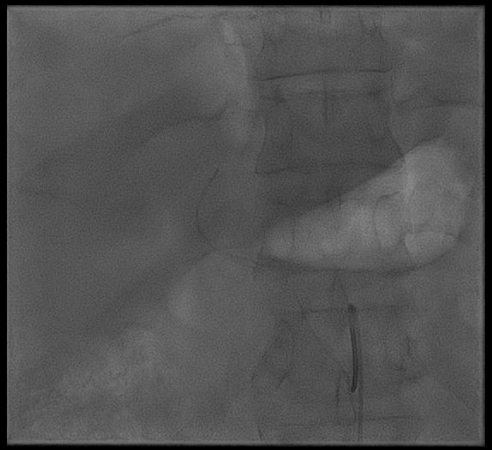


7.6 mGy/min

High Dose Mode



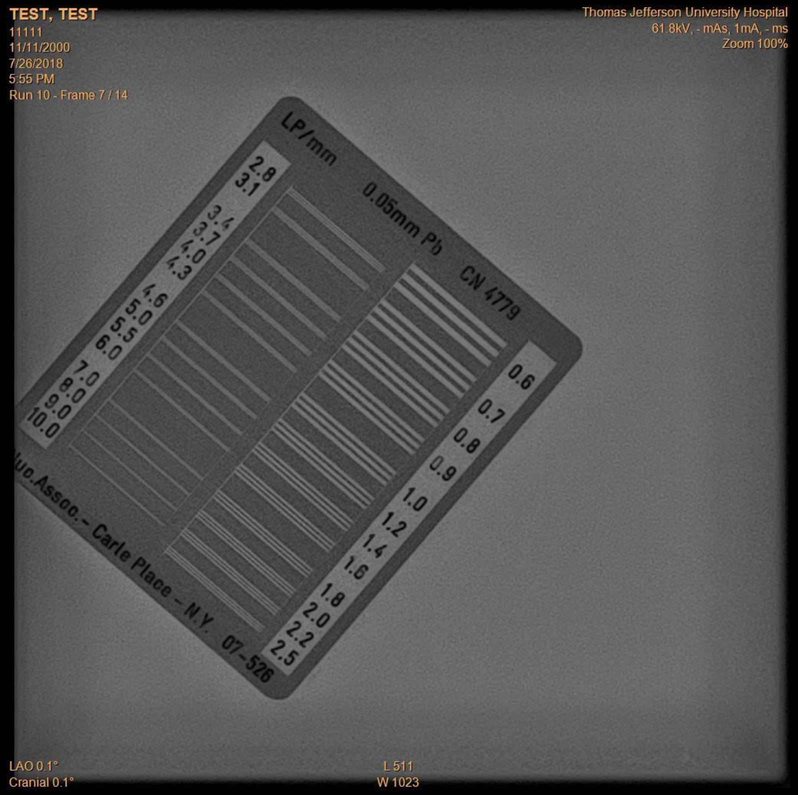
17.0 mGy/min

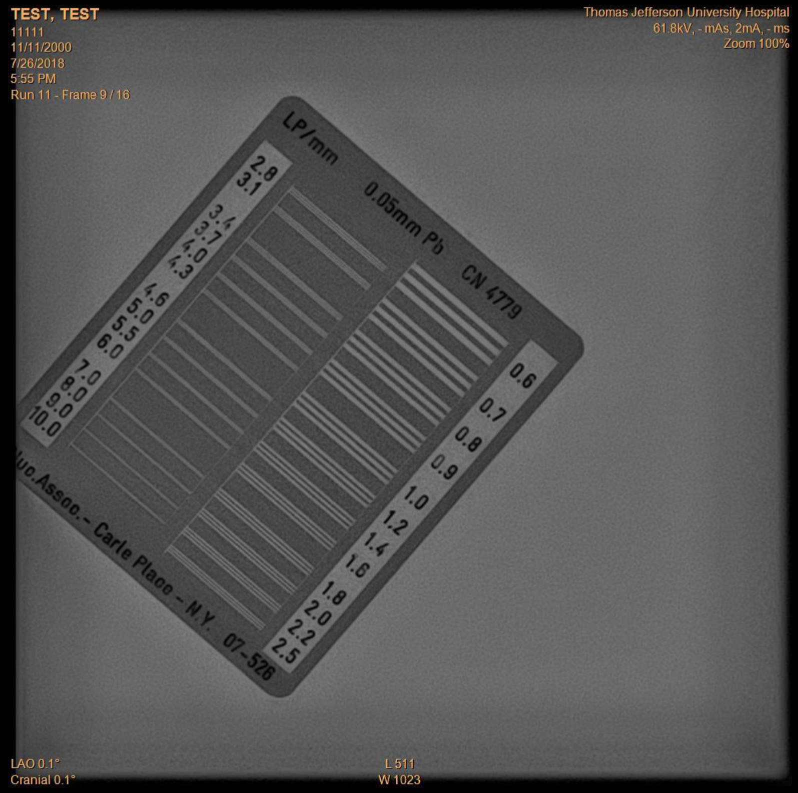


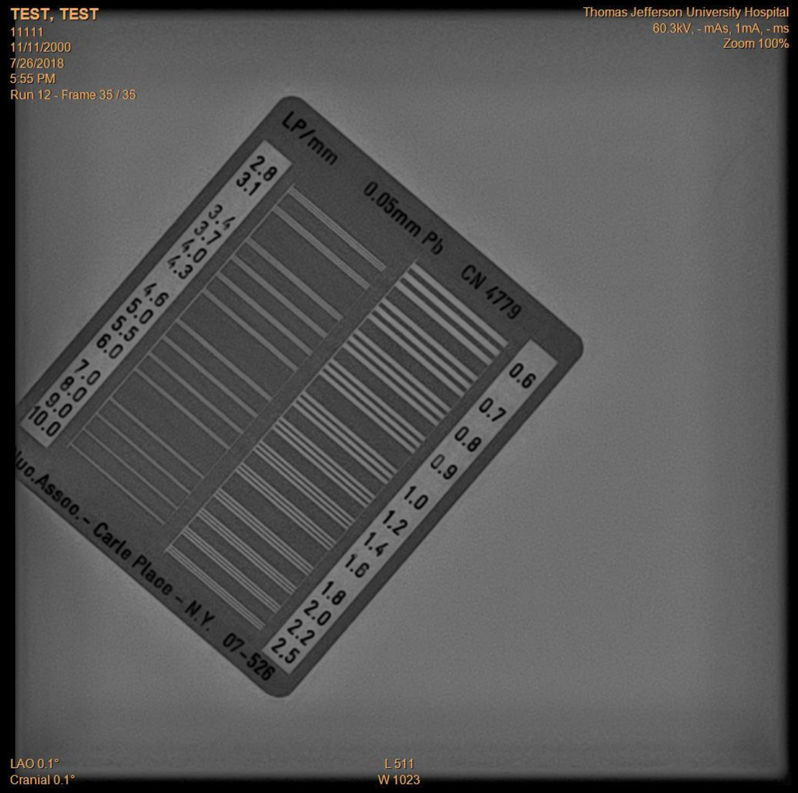
Low Dose Mode

Medium Dose Mode

High Dose Mode



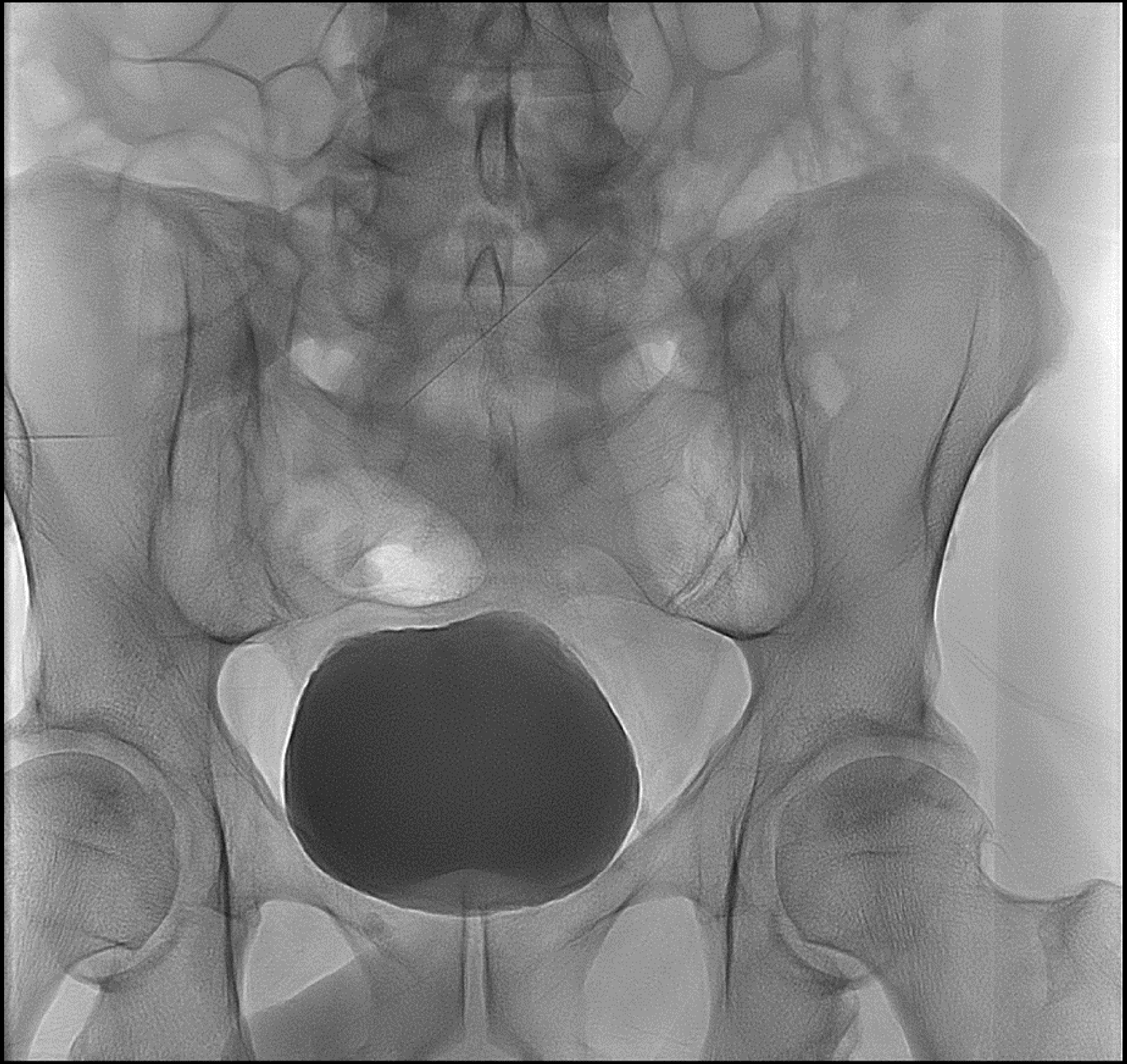


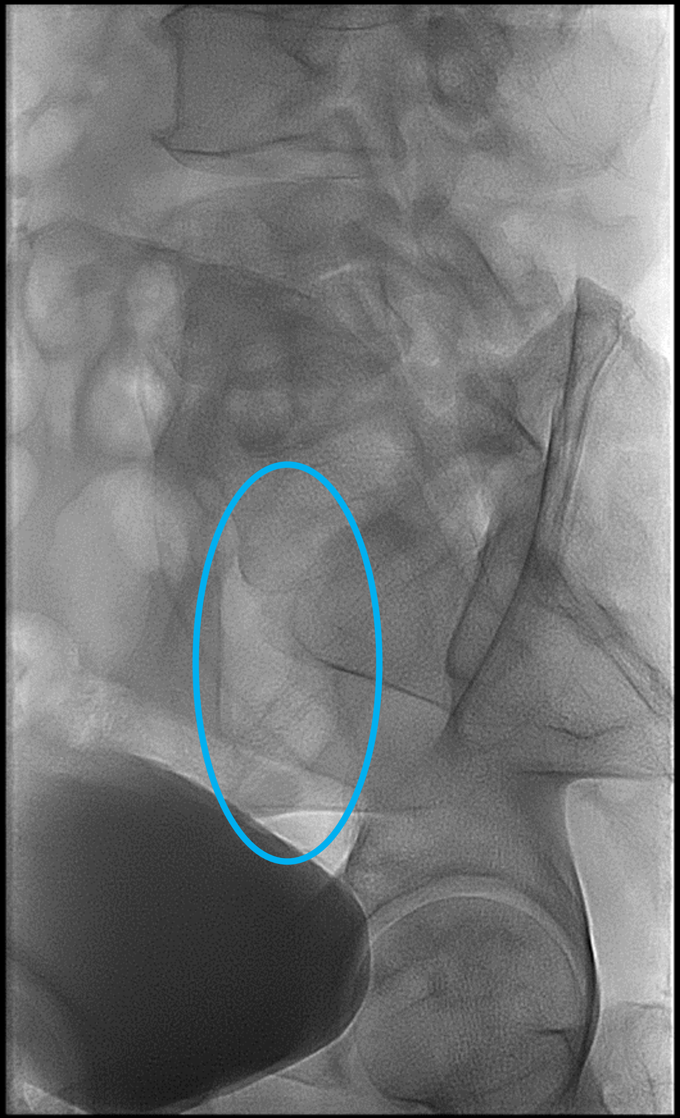


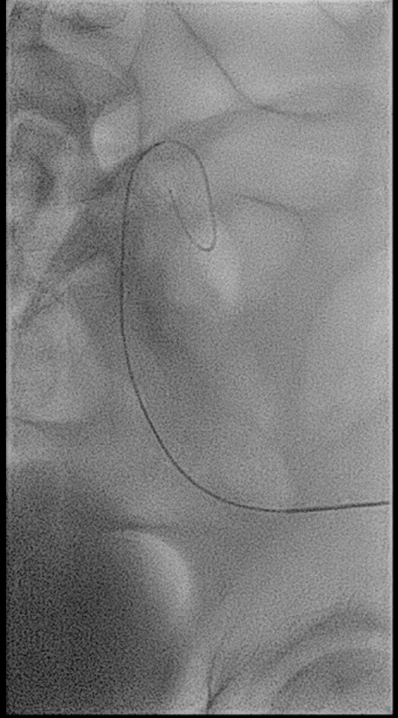
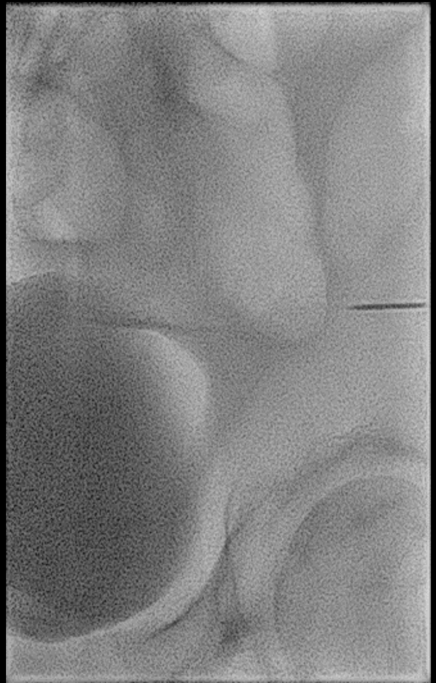
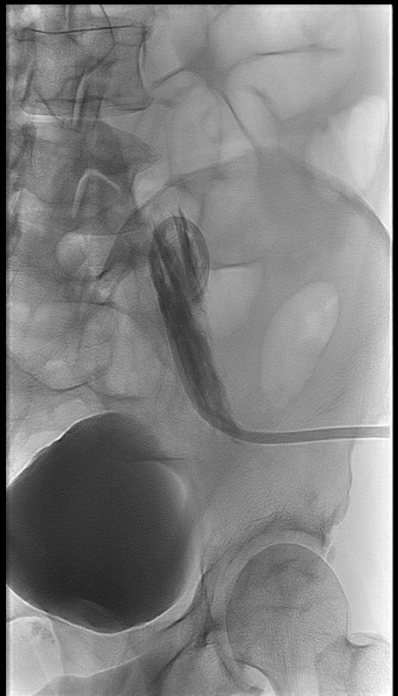
Case 2

- Patient: BMI ~ 28; weight ~ 205 lbs

- Procedure:
  - Left iliopsoas abscess drainage using fluoroscopic guidance
  - Gas in the abscess as a target



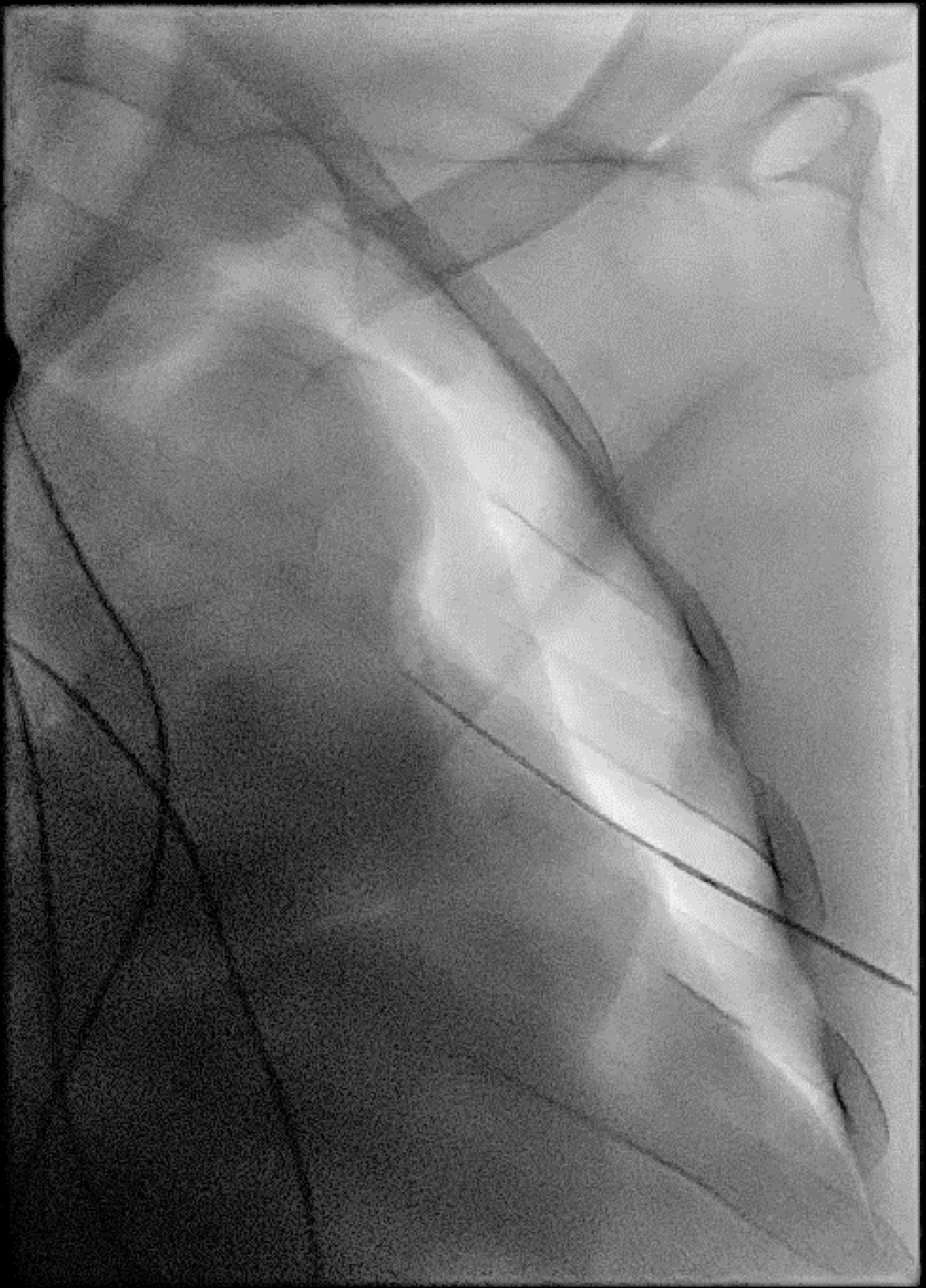


Case 3

- Patient: BMI ~ 24; weight ~ 150 lbs

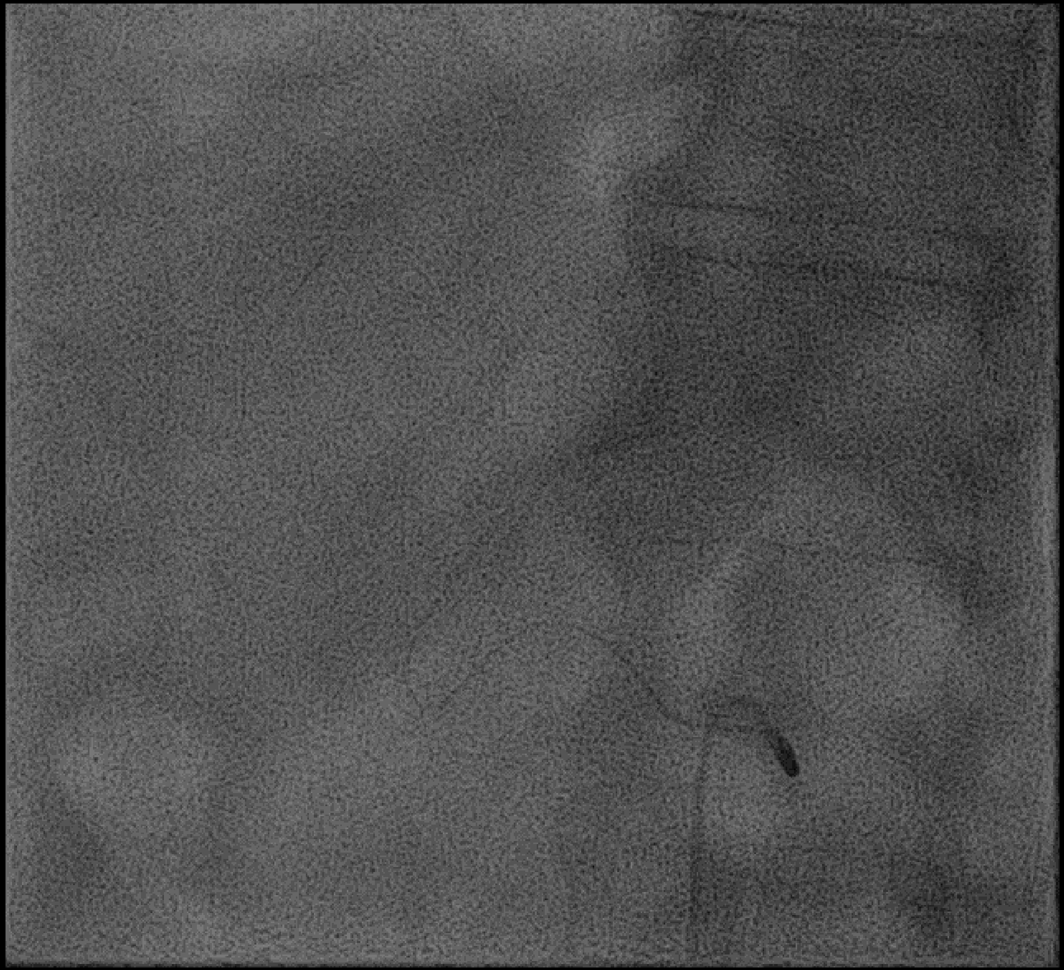
- Procedure:
  - Pneumothorax
  - Drainage catheter placement



Case 4

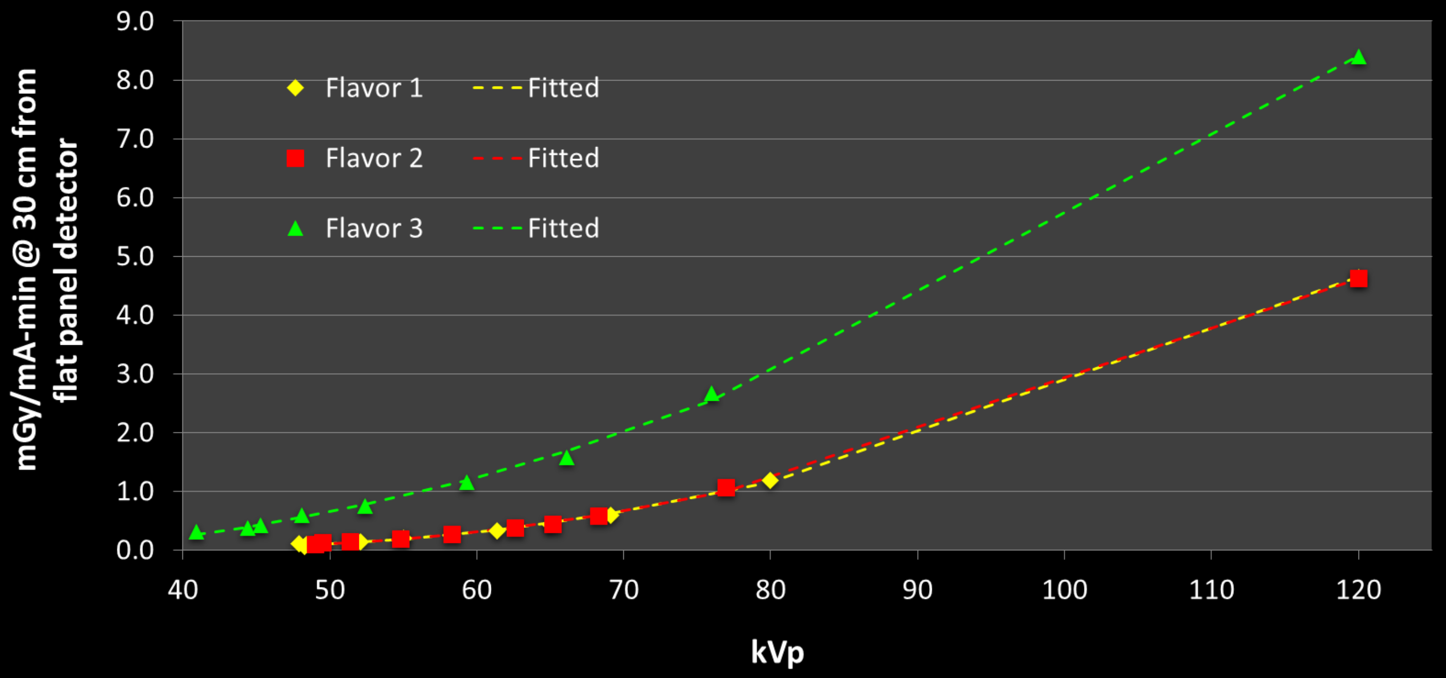
- Patient: BMI ~ 26; weight ~ 180 lbs

- Procedure:
  - Chemo/Immuno embolization



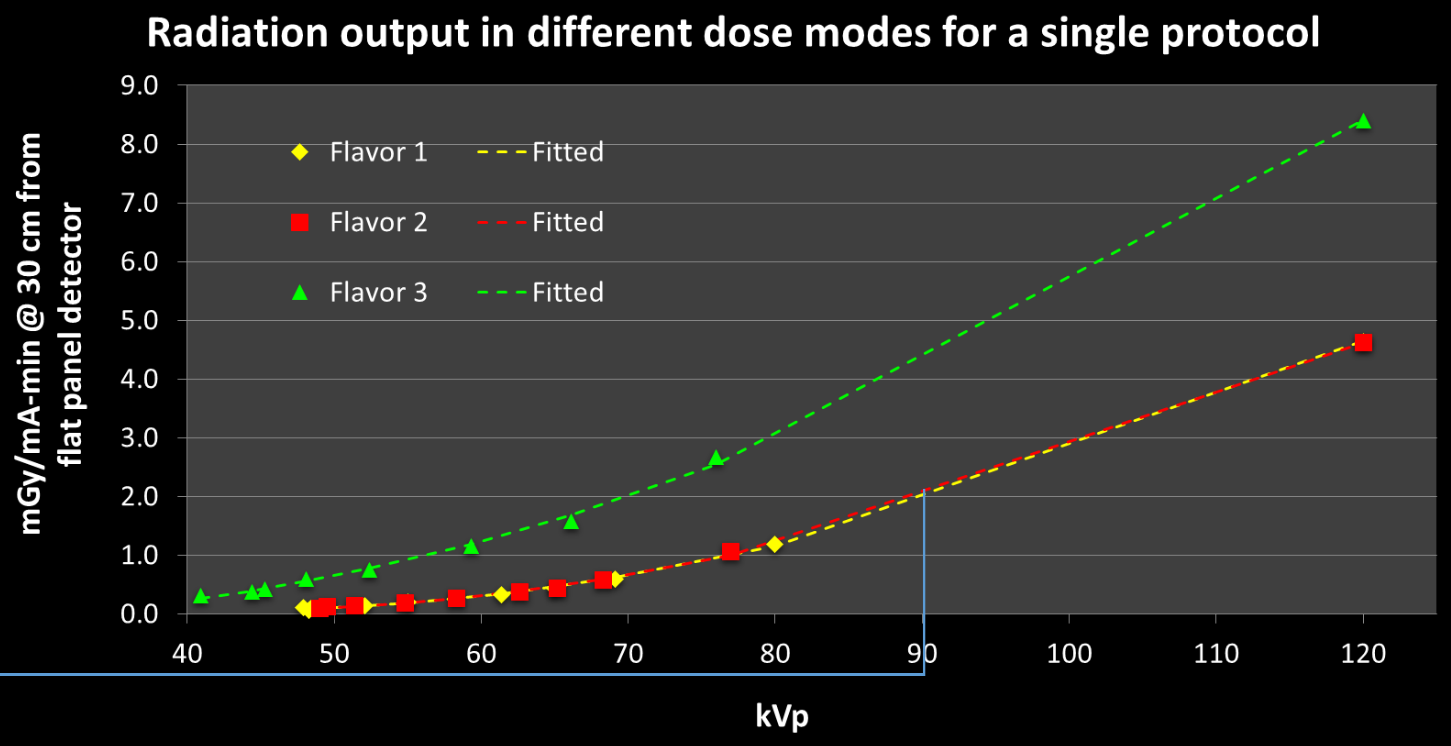
Run no.	No. of images	Procedure	Speed fr/sec	kV	mA mAS	ms	DAP [mGycm²]	AK [mGy]	Rotation	Angulation	SID [cm]
1	[redacted]										
2											
3											
4	93	Fluoroscopy	15	90	6		147	1.20	LAO20	0	94
5	118	Fluoroscopy	15	115	2		132	1.08	LAO20	0	94

Radiation output in different dose modes for a single protocol



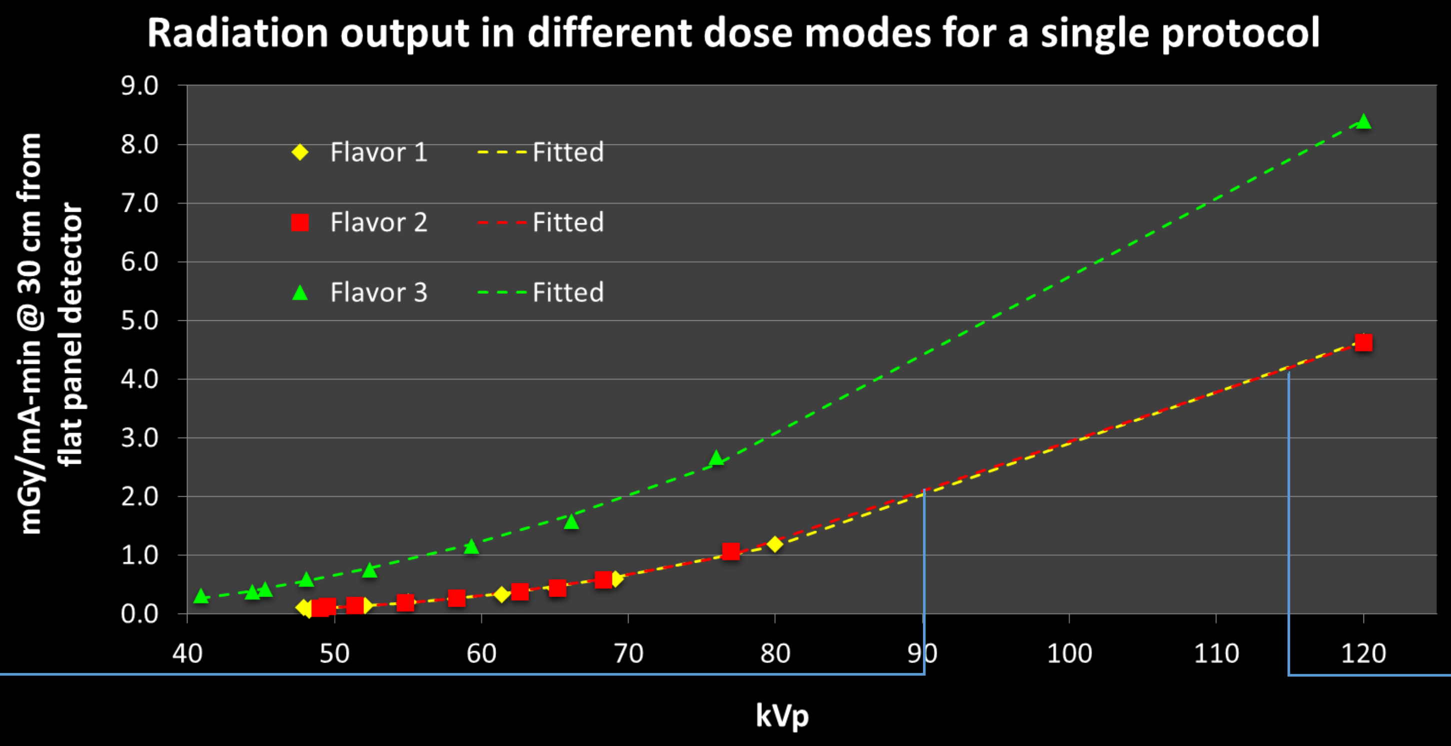
Run no.	No. of images	Procedure	Speed fr/sec	kV	mA	mAS	ms	DAP [mGycm²]	AK [mGy]	Rotation	Angulation	SID [cm]
1	[redacted]											
2												
3												
4	93	Fluoroscopy	15	90	6			147	1.20	LAO20	0	94
5	118	Fluoroscopy	15	115	2			132	1.08	LAO20	0	94

Dose Calculation = 2 mGy/mA-min * 6 mA * (93/15/60) min = 1.2 mGy



Run no.	No. of images	Procedure	Speed fr/sec	kV	mA mAs	ms	DAP [mGycm²]	AK [mGy]	Rotation	Angulation	SID [cm]
1	[redacted]										
2											
3											
4	93	Fluoroscopy	15	90	6		147	1.20	LAO20	0	94
5	118	Fluoroscopy	15	115	2		132	1.08	LAO20	0	94

Dose Calculation = 2 mGy/mA-min * 6 mA * (93/15/60) min = 1.2 mGy



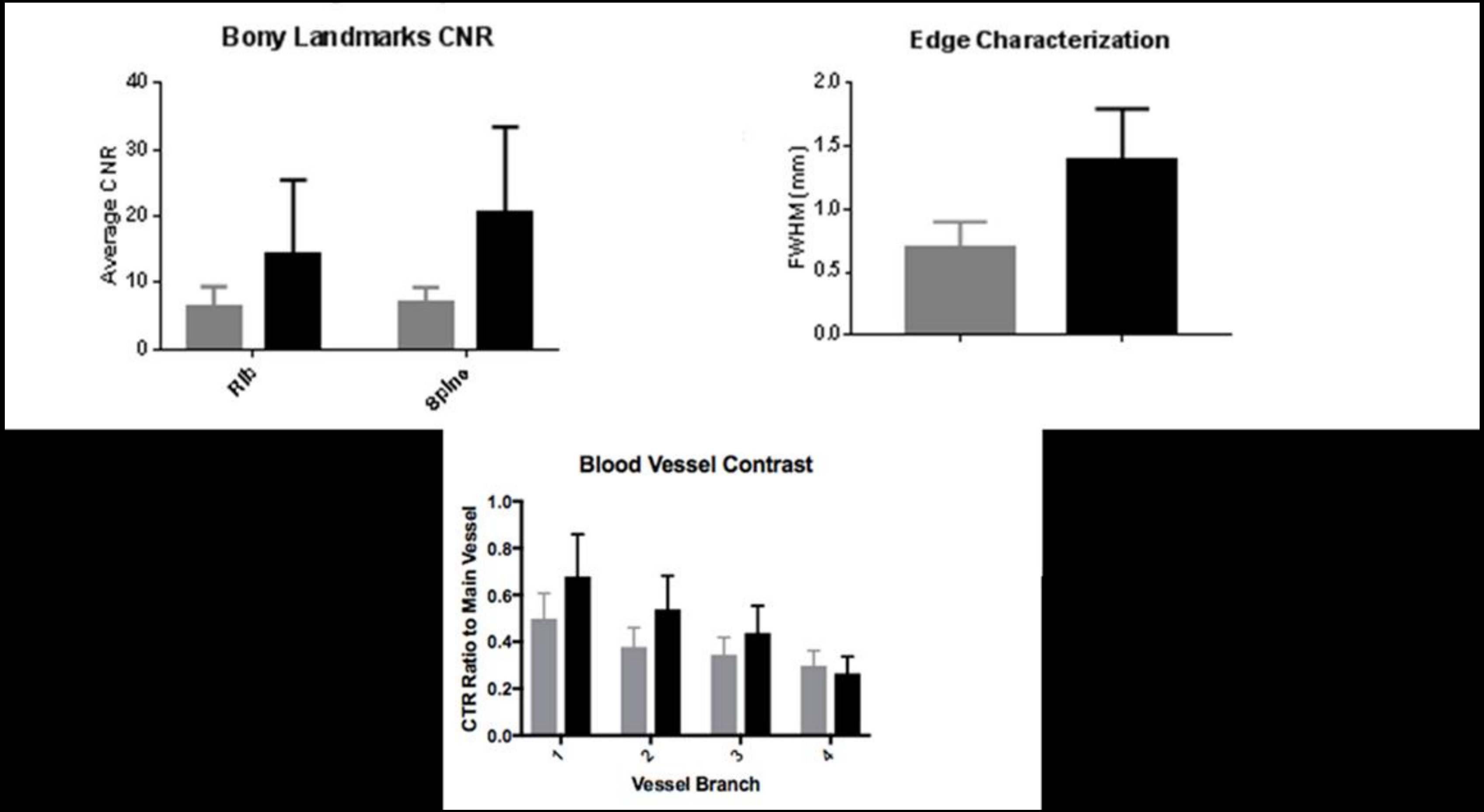
Dose Calculation = 4.2 mGy/mA-min * 2 mA * (118/15/60) min = 1.1 mGy

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
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    - Sonazoid vials from GE Healthcare
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    - National Institutes of Health – NHLBI
    - Philips Healthcare