Radiologists and medical physicists – Working together to achieve common goals

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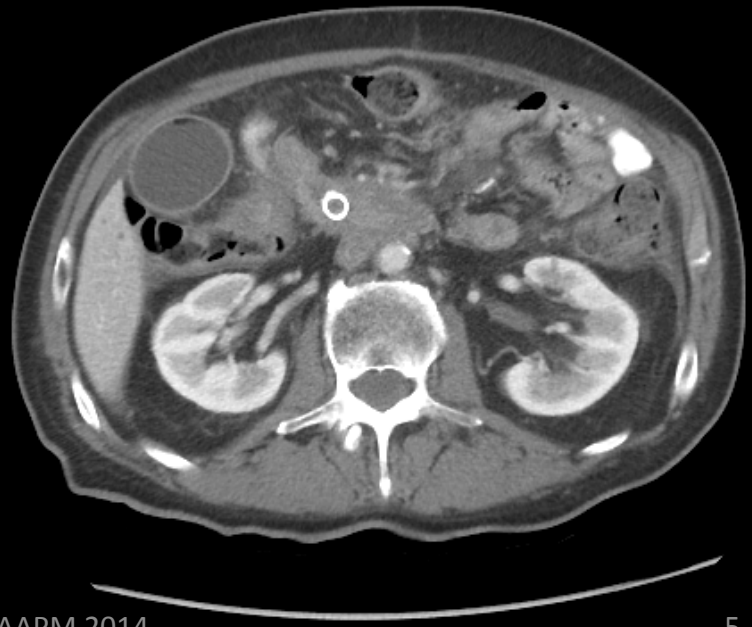
Disclosure

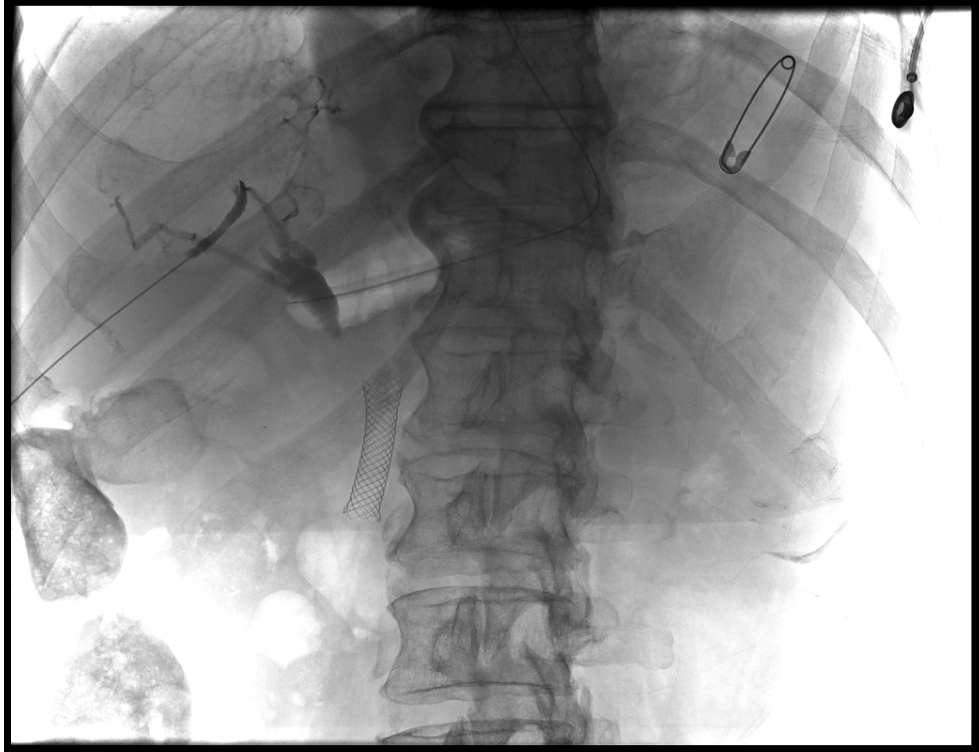
- A. Kyle Jones is co-owner of Fluoroscopic Safety, LLC, a company that markets educational programs on the safe use of fluoroscopy

CASE 1

Biliary catheter placement

- Tumors of the liver and pancreas can cause obstruction of the bile duct
- This obstruction can be relieved by endoscopically placing a stent in the bile duct
- Re-obstruction may require placement of a biliary catheter to drain bile externally
- Is the guidewire through the struts or through the lumen of the stent?





Sharpness

- What affects sharpness in fluoroscopy?
- Considering the task and equipment configuration, what is the currently factor that is limiting resolution?

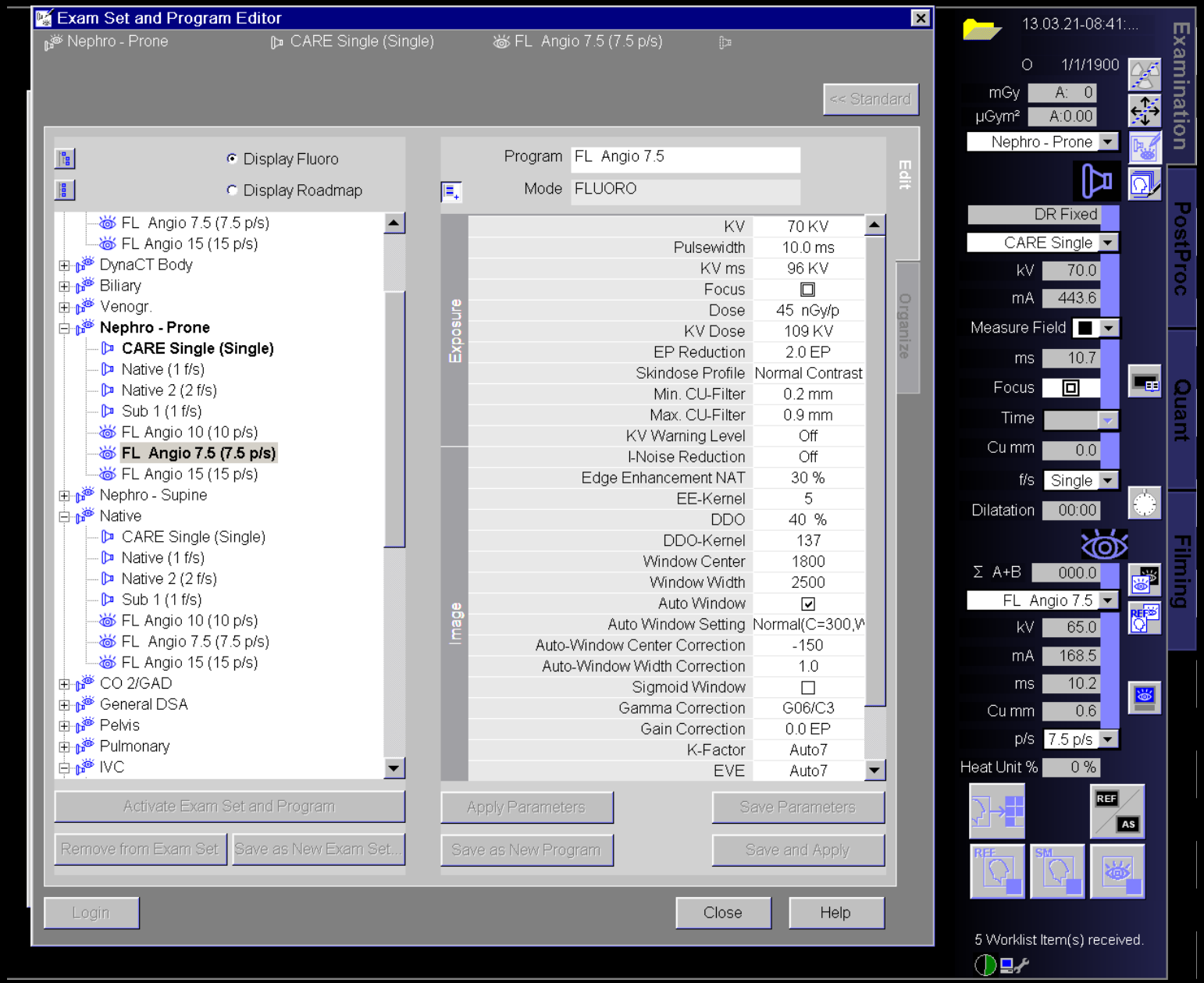
Focal spot size

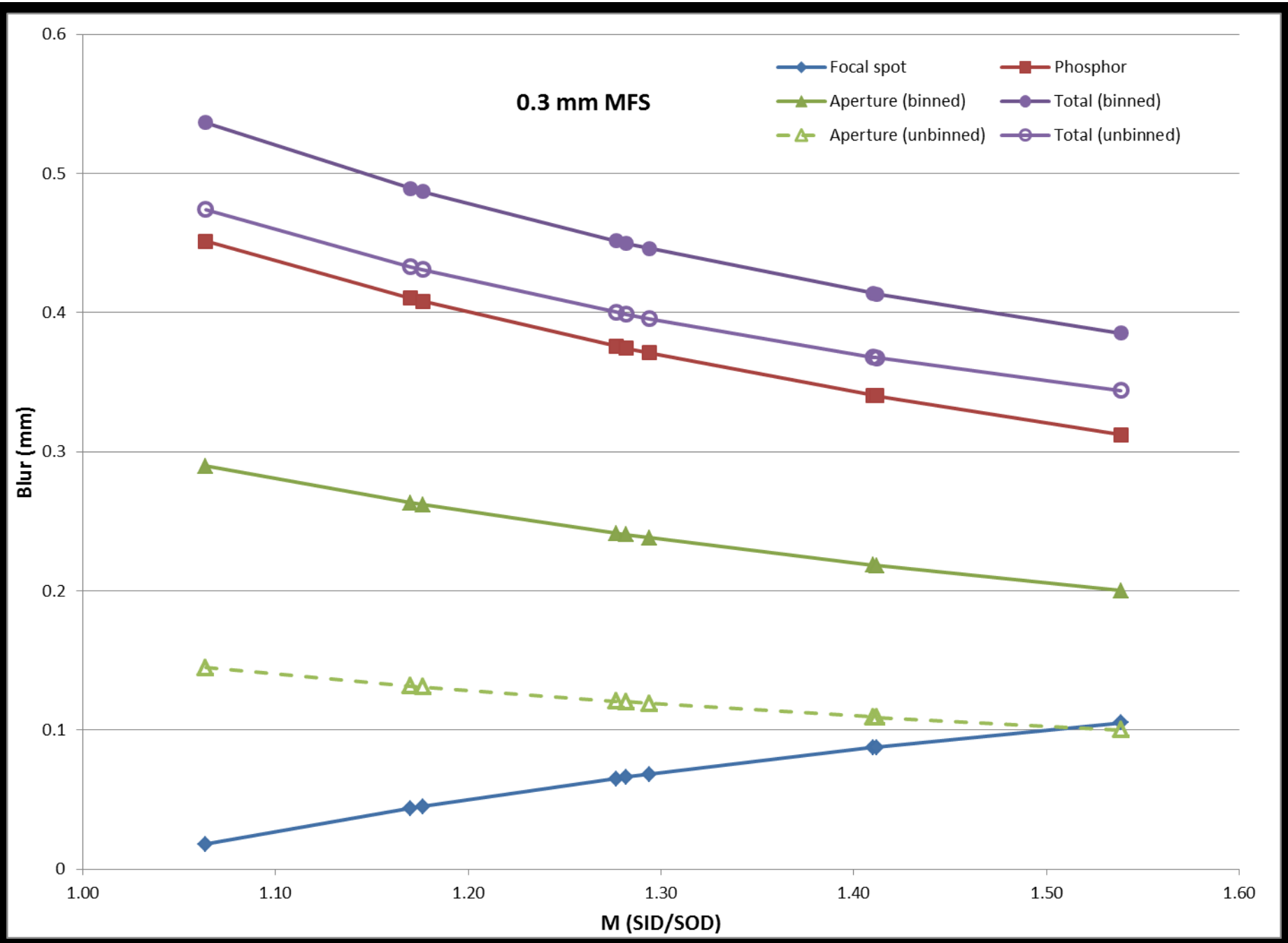
- Many modern interventional x-ray tubes have three focal spots
  - Artis zee: MFS (0.3), SFS (0.6), LFS (1.0)
- Focal spot preference may only be selectable in FLU or ACQ , but one setting affects the other
  - Focal spot size may increase from FLU to ACQ, causing blur that wasn't present in FLU
- Preference for a smaller focal spot will favor selection of a higher kV or a longer pulse width by the ADRC system

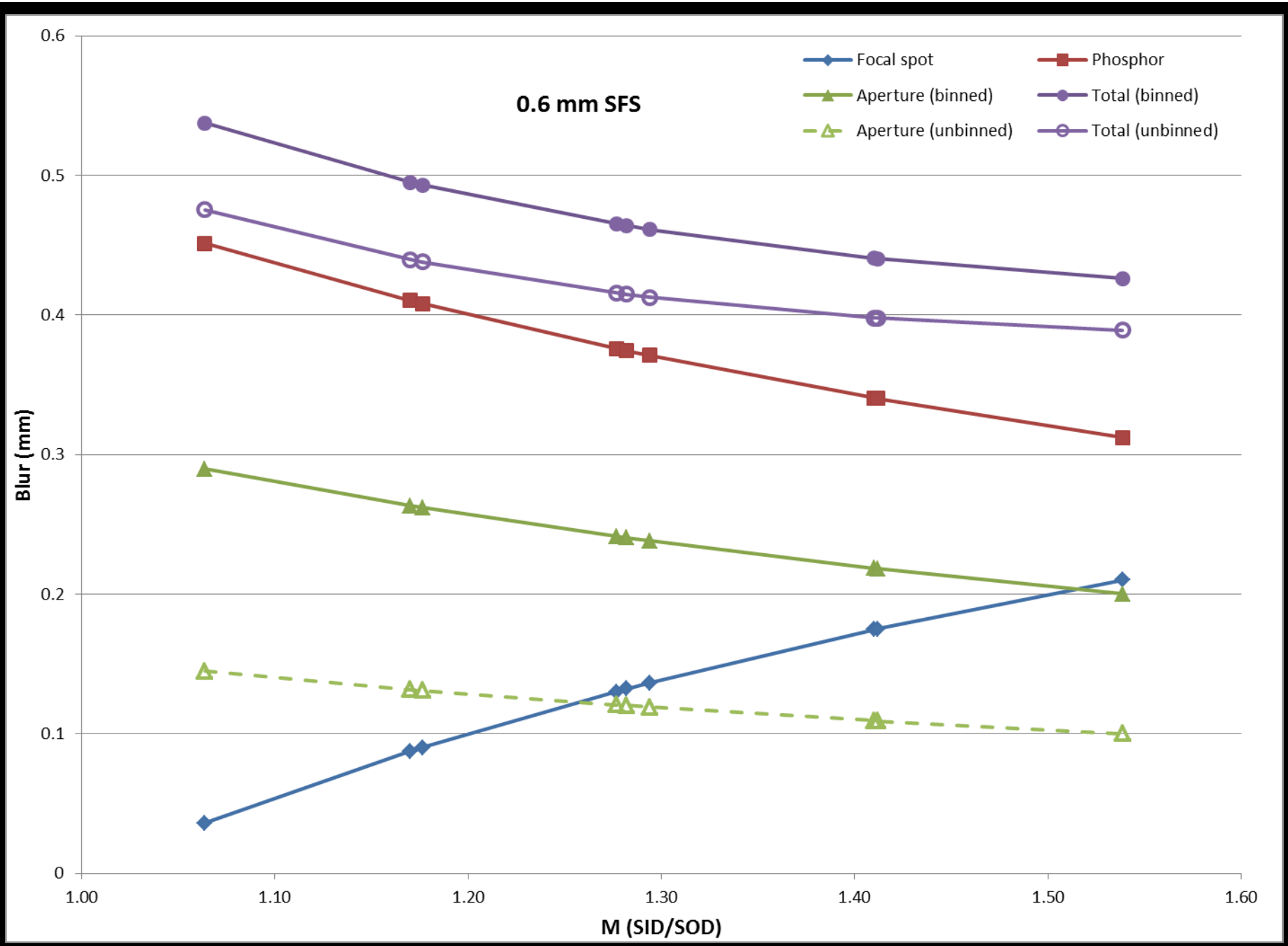
The tube current of the micro focus is limited to 15 – 66 mA during pulsed fluoroscopy.
The tube current of the small focus is limited to 15 – 250 mA during pulsed fluoroscopy.

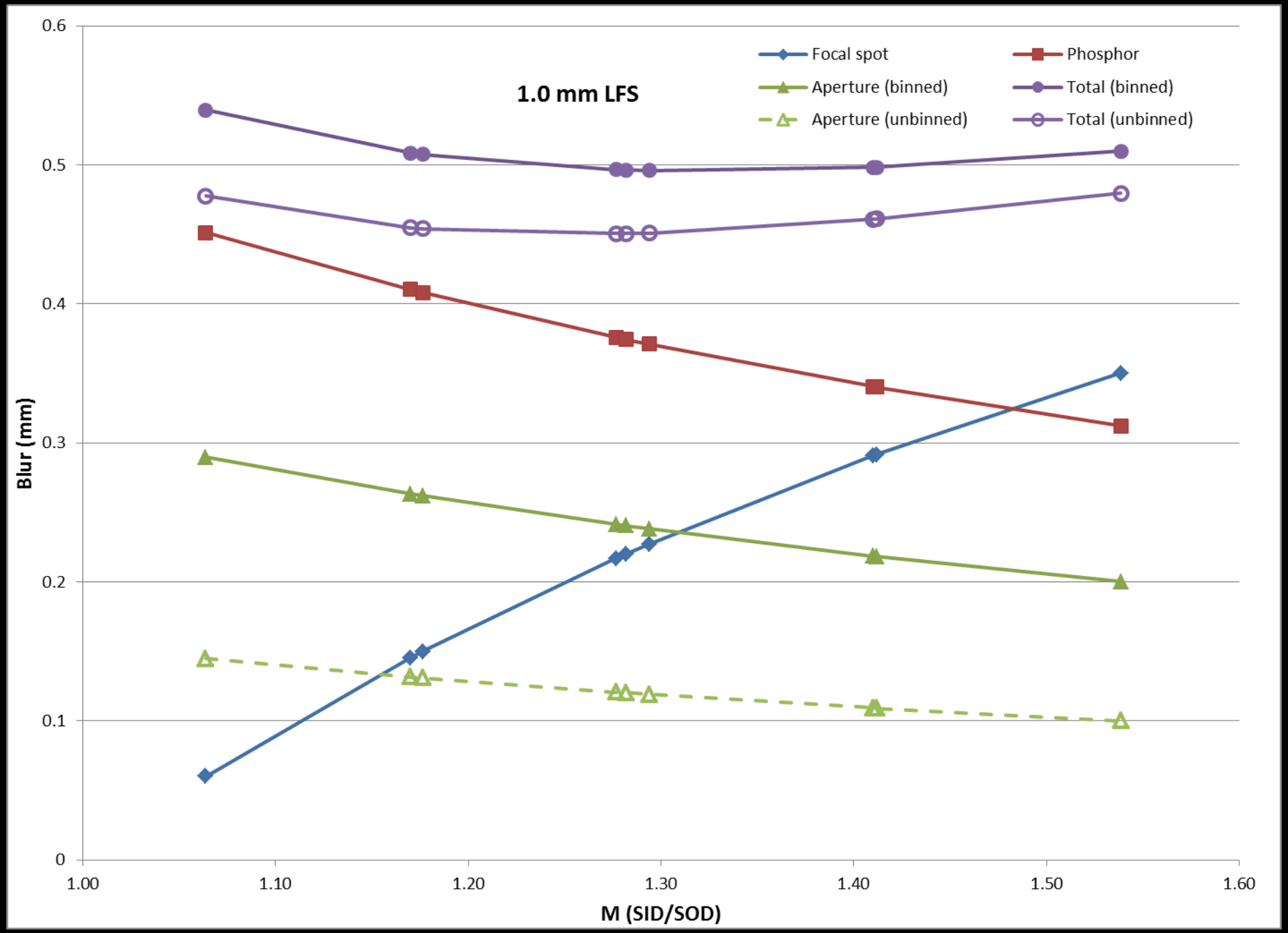
The tube current of the micro focus is limited to 15 – 190 mA during acquisition.
The tube current of the small focus is limited to 15 – 444 mA during acquisition.
The tube current of the large focus is limited to 15 – 800 mA during acquisition.

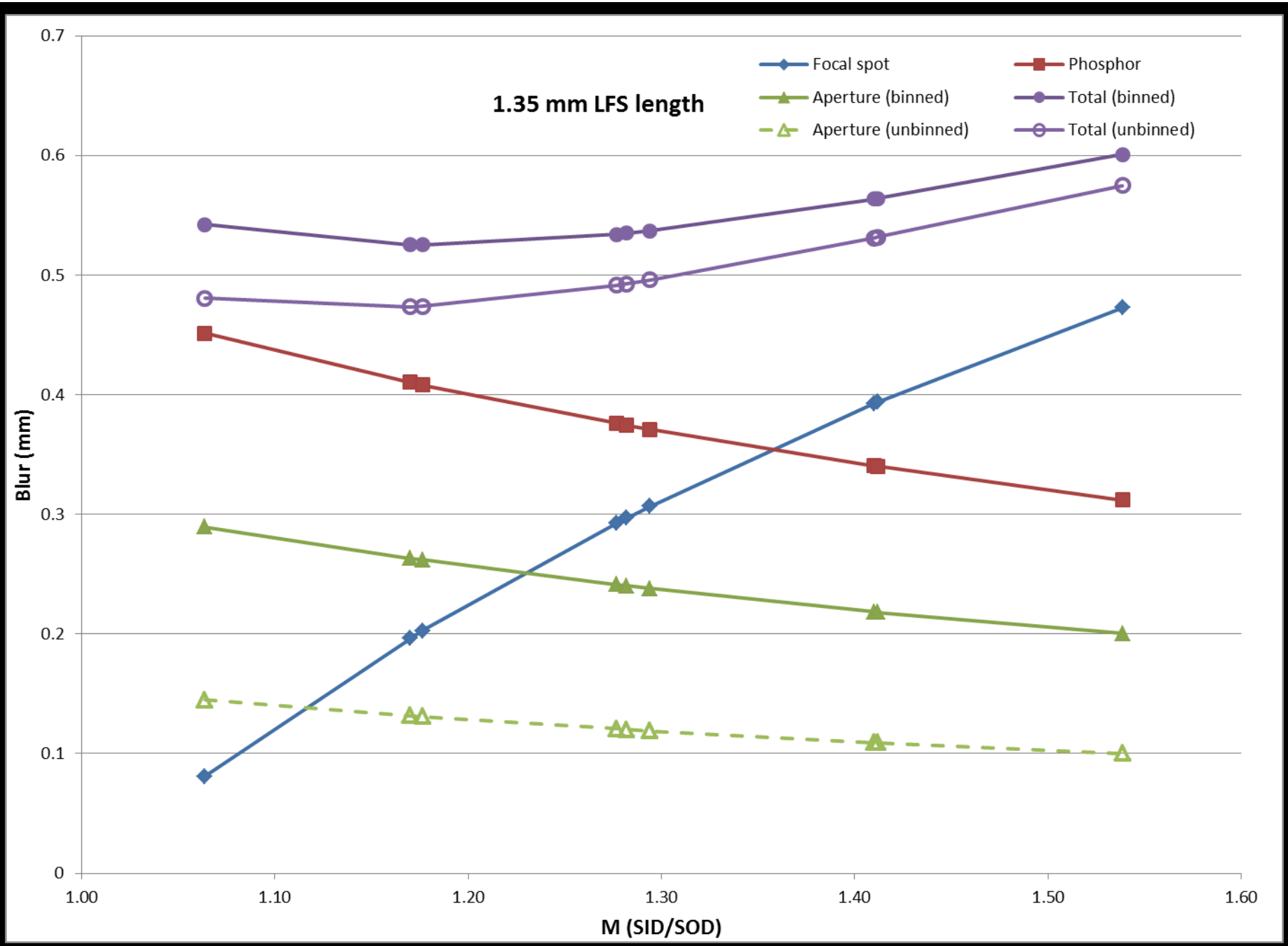
Artis zee owner's manual

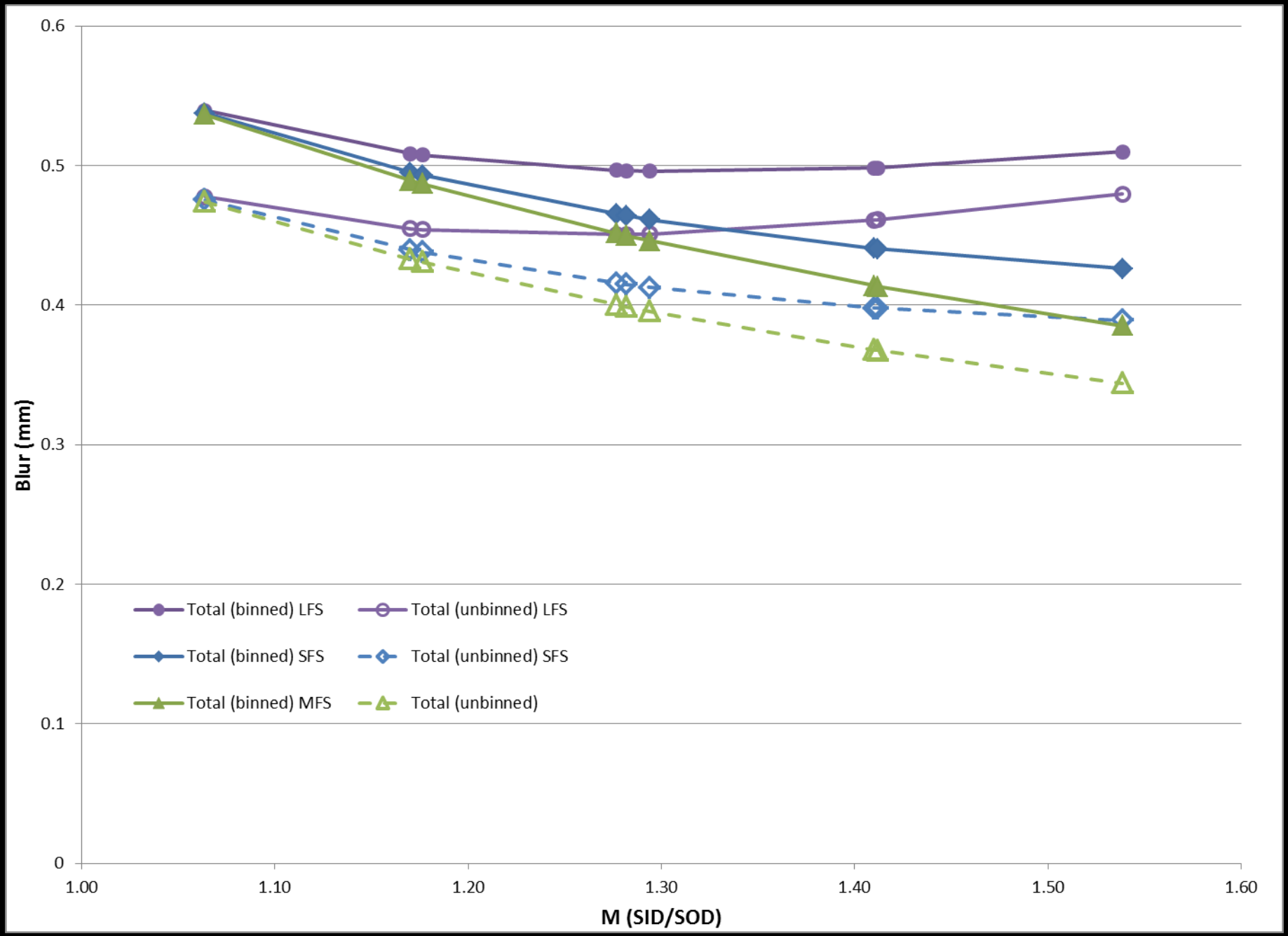

Exam Set and Program Editor
Nephro - Prone
CARE Single (Single)
FL Angio 7.5 (7.5 p/s)
<< Standard
Display Fluoro
Display Roadmap
FL Angio 7.5 (7.5 p/s)
FL Angio 15 (15 p/s)
DynaCT Body
Biliary
Venogr.
Nephro - Prone
CARE Single (Single)
Native (1 f/s)
Native 2 (2 f/s)
Sub 1 (1 f/s)
FL Angio 10 (10 p/s)
FL Angio 15 (15 p/s)
Nephro - Supine
Native
CARE Single (Single)
Native (1 f/s)
Native 2 (2 f/s)
Sub 1 (1 f/s)
FL Angio 10 (10 p/s)
FL Angio 7.5 (7.5 p/s)
FL Angio 15 (15 p/s)
CO 2/GAD
General DSA
Pelvis
Pulmonary
IVC
Activate Exam Set and Program
Remove from Exam Set
Save as New Exam Set...
Program FL Angio 7.5
Mode FLUORO
Exposure
KV 70 KV
Pulsewidth 10.0 ms
KV ms 96 KV
Focus
Dose 45 nGy/p
KV Dose 109 KV
EP Reduction 2.0 EP
Skindose Profile Normal Contrast
Min. CU-Filter 0.2 mm
Max. CU-Filter 0.9 mm
KV Warning Level Off
Image
I-Noise Reduction Off
Edge Enhancement NAT 30 %
EE-Kernel 5
DDO 40 %
DDO-Kernel 137
Window Center 1800
Window Width 2500
Auto Window
Auto Window Setting Normal(C=300,W
Auto-Window Center Correction -150
Auto-Window Width Correction 1.0
Sigmoid Window
Gamma Correction G06/C3
Gain Correction 0.0 EP
K-Factor Auto7
EVE Auto7
Edit
Organize
Apply Parameters
Save Parameters
Save as New Program
Save and Apply
Login
Close
Help
13.03.21-08:41:...
1/1/1900
mGy A: 0
µGym² A:0.00
Nephro - Prone
DR Fixed
CARE Single
kV 70.0
mA 443.6
Measure Field
ms 10.7
Focus
Time
Cu mm 0.0
f/s Single
Dilatation 00:00
Σ A+B 000.0
FL Angio 7.5
kV 65.0
mA 168.5
ms 10.2
Cu mm 0.6
p/s 7.5 p/s
Heat Unit % 0 %
REF
AS
SM
5 Worklist Item(s) received.
Examination
PostProc
Quant
Filming


0.3 mm MFS
Focal spot
Phosphor
Aperture (binned)
Total (binned)
Aperture (unbinned)
Total (unbinned)
Blur (mm)
0.6
0.5
0.4
0.3
0.2
0.1
0
1.00
1.10
1.20
1.30
1.40
1.50
1.60
M (SID/SOD)


0.6 mm SFS
Focal spot
Phosphor
Aperture (binned)
Total (binned)
Aperture (unbinned)
Total (unbinned)
Blur (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
1.00
1.10
1.20
1.30
1.40
1.50
1.60
M (SID/SOD)


1.0 mm LFS
Focal spot
Phosphor
Aperture (binned)
Total (binned)
Aperture (unbinned)
Total (unbinned)
Blur (mm)
0.6
0.5
0.4
0.3
0.2
0.1
0
1.00
1.10
1.20
1.30
1.40
1.50
1.60
M (SID/SOD)

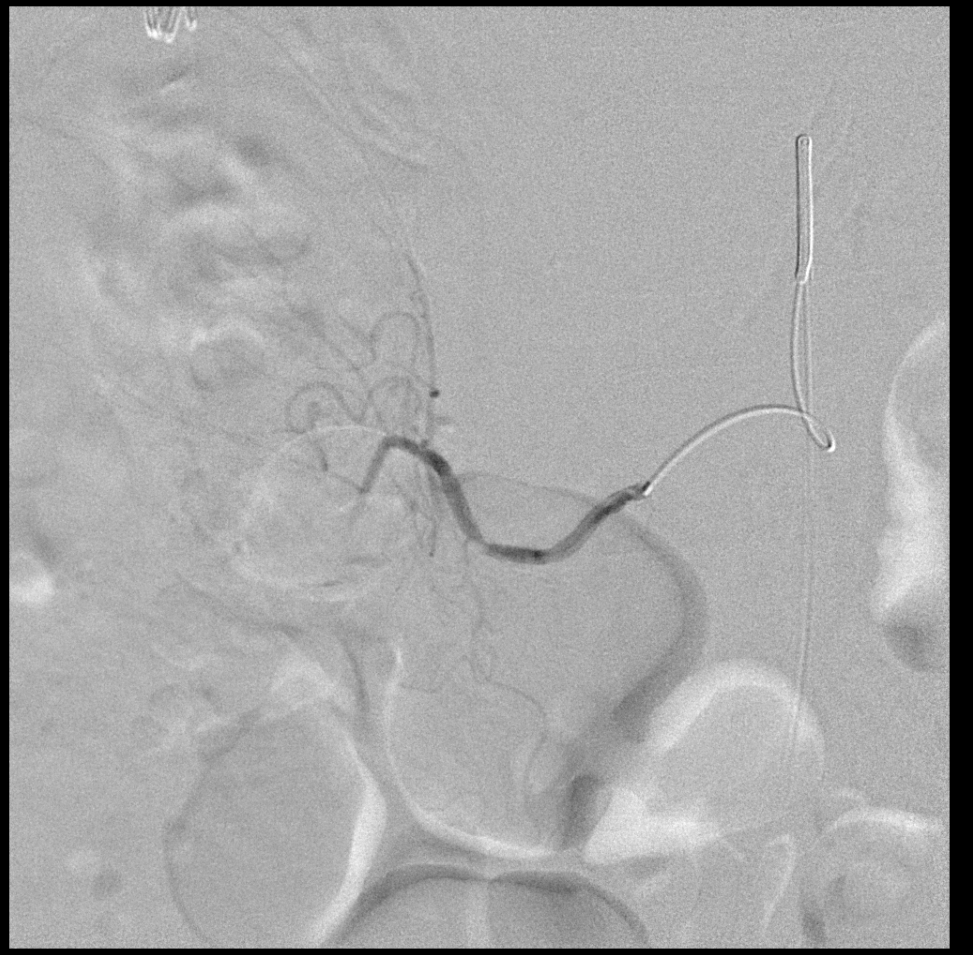

1.35 mm LFS length
Focal spot
Phosphor
Aperture (binned)
Total (binned)
Aperture (unbinned)
Total (unbinned)
Blur (mm)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.00
1.10
1.20
1.30
1.40
1.50
1.60
M (SID/SOD)


0.6
0.5
0.4
0.3
0.2
0.1
0
Blur (mm)
1.00
1.10
1.20
1.30
1.40
1.50
1.60
M (SID/SOD)
Total (binned) LFS
Total (unbinned) LFS
Total (binned) SFS
Total (unbinned) SFS
Total (binned) MFS
Total (unbinned)

CASE 2

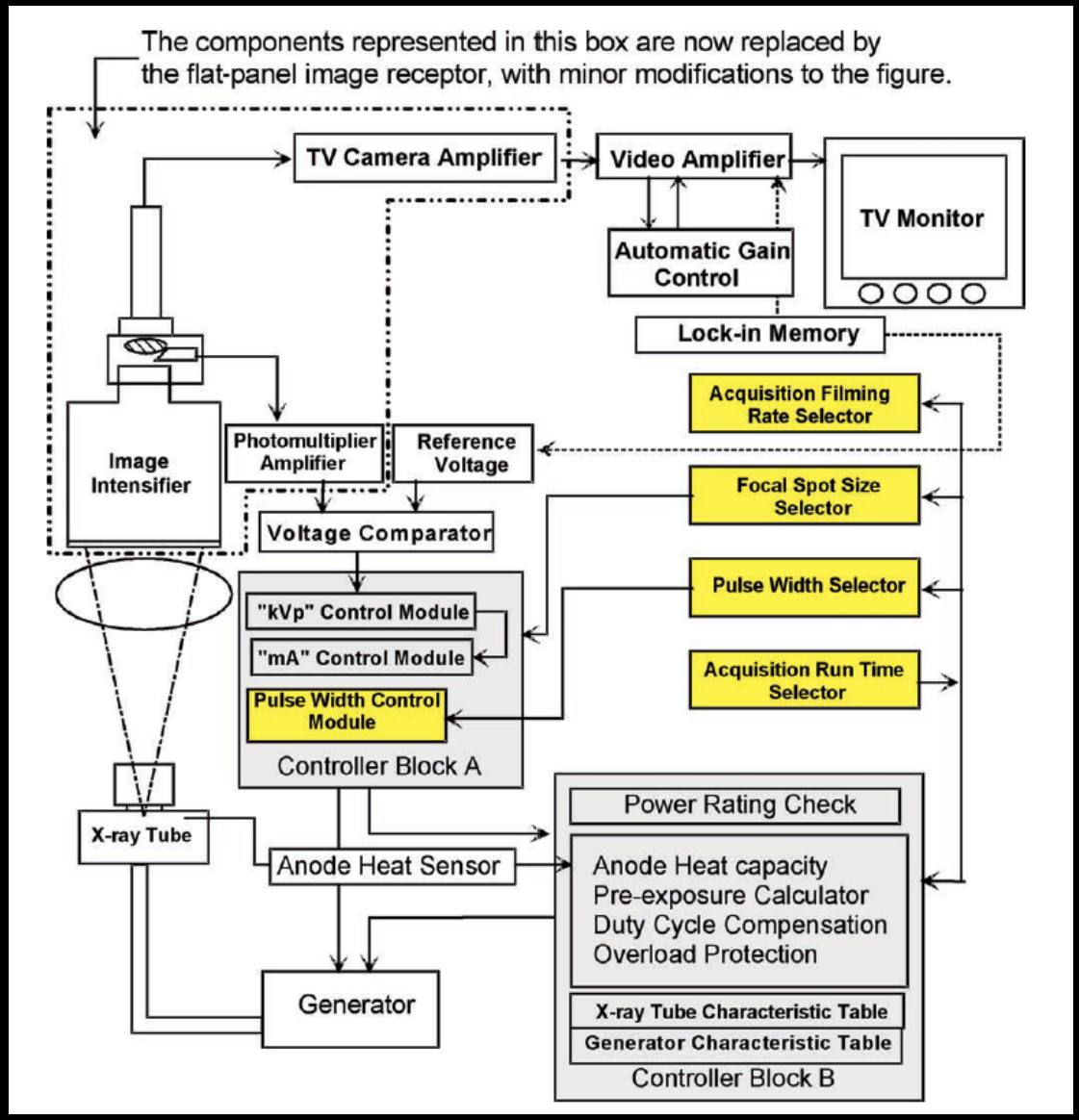
GI bleeder

- Bleeding from the GI tract or kidneys can be life threating if not treated
- Catheter based interventions are preferred to laparotomy
- Small guidewires and catheters are used to minimize risk of bowel infarct
- Must see guidewire and small amounts of contrast agent in a background of peristaltic motion



Contrast to noise ratio

- What affects contrast in fluoroscopy?
  - Beam quality (kV + filtration)
  - Contrast agent
    - Volume, type, rate
  - Recursive filtering
  - Image processing



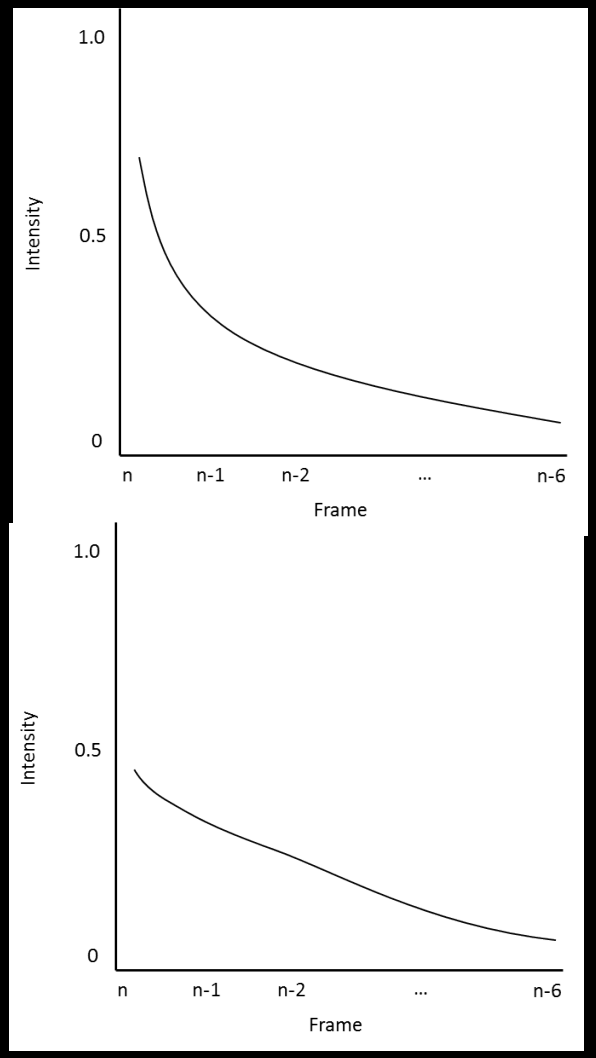
Report of AAPM TG 125, 2012

Parameters are no longer linked

PMMA (in.)	Norm. FLU	ACQ 2	ACQ 4	DSA 2	DSA 4
6	1.0	75.0	75.9	148.1	143.4
7	2.0	82.5	77.3	111.6	122.8
8	3.0	78.1	90.9	136.3	107.5
9	7.0	65.6	47.3	76.6	81.0
10	11.5	48.3	51.4	95.9	103.0
11	17.0	60.8	71.1	69.0	78.6
12	21.0	56.5	64.1	108.8	69.9
13	26.5	87.1	55.6	98.3	55.6
14	32.5	78.5	46.0	92.5	47.4

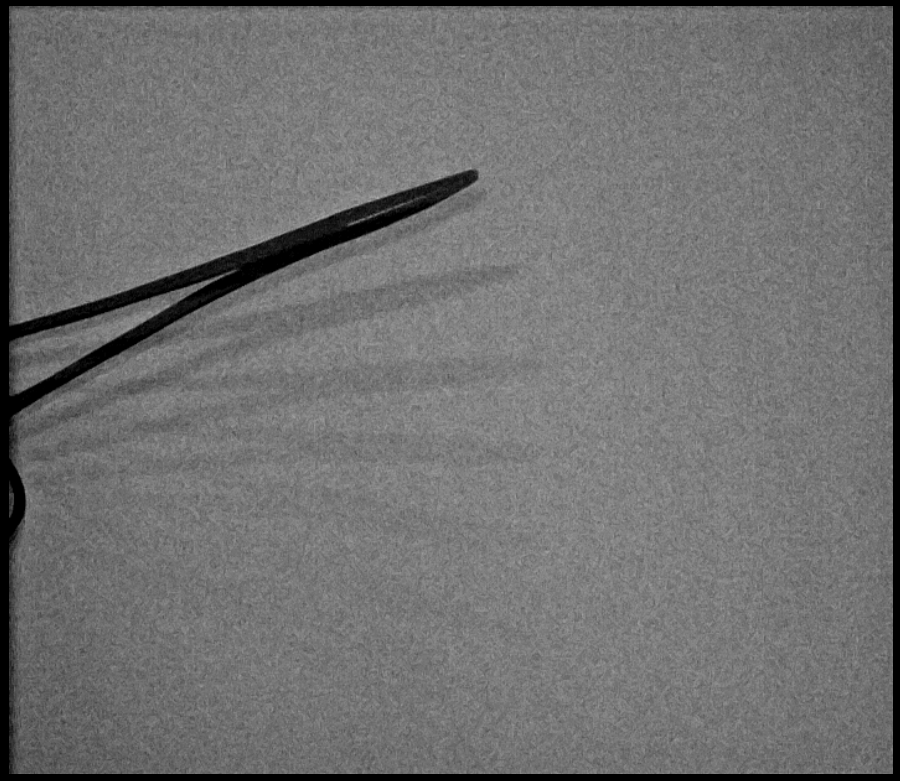
Recursive filtering

- A moving weighted sum of fluoroscopic frames
- Multiple realizations of electronic and quantum noise results in a reduced noise level in the displayed image
  - Many variations – e.g., Auto, Manual, strength parameters
- However, image noise is not the only thing that changes
  - Artificial lag
  - Reduced contrast



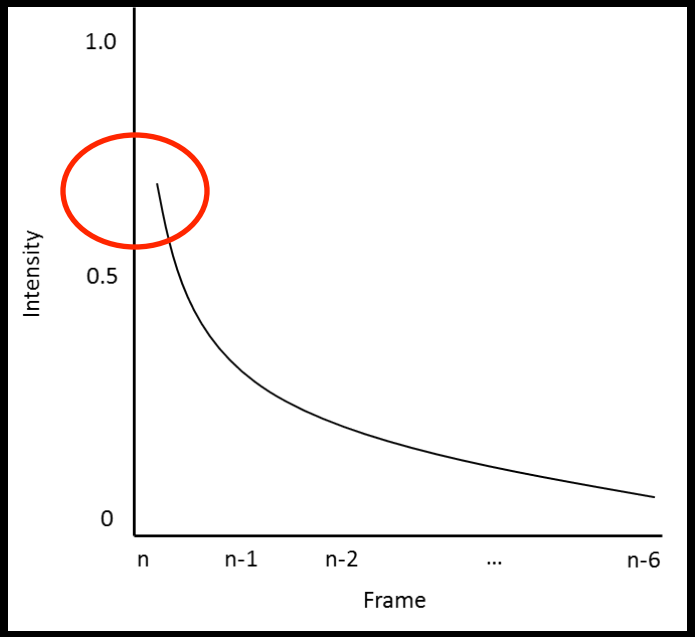
Artificial lag

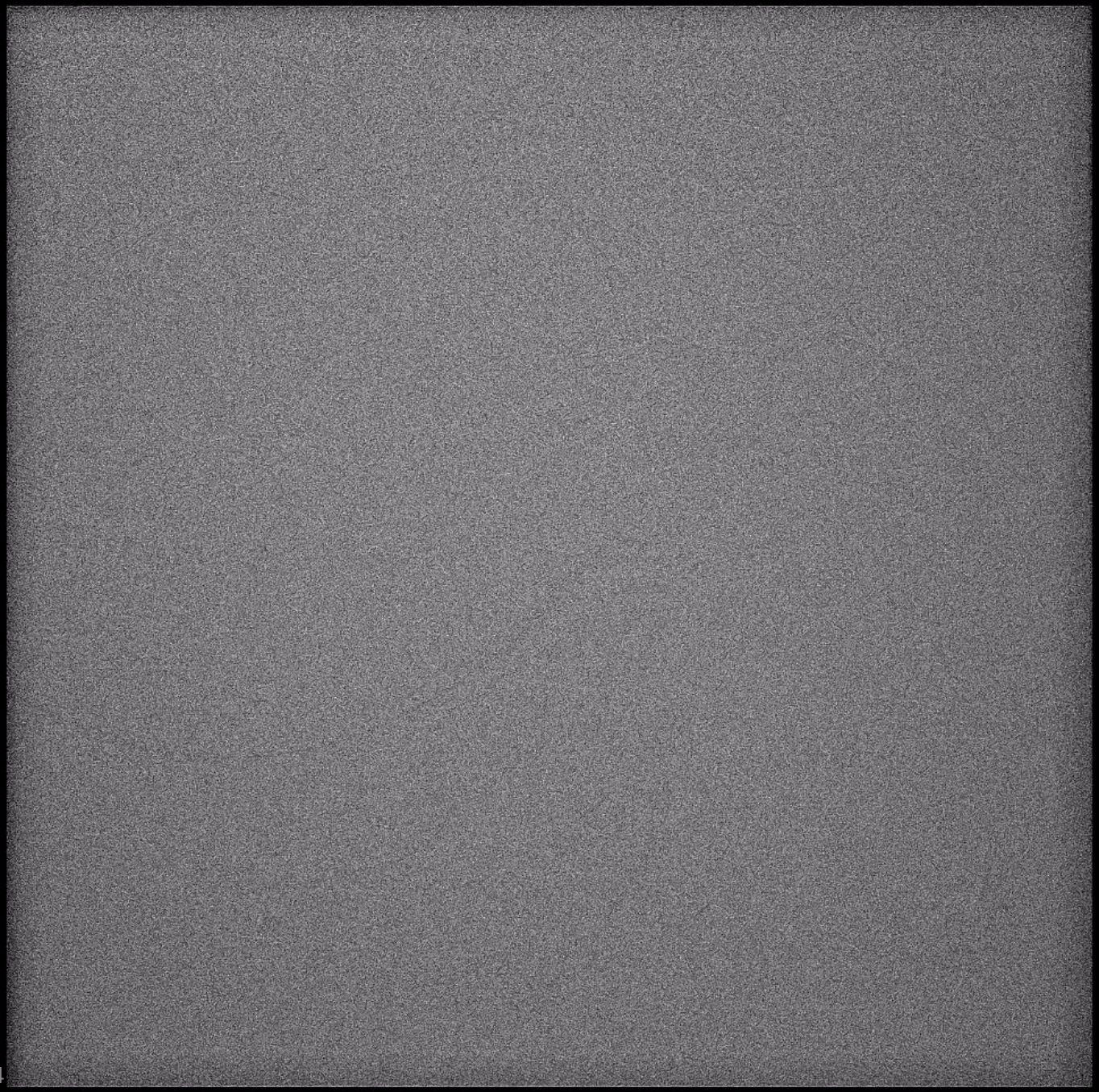
- Recursive filtering can introduce *artificial lag* into images with substantial motion
- The source of the residual signal seen in the image to the right is not the image receptor, but information from previous pulses
- The severity of artificial lag depends on several factors
  - Pulse rate
  - Speed of motion
  - Strength of recursive filter

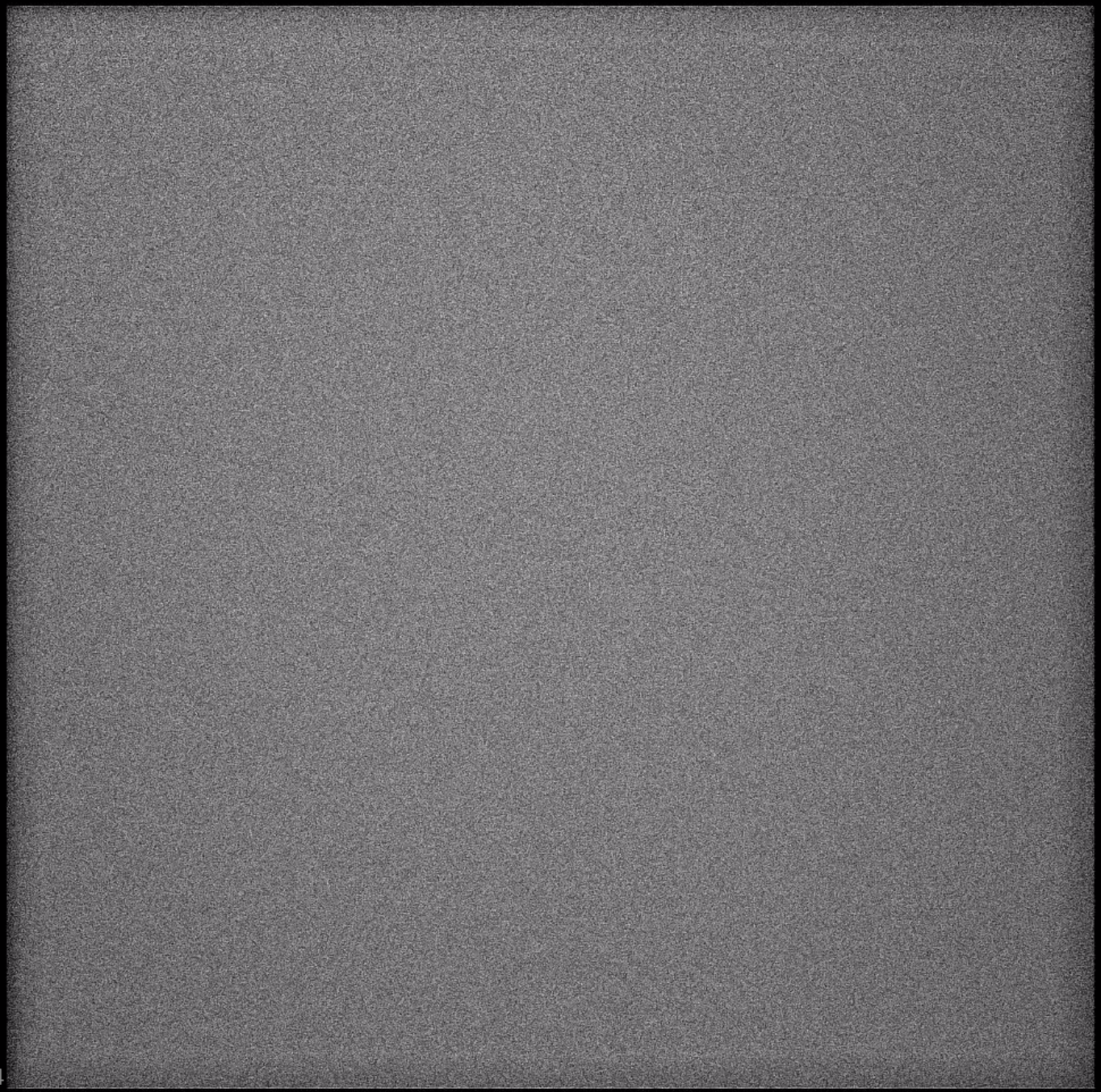


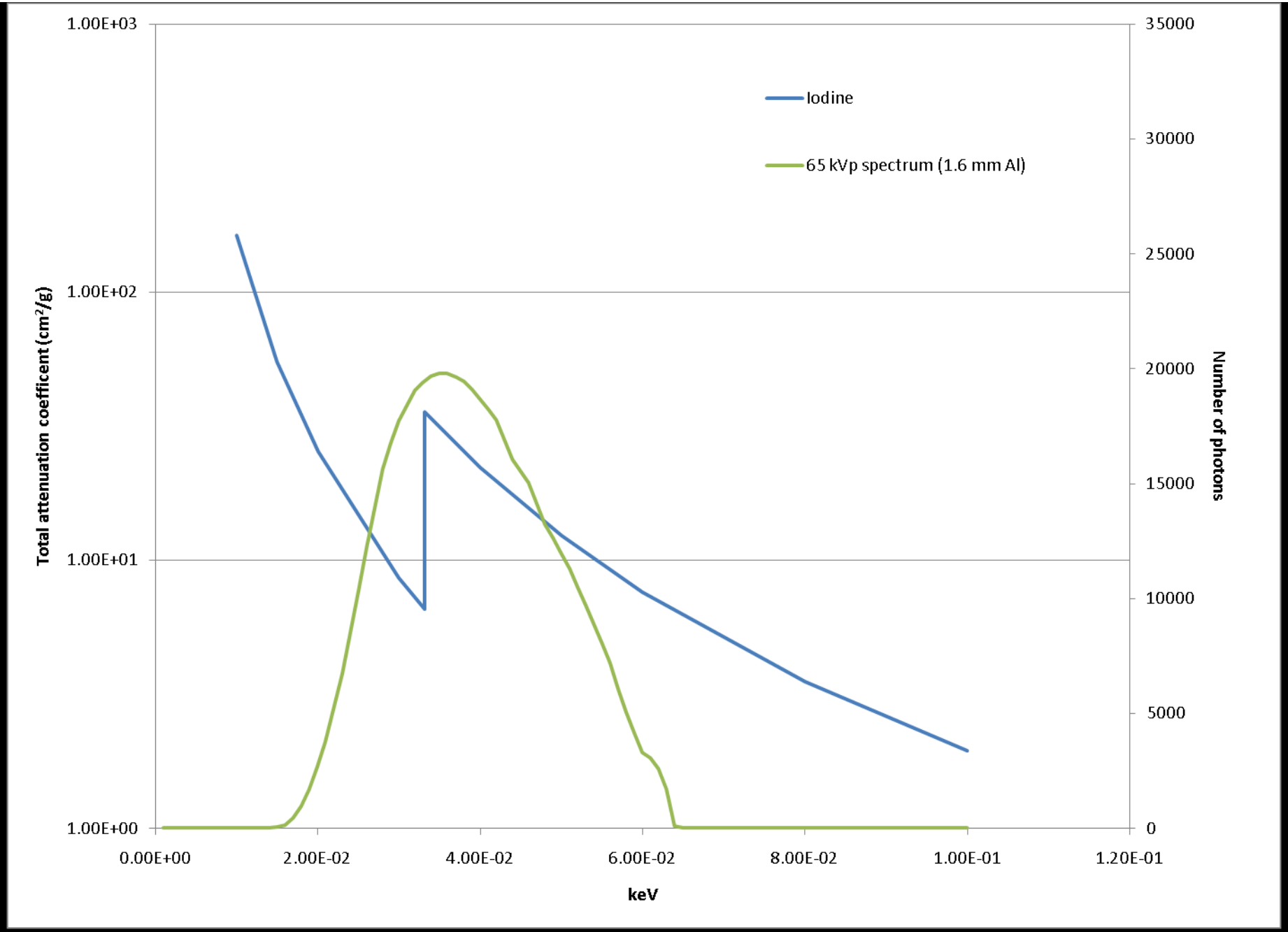
Contrast and recursive filtering

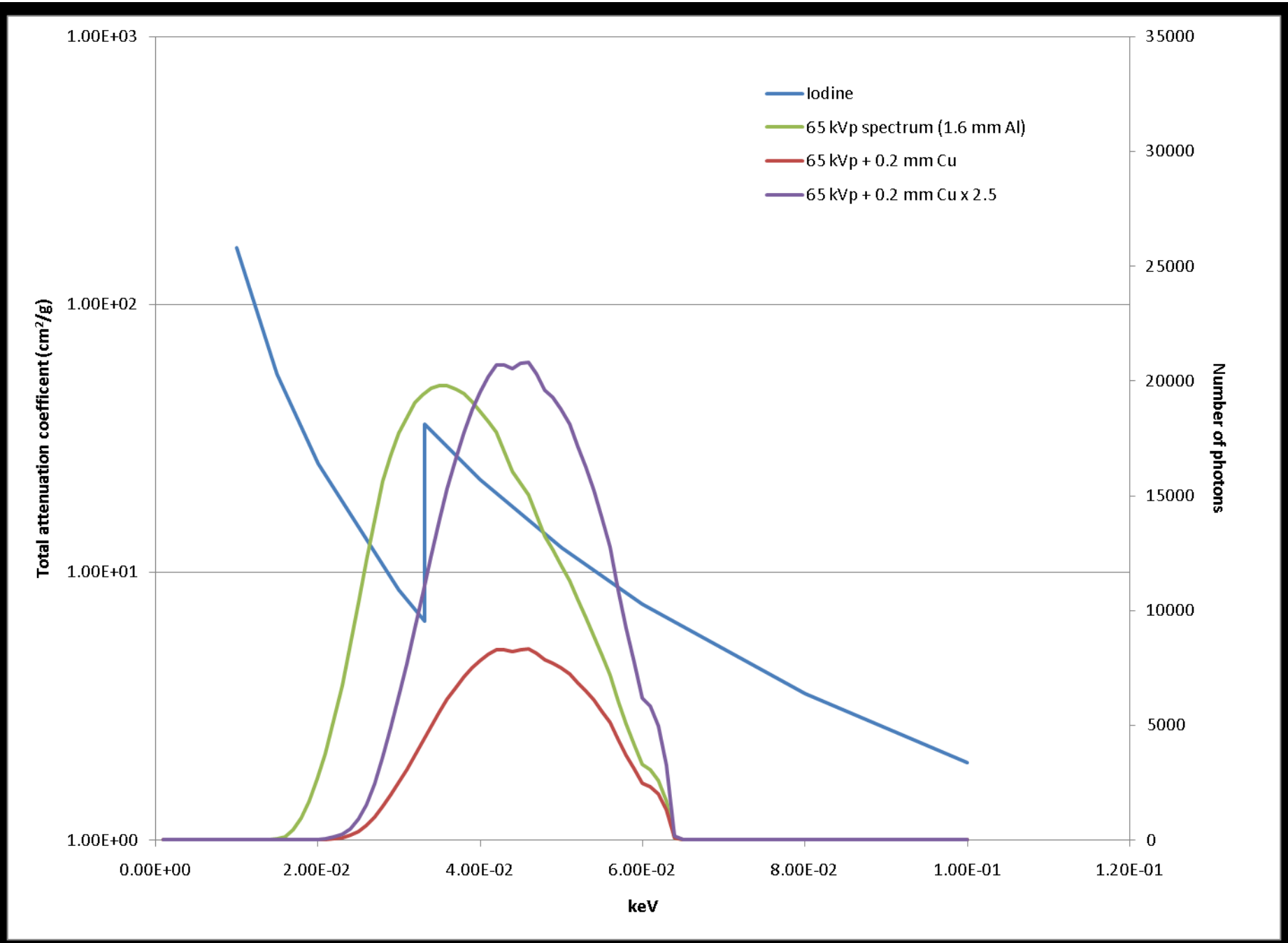
- Most of us understand artificial lag
- However, what we often overlook is the impact of recursive filtering on contrast
- Let's look at some movies of a 0.025" guidewire





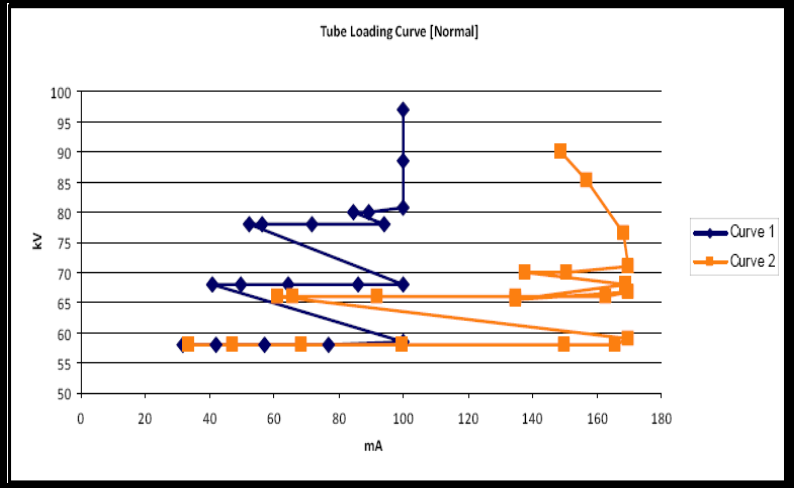


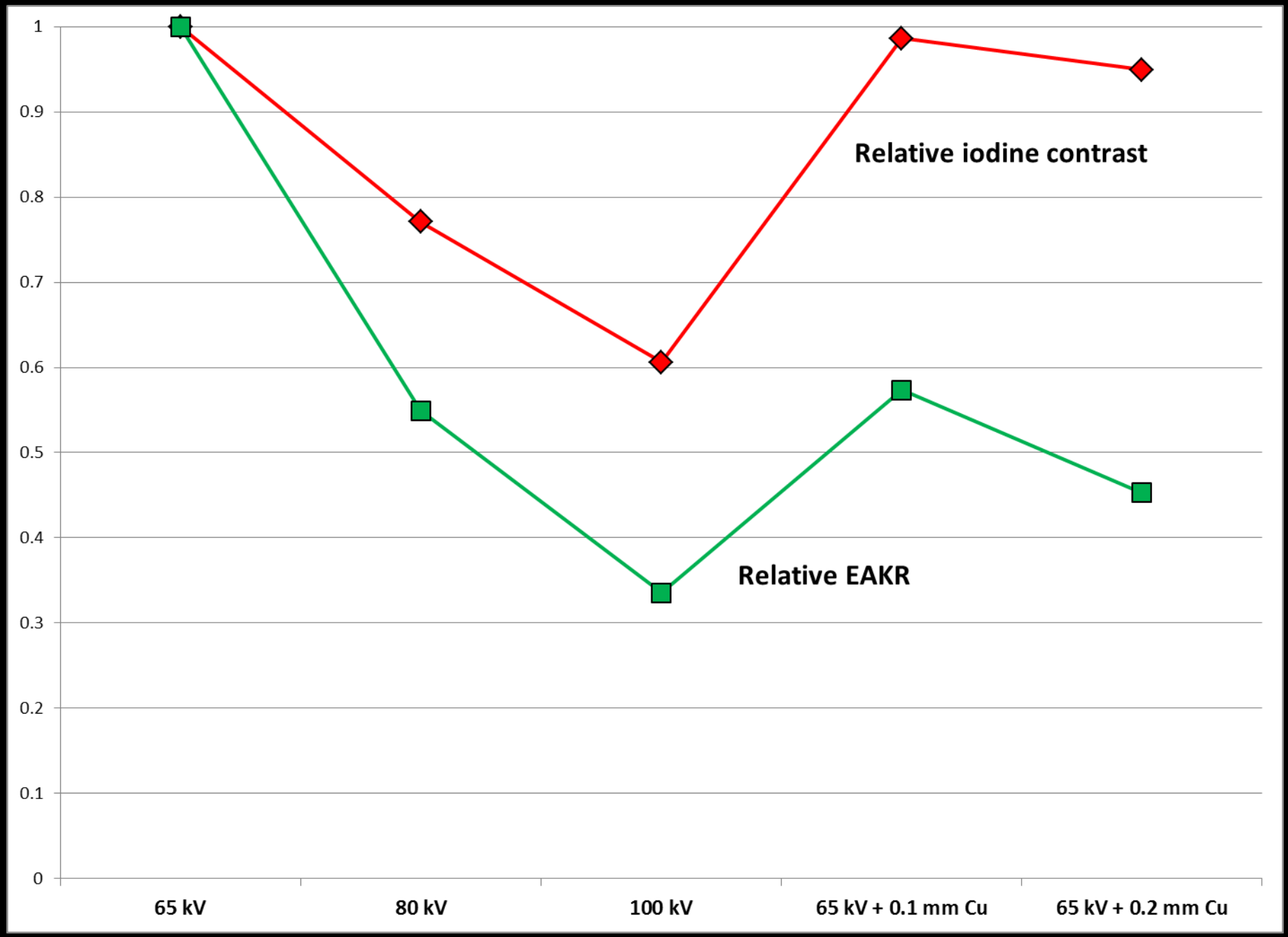

1.00E+03
1.00E+02
1.00E+01
1.00E+00
35000
30000
25000
20000
15000
10000
5000
0
Total attenuation coefficent (cm²/g)
Number of photons
Iodine
65 kVp spectrum (1.6 mm Al)
0.00E+00
2.00E-02
4.00E-02
6.00E-02
8.00E-02
1.00E-01
1.20E-01
keV


1.00E+03
1.00E+02
1.00E+01
1.00E+00
35000
30000
25000
20000
15000
10000
5000
0
0.00E+00
2.00E-02
4.00E-02
6.00E-02
8.00E-02
1.00E-01
1.20E-01
keV
Total attenuation coefficent (cm²/g)
Number of photons
Iodine
65 kVp spectrum (1.6 mm Al)
65 kVp + 0.2 mm Cu
65 kVp + 0.2 mm Cu x 2.5

Contrast and beam quality

- Iodine contrast is strongly affected by beam quality
- The addition of filtration allows the use of low kV while maintaining dose at an acceptable level
  - Traditional, Program-Switched
- Sacrifices may need to be made to maintain kV at desired level
  - E.g., focal spot

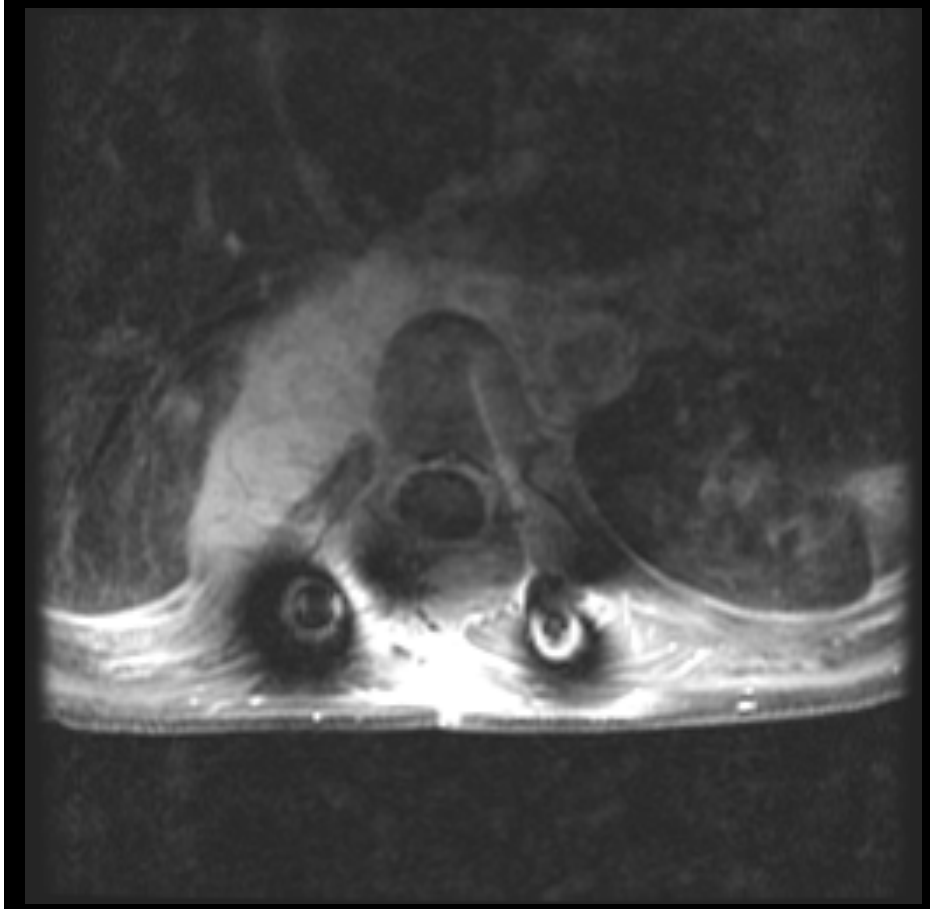


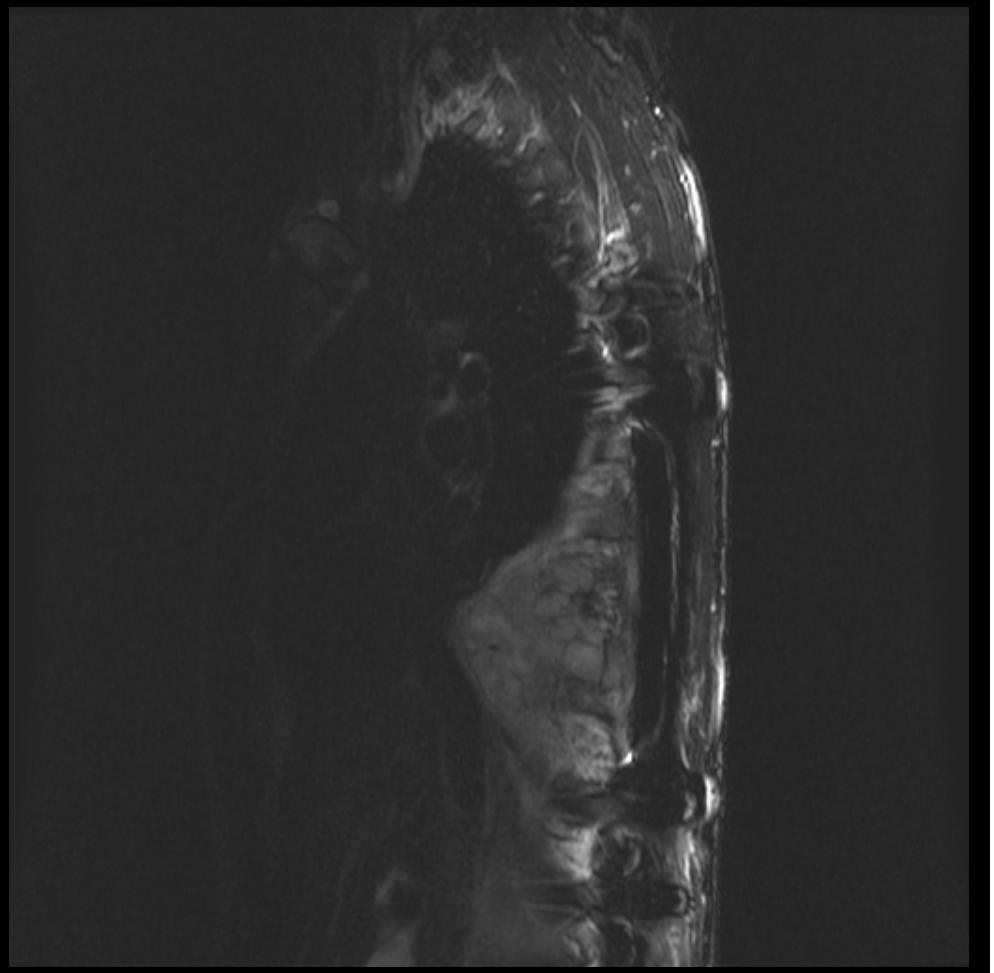

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative iodine contrast
Relative EAKR
65 kV
80 kV
100 kV
65 kV + 0.1 mm Cu
65 kV + 0.2 mm Cu

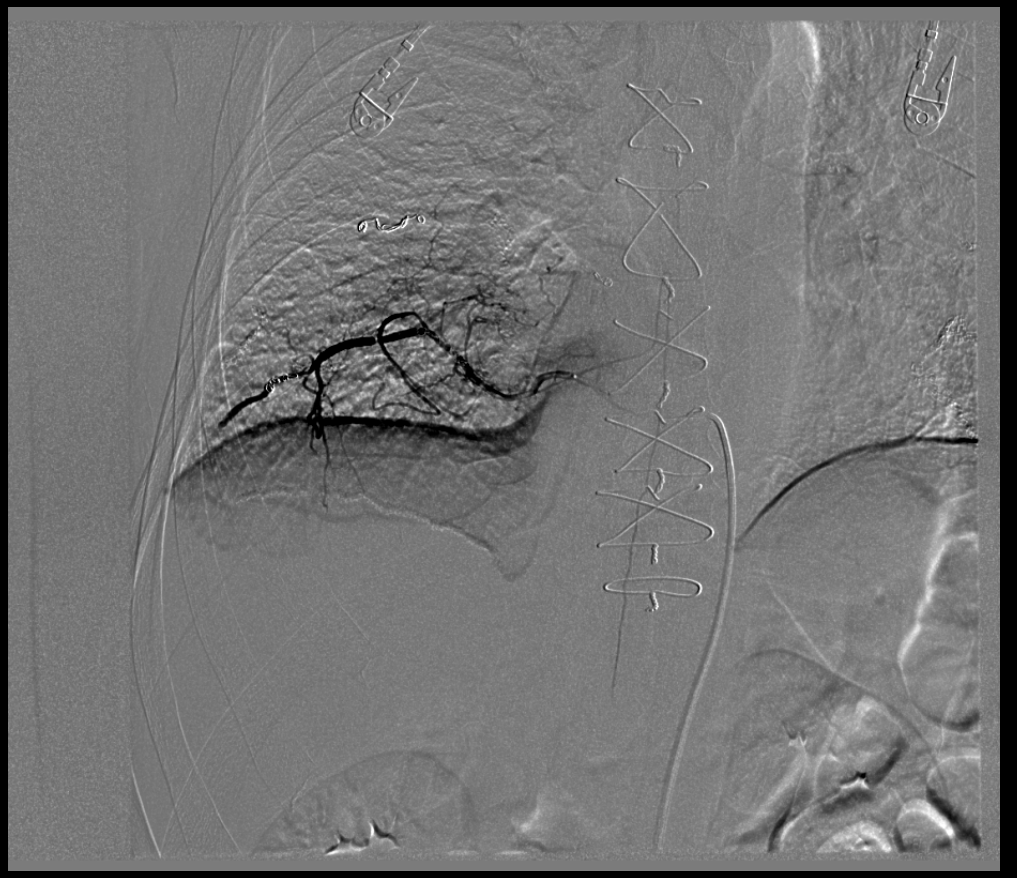
CASE 3

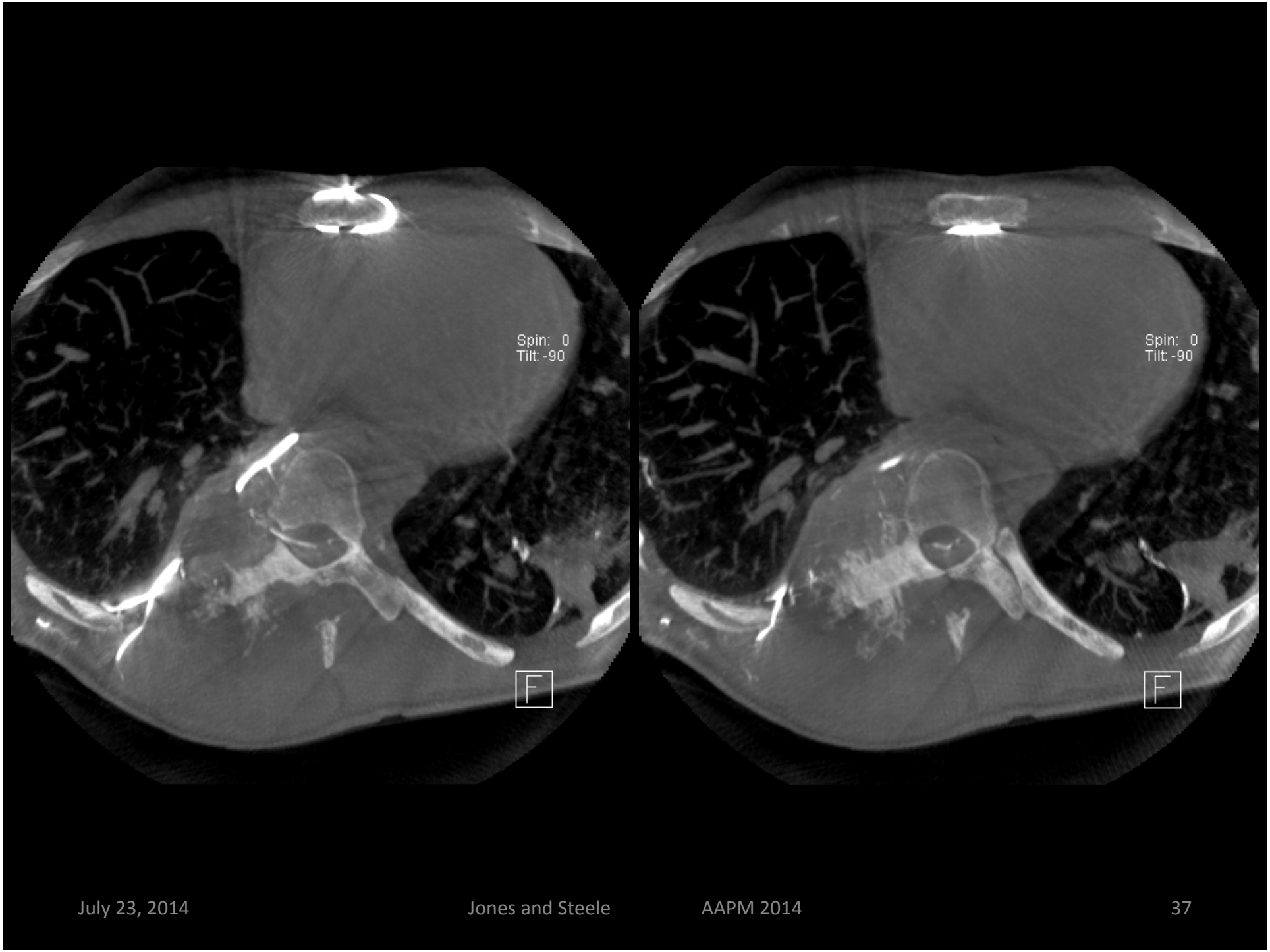
Spinal embolization

- Metastatic or primary tumors of the spine can cause many symptoms, including instability, pain, and symptoms related to compression of the spinal cord
- Many metastatic tumors, including RCC, are hypervascular
- Pre-surgical embolization has been proven to reduce blood loss when tumor is hypervascular
- Non-target embolization can result in permanent paralysis

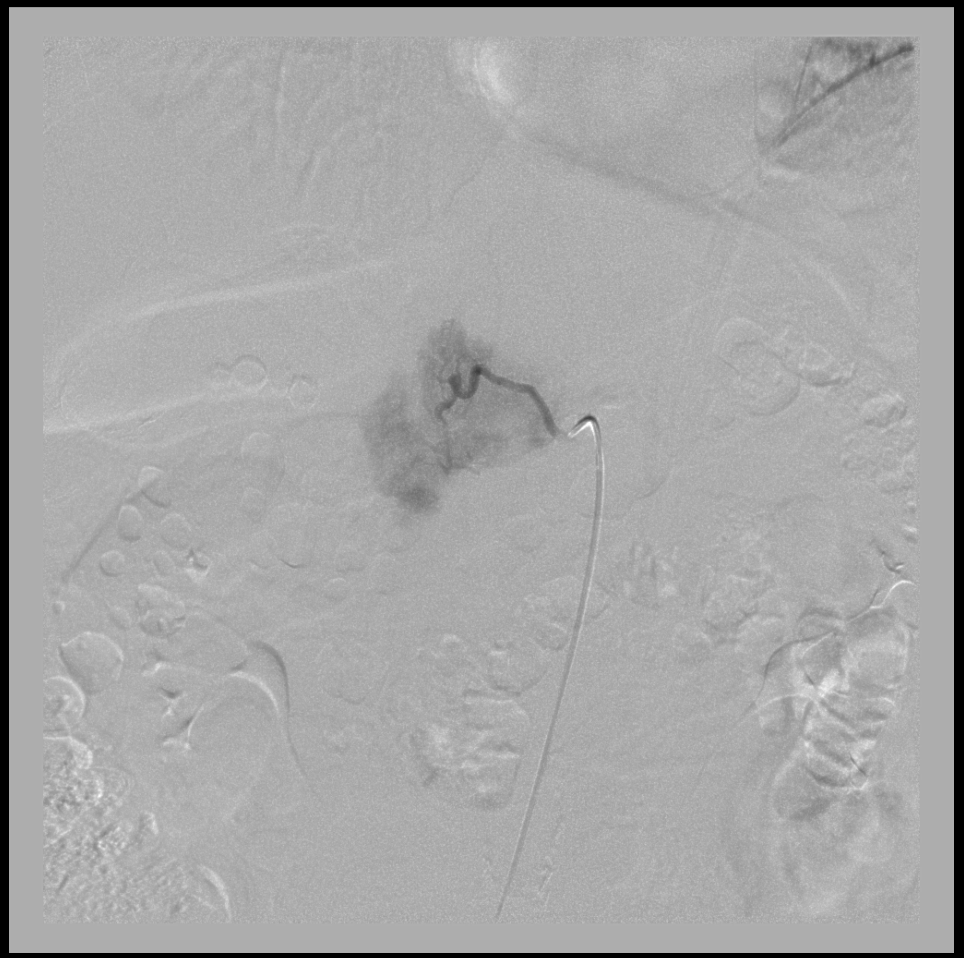


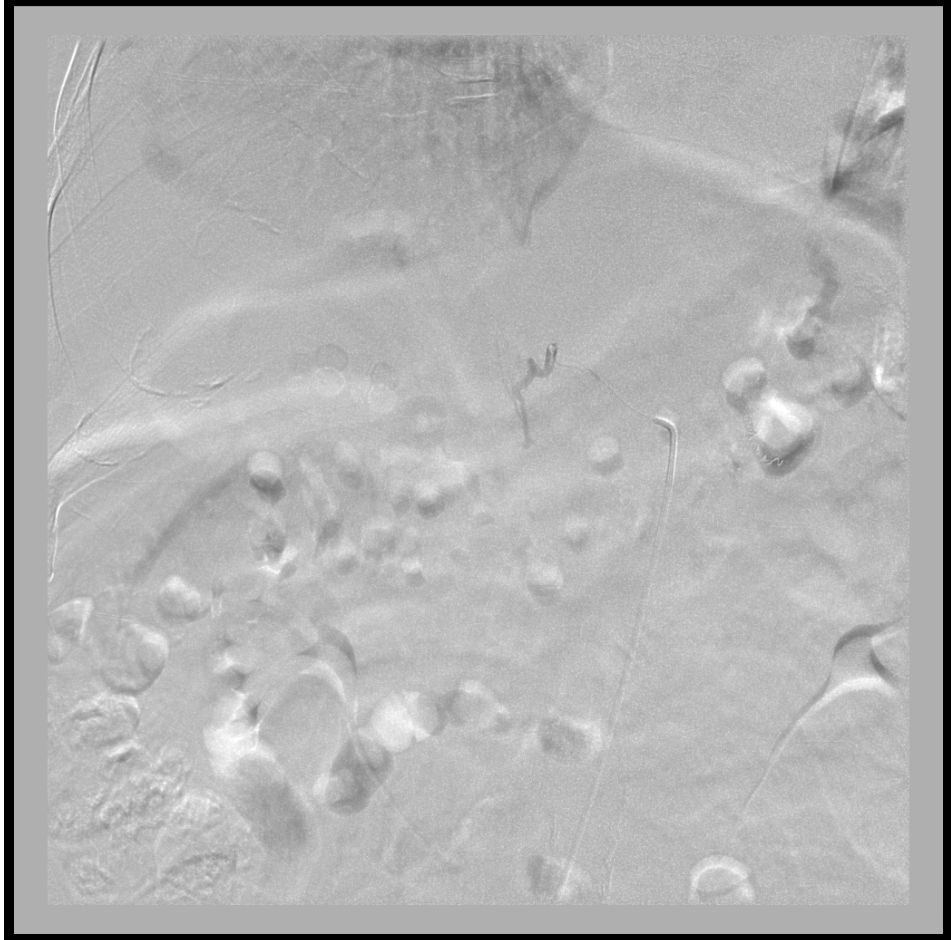


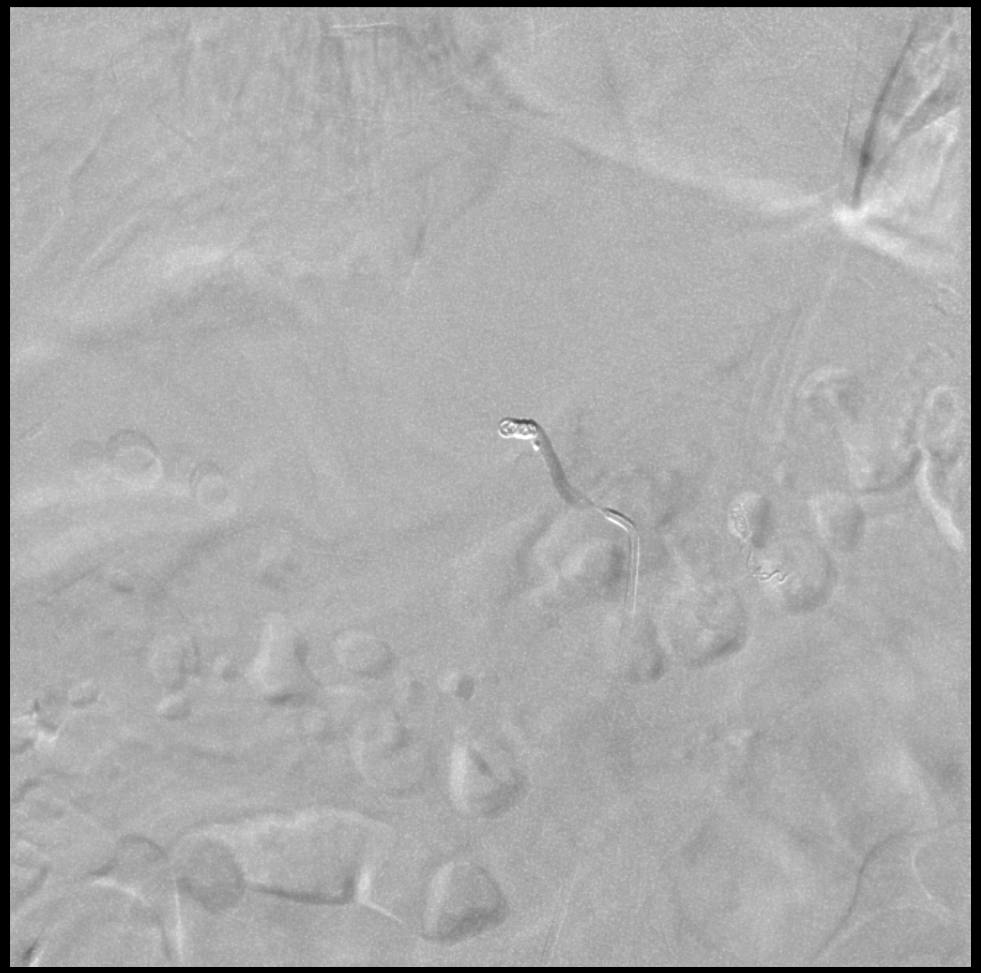



Spin: 0
Tilt: -90
F
Spin: 0
Tilt: -90
F


Spin: -0
Tilt: 0
A







Peak CNR is critical

- Beam quality
  - Favor SFS or LFS to maintain low kV
  - Siemens Artis zee: SFS = 70 kVp, MFS = 90 kVp
  - Keep in mind that higher frame rates and longer scene times will increase kV
- Maximum opacification of vessels
  - Flow rate ↑ closer to the heart
  - Frame rate must be adequate to capture this
- Noise is also an important factor

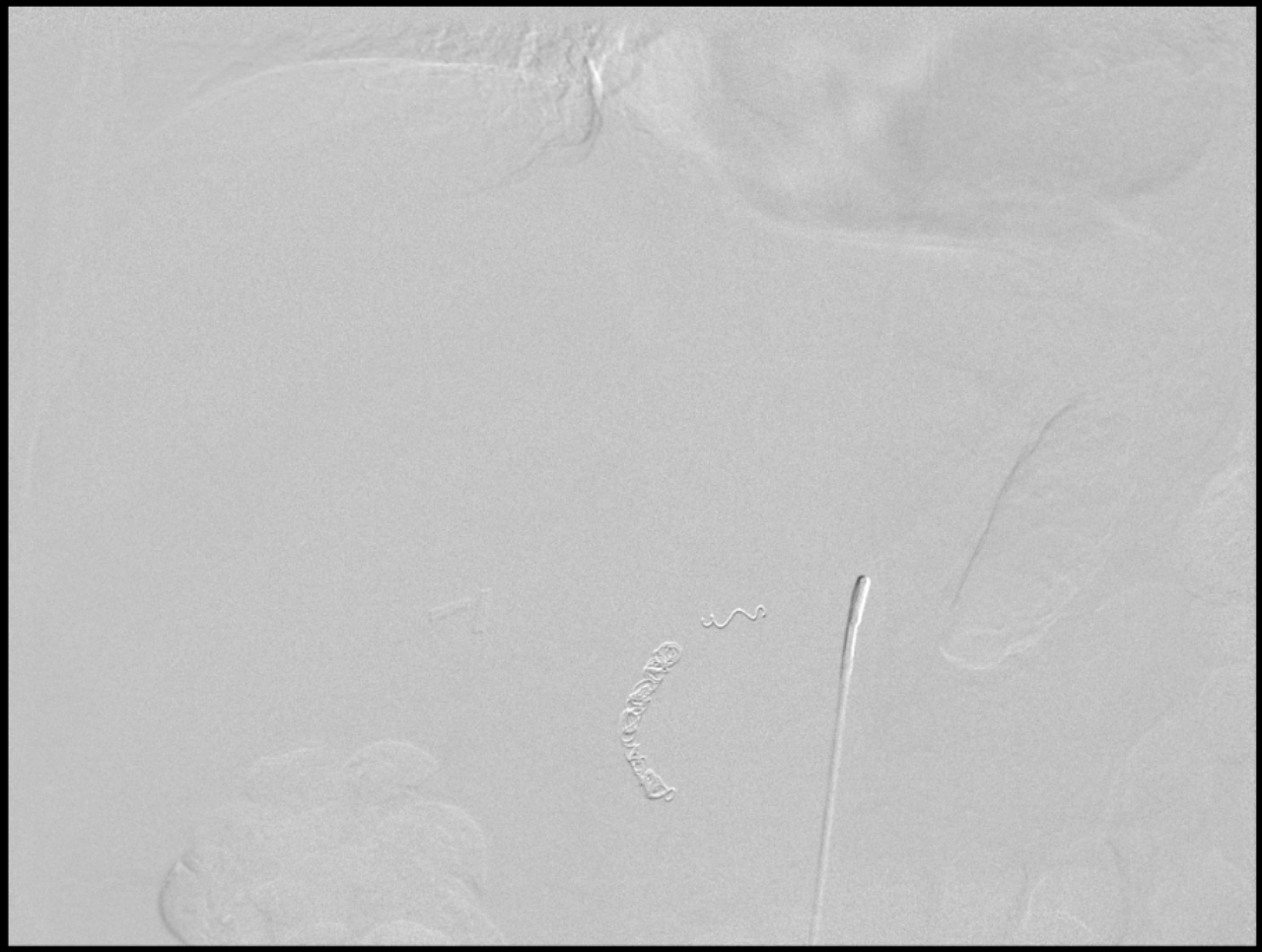
Scene time and kVp

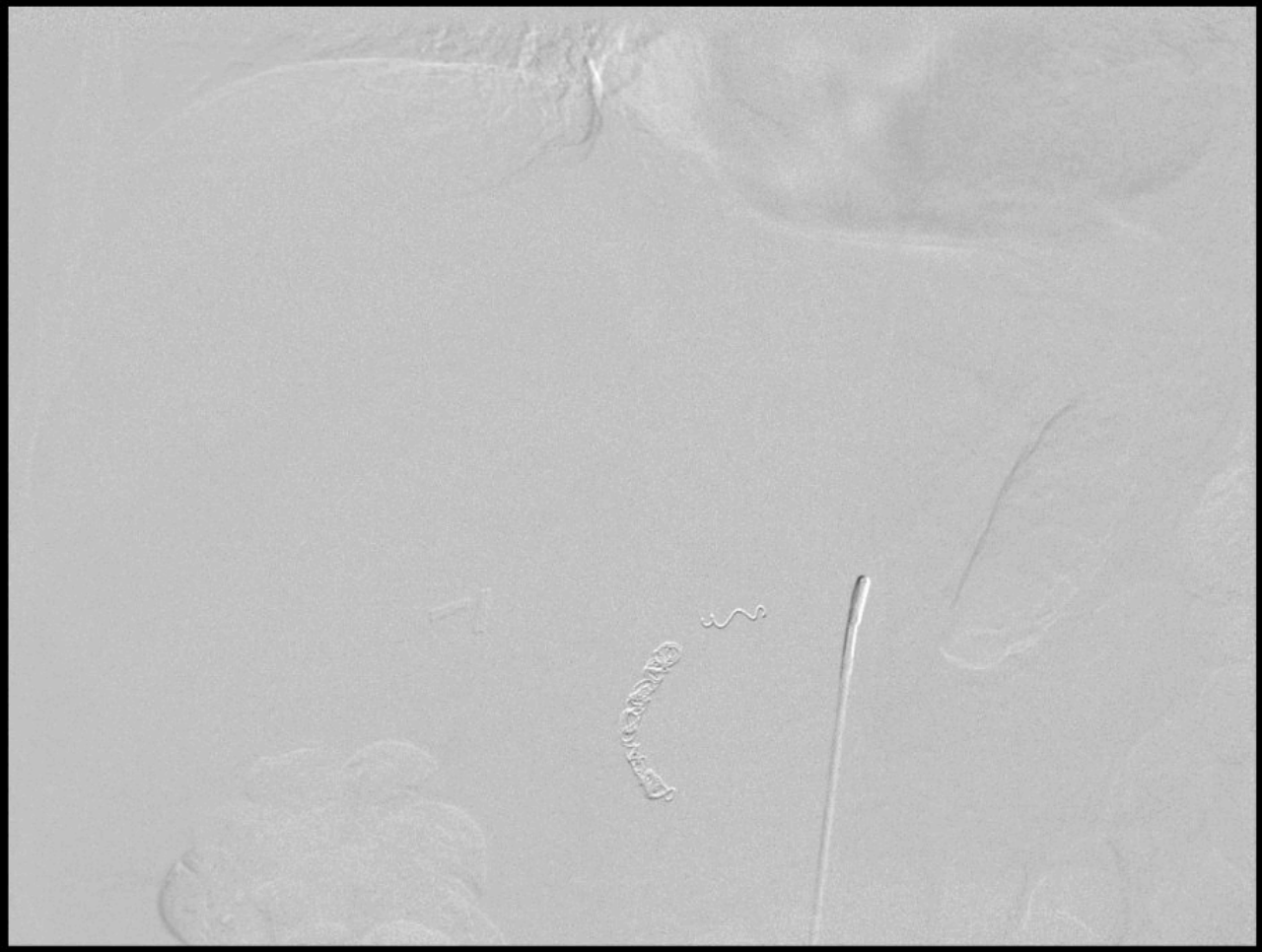
pulse width in ms x framerate in s^{-1}	Series duration (IEC 60613:1989)													
	1 s	2 s	4 s	6 s	10 s	16 s	20 s	25 s	40 s	63 s	100 s	120 s	600 s	pulse power in kW
50	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	14.0	
100	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.7	15.4	15.3	15.2	15.1	14.0	
150	15.4	15.3	15.2	15.1	15.0	14.8	14.8	14.7	14.2	14.0	13.6	13.4	12.5	
200	15.1	15.0	14.7	14.6	14.3	14.0	13.9	13.8	13.3	12.9	12.3	12.2	11.0	
250	14.9	14.7	14.3	14.1	13.7	13.4	13.2	13.0	12.5	12.1	11.4	11.2	9.0	
300	14.6	14.3	13.8	13.5	13.0	12.7	12.4	12.2	11.6	11.1	10.4	10.2	7.5	
350	14.4	14.1	13.5	13.2	12.5	12.2	11.9	11.7	11.0	10.5	9.6	9.2	7.0	
400	14.3	13.9	13.1	12.7	12.0	11.6	11.3	11.1	10.4	9.9	9.0	8.6	7.0	
450	14.2	13.7	12.7	12.2	11.2	11.2	10.8	10.6	9.9	9.3	8.4	8.1	6.0	
500	14.0	13.4	12.3	11.9	11.2	10.7	10.3	10.1	9.3	8.8	7.9	7.6	5.2	
550	13.8	13.2	12.0	11.6	10.9	10.3	10.0	9.7	8.9	8.4	7.5	7.2	4.5	
600	13.5	12.9	11.7	11.3	10.6	9.9	9.6	9.3	8.5	7.9	7.0	6.7	4.0	
650	13.4	12.8	11.5	11.1	10.3	9.5	9.3	9.0	8.2	7.6	6.7	6.3	3.5	
700	13.3	12.6	11.3	10.8	9.9	9.1	9.0	8.7	7.8	7.2	6.3	5.9	3.2	
750	13.2	12.5	11.1	10.6	9.7	8.8	8.7	8.4	7.5	7.0	6.1	5.7	3.0	
800	13.1	12.4	10.9	10.4	9.5	8.5	8.4	8.1	7.2	6.7	5.9	5.5	2.8	
1000	12.6	12.2	10.2	9.9	8.4	8.0	7.5	7.0	6.4	5.7	4.9	4.5	2.5	

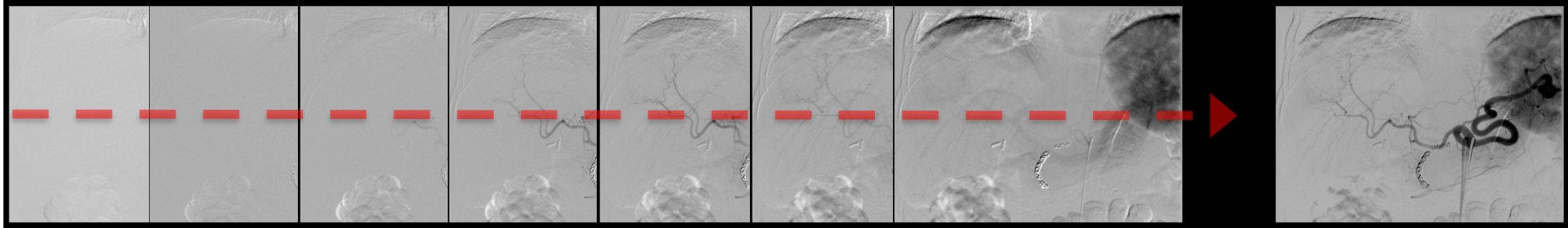
pulse width in ms x framerate in s^{-1}	Series duration (IEC 60613:1989)													
	1 s	2 s	4 s	6 s	10 s	16 s	20 s	25 s	40 s	63 s	100 s	120 s	600 s	pulse power in kW
50	34.5	34.5	34.4	34.3	34.2	32.5	32.4	32.3	32.0	31.7	31.1	30.6	27.8	
100	32.8	32.7	32.6	32.5	32.4	32.0	31.1	30.9	30.3	29.6	28.4	27.9	23.7	
150	31.5	31.1	30.4	30.1	29.4	28.8	28.4	28.0	26.9	25.9	24.4	23.7	20.0	
200	30.3	29.6	28.2	27.7	26.8	25.8	25.3	24.8	23.6	22.5	20.6	19.9	14.6	
250	29.0	28.1	26.2	25.6	24.3	24.1	23.5	22.9	21.4	20.2	18.2	17.4	12.0	
300	27.9	26.8	24.5	23.7	22.1	22.0	21.5	20.7	19.2	17.9	15.9	15.2	10.0	
350	26.9	25.8	23.5	22.6	20.7	20.1	19.3	18.6	17.0	15.8	13.8	12.8	8.6	
400	26.0	24.8	22.5	21.5	19.4	18.3	17.5	16.7	15.1	13.9	11.9	11.2	7.5	
450	25.4	24.2	21.7	20.6	18.3	17.0	16.2	15.4	13.7	12.5	10.6	9.5	6.8	
500	24.7	23.4	20.8	19.6	17.1	15.7	14.8	14.0	12.3	11.2	9.3	7.7	6.0	
550	24.2	22.8	20.0	18.7	16.2	14.7	13.9	13.2	11.6	10.4	8.5	7.2	5.5	
600	23.6	22.1	19.2	17.9	15.2	13.7	12.9	12.4	10.8	9.6	7.7	6.6	5.0	
650	23.2	21.5	18.2	16.8	14.1	13.0	12.4	11.7	10.1	8.9	7.0	6.1	4.6	
700	22.7	20.8	17.1	15.7	13.0	12.3	11.8	11.0	9.3	8.2	6.3	5.5	4.3	
750	22.3	20.2	16.1	14.8	12.2	11.6	11.1	10.4	8.8	7.7	5.8	5.0	4.0	
800	21.9	19.6	15.1	13.8	11.3	10.9	10.3	9.8	8.2	7.1	5.2	4.5	3.8	
1000	20.0	17.6	13.3	12.2	10.0	9.7	9.3	8.7	7.3	6.3	4.7	4.1	3.3	

Max opacification

- Max (or peak) opacification is a temporal MIP
- The MaxOpac image is formed by updating each pixel in the image with the minimum (or maximum) pixel value in each new frame as the run is stepped through
- Reduces problems with washout
- Motion can be a problem







Reducing image noise

- Recursive filtering
  - Potential negative impact on contrast
- Higher dose per frame
  - Already a high dose procedure
- Image processing

Mask averaging

- We know that noise adds in quadrature when we perform image subtraction
- We also know that frame averaging or recursive filtering reduces image noise

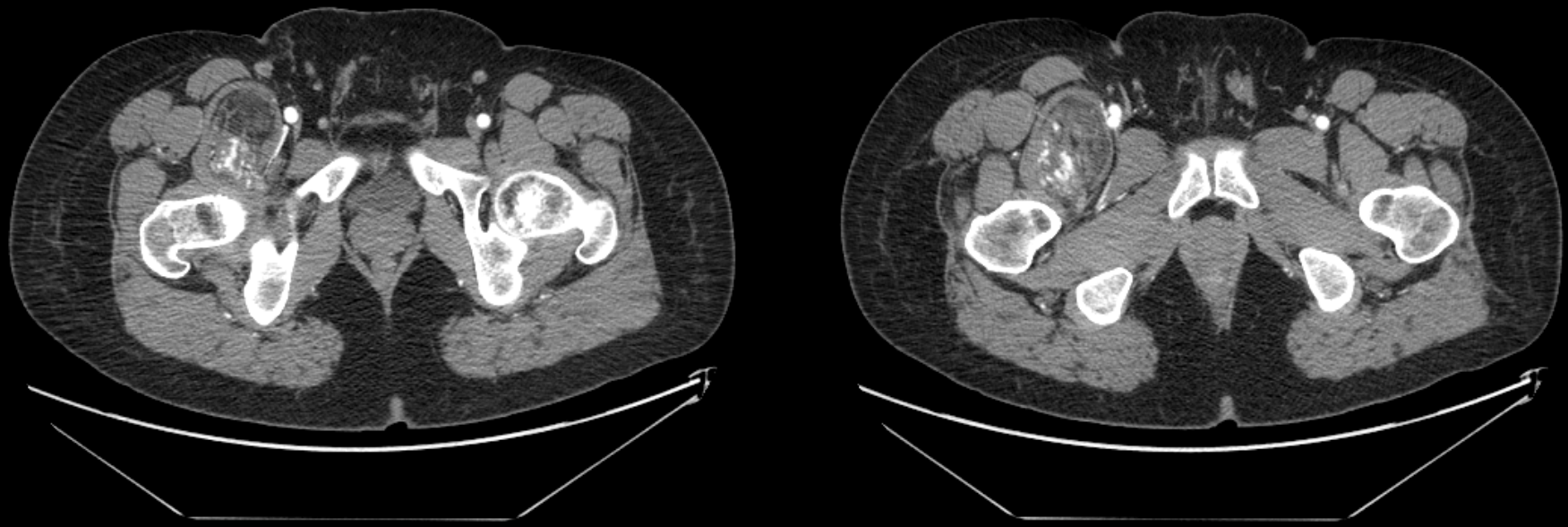
3.6 uGy/fr

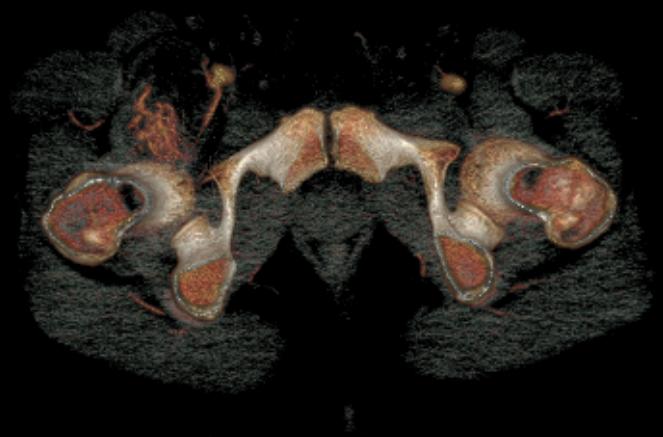
2.4 uGy/fr

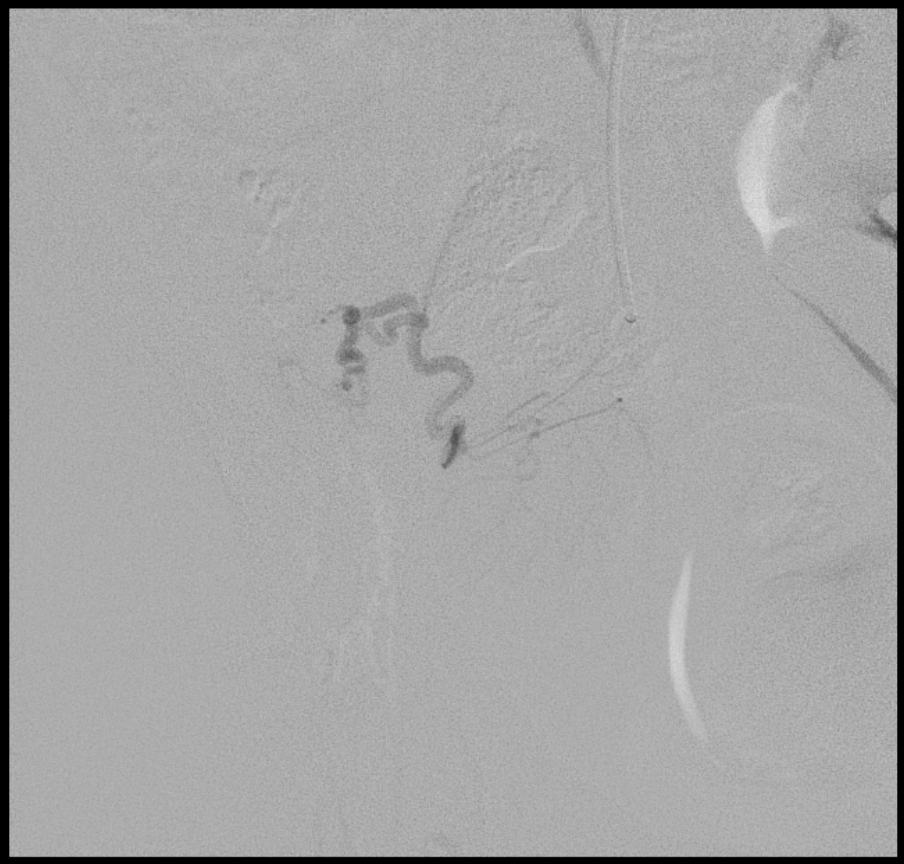
CASE 4

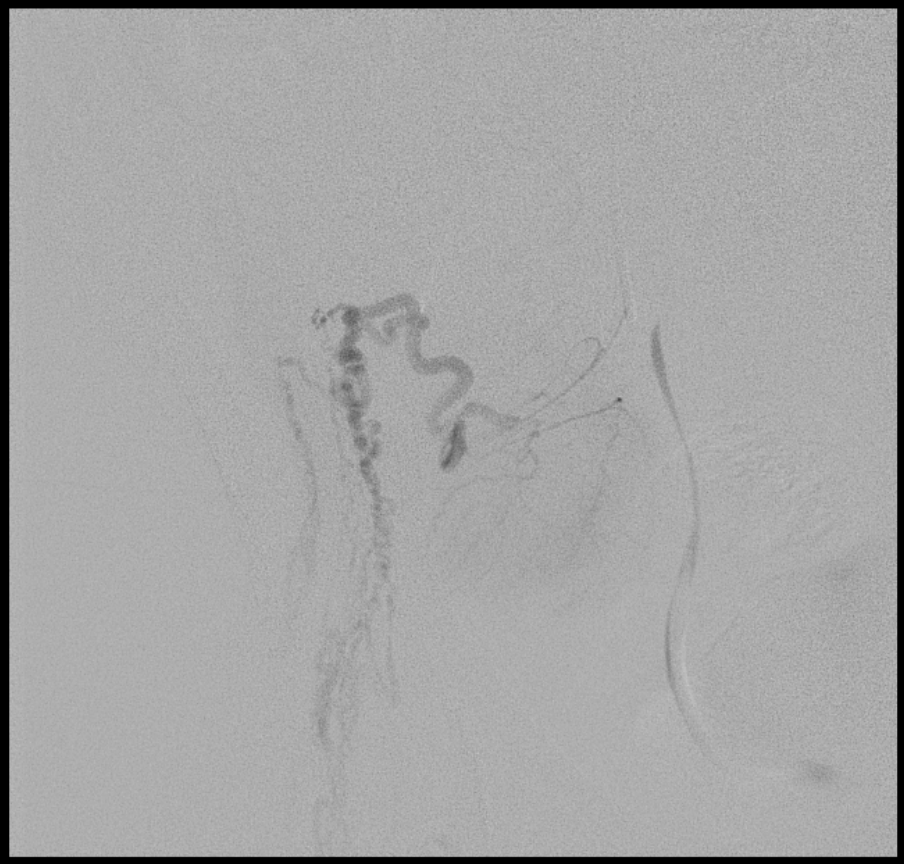
Management of high dose cases

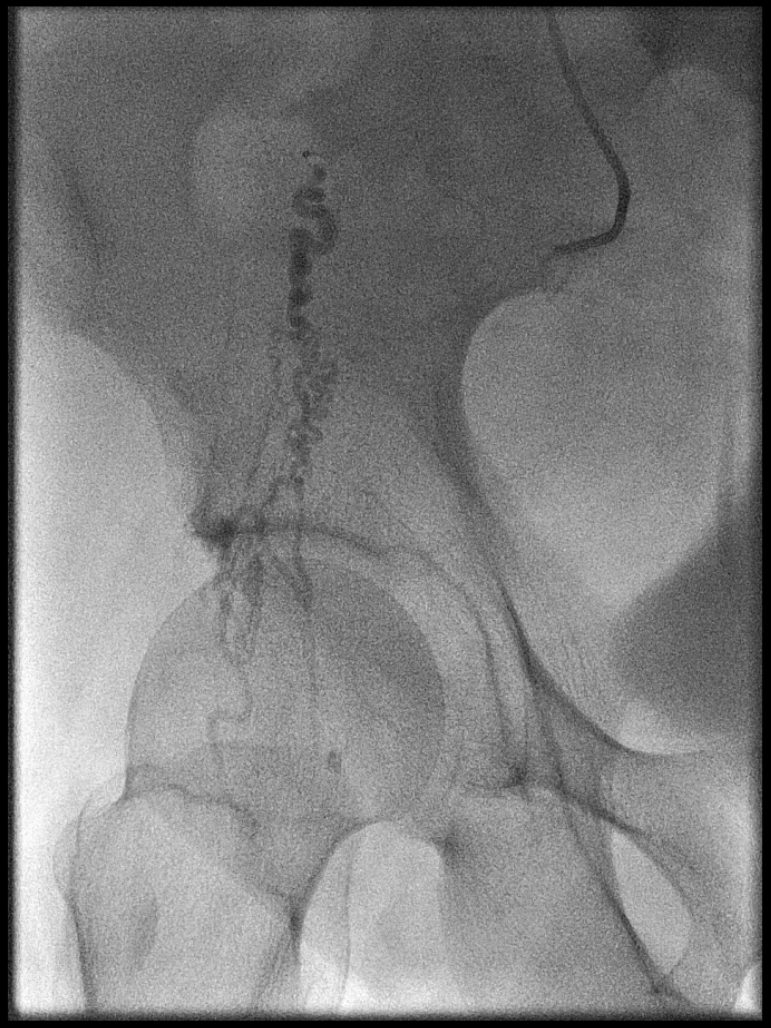
- The true complexity of a case is often unknown until the first angiogram is performed
- Decisions must be made to continue treatment or stop based on pace of procedure
  - Radiation dose, contrast dose

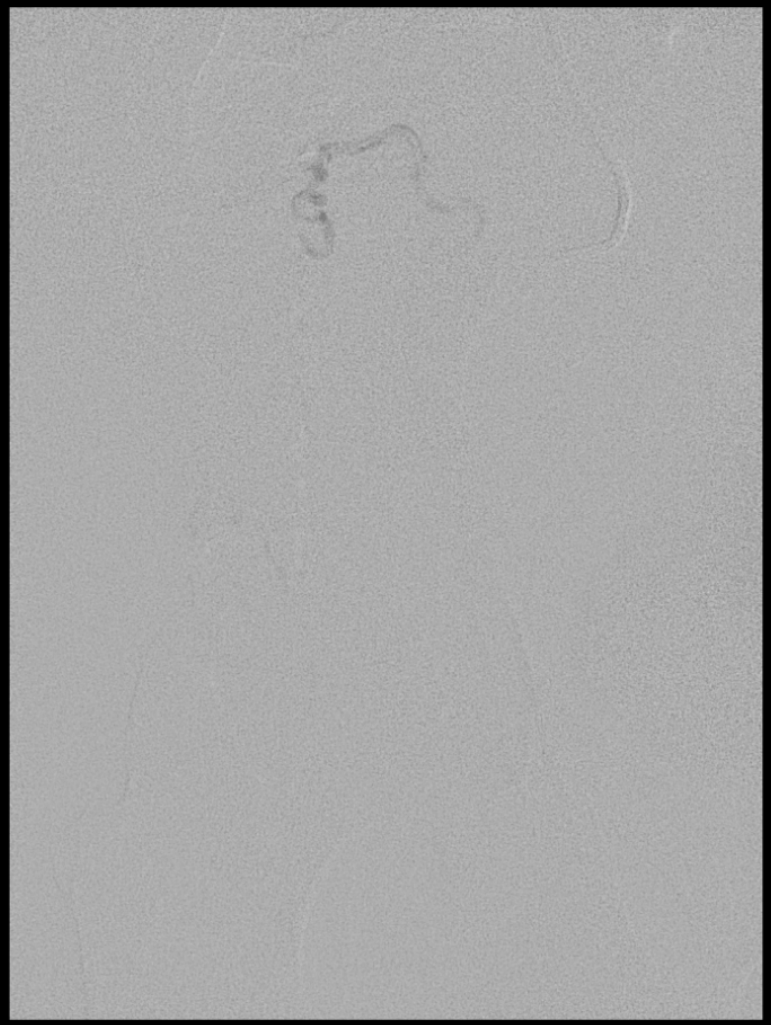












Three-pronged safety program

- Pre-procedure actions
- Intra-procedure actions
- Post-procedure actions

RadioGraphics

Quality Initiatives

Establishing an Interventional Radiology Patient Radiation Safety Program

Joseph R. Steele, MD • A. Kyle Jones, PhD • Elizabeth P. Ninan, PA-C

ONLINE-ONLY CME

See www.rsna.org/education/rg_cme.html

LEARNING OBJECTIVES

After completing this journal-based CME activity, participants will be able to:

- List the radiation dose descriptors that should be recorded at the conclusion of a fluoroscopy-guided procedure.
- Describe the actions that may be taken during the three phases of a fluoroscopy-guided procedure to enhance patient safety.
- Discuss how to recognize cases that are outside the normal control limits of an interventional radiology practice.

TEACHING POINTS

See last page

The Interventional Radiology Patient Radiation Safety Program was created to better educate patients who are scheduled to undergo high-dose interventional radiologic procedures about the risks of radiation, better monitor the delivered doses, and reduce the risk for deterministic effects. The program combines preprocedure evaluation and counseling, intraprocedure monitoring, and postprocedure documentation and counseling with the guidelines of the National Cancer Institute and the Society of Interventional Radiology. Between July 2009, when the program was implemented, and September 2010, over 3500 interventional radiologic procedures were monitored and documented, and 63 procedures with an adjusted cumulative dose of more than 3 Gy were identified and further analyzed; four procedures were found to be outside the control limits. Additional review of these four procedures resulted in practice modifications. Anecdotal feedback from physician assistants and attending physicians indicated that the program had another positive effect: Patients who required postprocedure counseling about the potential for radiation-induced skin injuries were no longer surprised by this information. Implementation of this program is straightforward, requires little infrastructure and few resources, and may be applied in most interventional radiology practices. Supplemental material available at *http://radiographics.rsna.org/lookup/suppl/doi:10.1148/rg.321115002/-/DC1.*

Abbreviations: CD = cumulative dose, CD_{adj} = adjusted cumulative dose, DAP = dose-area product, RAD-IR = Radiation Doses in Interventional Radiology Procedures

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Intra-Procedure

- $K_{a,r}$ notification levels
- Ongoing faculty and staff education
  - Dose management techniques
    - Store loop/store monitor, not acquisition
  - Be in the room
    - YDNKWIHUYKWIH
- Reduced dose protocols
  - Patients identified during pre-procedure process
- Situational awareness
  - Prior high-dose procedure – projection considerations

Post-Procedure

- Follow-up protocol
- Record dose descriptors
  - $K_{a,r}$/KAP/# of runs/time
    - RIS
    - Medical record
    - PACS
    - Structured dose reporting is here
- Flag high-dose cases for f/u
  - $K_{a,r}$ = 5 Gy (NCRP 168)
  - Procedure specific?