3D Cardiovascular Imaging:

Acquisition, Reconstruction, Post-Processing, and Results in 2011

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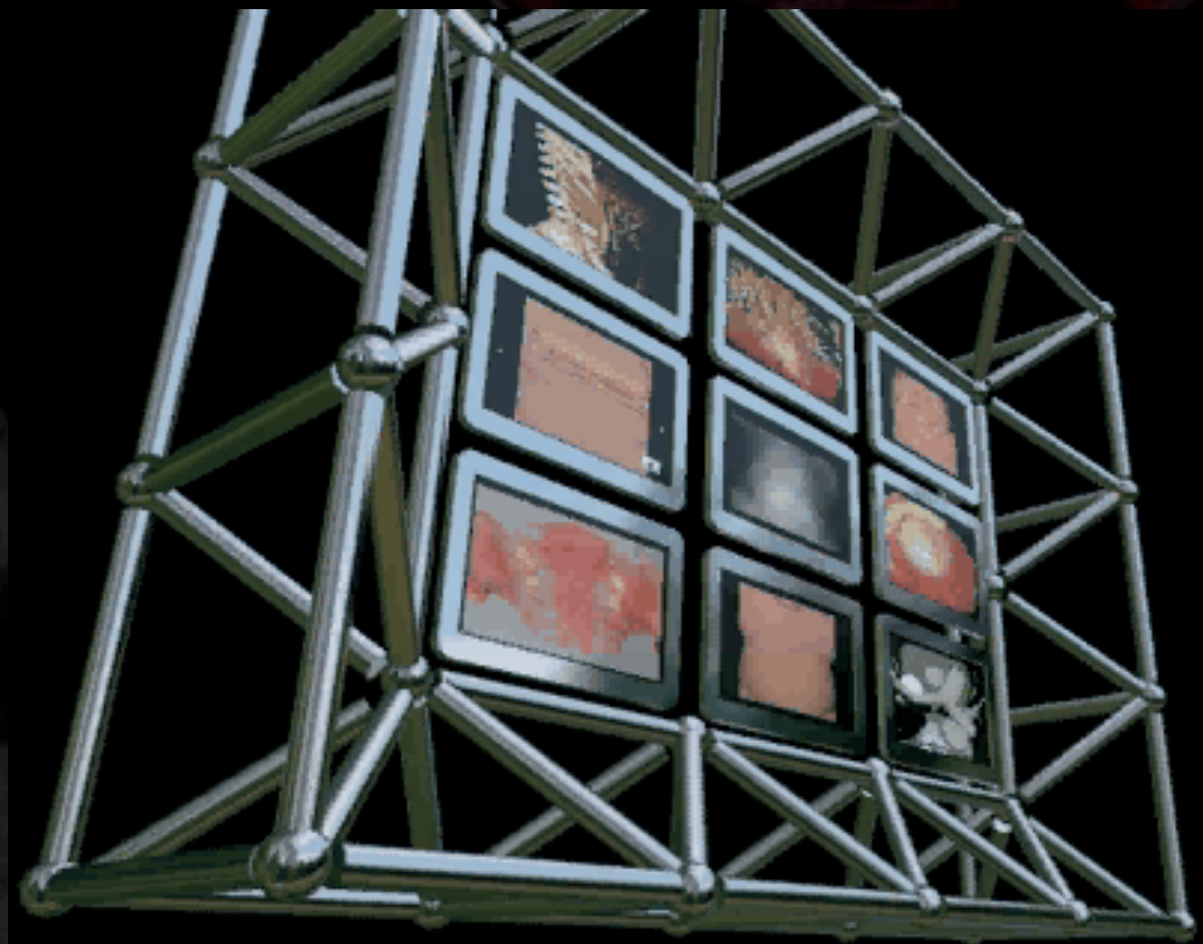


IU Health - Methodist Hospital 15 October 2011 1430-1530

Disclosures: None

Online Handouts from Lecture:

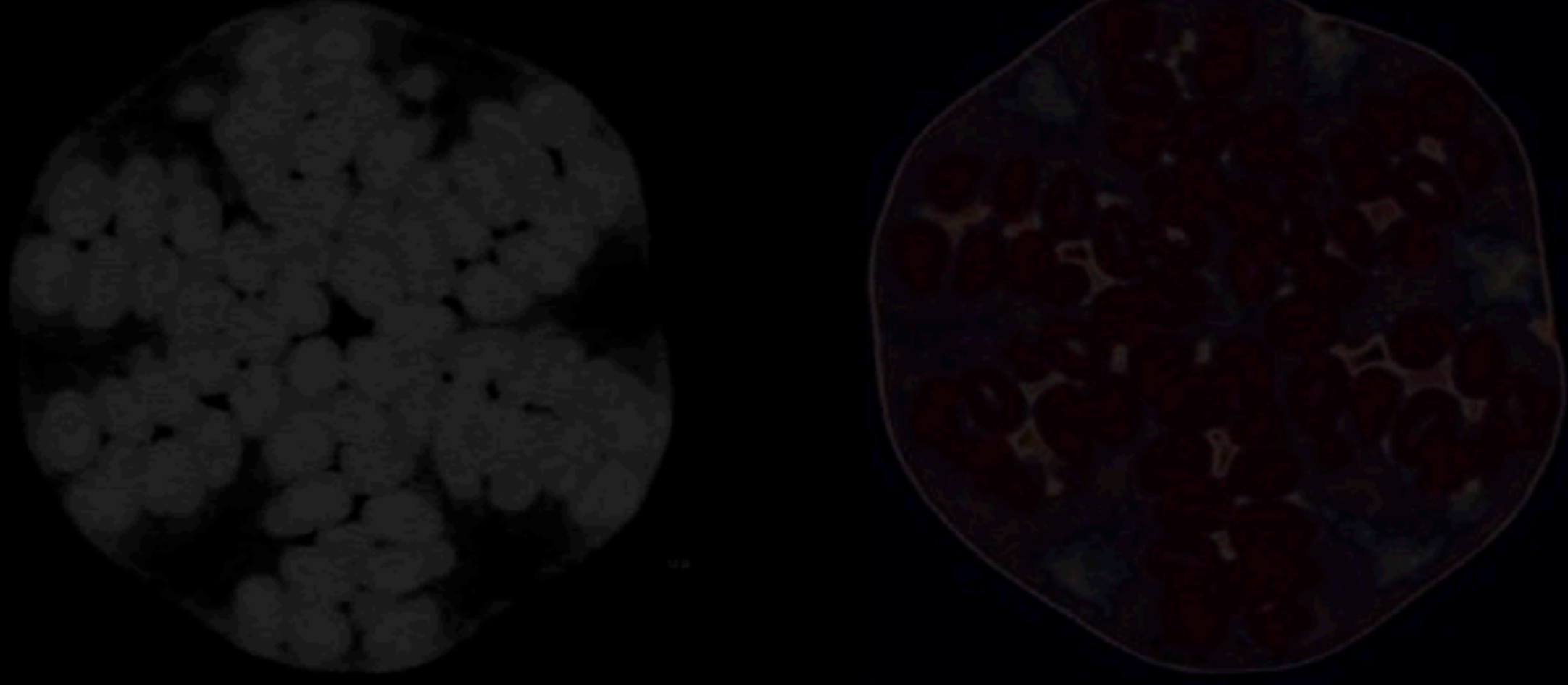
www.stanford.edu/~hallett

Choose "IU"

Outline

Outline

I. CTA Image Acquisition



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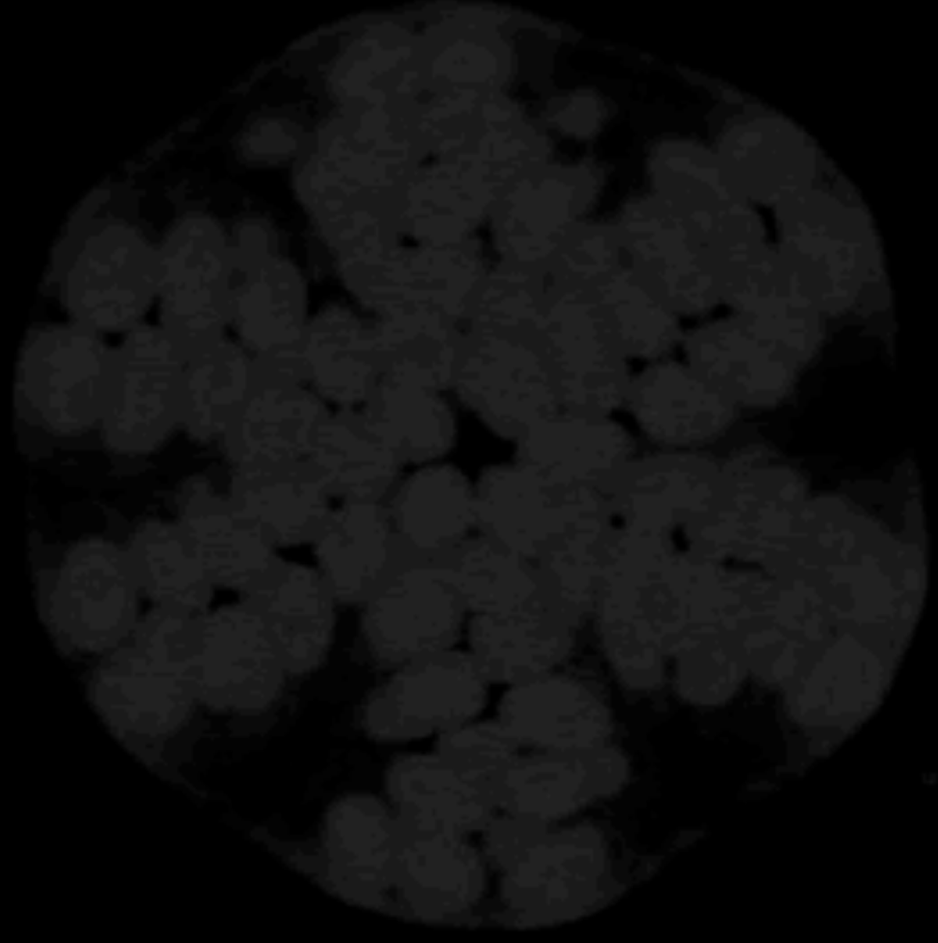
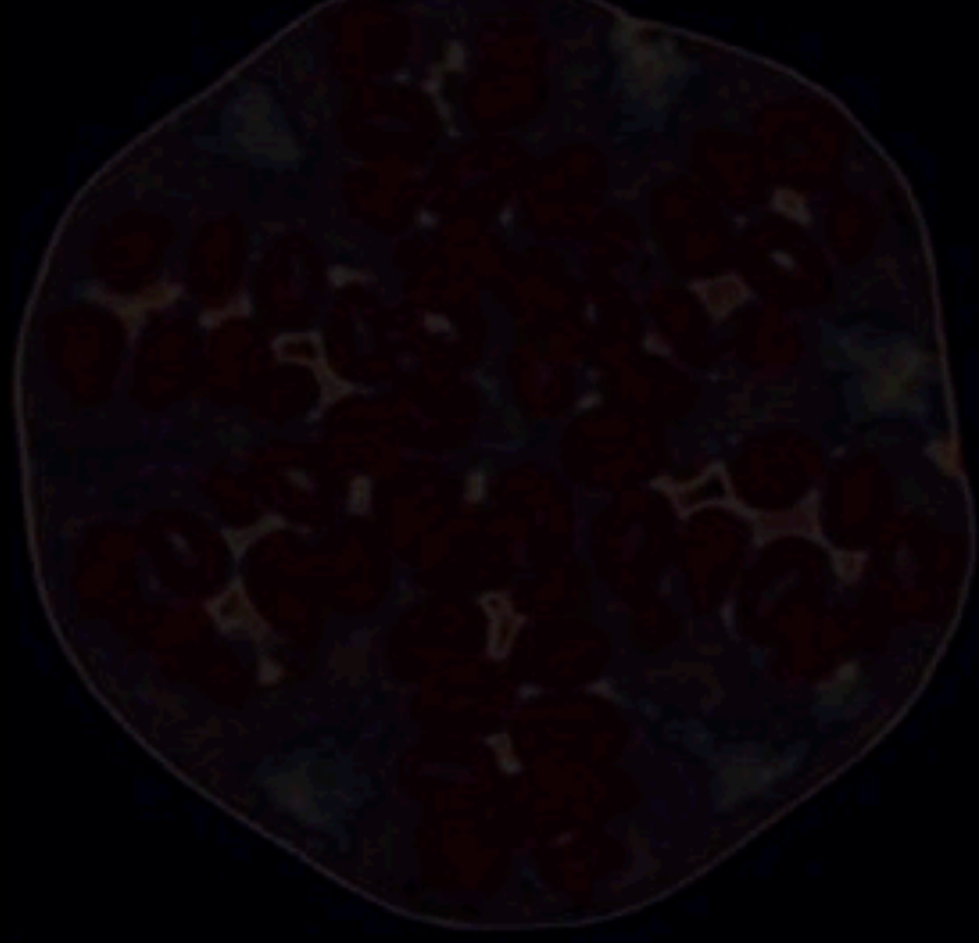
I. CTA Image Acquisition

II. CTA Image Reconstruction



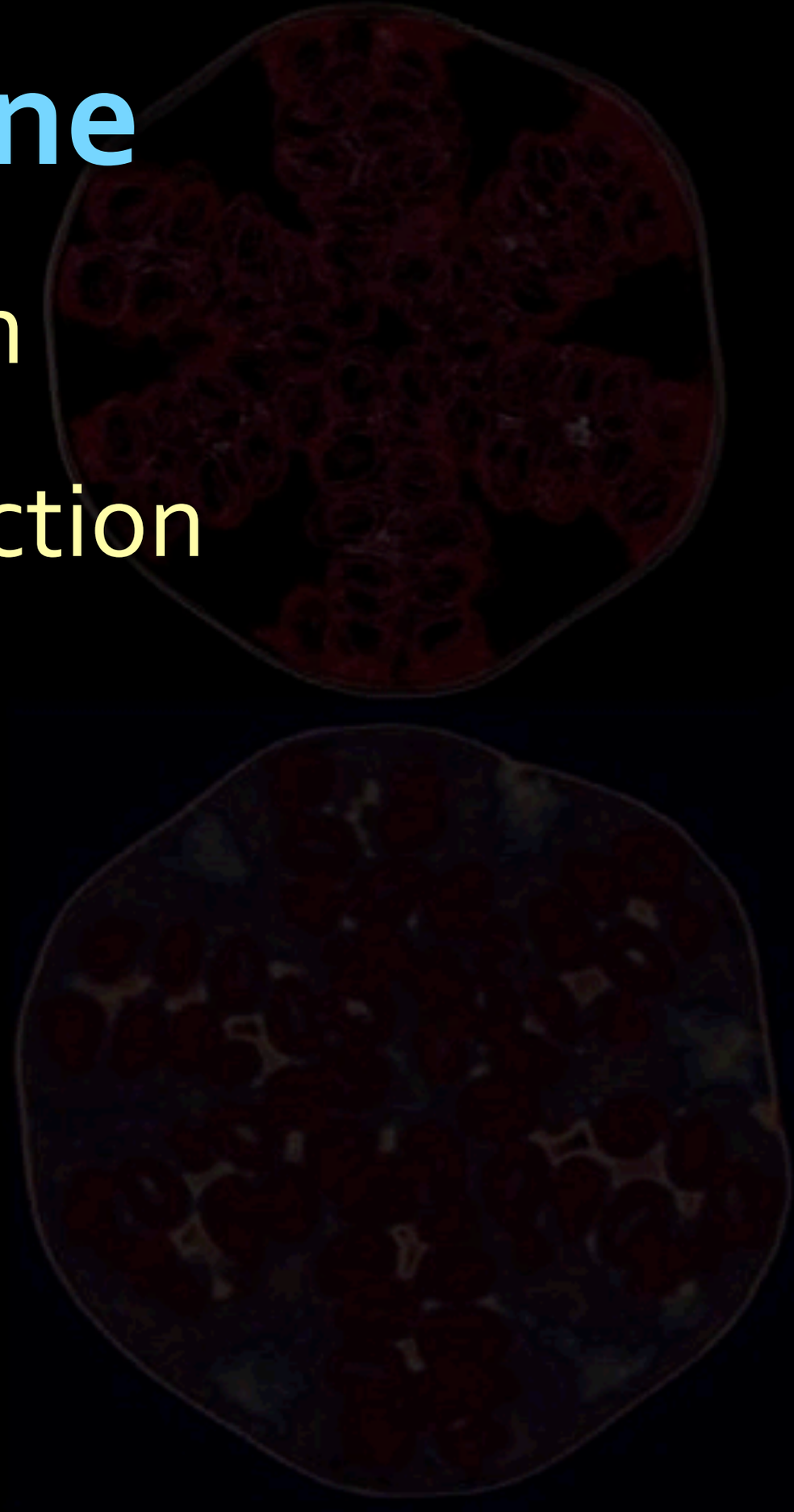


Outline

I. CTA Image Acquisition

II. CTA Image Reconstruction

III. Post-processing techniques



Outline

I. CTA Image Acquisition

II. CTA Image Reconstruction

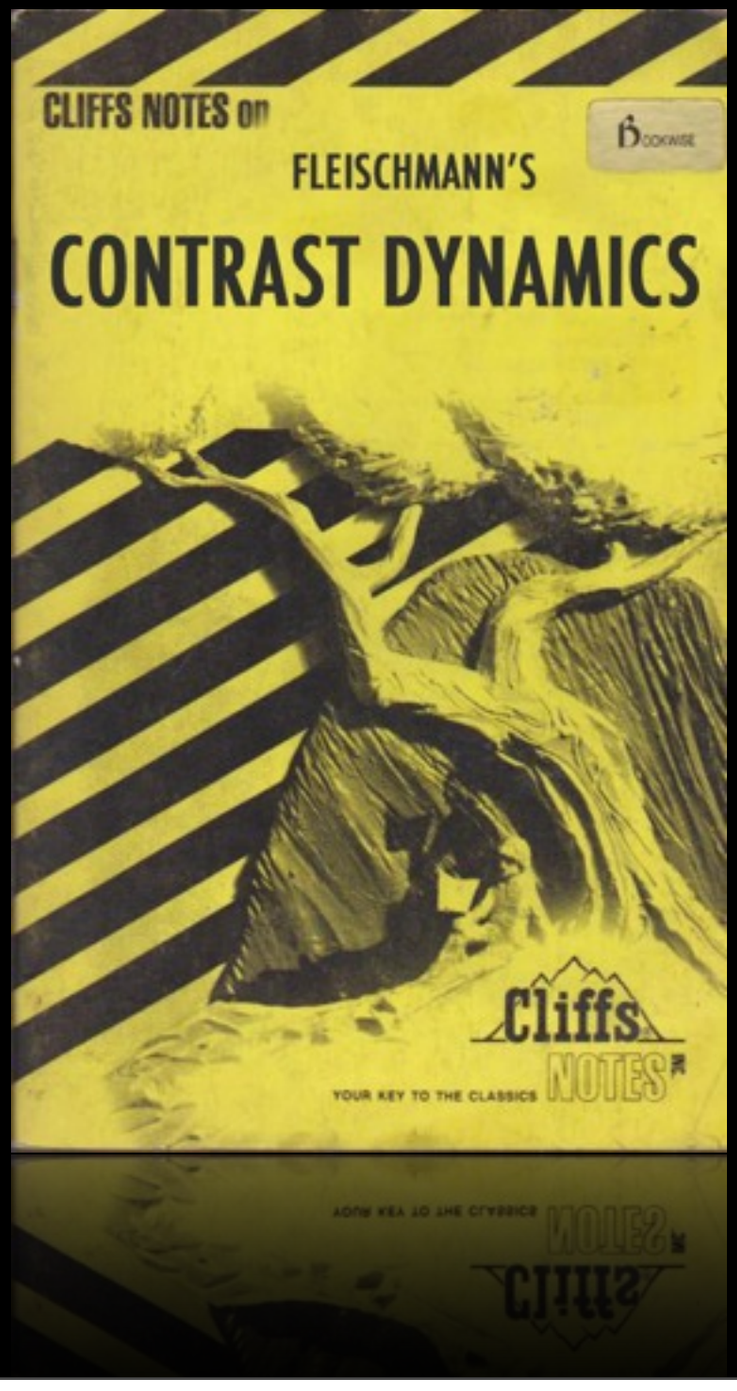
III. Post-processing techniques

IV. Applying what we've learned - Coronary CTA

Cardiovascular CTA Acquisition

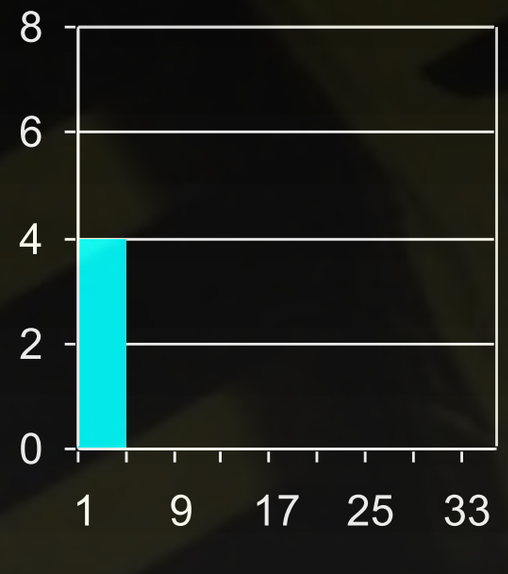
- **Contrast Medium Dynamics**
- **Scan protocol tweaks**

Contrast Medium Administration for CTA

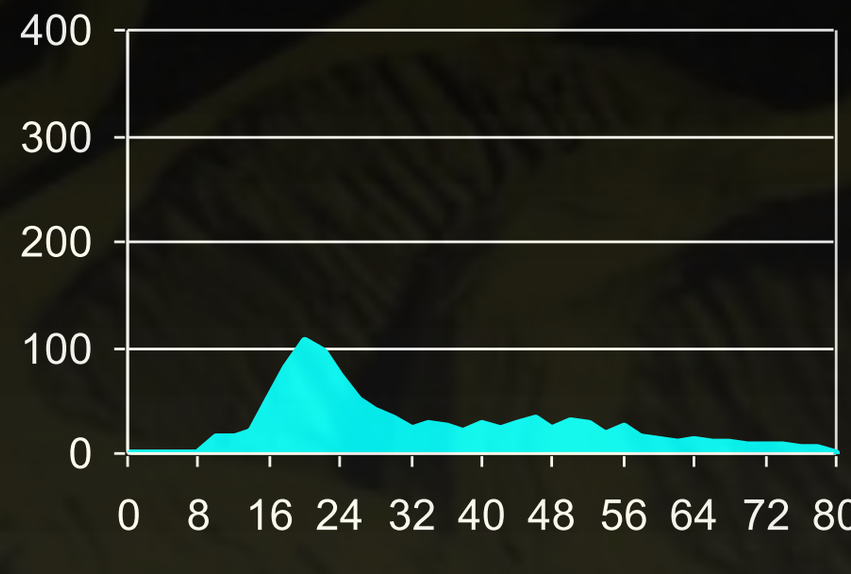


INPUT
intravenous
injection rate
(mL/s)

4 mL/s
(16 mL)



OUTPUT
arterial
enhancement
(ΔHU)



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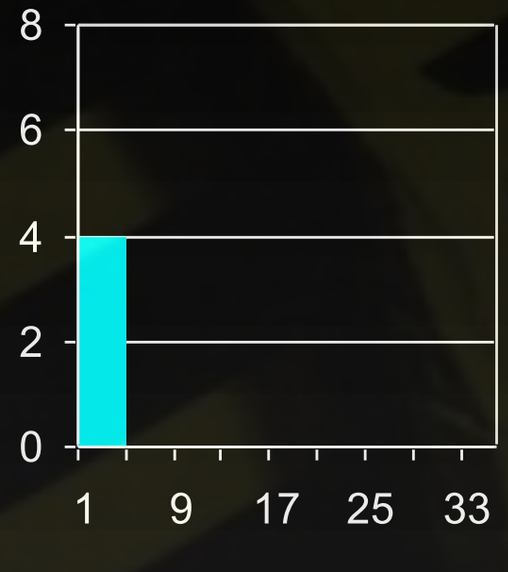
(16 mL)



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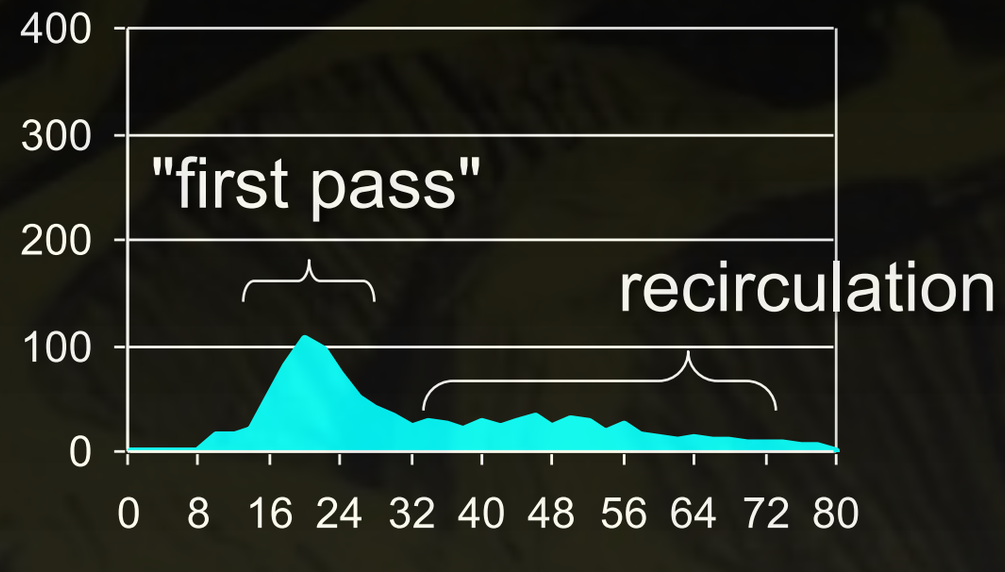

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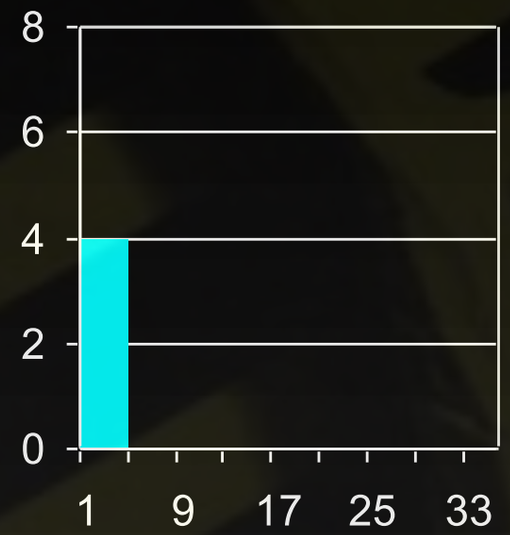
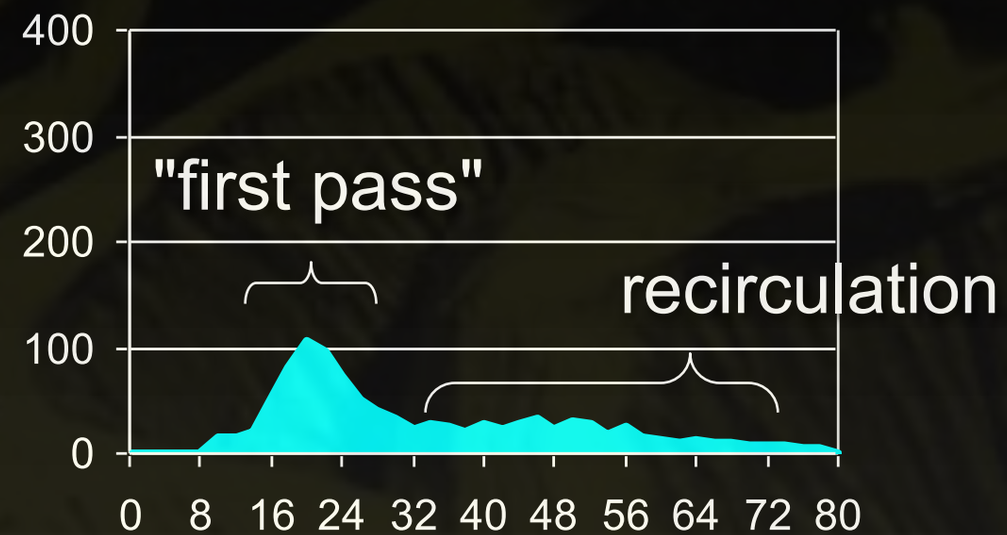
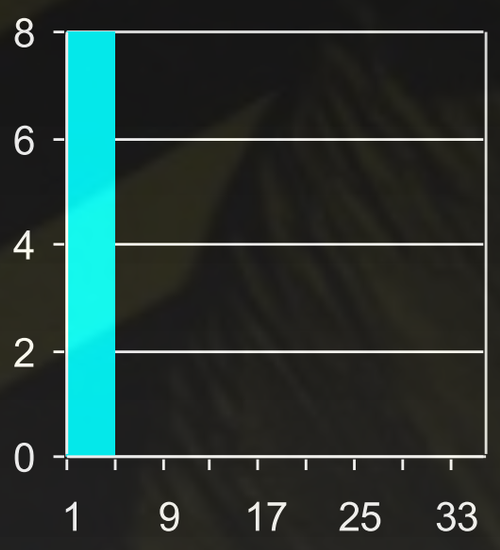
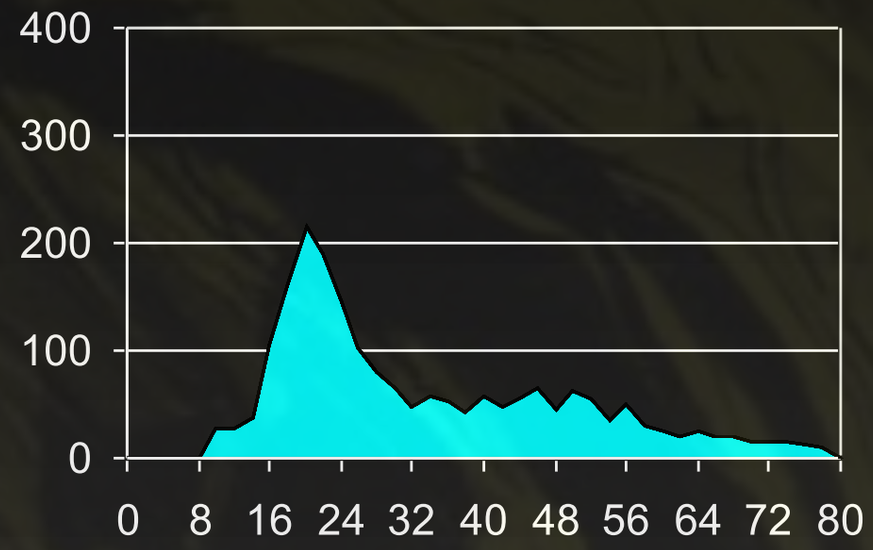




8 mL/s
(32 mL)





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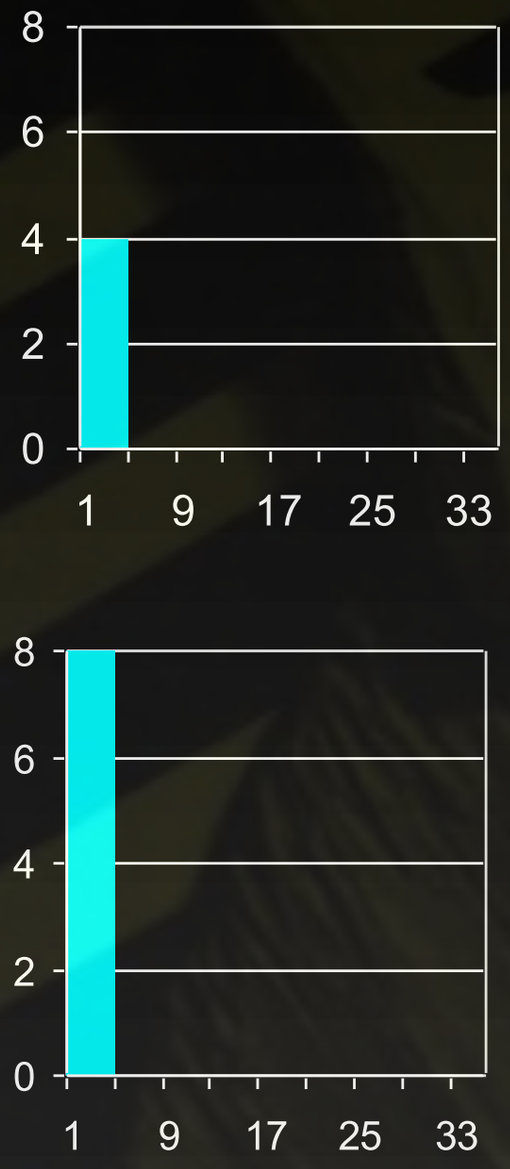

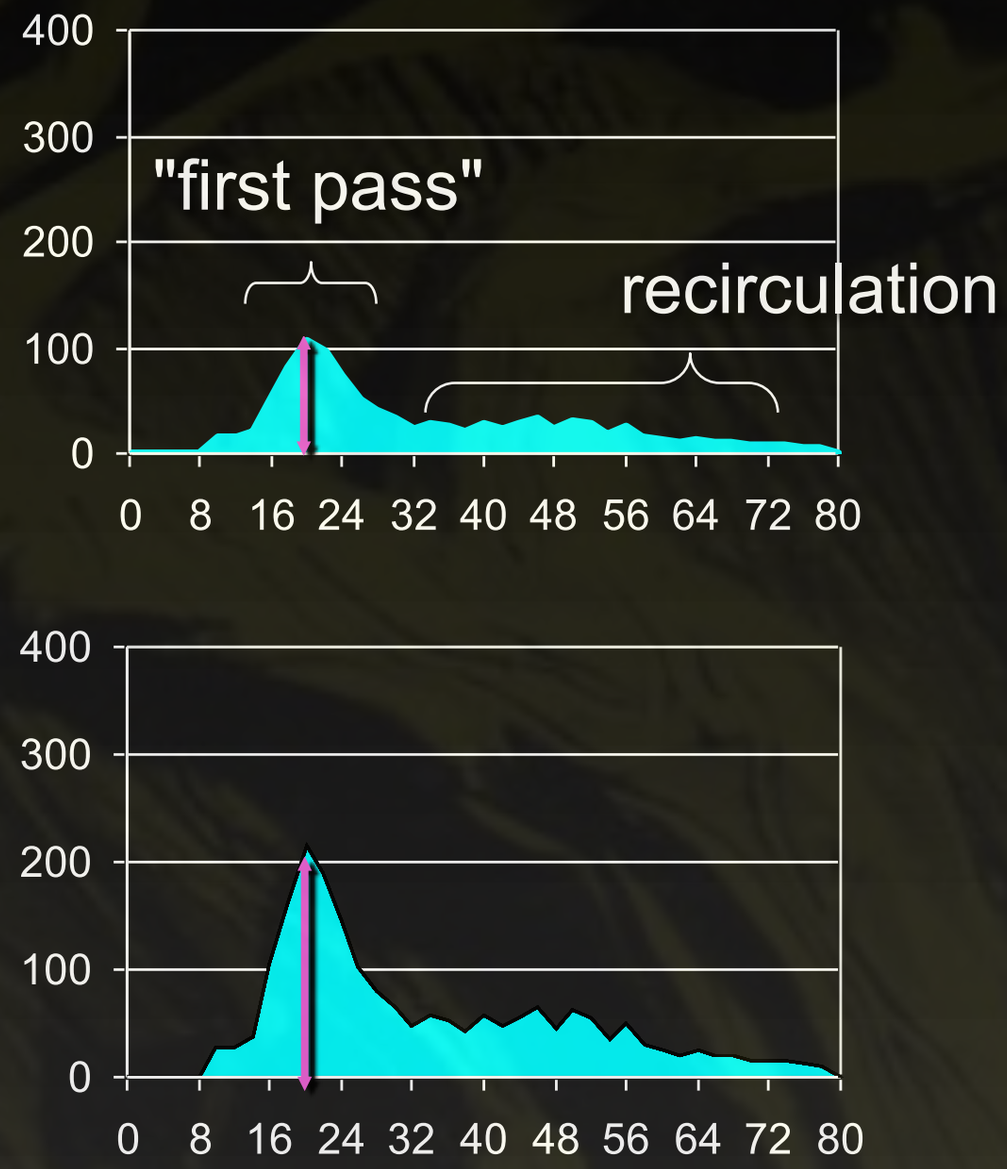

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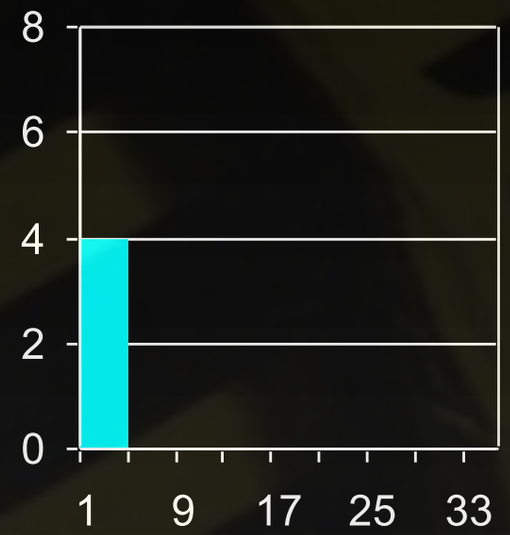

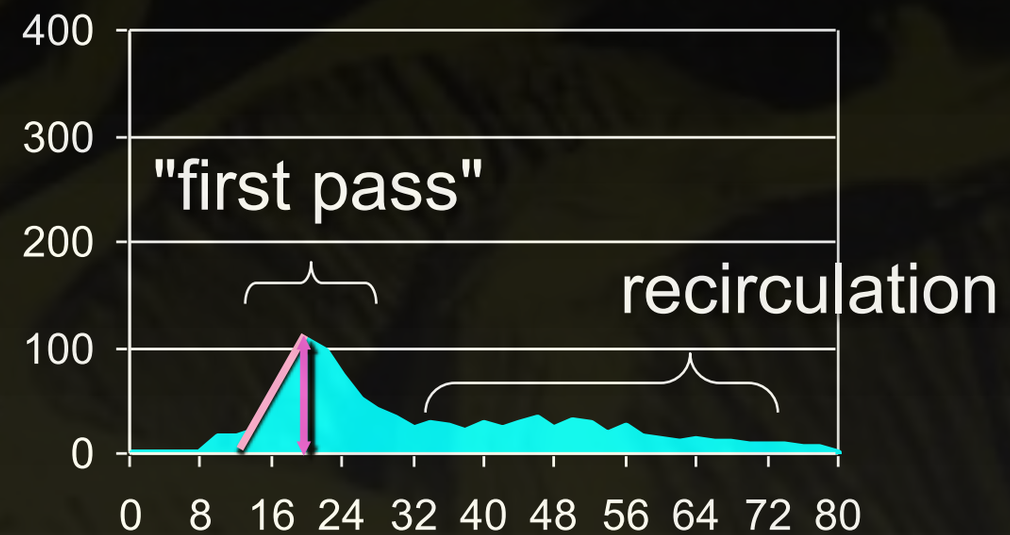

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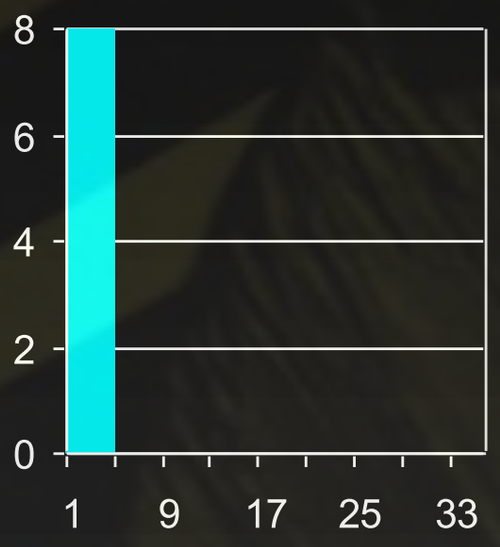

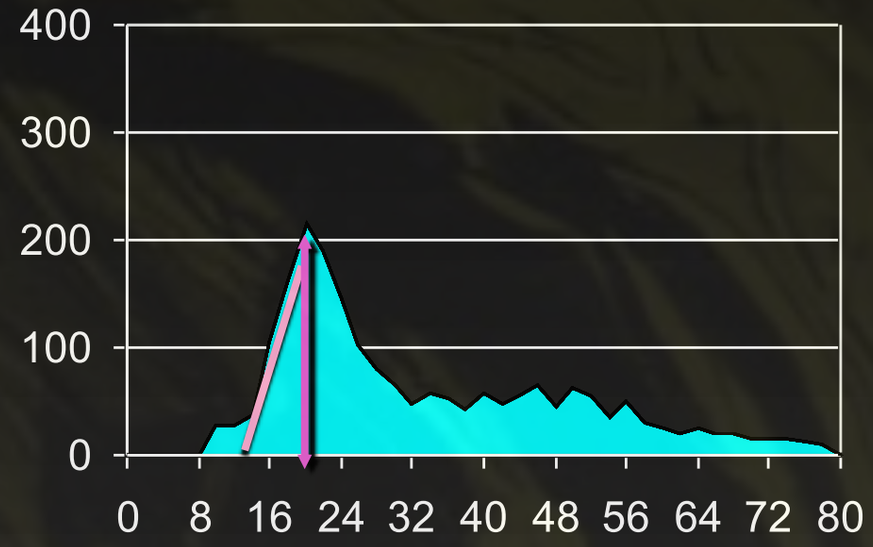

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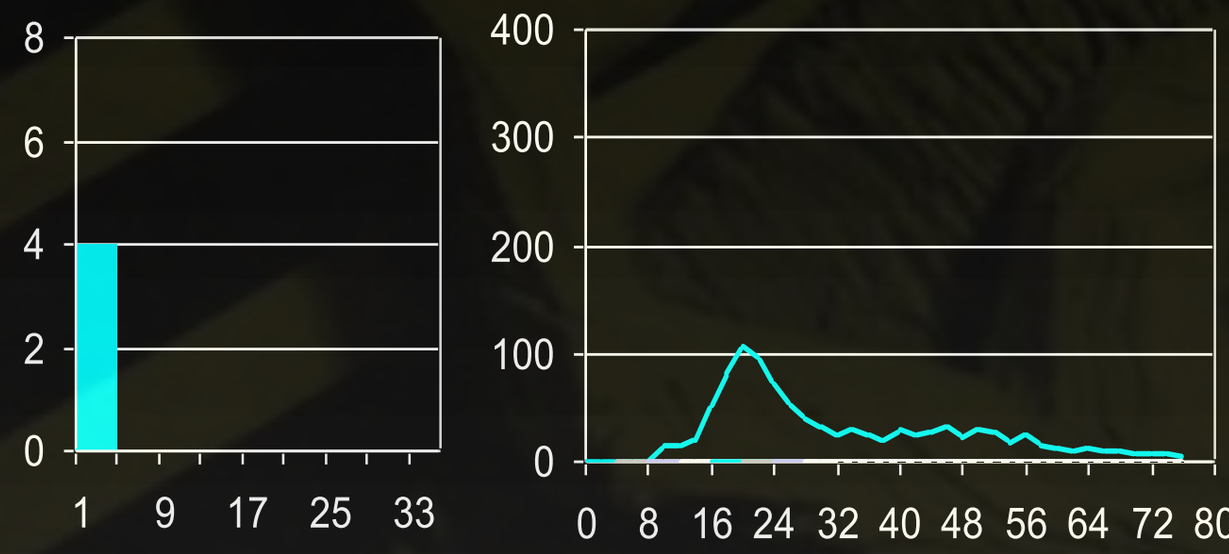
+16 mL



Europ Radiol 2002; 12:S11-16

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(4 mL/s)

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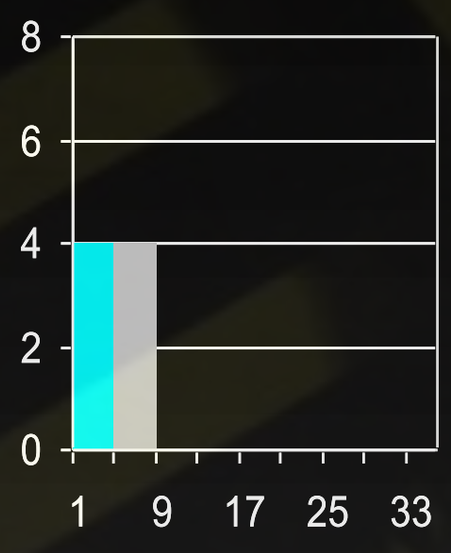

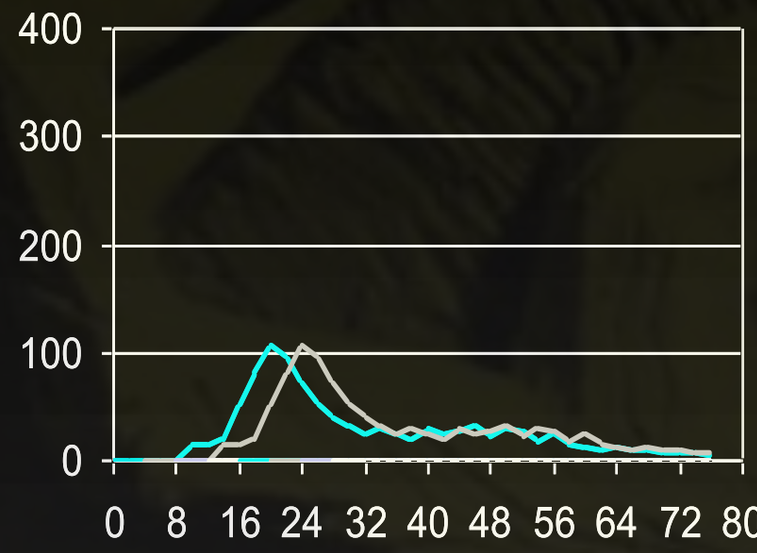

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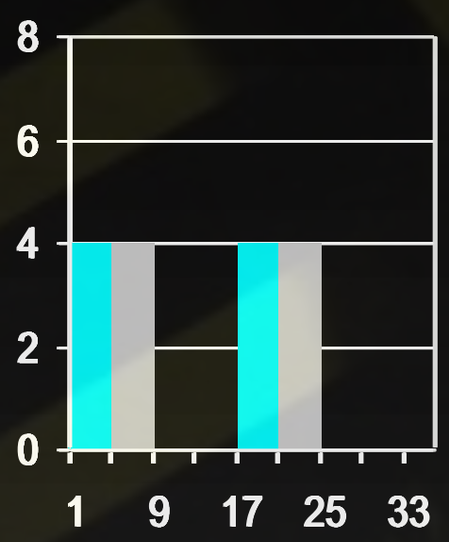
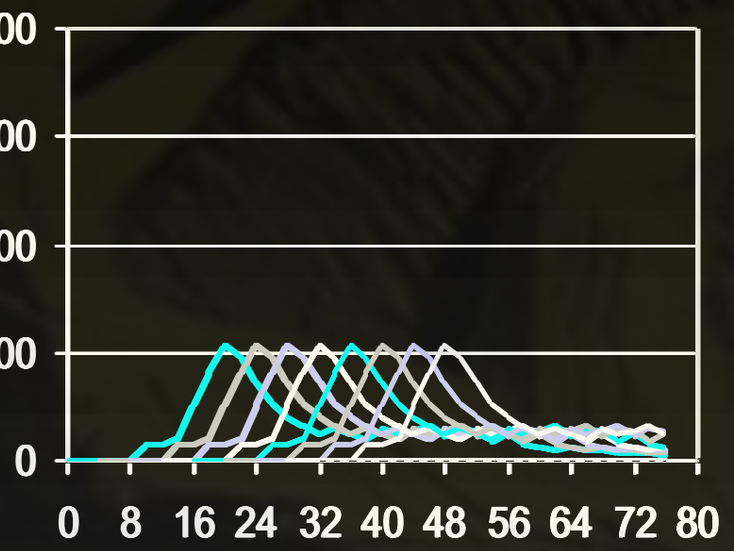
+16 mL

+.....

128 mL





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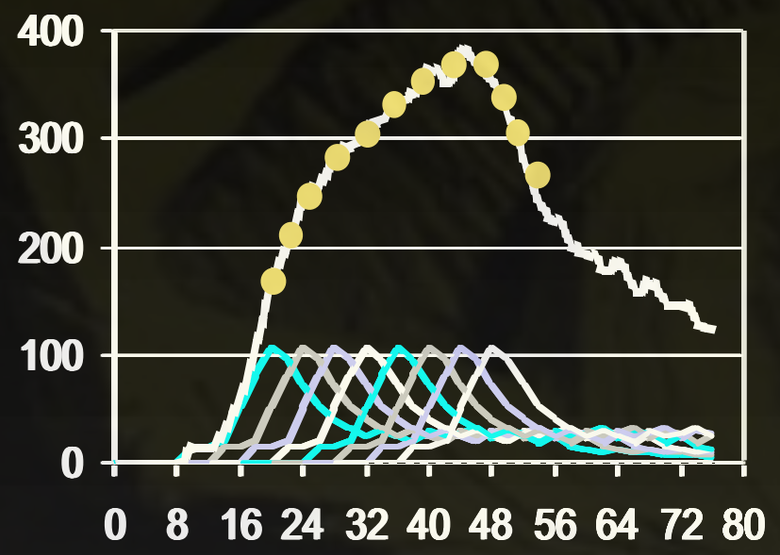

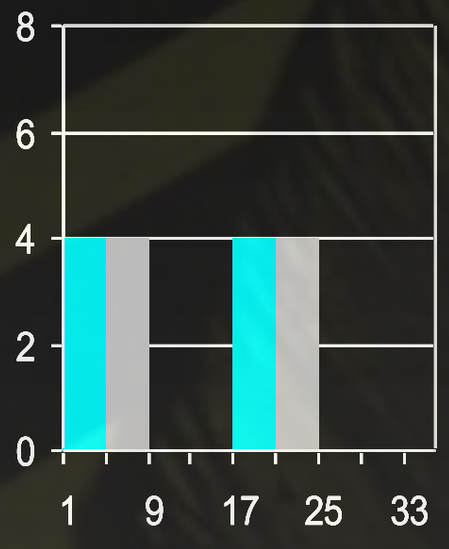

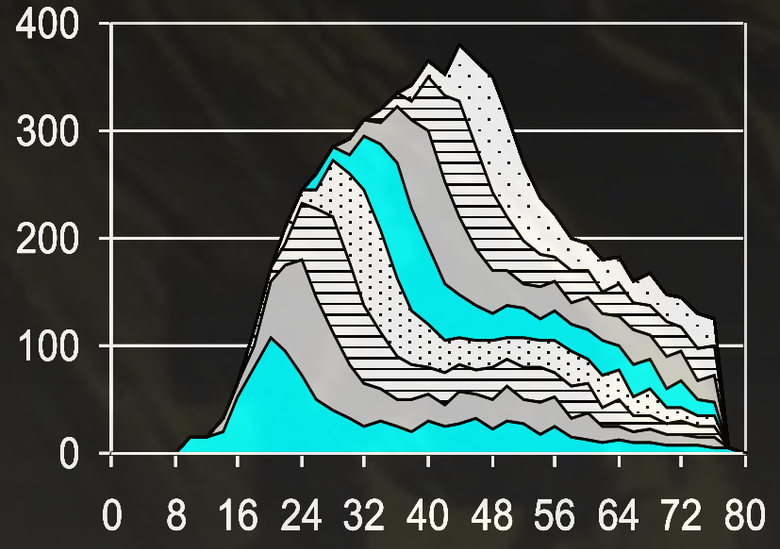

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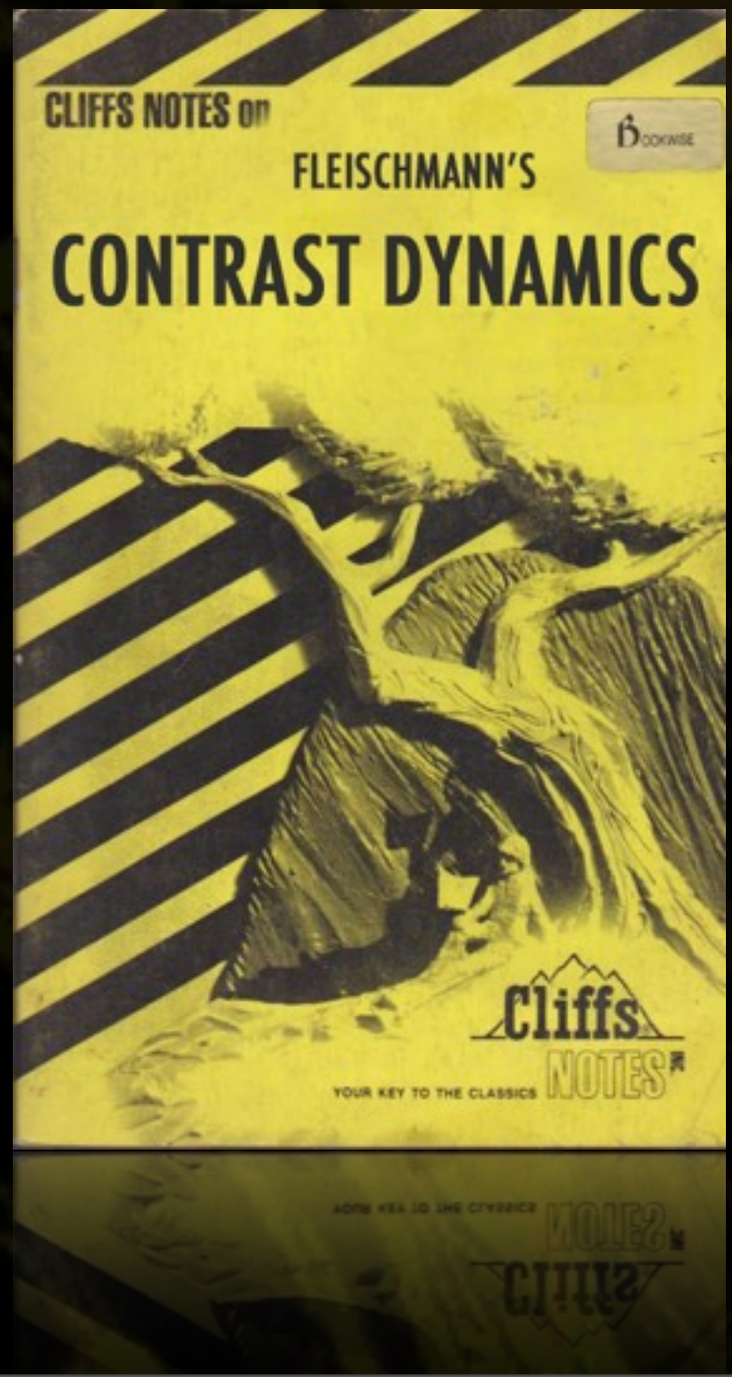
Key Points:
Contrast Medium Dynamics

- Arterial enhancement is proportional to Iodine flow rate
- Enhancement increases (cumulative) over time
- "Inject Faster and/or wait longer"
- **adjust inj. rate and CM volume (±20%) for pts. ≤60kg and ≥90kg**



Contrast Media: Patient Factors

Arterial enhancement is **inversely** related to:

Cardiac output (CO)

Central blood volume (CBV)

CO (and CBV) correlate with body weight[1] at least in pts. with ~ normal cardiac function

[1)] Hittmair & Fleischmann, JCAT 2001

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CTA Scan Acquisition Tips

- Fast Scanners
- Slow Transit times
- Patient Factors

Caveat: Fast scanners need special attention to protocols!!

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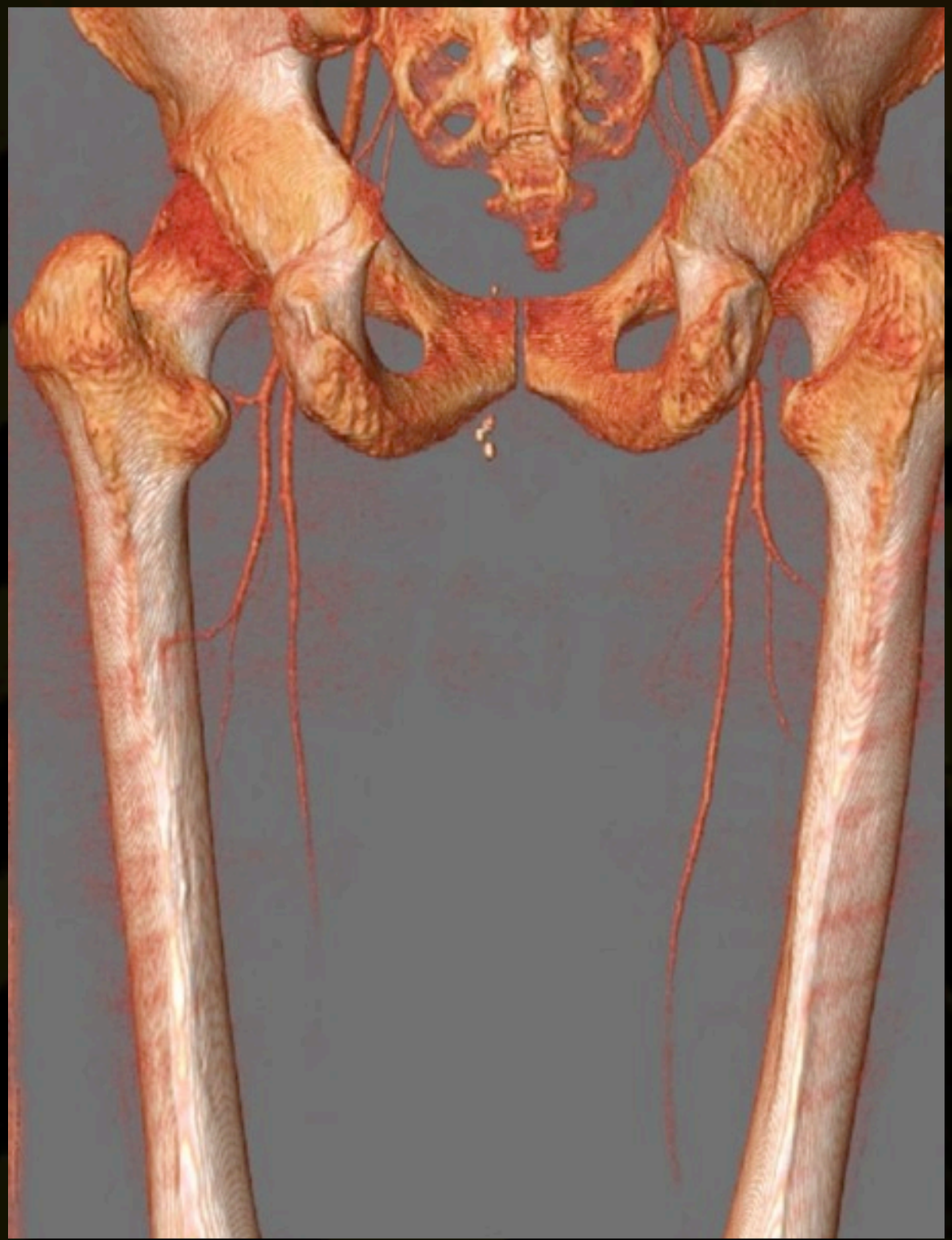

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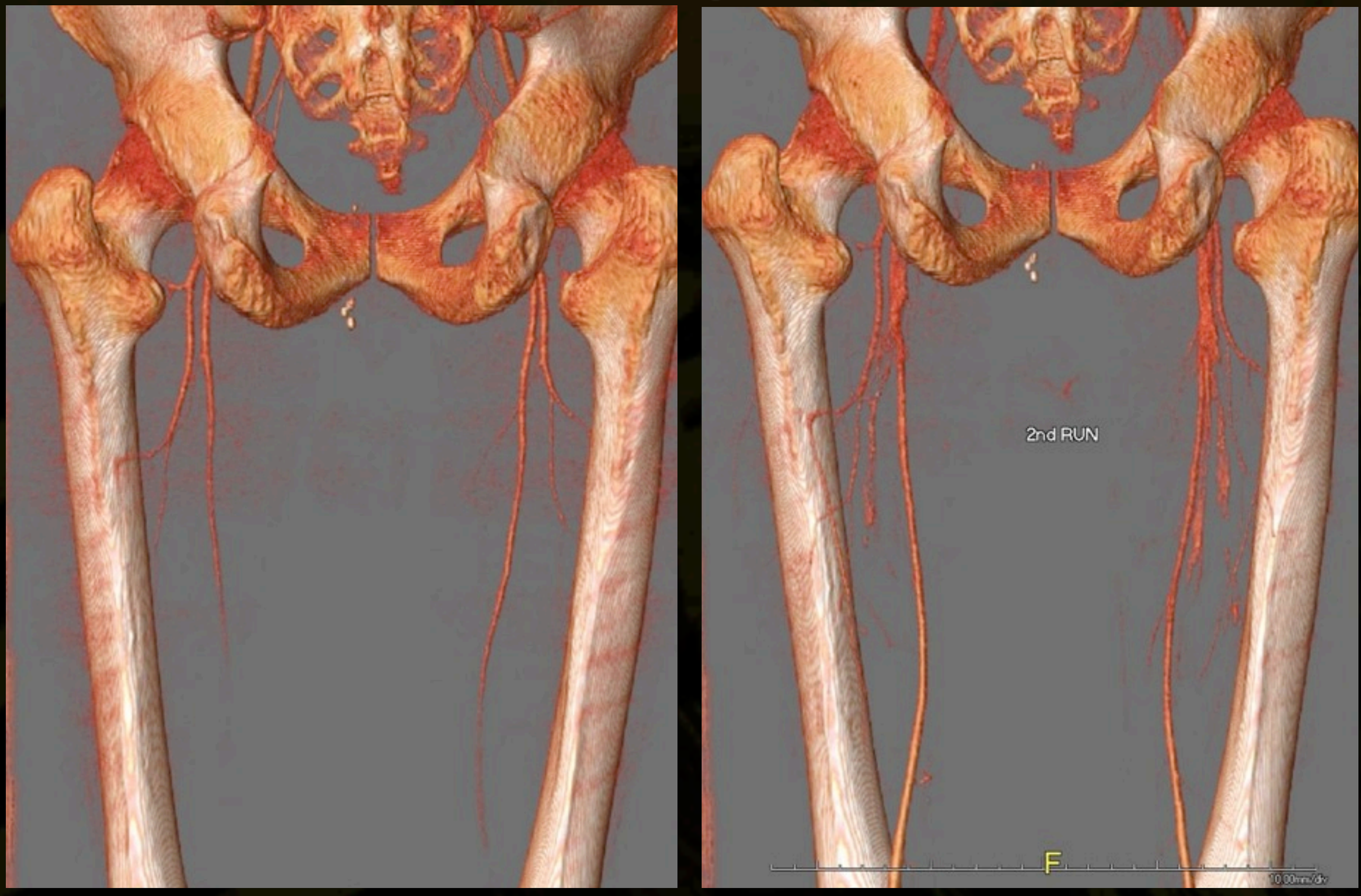

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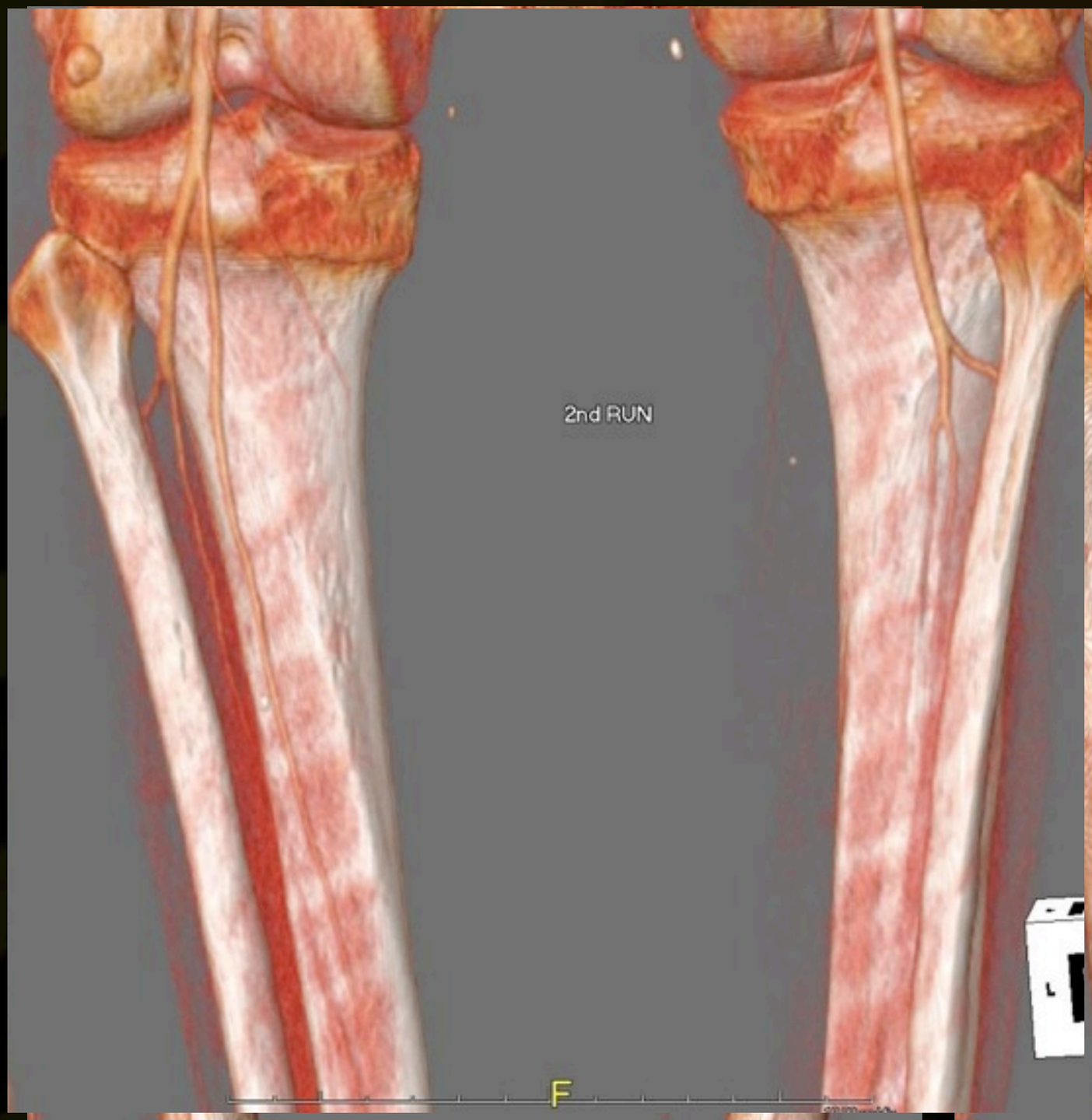

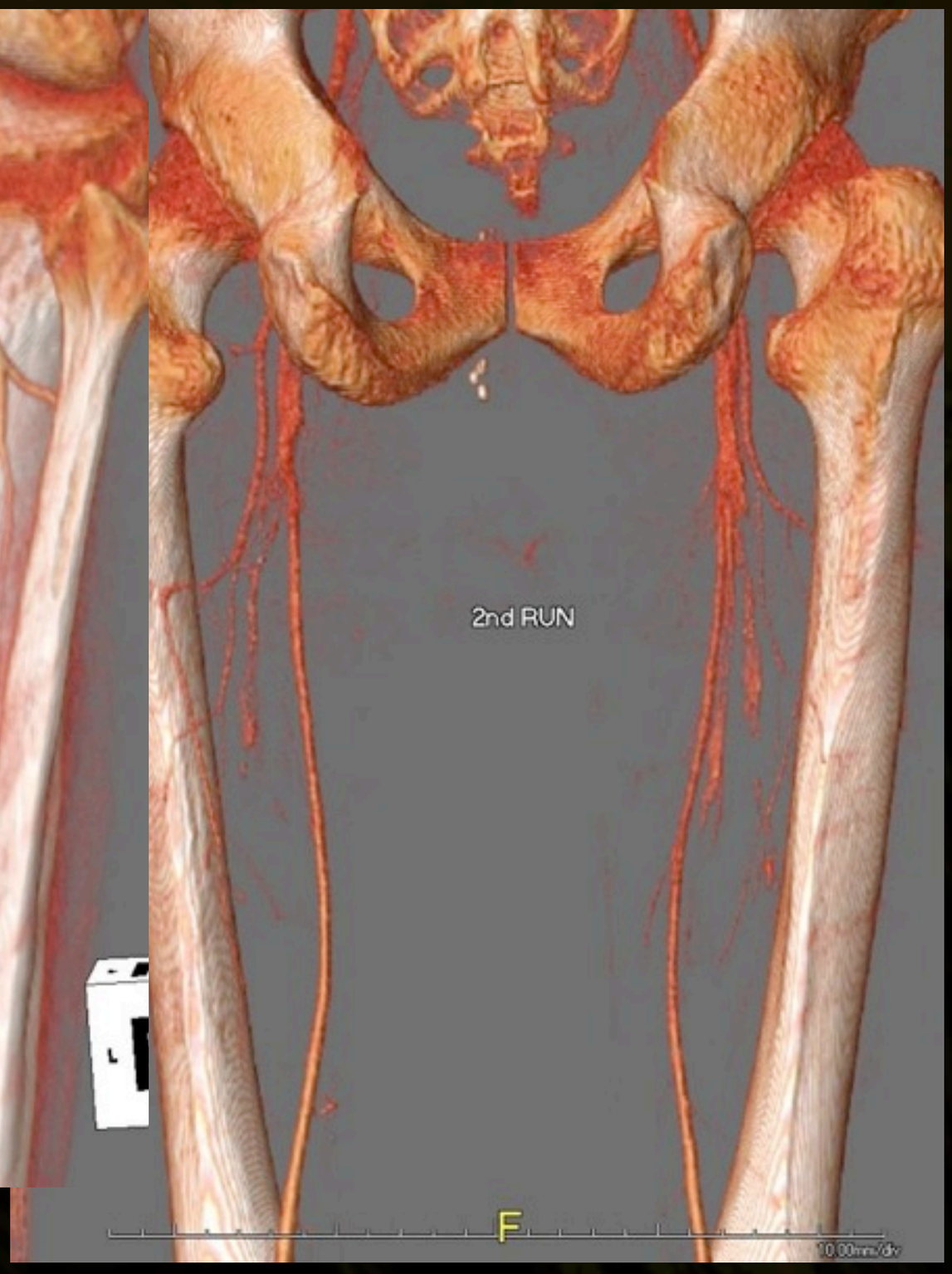

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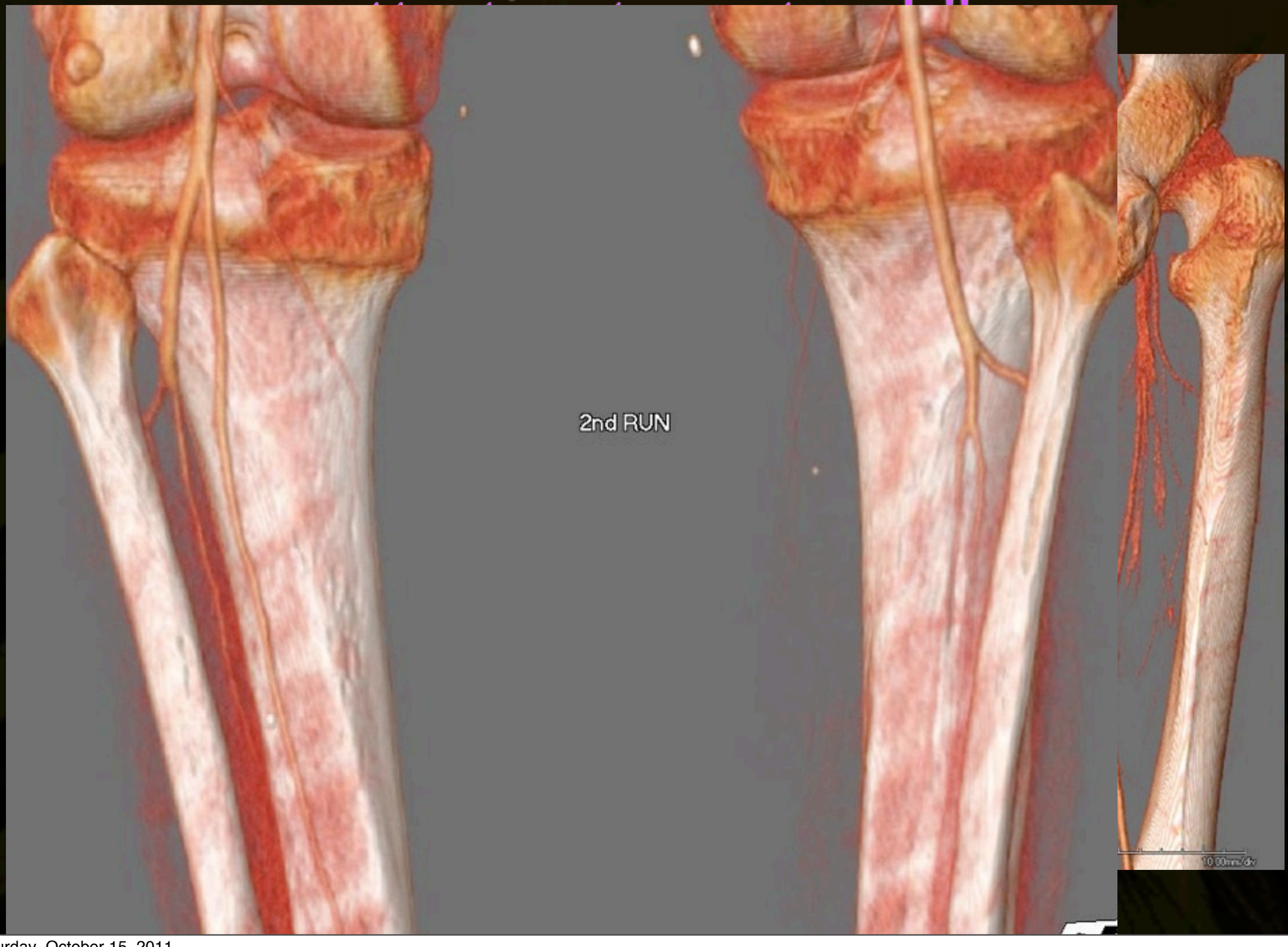

Caveat: Fast scanners need special

Arteriomegaly

1st acquisition

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1st acquisition

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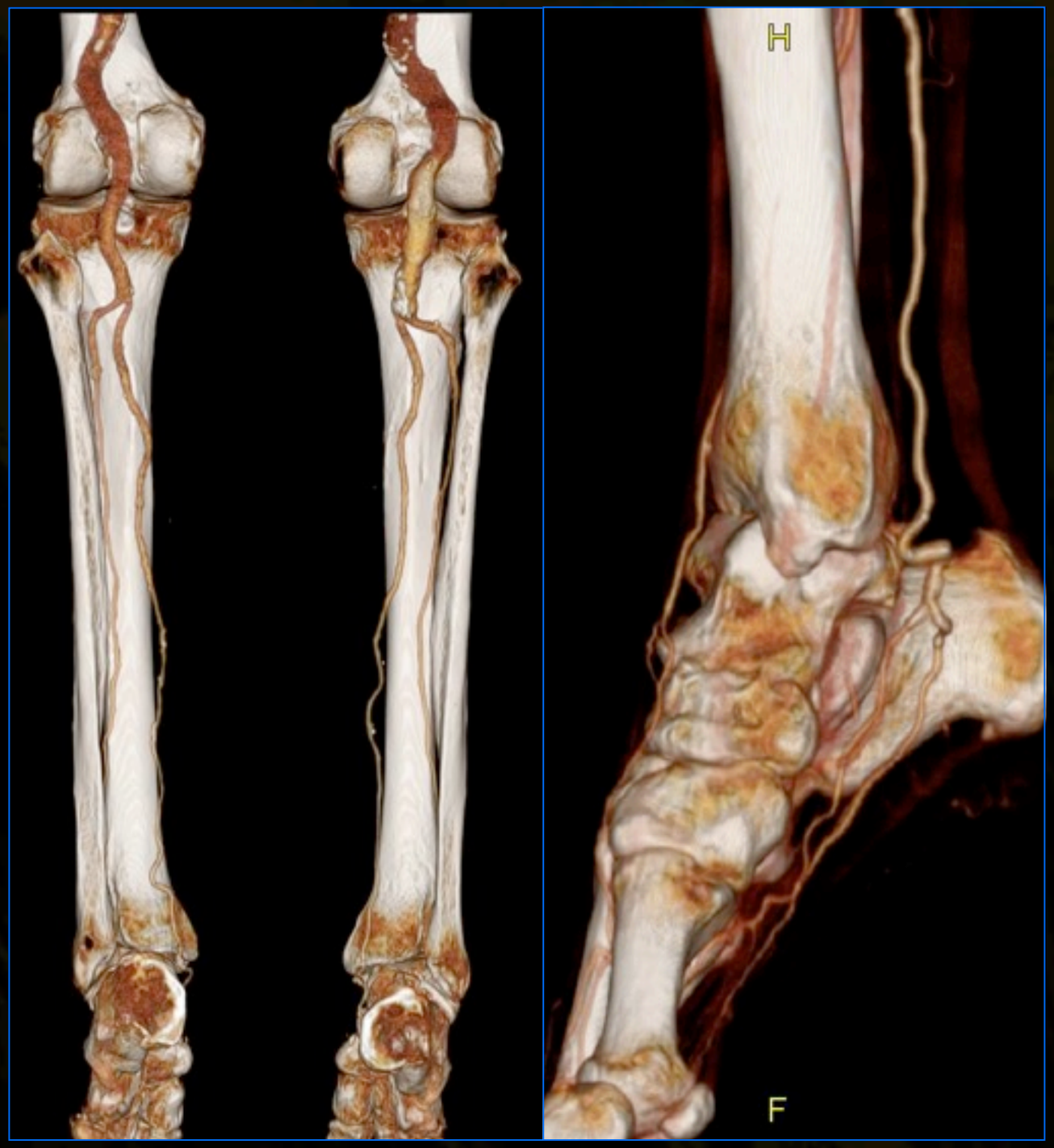
1st acquisition

Arteriomegaly

preprogrammed,
optional 2nd acquisition

1st acquisition



Patient-Specific Tips

- **LARGE** Patients:
    - Scan with thicker collimation (1.25 - 2.5 mm)
    - Use 140 kV
    - Slow down gantry rotation
- Smaller Patients:
    - Use 100 kV
- In all: Use Automated Tube Current Modulation!!

Integrated Contrast / Scan Protocol

- Simple, weight based injection volumes and flow rates, combined with a fixed scan time or scan time/diagnostic delay sum.
- automated bolus triggering

Integrated Injection / Scan Protocol: Rule of Thumb

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- **Injection Duration = Scan time + 8 ± "Delay"**

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- **Injection Duration = Scan time + 8 ± "Delay"**
  - NOTE: Need at least 10 sec injection for adequate filling

Integrated Contrast / Scan Protocol

- BENEFITS:
  - Decrease patient to patient variability in scan quality
    - Optimize imaging timing
    - Image all of the contrast given!
  - (Potentially) save contrast

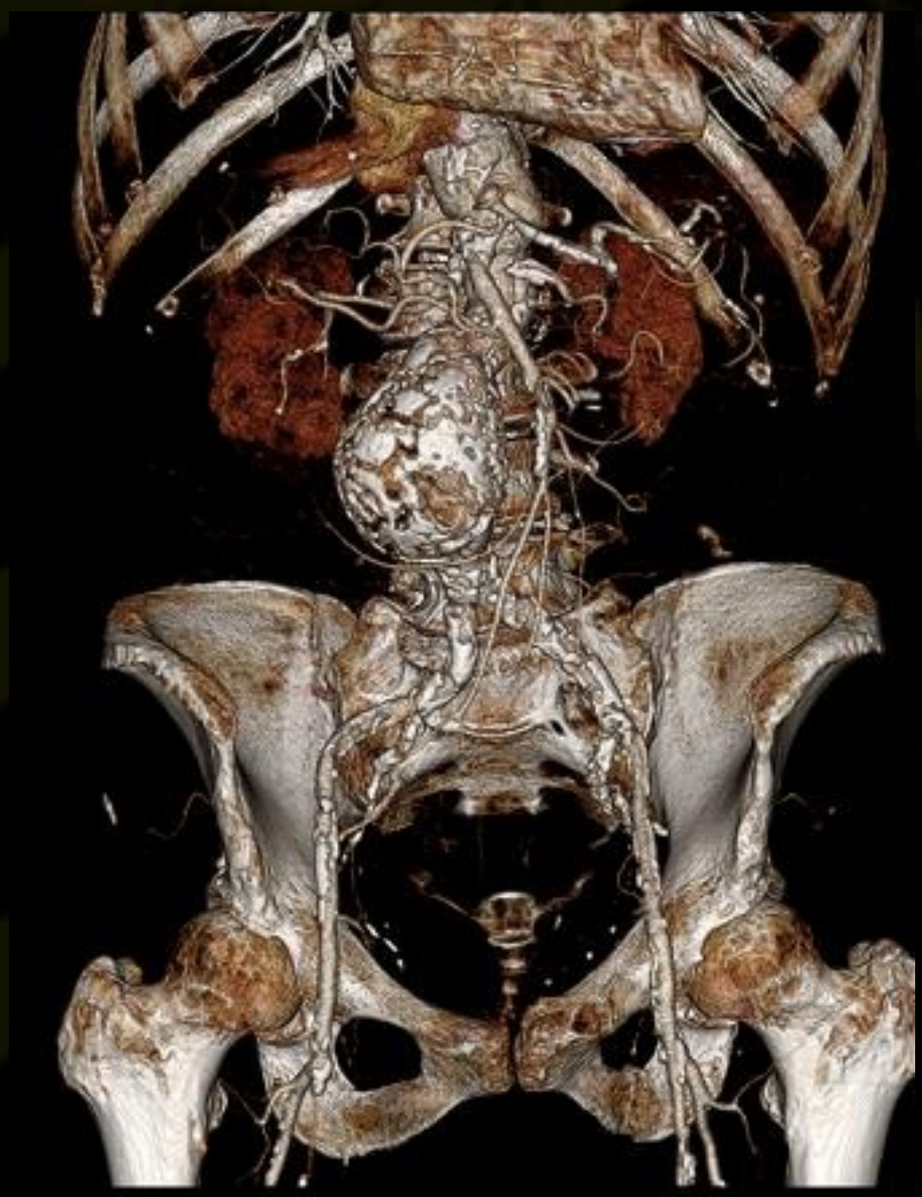
Integrated Scan/Injection Protocol: Abdomen CTA

Acquisition	64 x 0.6 mm (channels x channel width); automated tube current modulation (250 mAs reference mAs)
Pitch	Variable (depends on volume coverage, usually <1.0)
Scan time	Fixed to 10 s (all patients)
Injection duration	Fixed to 18 s (all patients)
Scanning delay	t_{CMT} + 8 s (scan starts 8s after CM arrival, as established by automated bolus triggering)
Contrast medium	High concentration (350-370 mg I/mL)
Injection flow rates and volumes	**Individualized to body weight:**

Body Weight (kg)	CM Flow Rate (mL/s)	CM Volume (mL)
≤ 55	4.0	72
56-65	4.5	81
66-85	5.0	90
86-95	5.5	99
> 95	6.0	108

RESULTS: Integrated Scan/Injection

q-ref.mAs: 250
eff.mAs: 136 mA:282–364



81 YO female
(161cm, 55 kg)

q-ref.mAs: 250
eff.mAs: 270 mA:318–530

83 YO male
(173cm, 95 kg)

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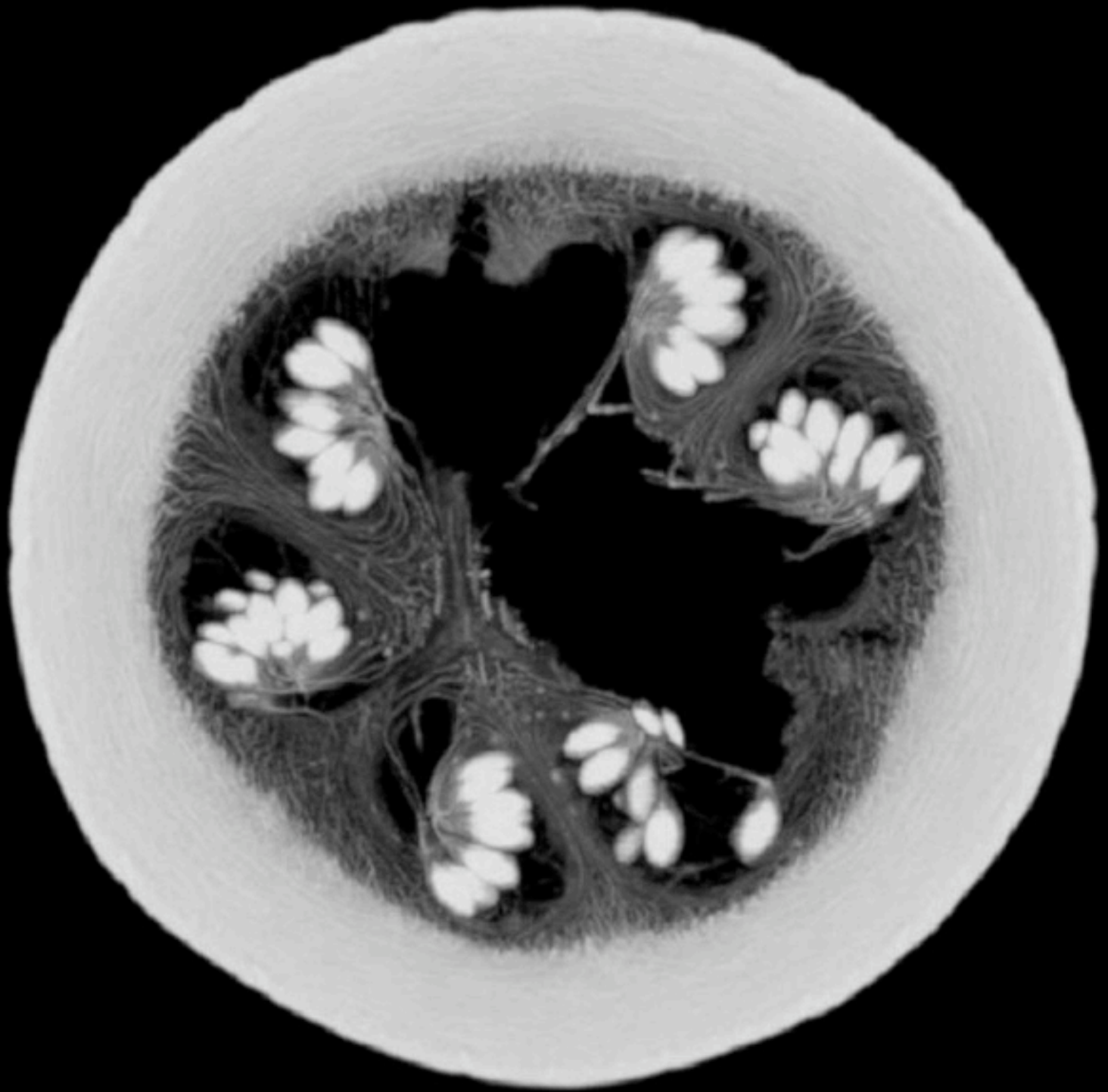
CTA Image Reconstruction



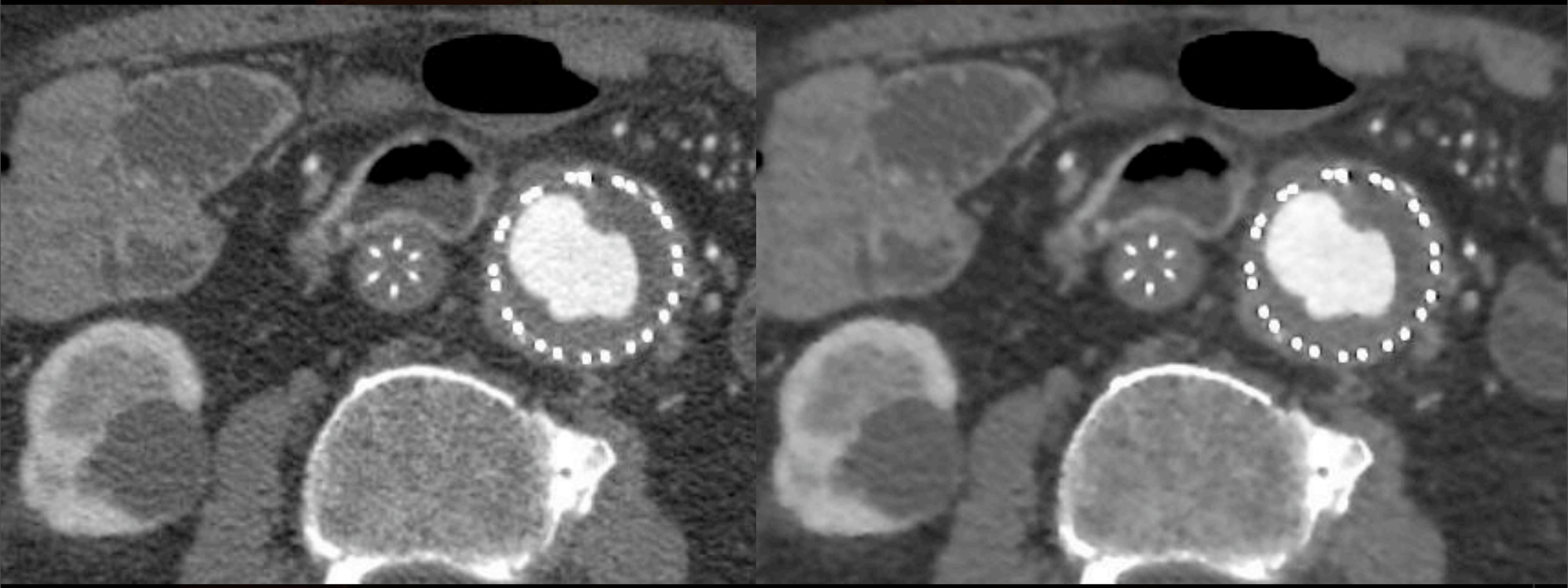
CTA Image Reconstruction

CTA Image Reconstruction

(Modifiable) Image reconstruction parameters

1. Raw Data Reconstruction Mathematics **
2. Individual Slice / Patient Characteristics
3. Field of View
4. Kernel

Iterative Reconstruction: Appearance



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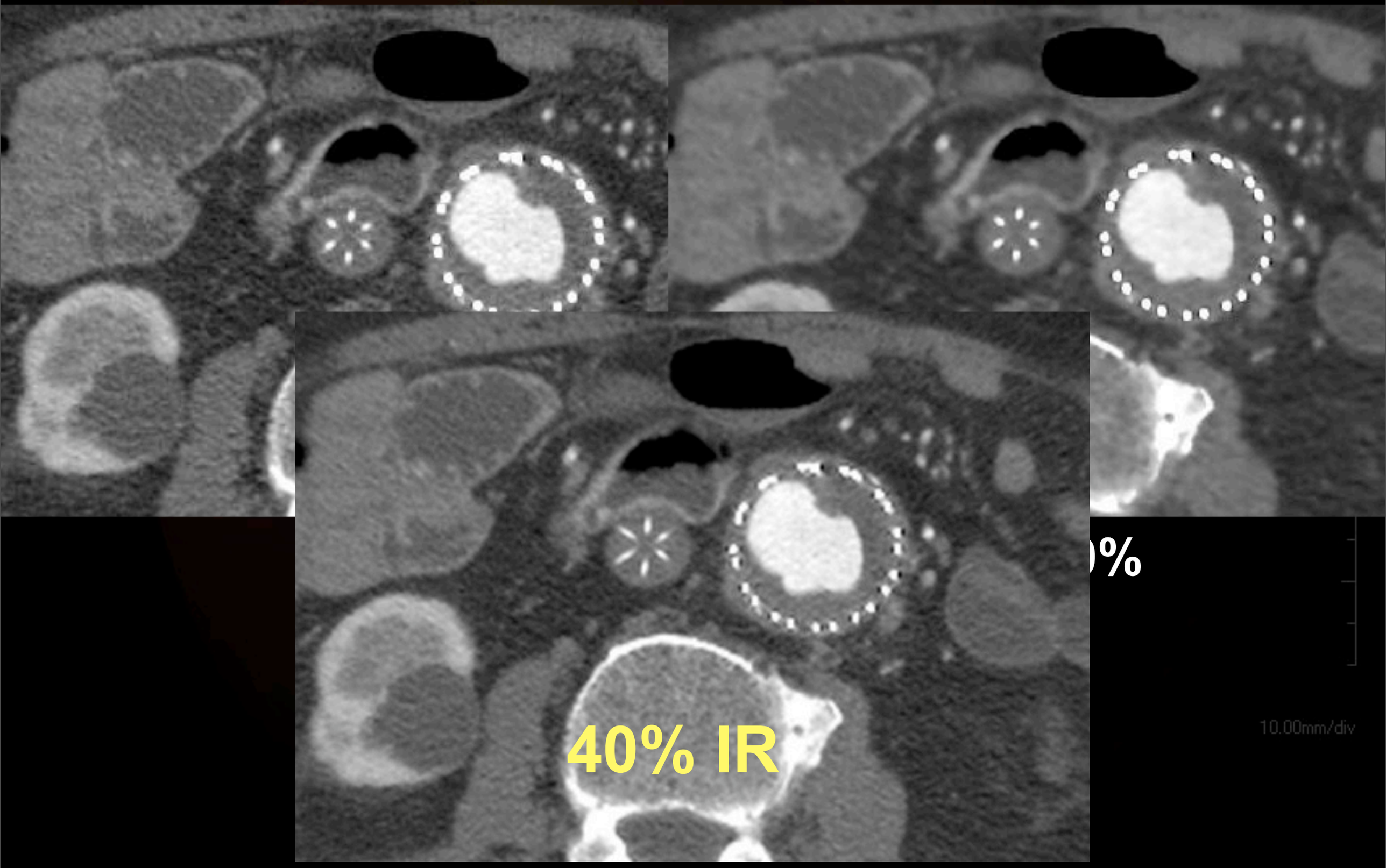

(Modifiable) Image reconstruction parameters

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CT "slice" Characteristics…

- "Effective" slice thickness
  - defined by the selection of collimator thickness during scan acquisition
- Thicker (but not thinner) recons
- Multiplanar Recons enhanced if your initial dataset is overlapped by ~ 30%
  - e.g. 1mm ST at 0.7 mm RI
  - Less "aliasing" (stairstep)

10.00mm/div

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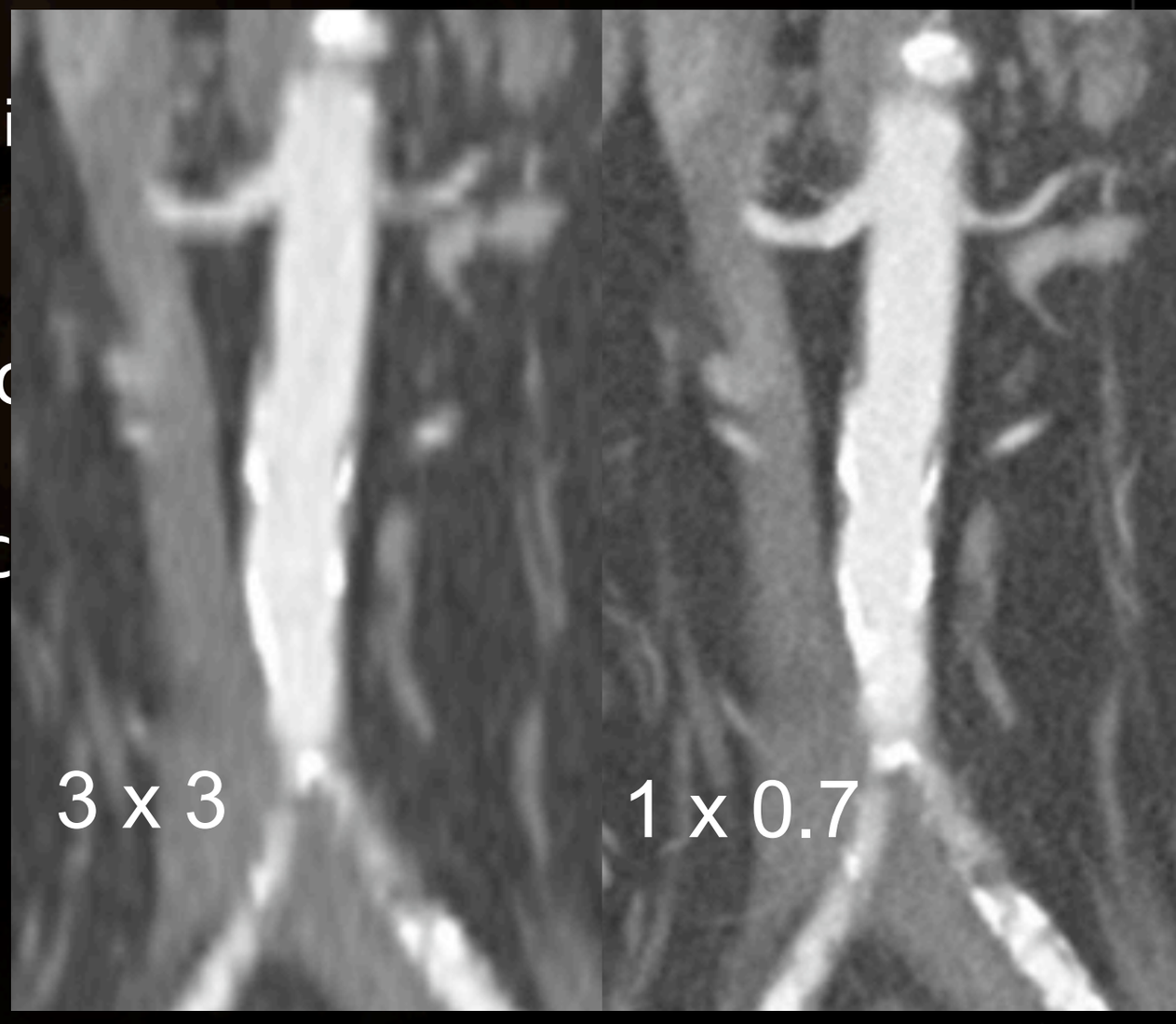

(Modifiable) Image reconstruction parameters

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Effect of changing FOV

- Standard CT image:
  - 512x512, FOV = 30 cm
  - Pixel size ~ 0.35 mm²
- Small FOV:
  - 512x512, FOV = 15 cm
  - Pixel size ~ 0.10 mm²
- BUT: "Isotropic" voxels easier to obtain at thicker slice / larger FOV

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(Modifiable) Image reconstruction parameters

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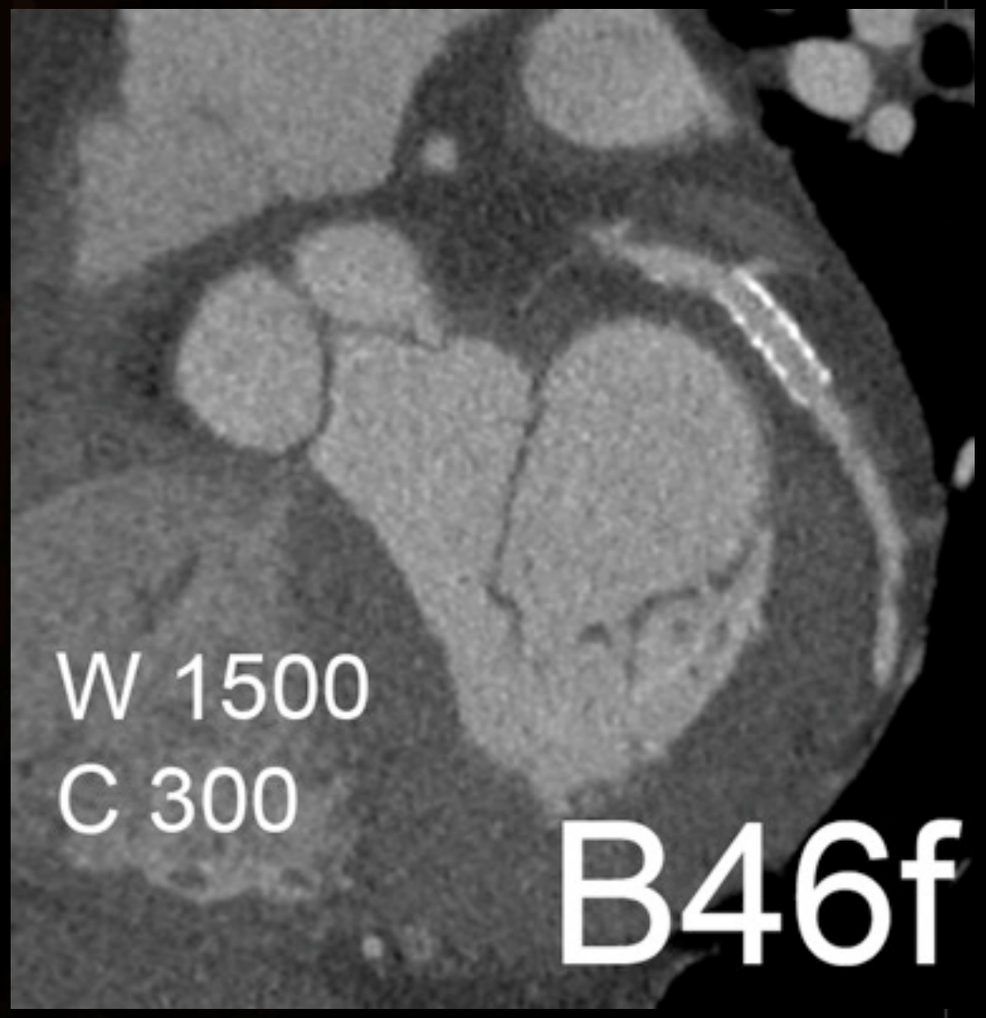
Effect of Recon Kernel

- Softer kernel: Less noise, less sharp
  - Better 3D / Multiplanar recons
- Sharper kernel: Higher detail, more noise
  - STENTS!! (coronary, peripheral)
    - Less blooming artifact



Pugliese, F. et al. Radiographics 2006;26:887-904

Image Post-Processing

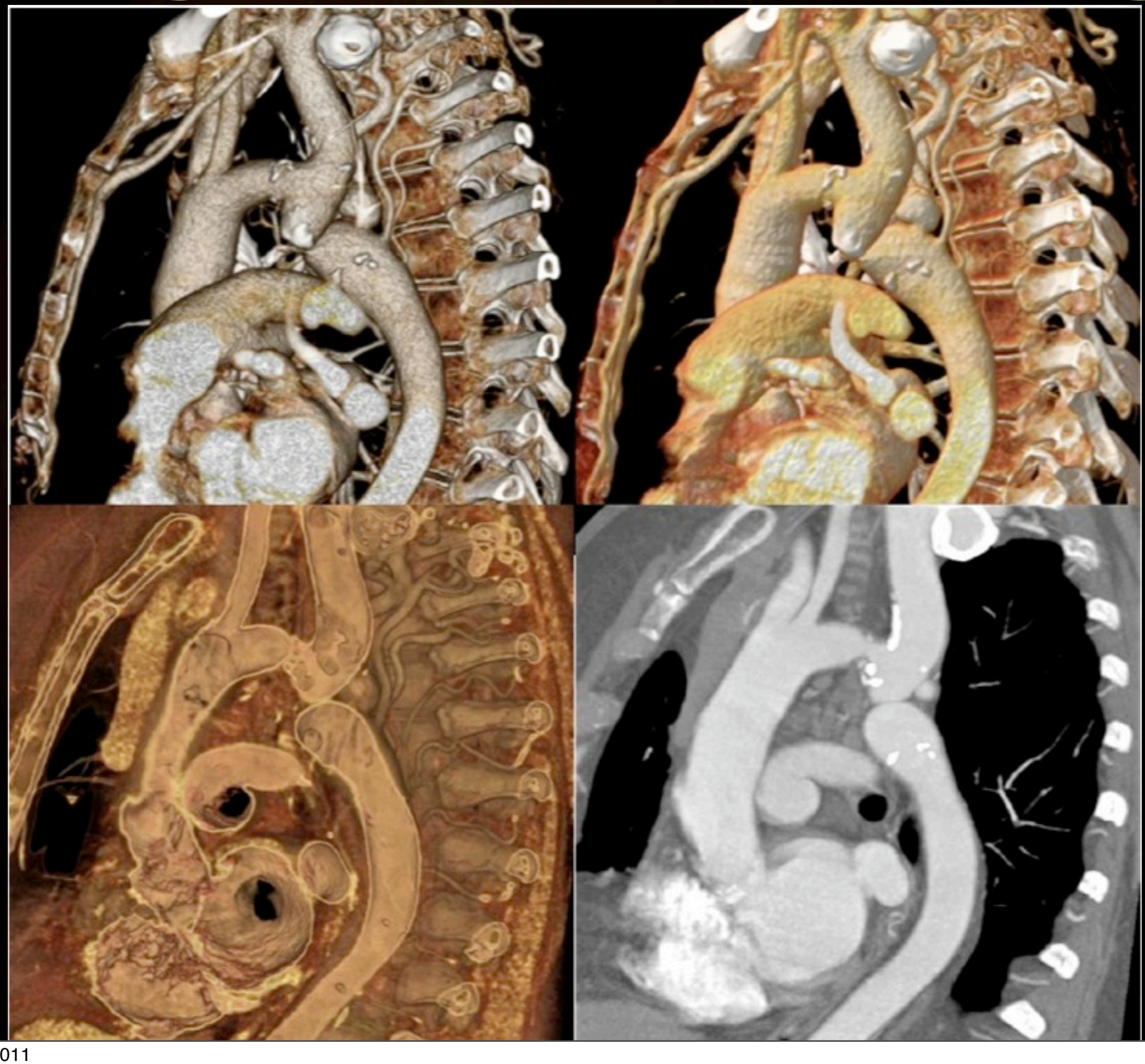
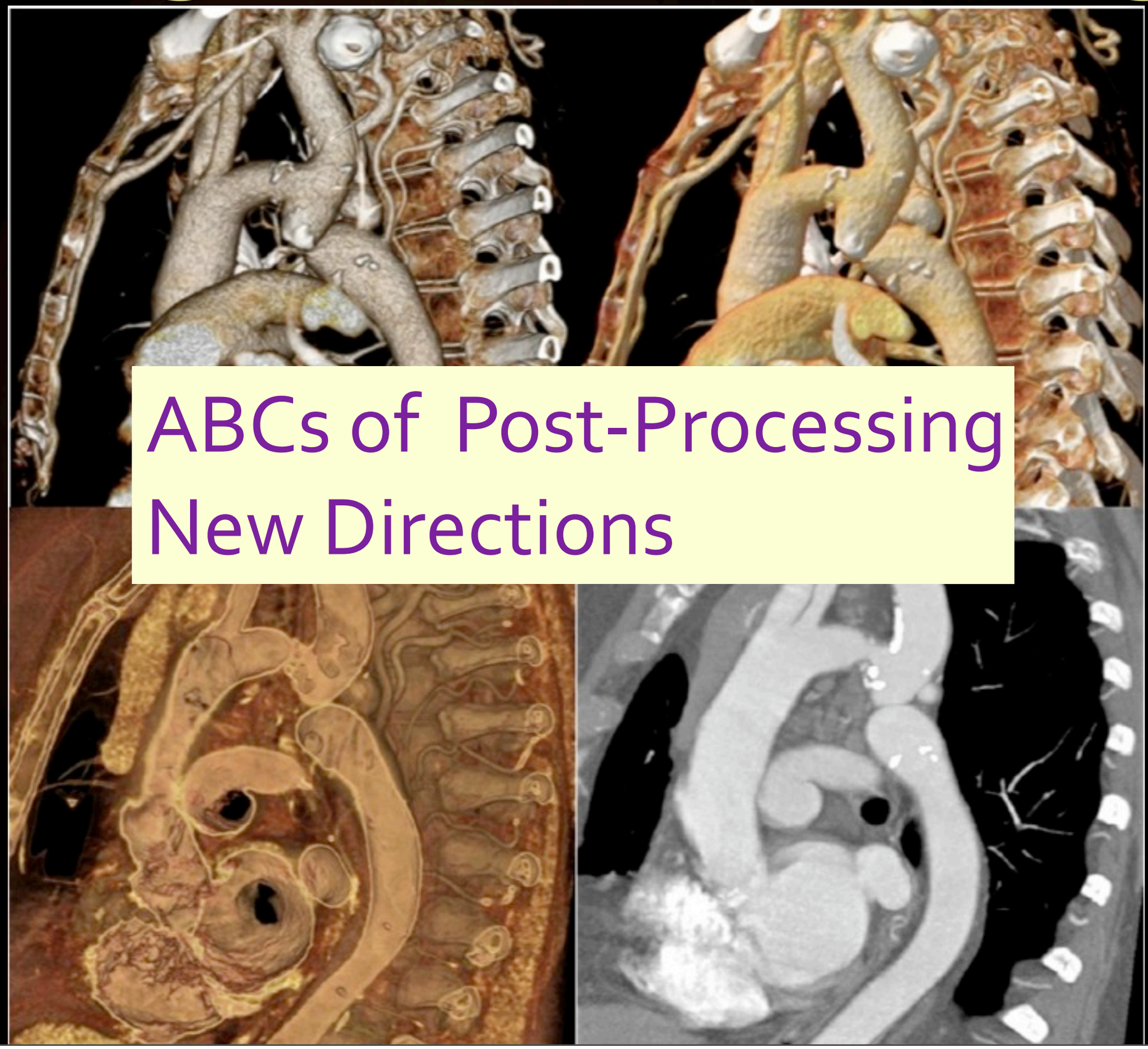
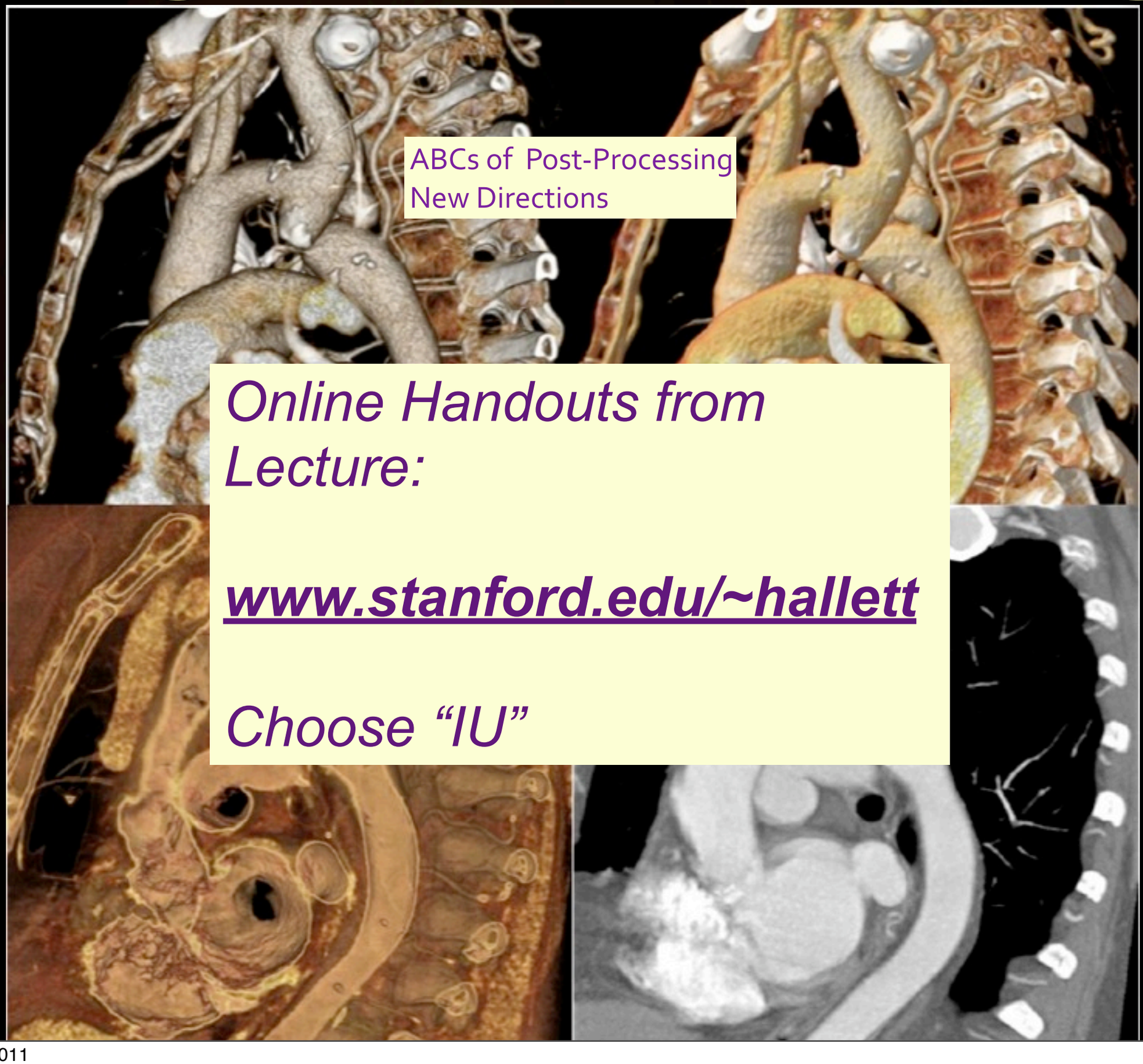


Image Post-Processing



ABCs of Post-Processing
New Directions

Image Post-Processing



Online Handouts from Lecture:

www.stanford.edu/~hallett

Choose "IU"

Post-Processing “Alphabet Soup”

ALWAYS REVIEW SOURCE DATA!!

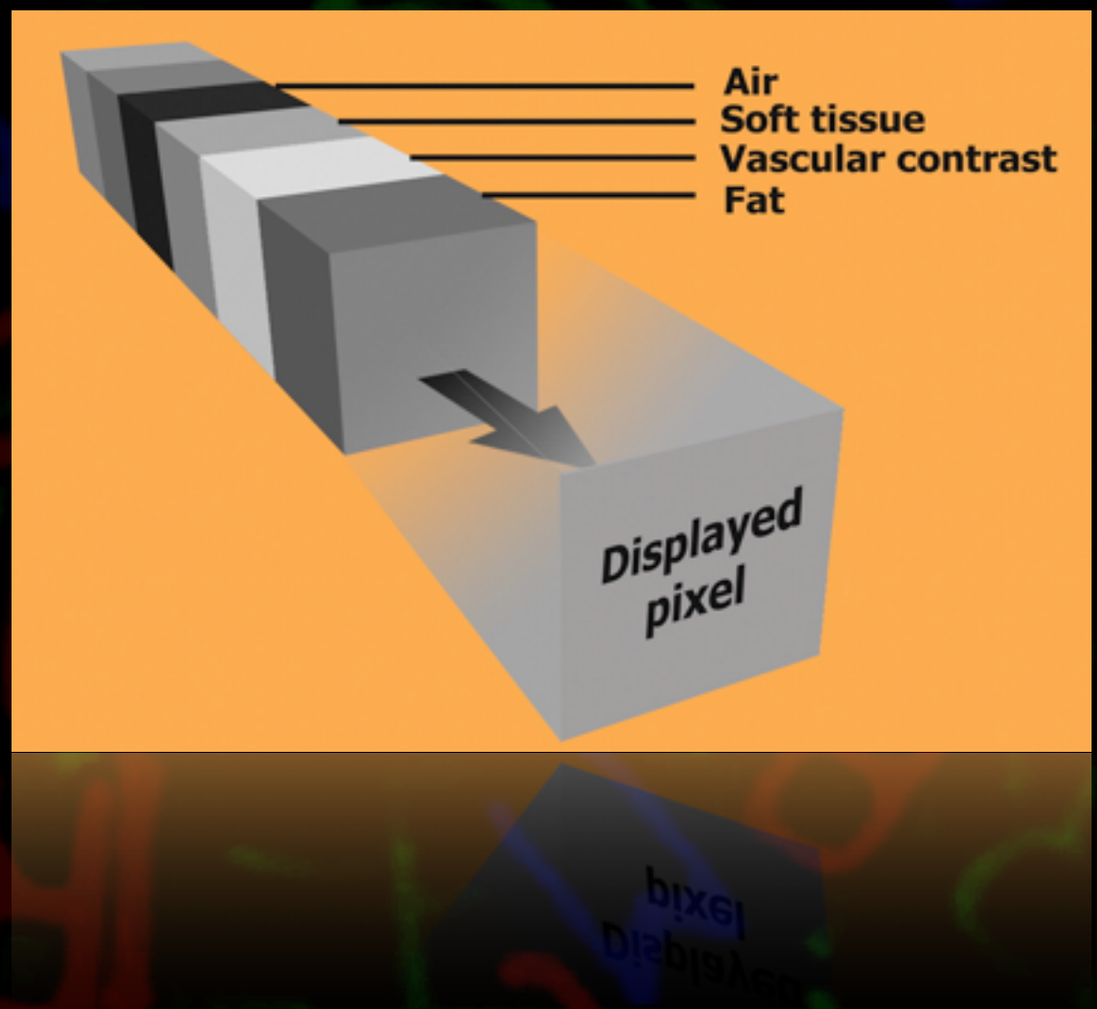
Post-Processing "Alphabet Soup"

- MPR
- MIP
- MINIP
- AIP (Raysum)
- CPR
- MP-CPR
- VR
- V-IVUS
- 4-D

ALWAYS REVIEW SOURCE DATA!!

Multi - Planar Reconstruction (MPR)

- A slice of nominal thickness (one voxel)
- *Average pixel value* along the ray
- **BUT:** Only includes a small amount of the scan data, and vessels are curved structures
- USES:
  - Stenosis Measurement
  - Nodule measurement
  - Orthogonal measurements



EXAMPLE: MPR - Orthogonal Measurements

- Axial measurements not as precise nor as reproducible as orthogonal measurements

- TIP: Rotate crosshairs perpendicular in 2 planes → 3rd is orthogonal!!
  - Can also auto generate from centerlines

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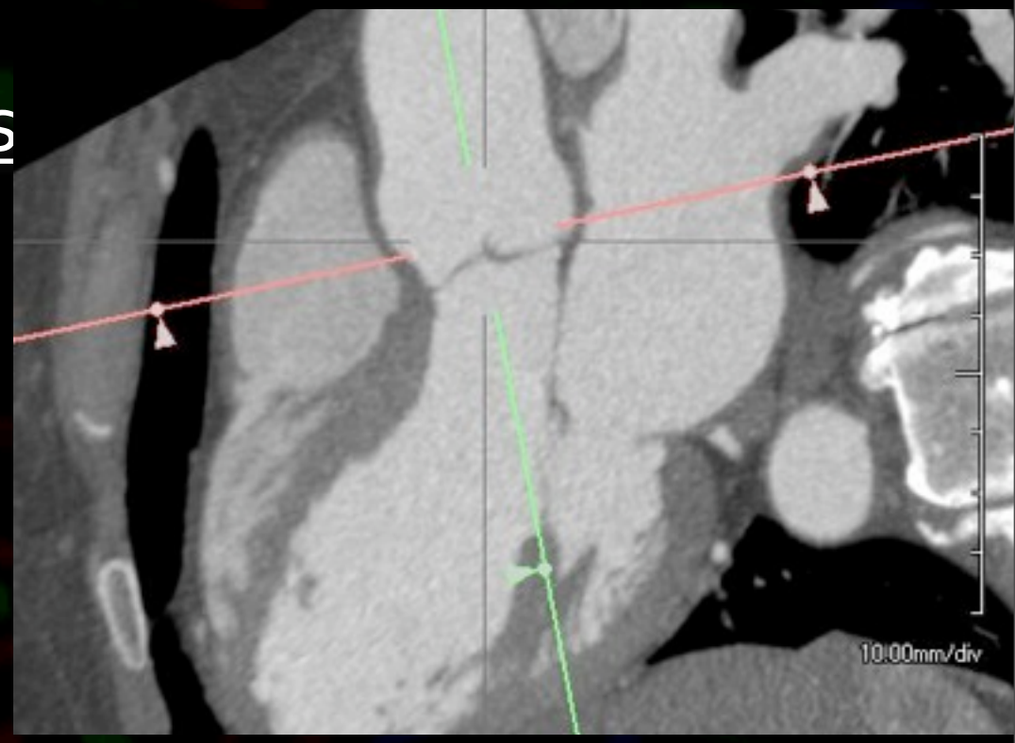

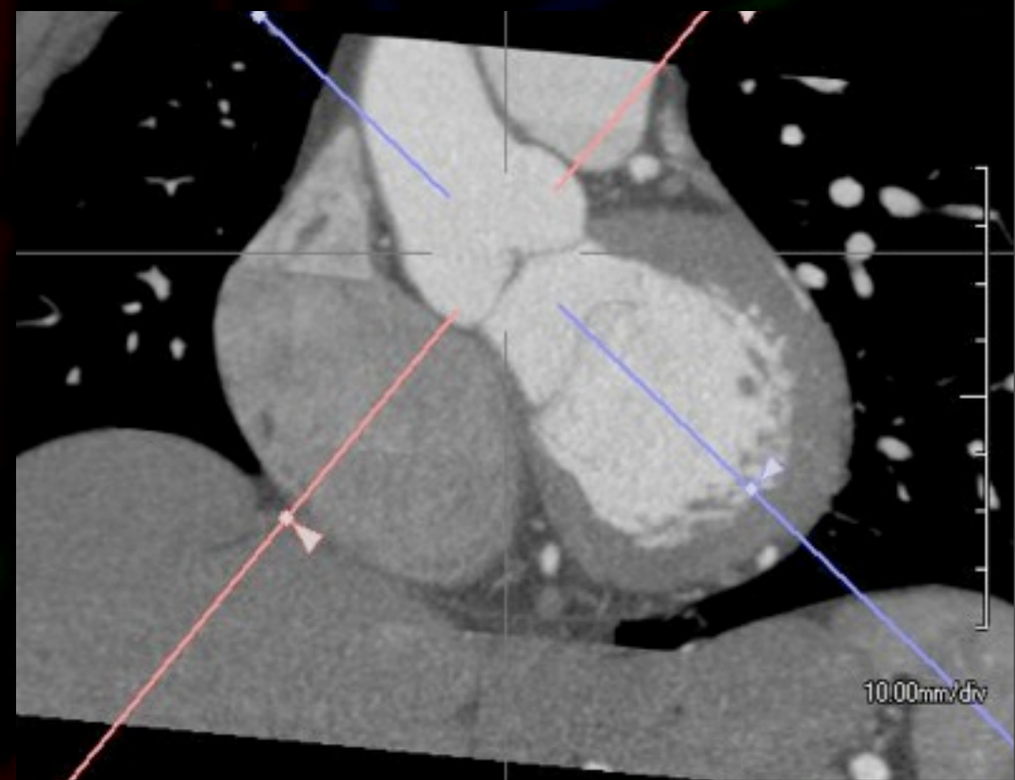

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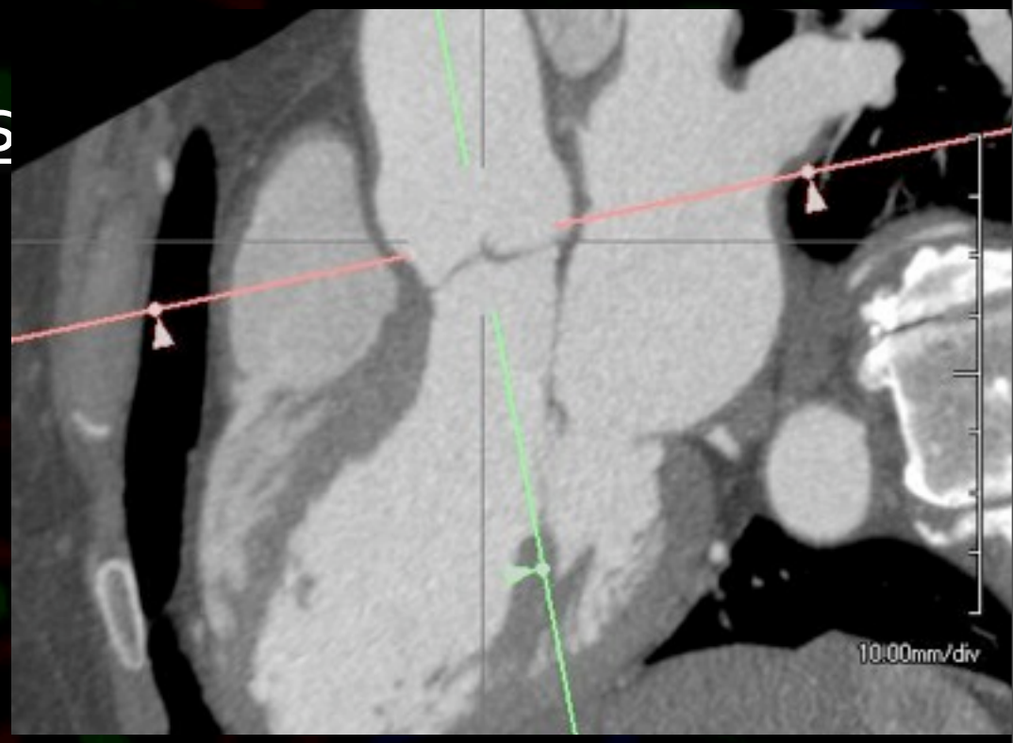
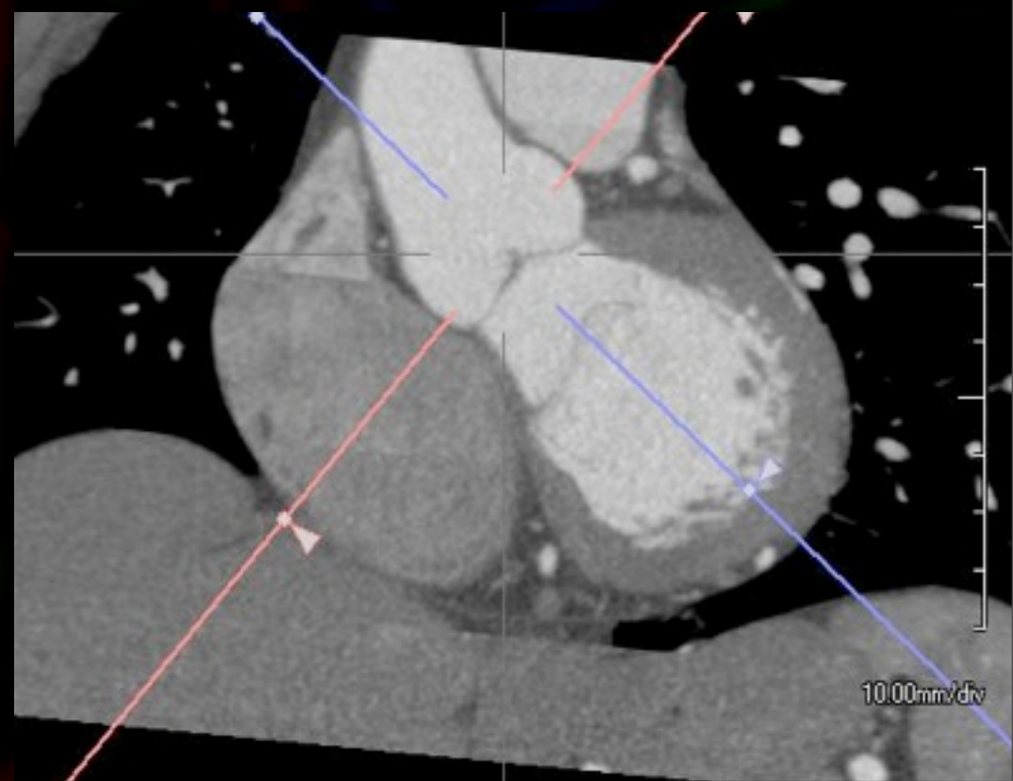
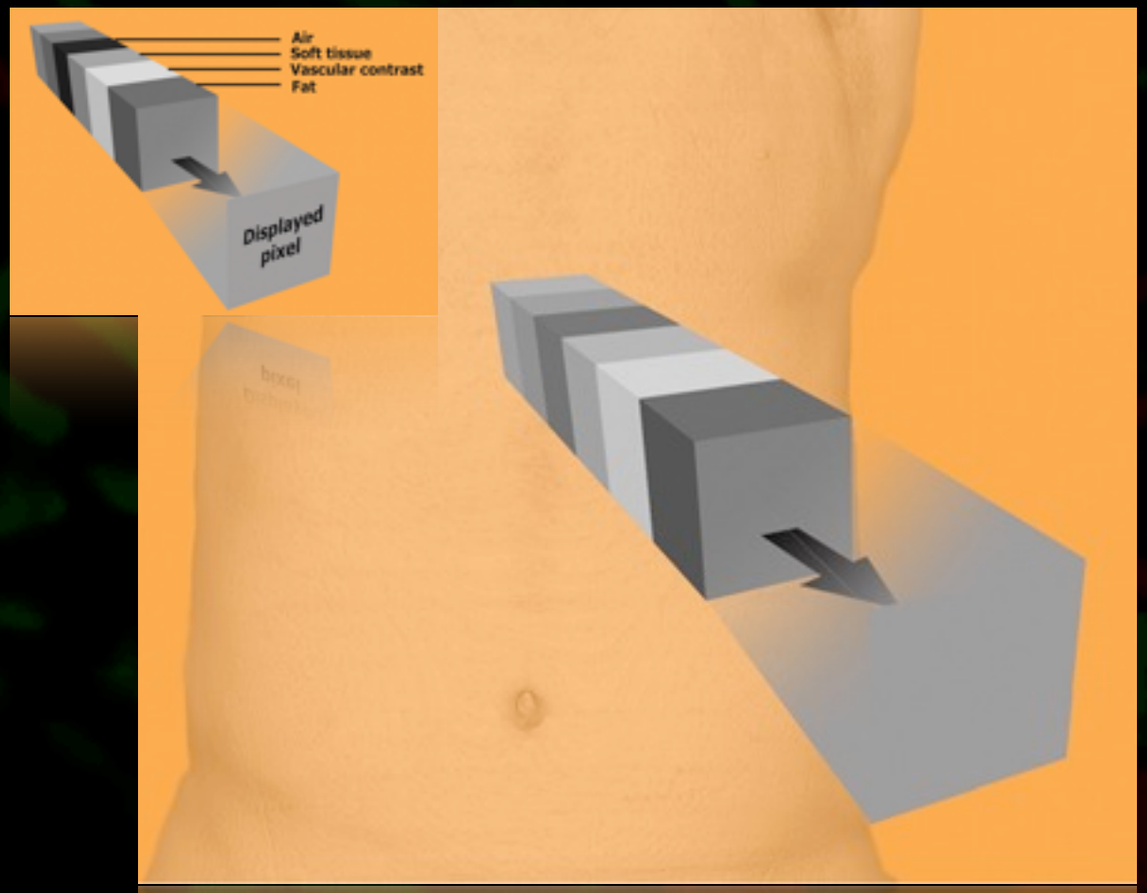




Average Intensity Projection (AIP)

= “Thick MPR”, “Raysum”



Dalrymple, N. C. et al. Radiographics 2005;25:1409-1428

- Average intensity along ray
- Decreased noise vs. MIP and MINIP
- Decreased edge detail
- Good to “salvage” studies when primary recons have too much noise

10 mm MIP

10 mm AIP

10 mm MIP

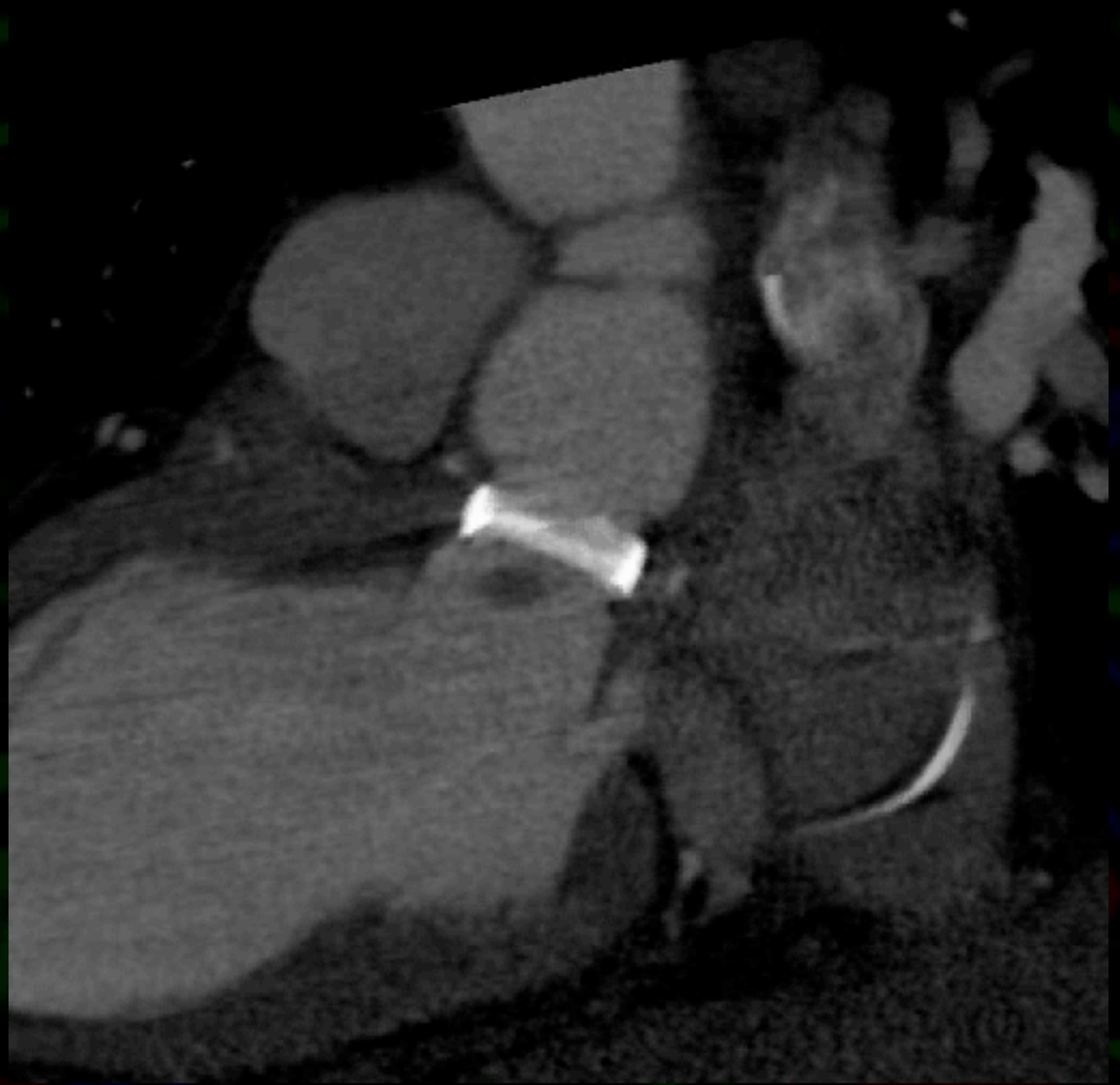
10 mm AIP

Noise

Detail

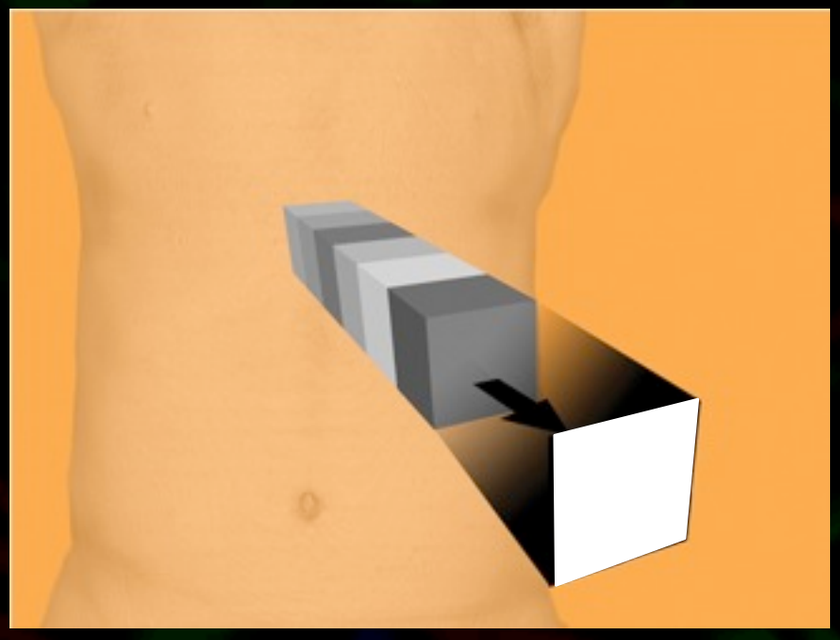
360 lb patient, non-Dx Echo Thick MPR Cine 4D

360 lb patient, non-Dx Echo Thick MPR Cine 4D



Maximum Intensity Projection (MIP)

- Voxel along ray with maximal HU value displayed
- Vessel/background contrast ↑
- Details are better seen



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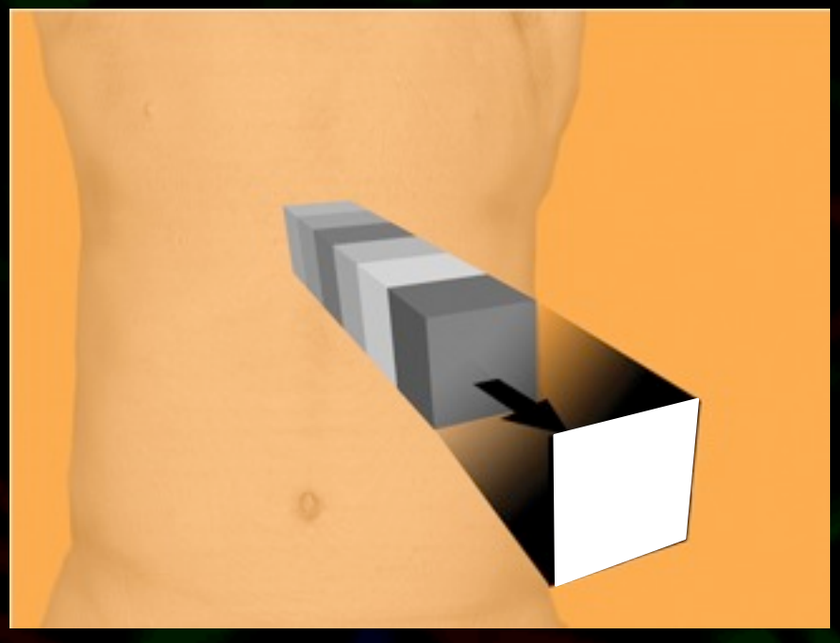
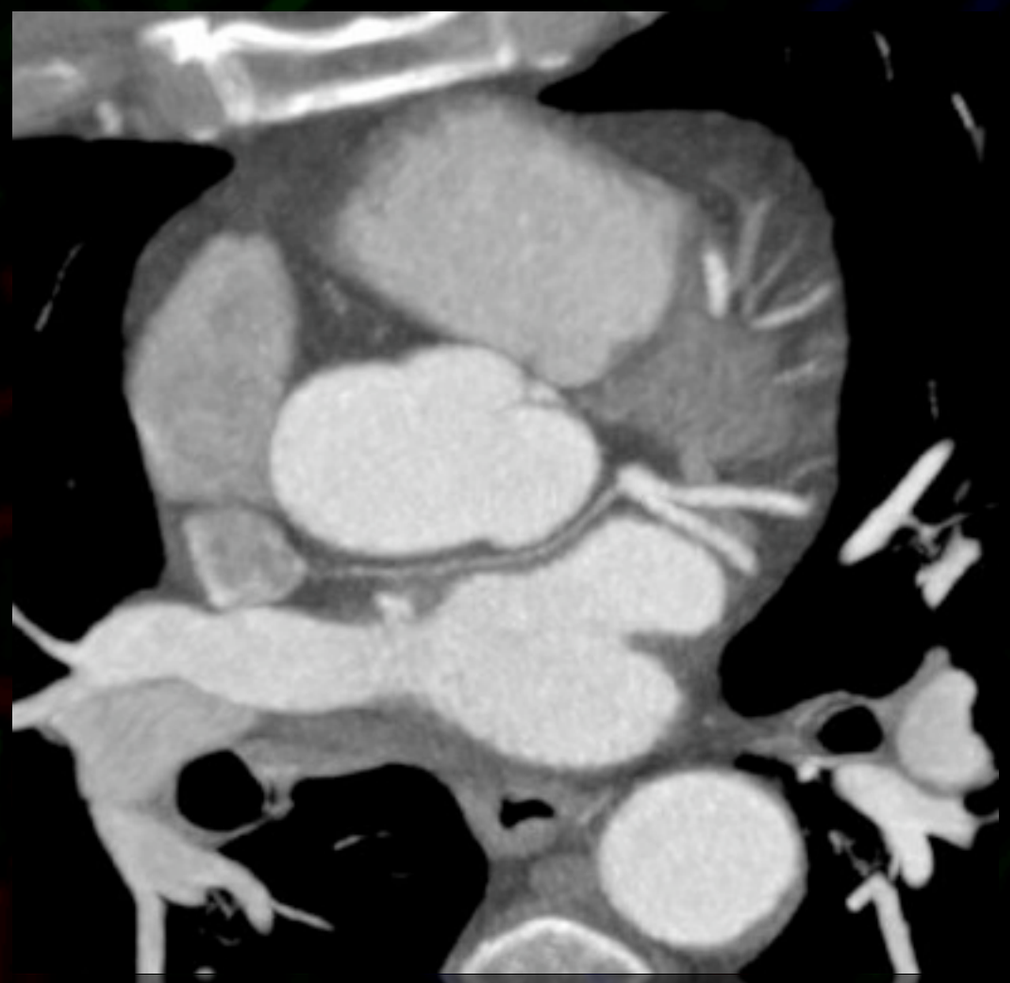


3 mm MIP



MIP Limitations

- Overlap:
  - Bones / Metallic clips
  - Vascular Calcium
- Intra-luminal defects may not be visible
- Noise (additive)
- Overestimation of stenosis
  - from background noise, W/L

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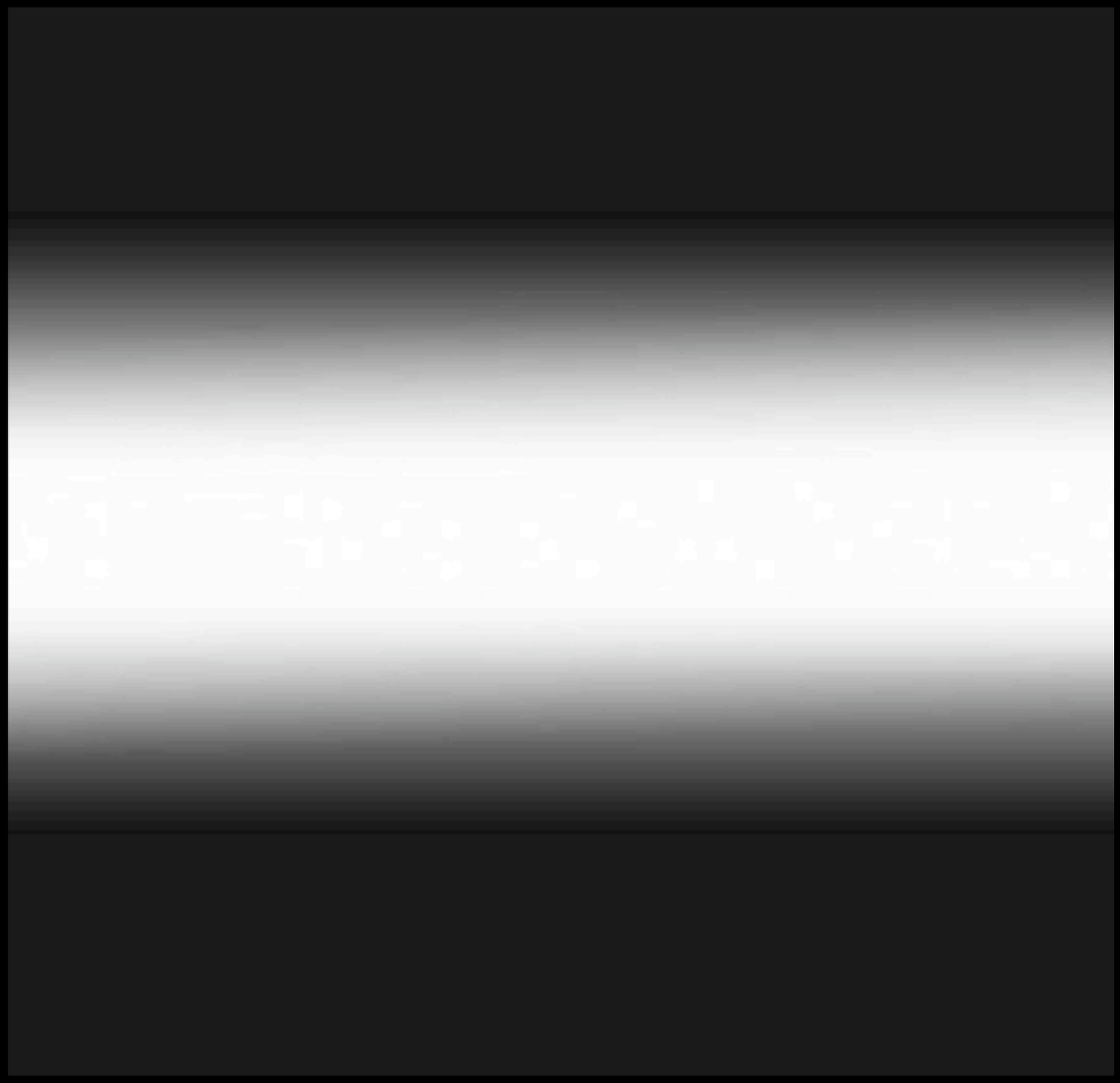
Caveat for MIP: Effect of Background Noise on apparent stenosis



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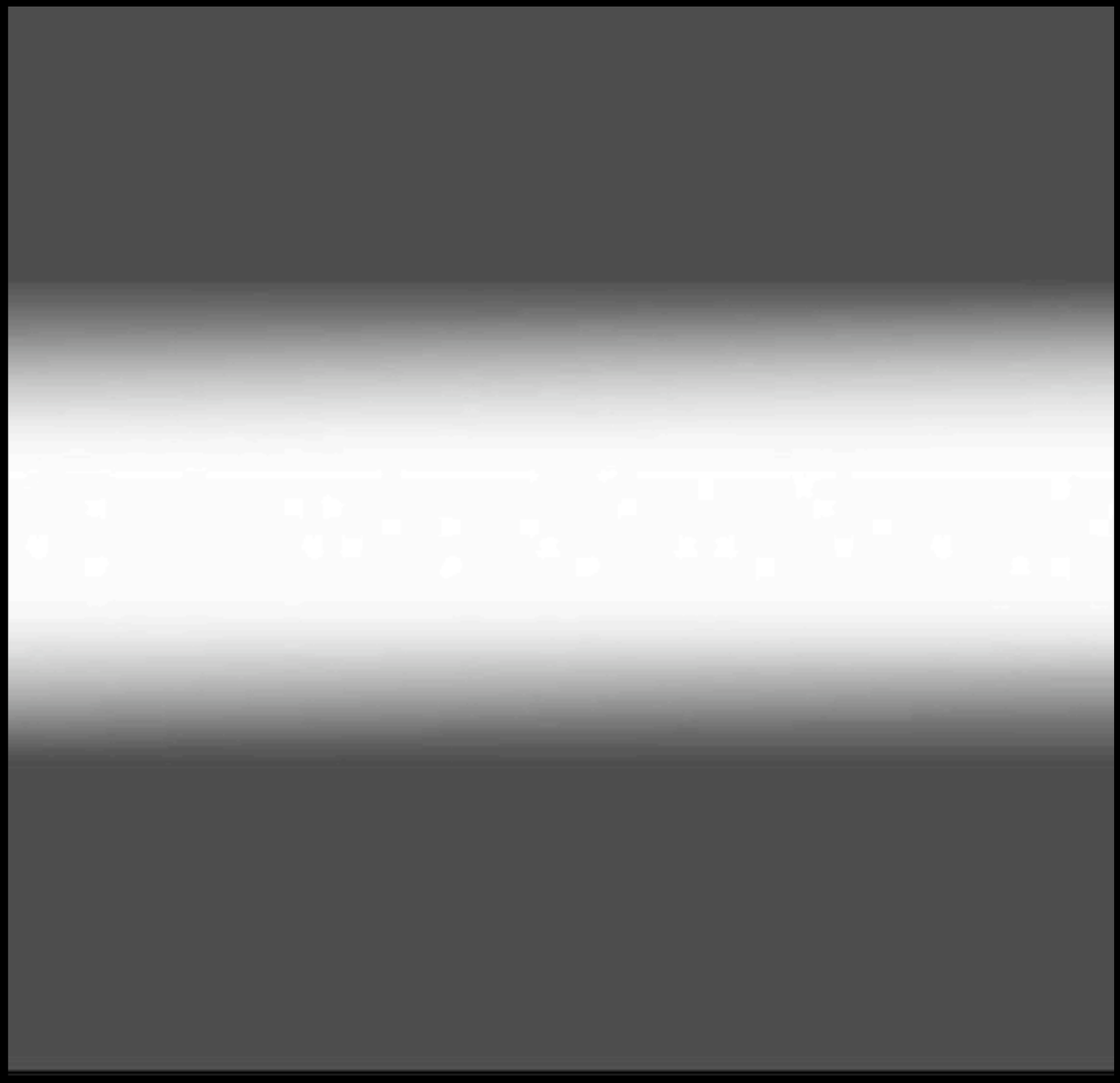

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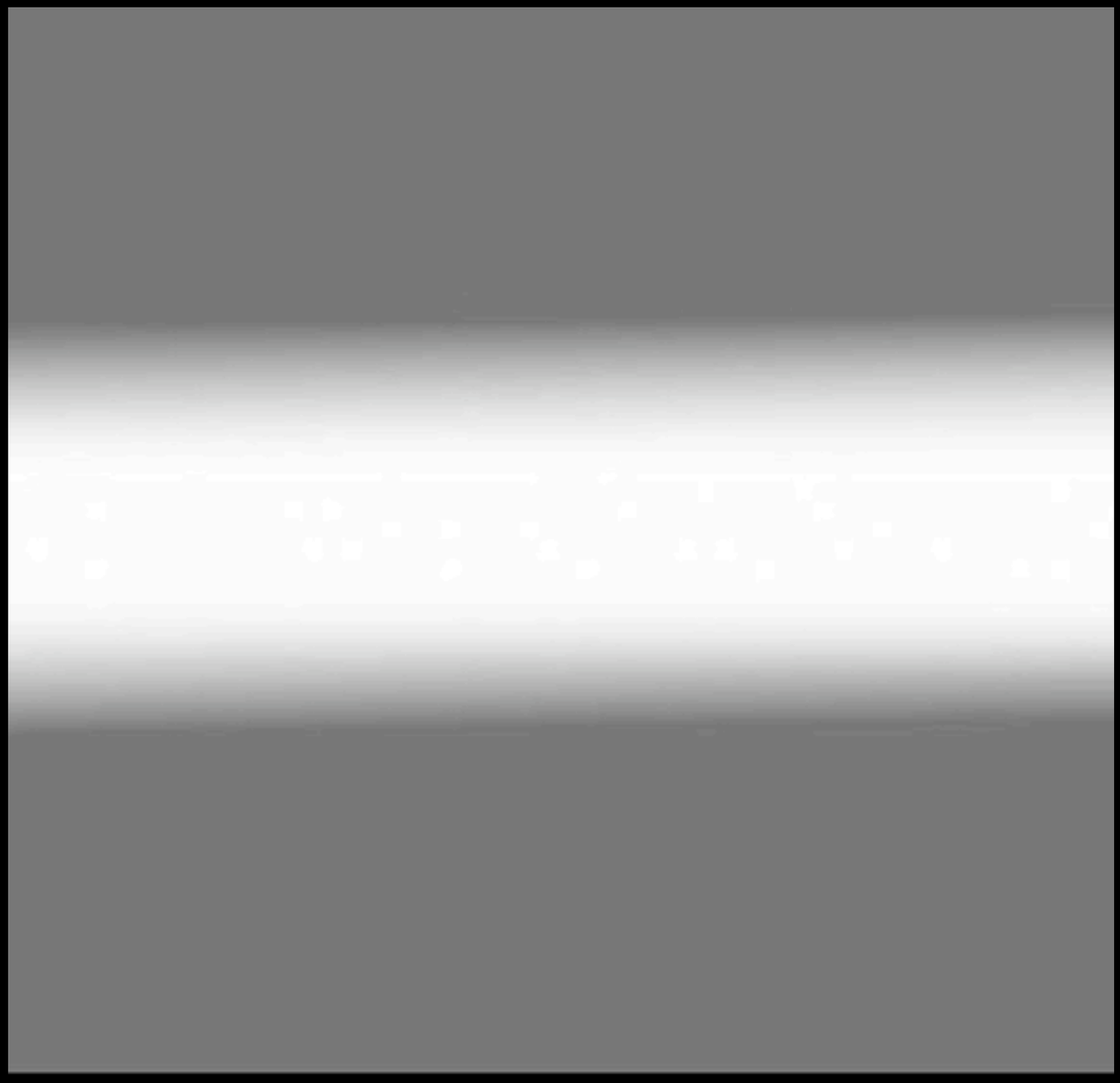
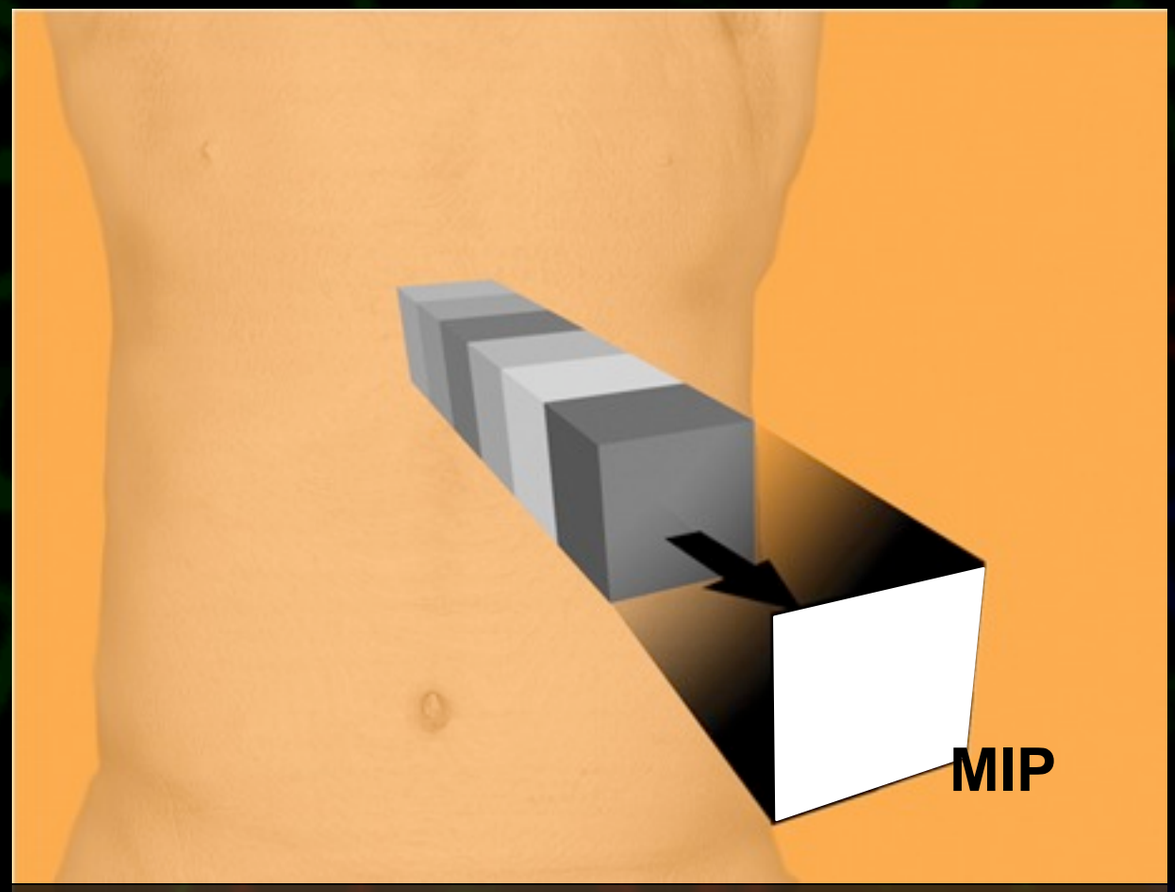
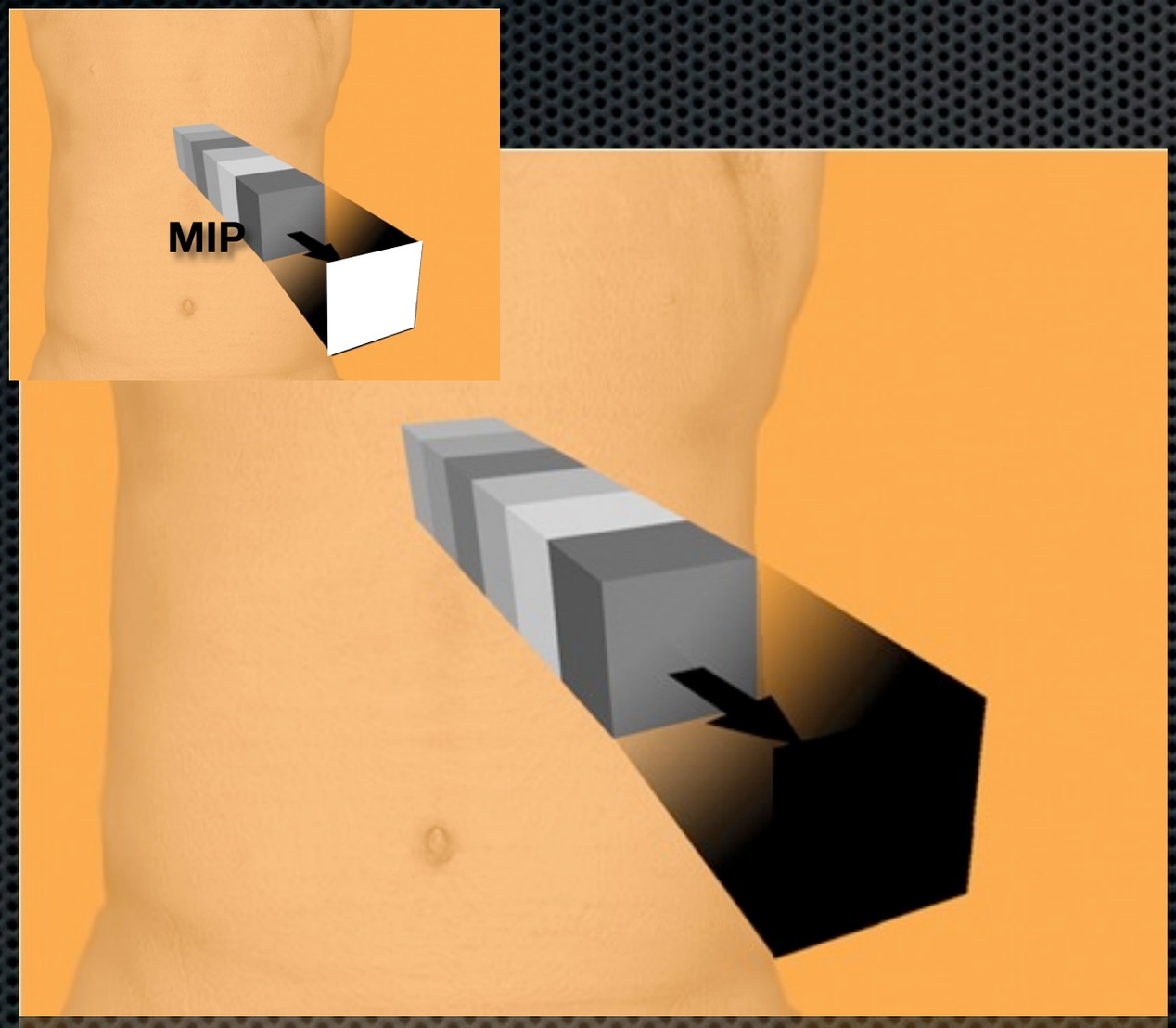


MIP has a cousin.....



Minimum Intensity Projection (MinIP)



Like MIP, but minimum voxel value along ray depicted

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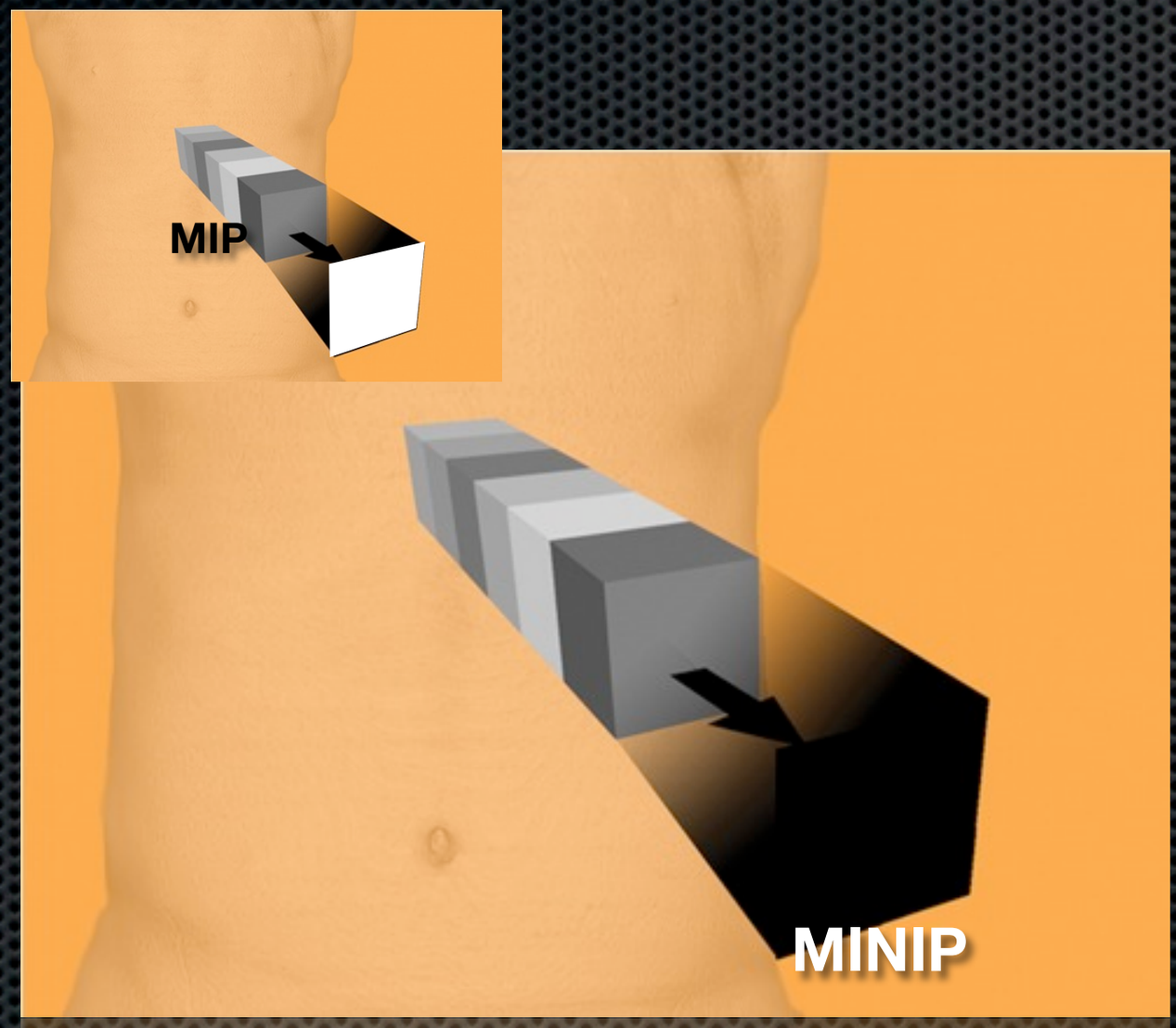

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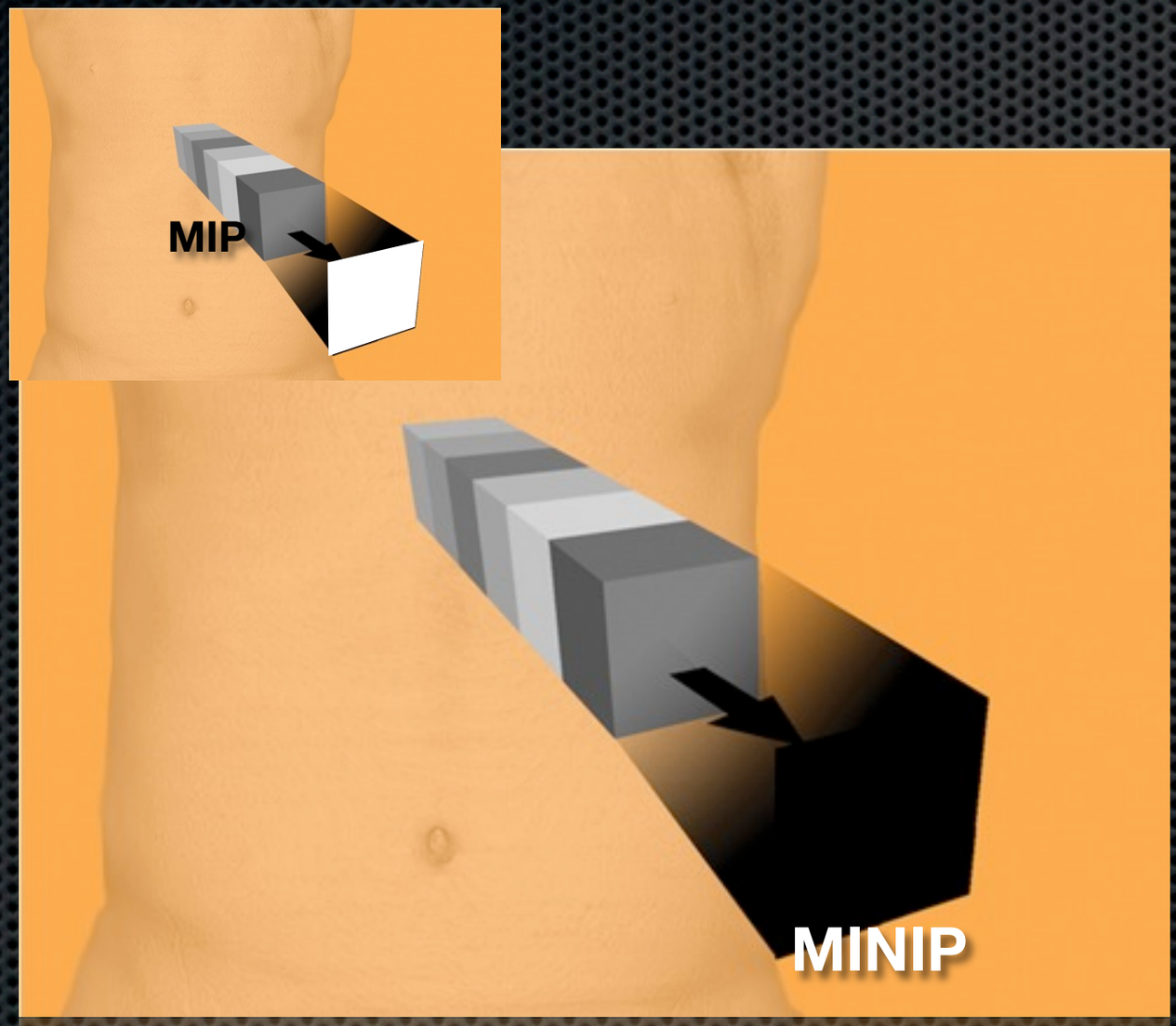

Uses:

Lungs

Central airways, air trapping

Cardiac Valves

≤5 mm slab; 4D review

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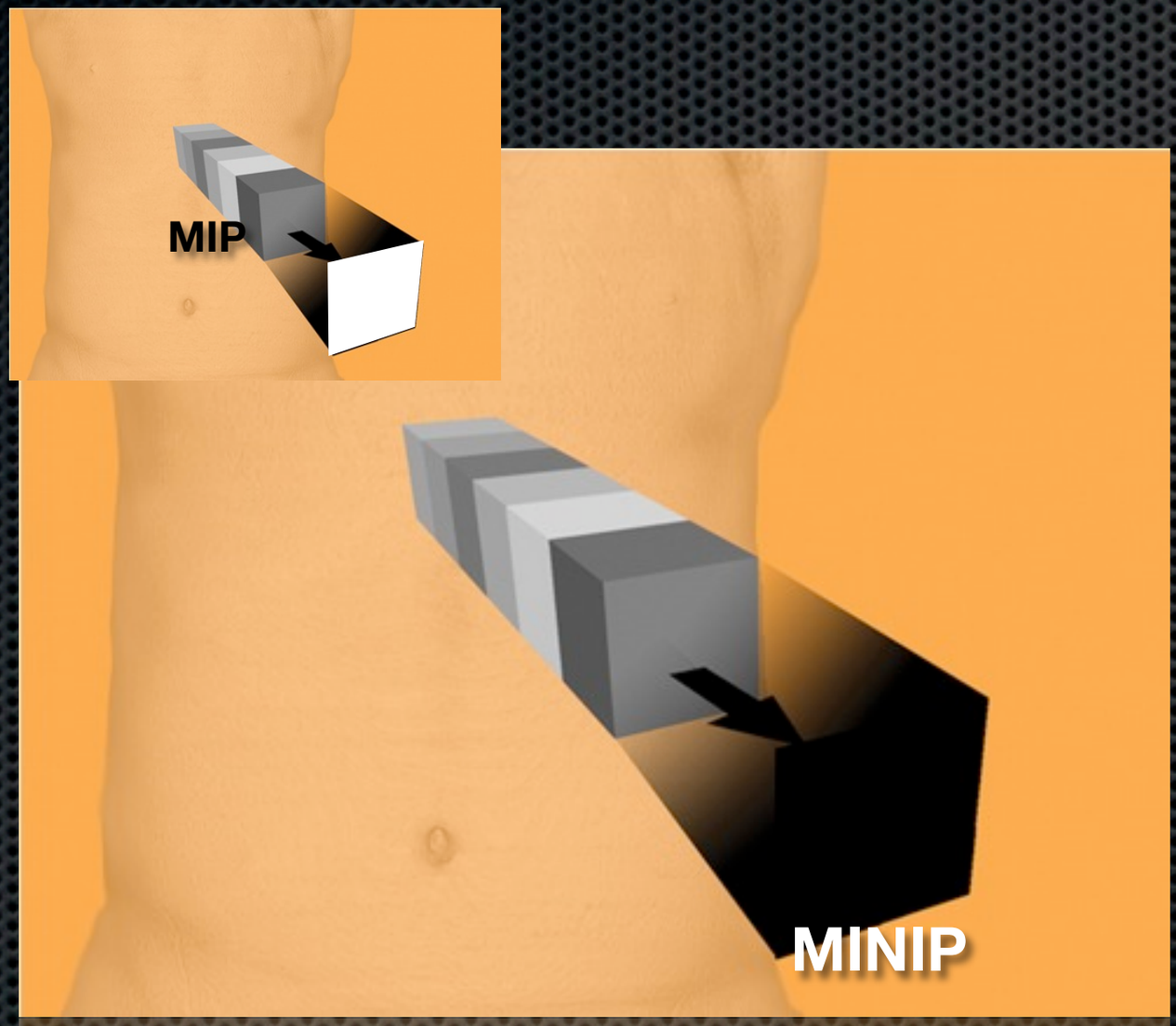

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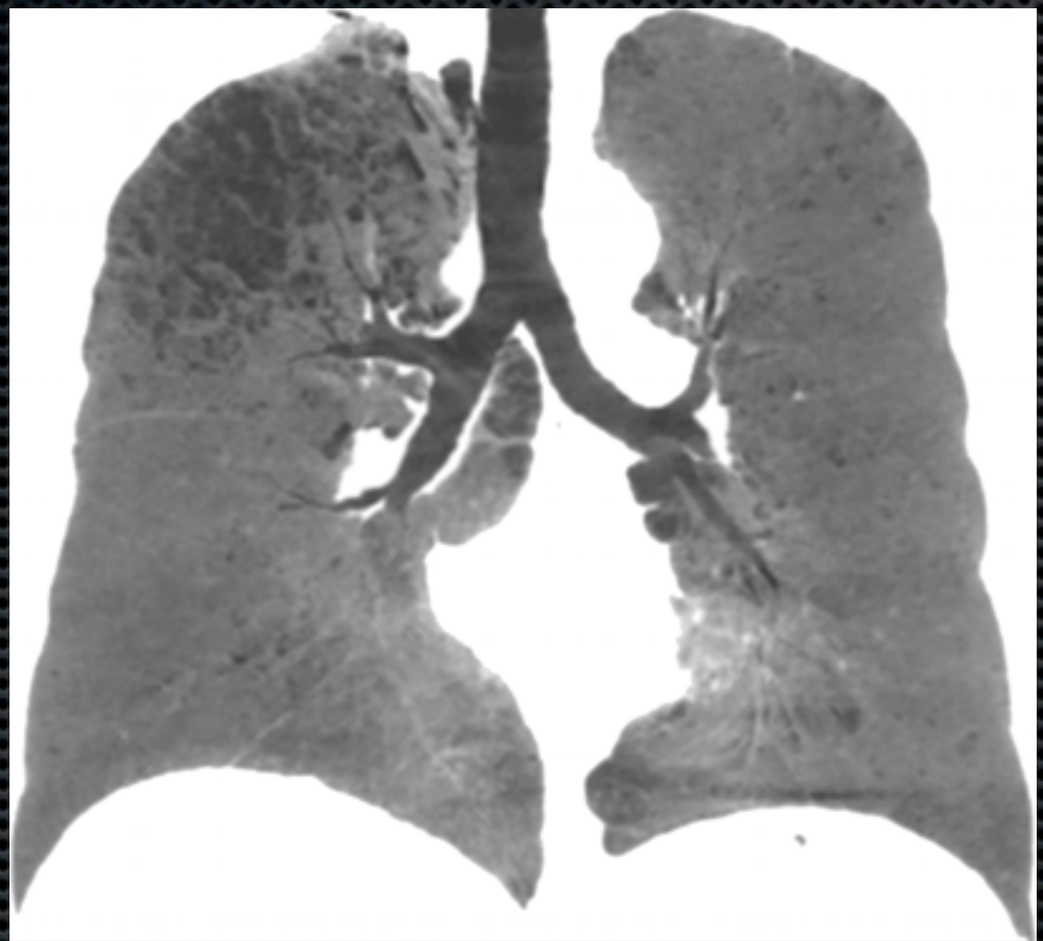

20 mm MINIP

Uses:

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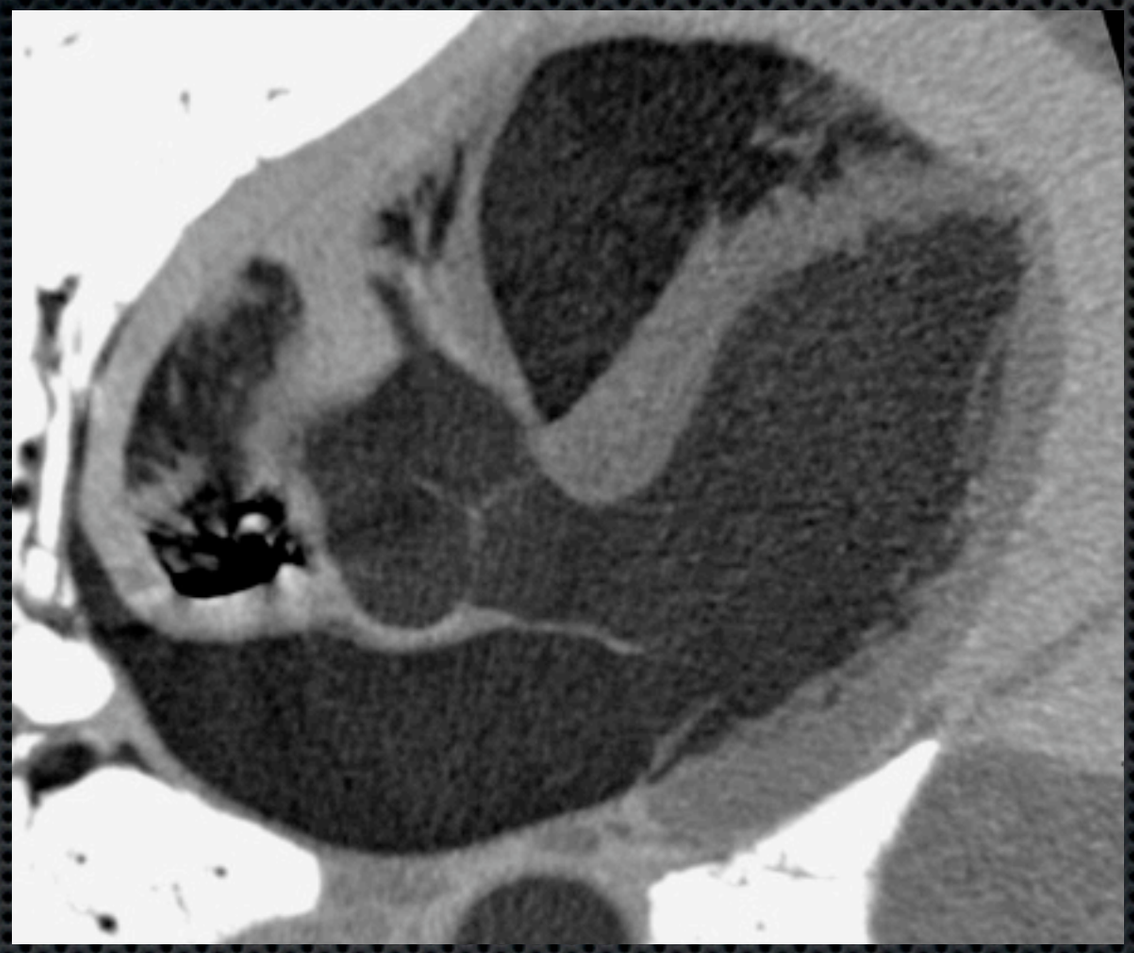

2 mm MINIP INVERSE

Uses:

Lungs

Central airways, air trapping

Cardiac Valves

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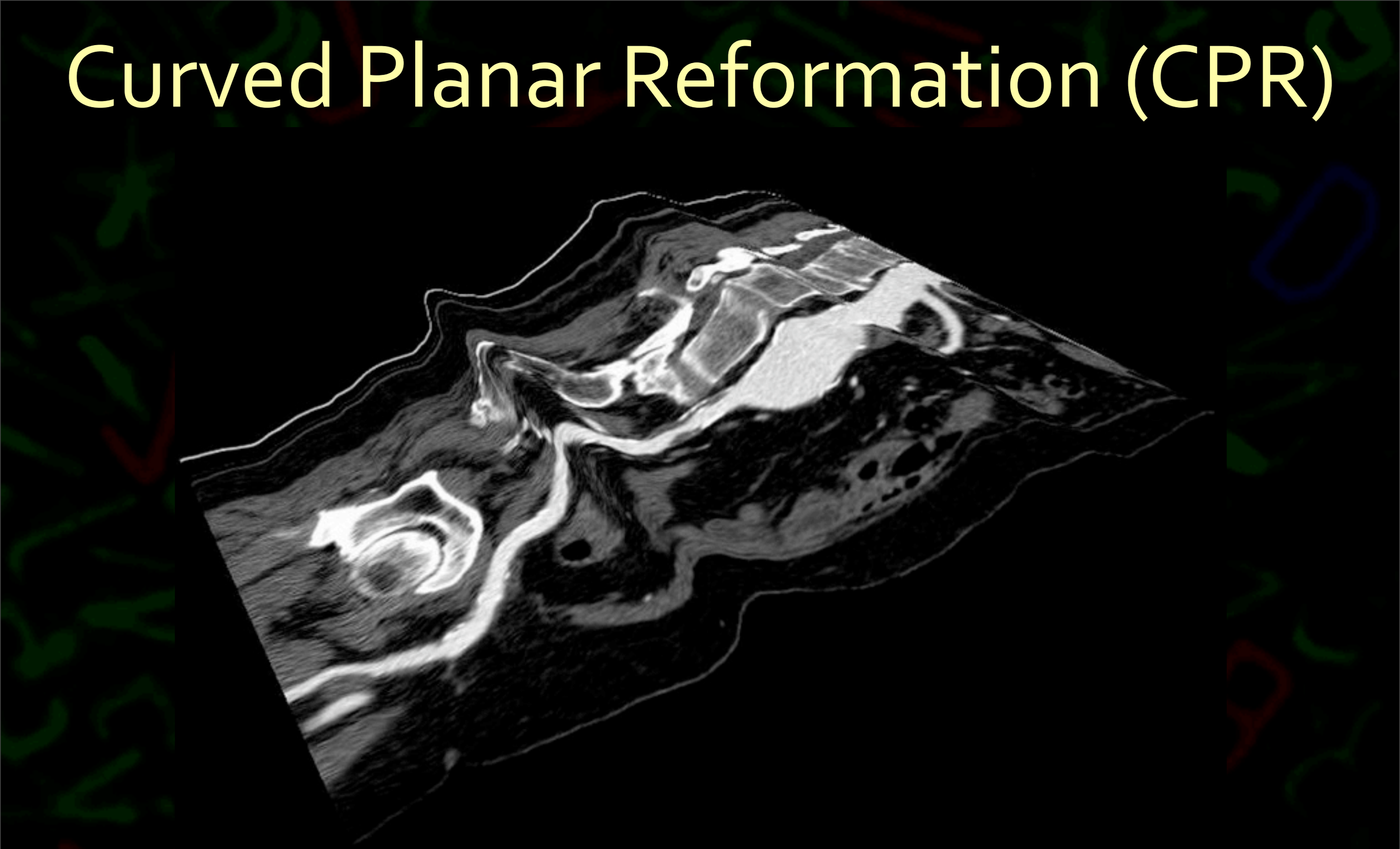
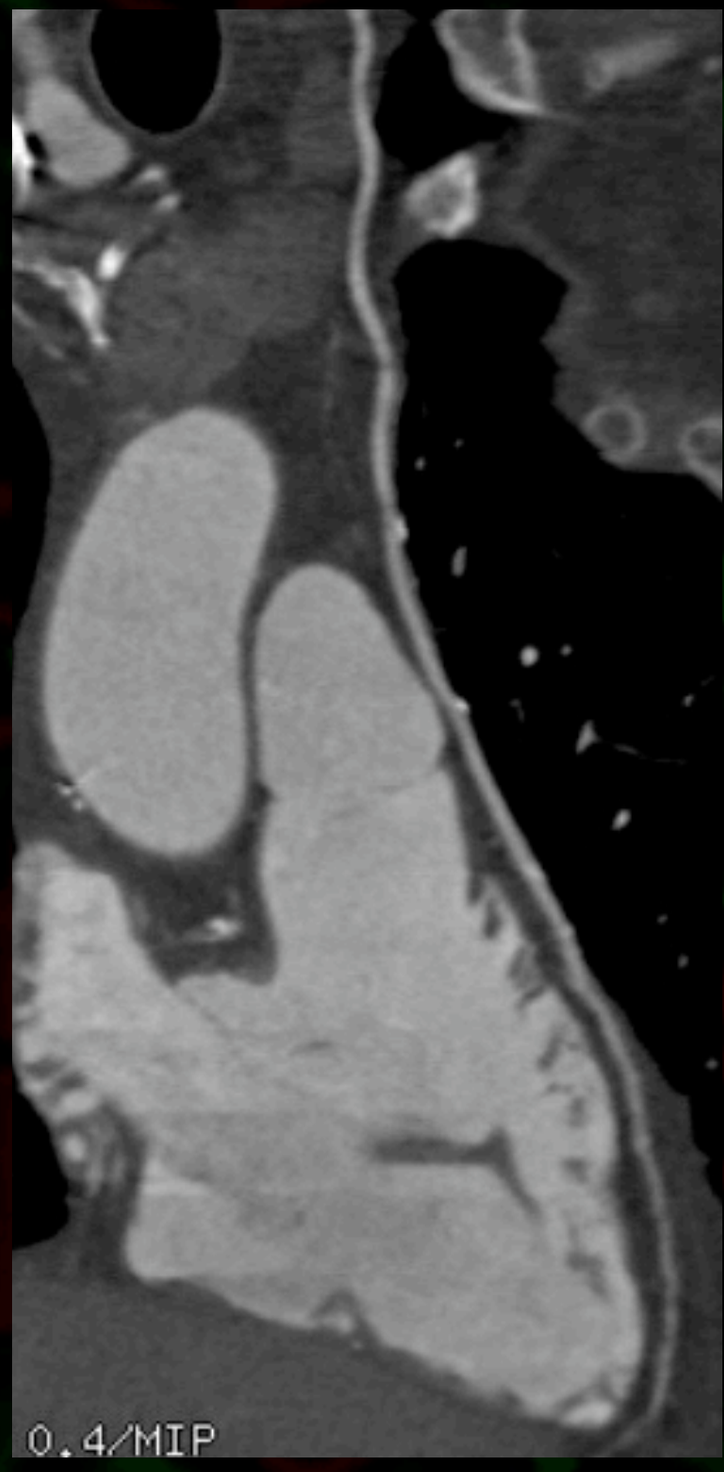
Curved Planar Reformation (CPR)



CPR = Curved MPR

- MPR generated along an arbitrary (**curved**) line
  - Usually a vessel centerline
  - get WHOLE VESSEL in a single plane
- Best to evaluate wall abnormalities along long segments of vessels:
  - Stents
  - Calcium
  - Soft plaque
  - Ulcers



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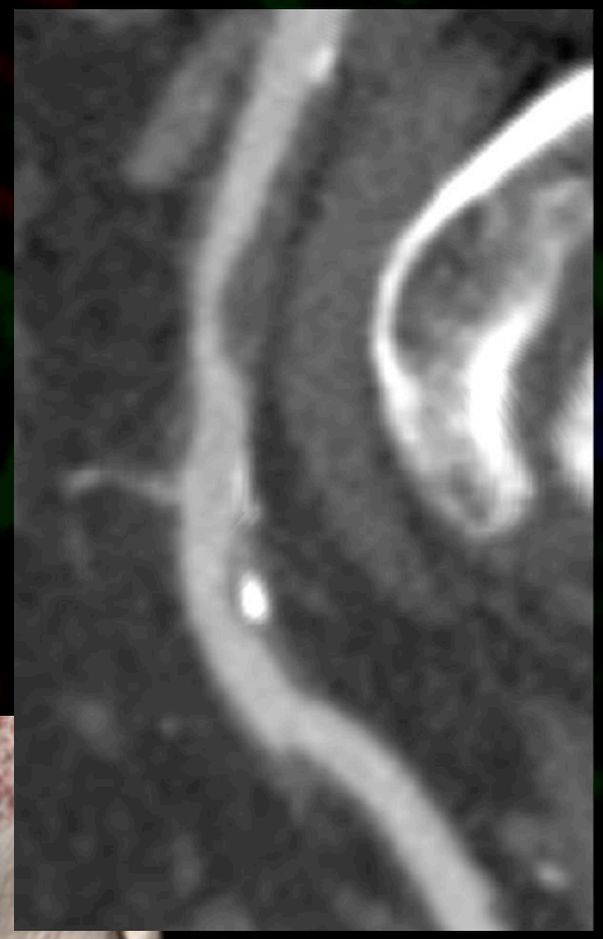
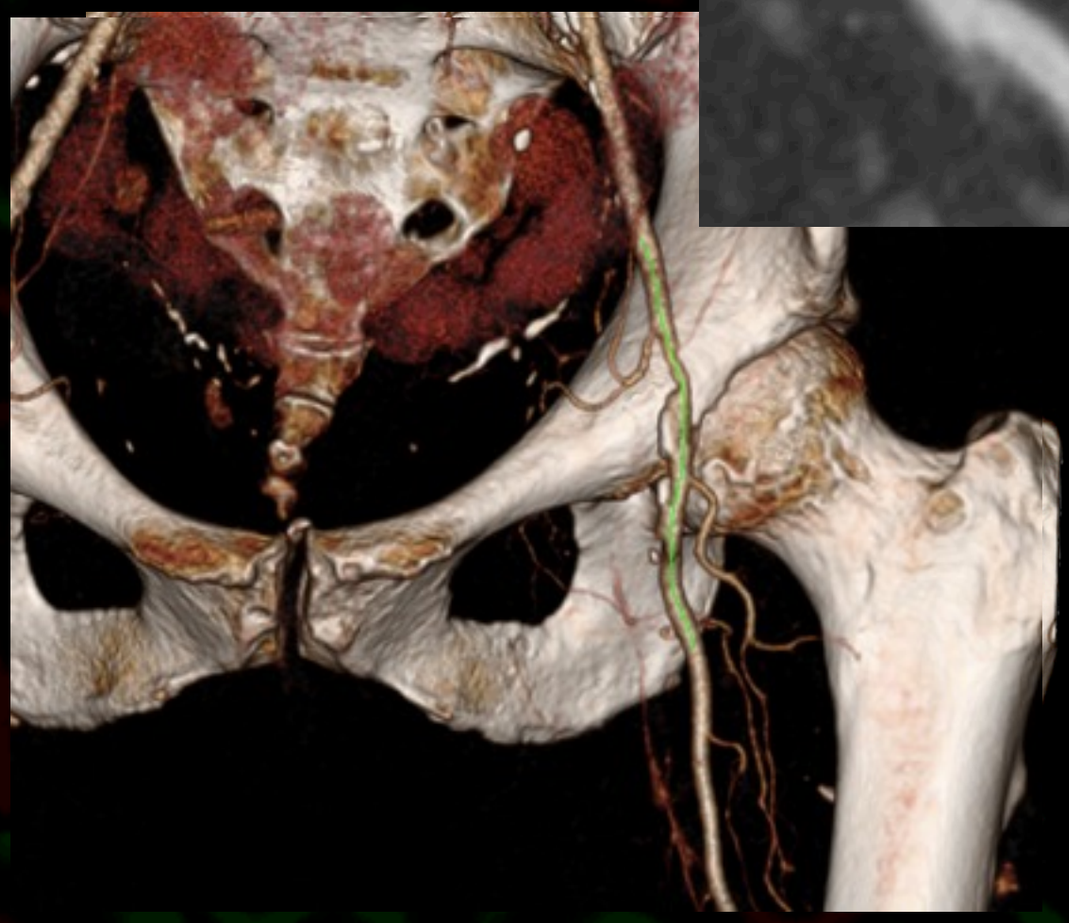
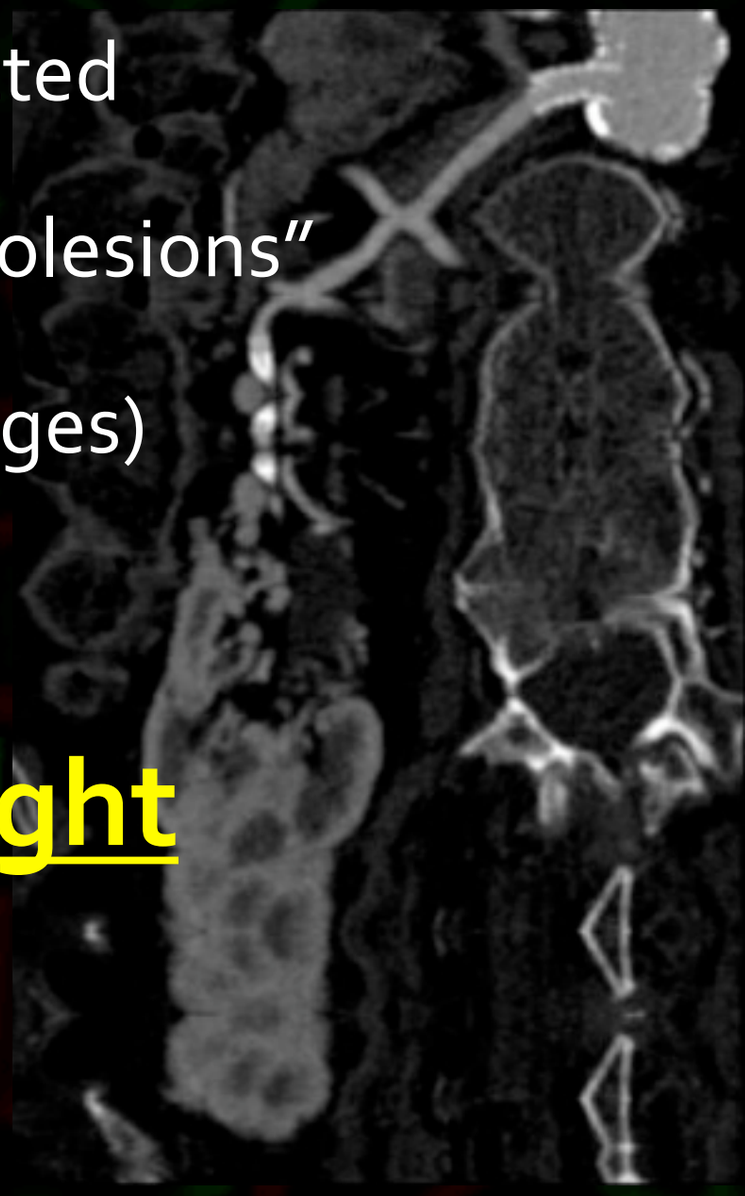




Curved MPR Limitations

- Information limited to plane reconstructed
- Bizarre anatomic relationships , “pseudolesions”
- Cannot be used alone (need source images)
- Time consuming if manual generation
- **<u>Still needs RT / MD oversight</u>**



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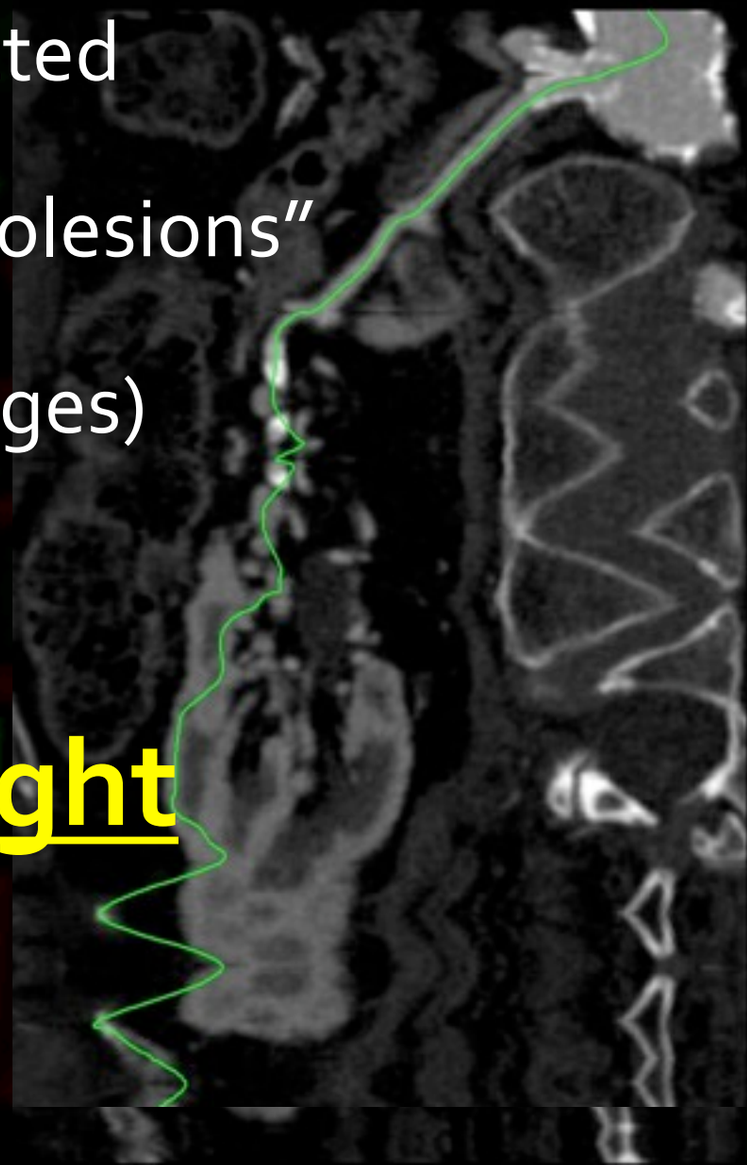

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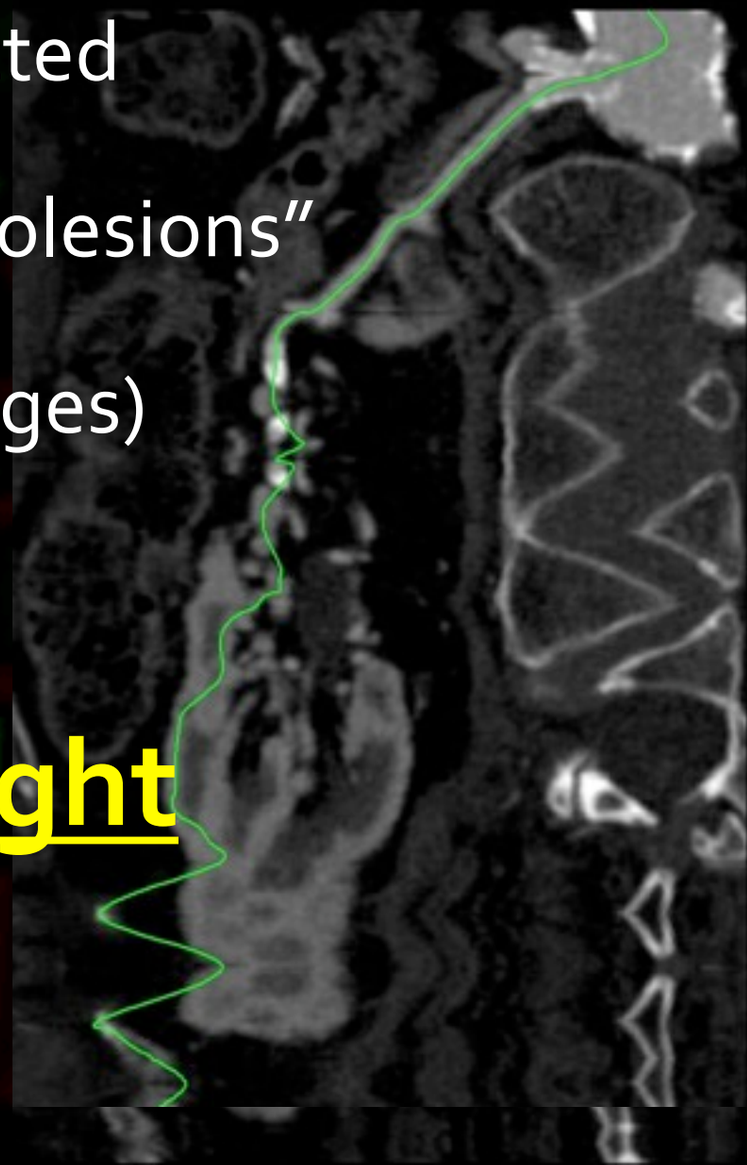
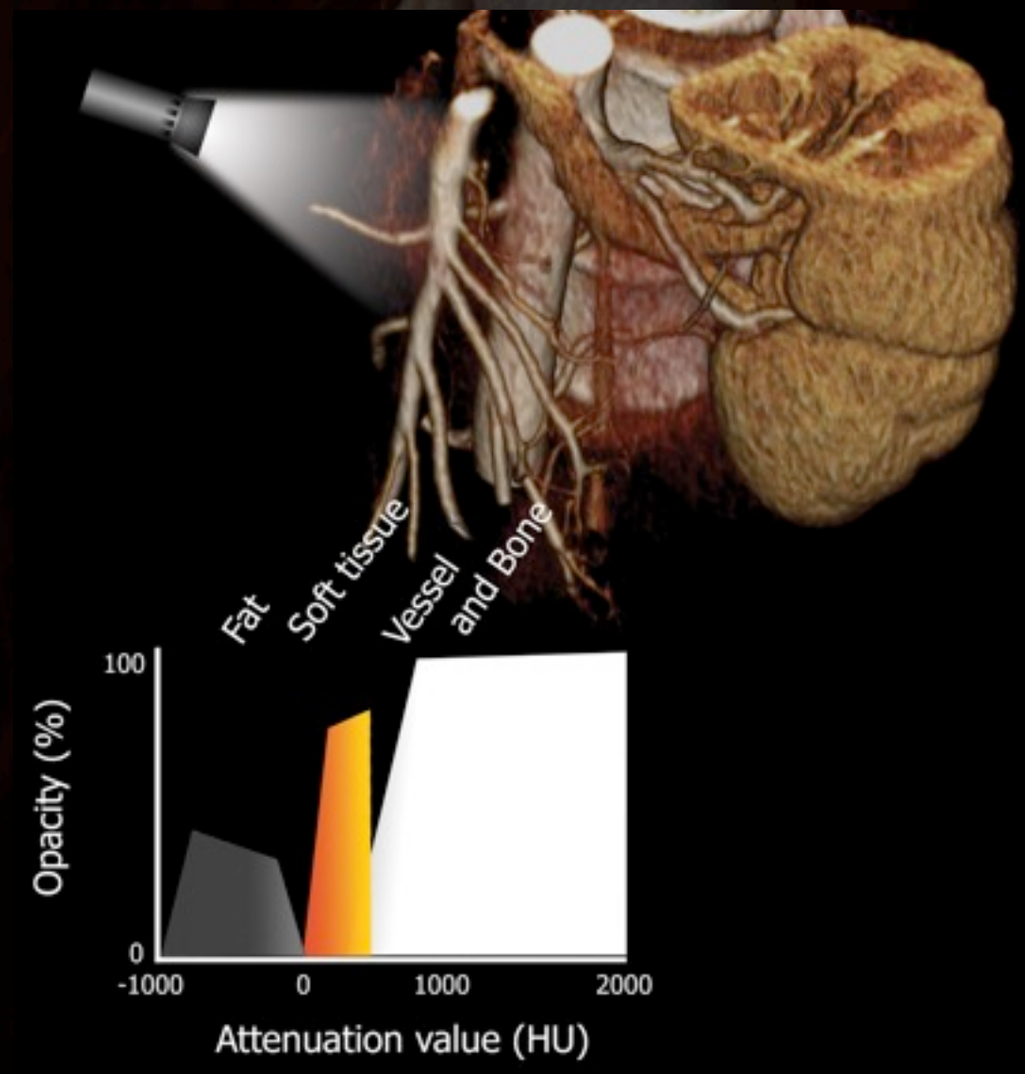


Volume Rendering (VR)

- Originally developed for motion picture animation
- Usually a COLOR technique
- Assigns color spectrum and opacity value (0-100 %) to voxels along artificial line of sight
- Multiple voxels can contribute to the output image (unlike MIP, MINIP)

- "Opacity Transfer Function": curve that describes relative opacities and colors
  - Changing the OTF
    - changes displayed tissues
- All CT data may be used to form image - robust computing power needed



Dalrymple, N. C. et al. Radiographics 2005;25:1409-1428

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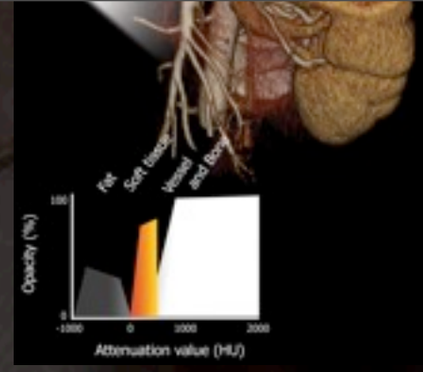
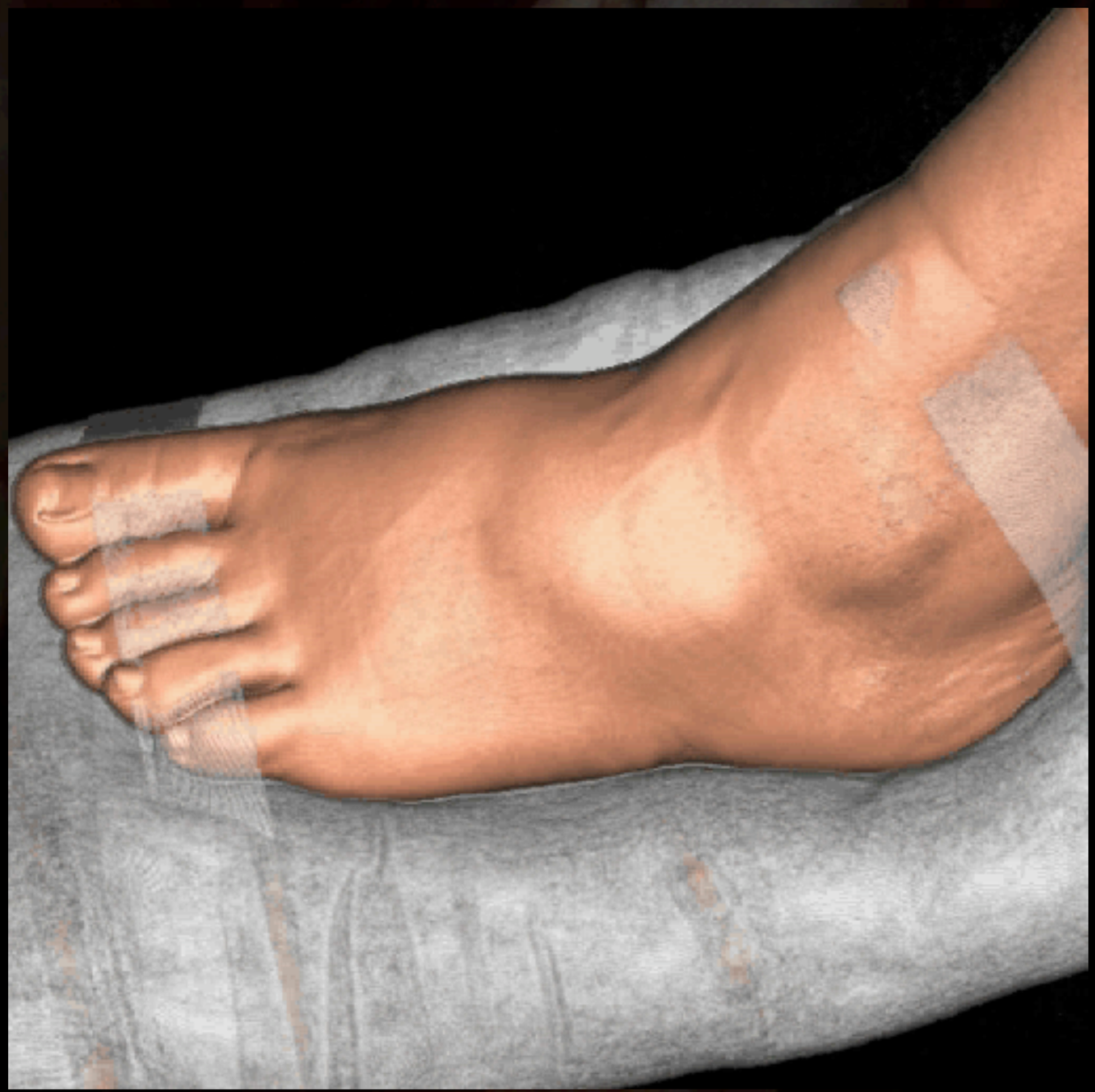




✦Changing the OTF changes displayed tissues

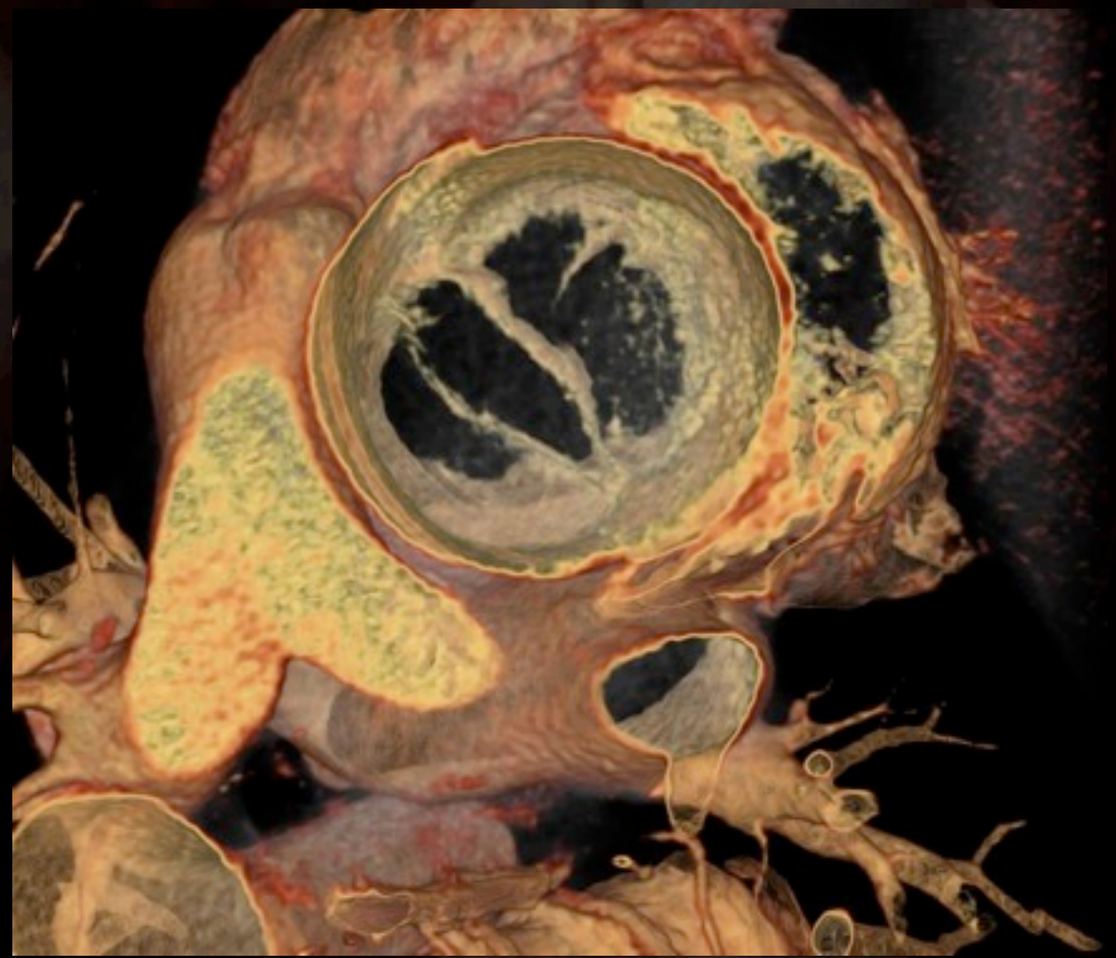
✦All CT data may be used to form image - robust computing power needed

Uses for VR

- Rapid communication of large amount of data in a few images
  - Surgical planning
  - Surrounding anatomy
- Cardiac / Vascular Interpretation
  - Allows quick overview, directs more detailed evaluation
  - Saves time

Blood Pool Inversion - Volume Rendering (BPI-VR)

- Can use mirror image of opacity ramp to render lumen transparent → endoluminal views



Entrikin DW, JCCT 2008; 2 (6) 366-71

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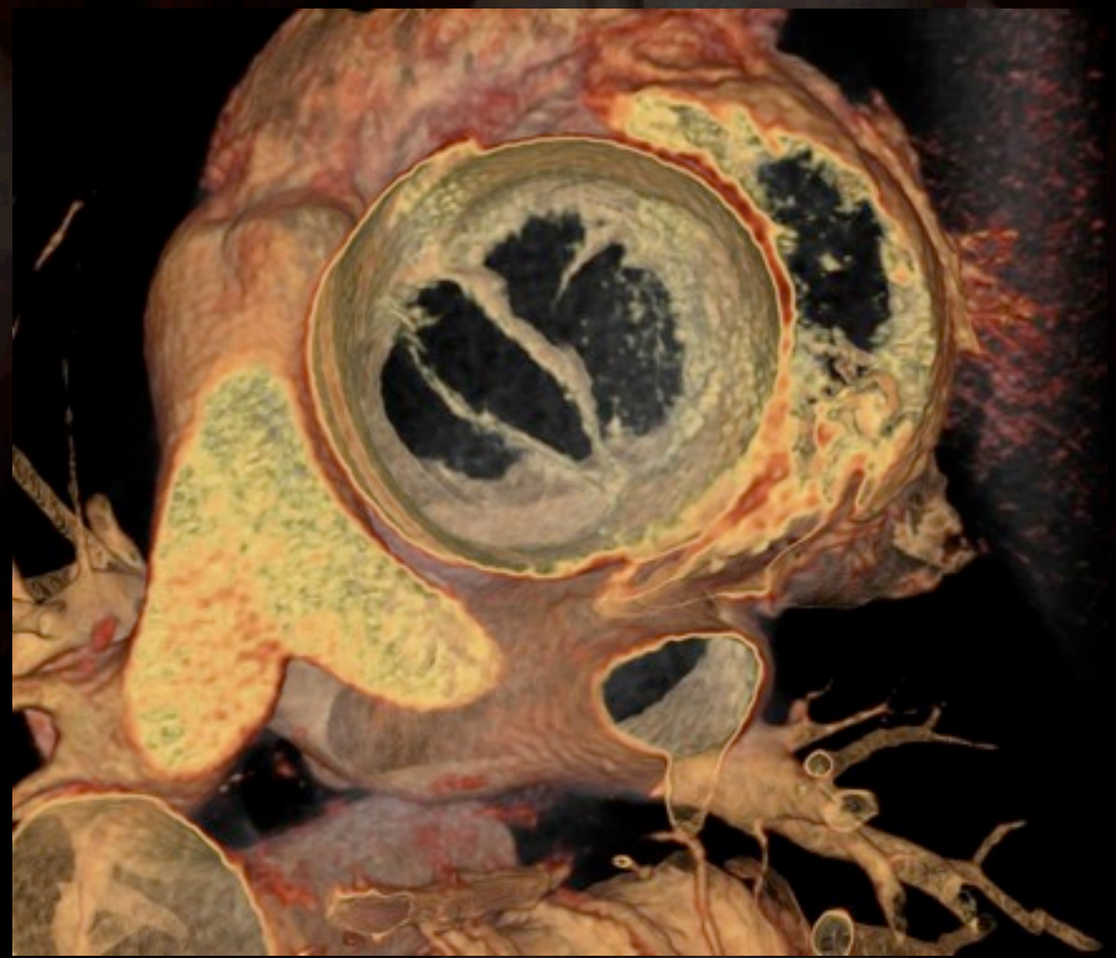

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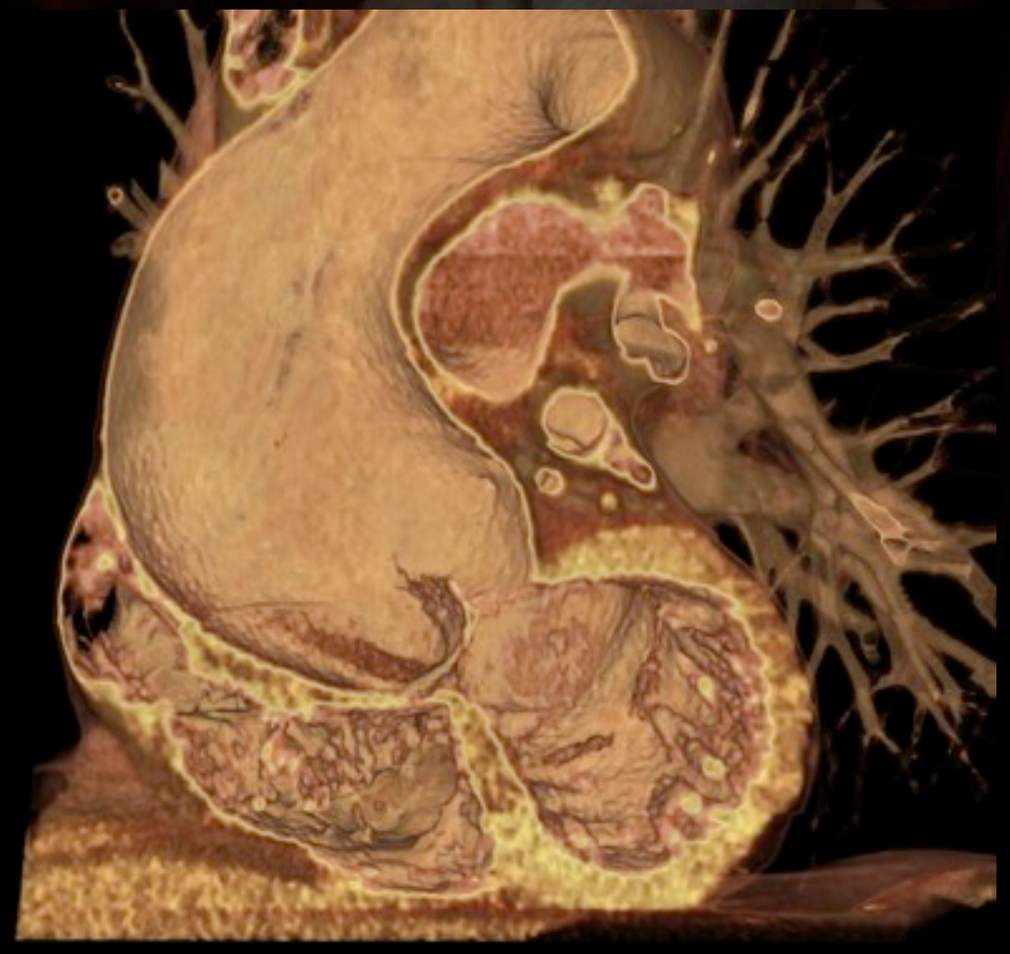

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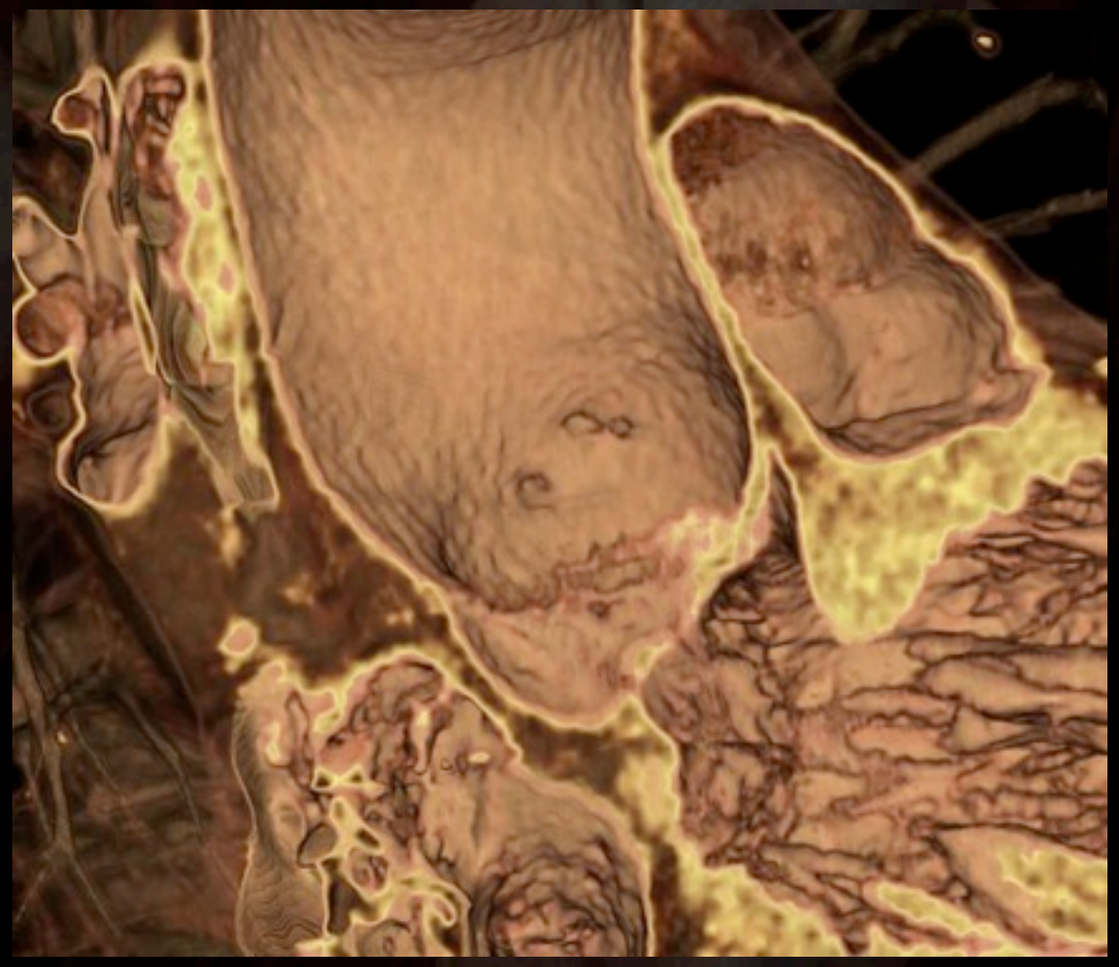
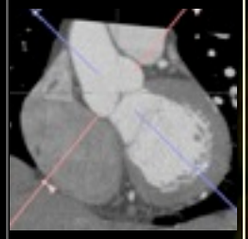
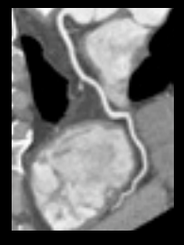
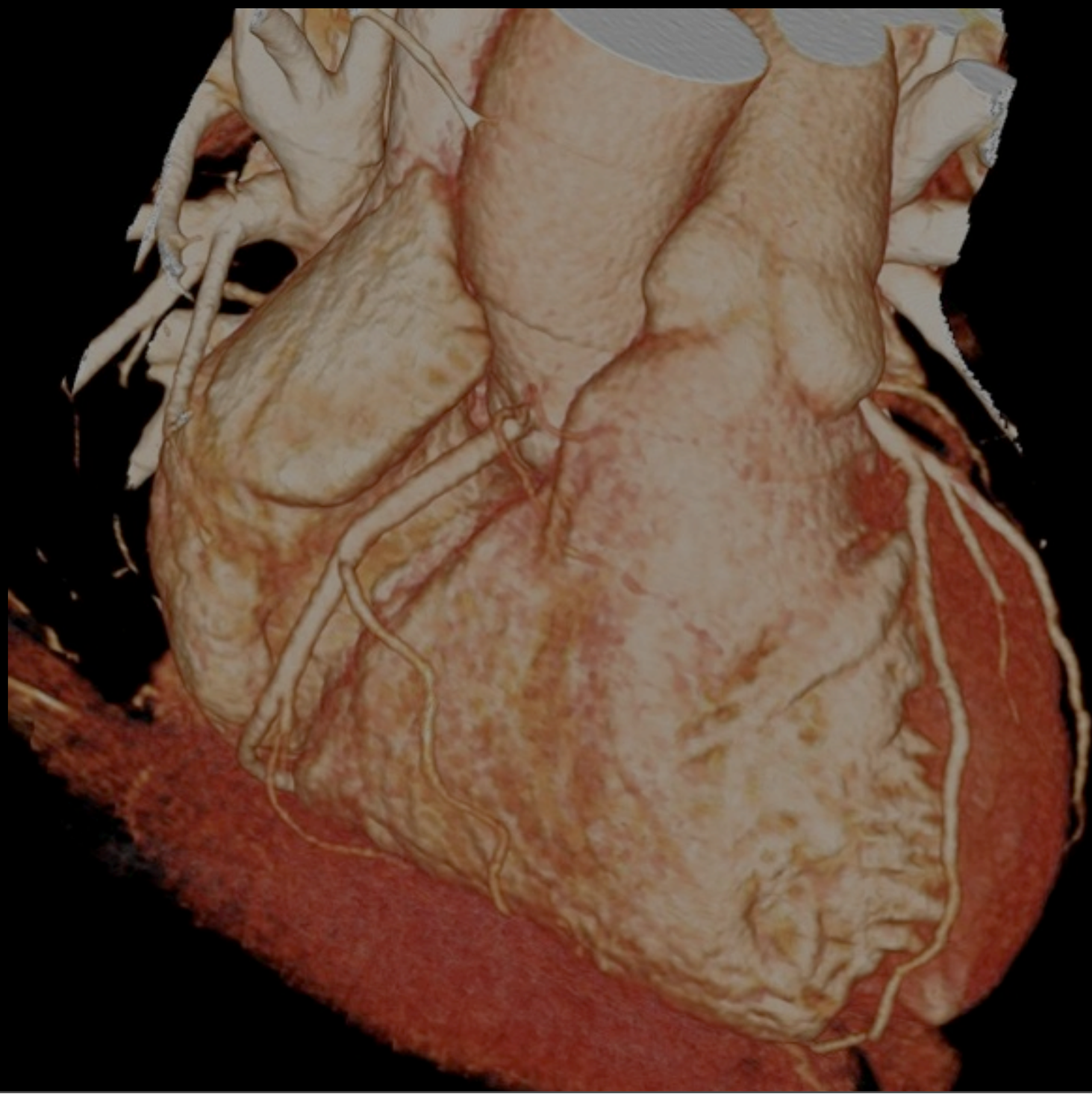


Entrikin DW, JCCT 2008; 2 (6) 366-71

	Major Uses	Advantages	Disadvantages
MPR 	Stenosis, vessel wall analysis Lung nodule measurement Orthogonal Measurements	Accurate for stenosis, nodule, orthogonal measurements Calcification, stent evaluation **"Thick MPR": salvage noisy datasets**	**Limited spatial relationships (so stack review)** **Limited display if curving vessel**
MIP **(MINIP)** 	Angiographic overview, contextual with adjacent structures Lung nodule detection (coronal STS) Valves, Airways (MINIP)	Depicts course of small and/ or poorly enhancing vessels Object - background contrast	**Vessel, bone, visceral overlap** **Limited stent, calcium evaluation** **Stenosis Overestimation** **NOISE IS ADDITIVE!!**
CPR 	Flow lumen, vessel wall analysis Curved Objects	Best for mural stenosis, occlusions, calcifications, stents Slice through display (perpendicular to CPR)	**Distortion of extra-vascular structures** **Dependent on accurate centerline (Needs Oversight)**

	Major Uses	Advantages	Disadvantages
VR 	Angiographic overview, contextual with adjacent structures Pre-procedural planning	• Best for complex relationship display •Valves •Vessel Origins •EVAR, DSX, etc **WOW** factor	**Opacity transfer function and operator dependent** **No accurate measurements**
BPI- VR 	Valves, vessel orifices, DSX flaps		

Putting it all together: Coronary / Cardiac CTA



Cardiovascular CTA - Technique

- B- blockers for HR control
- NTG
- Timing bolus or bolus tracking
- ECG synchronized
  - prospective, retrospective gating
- 3D and 4D review / interpretation / communication

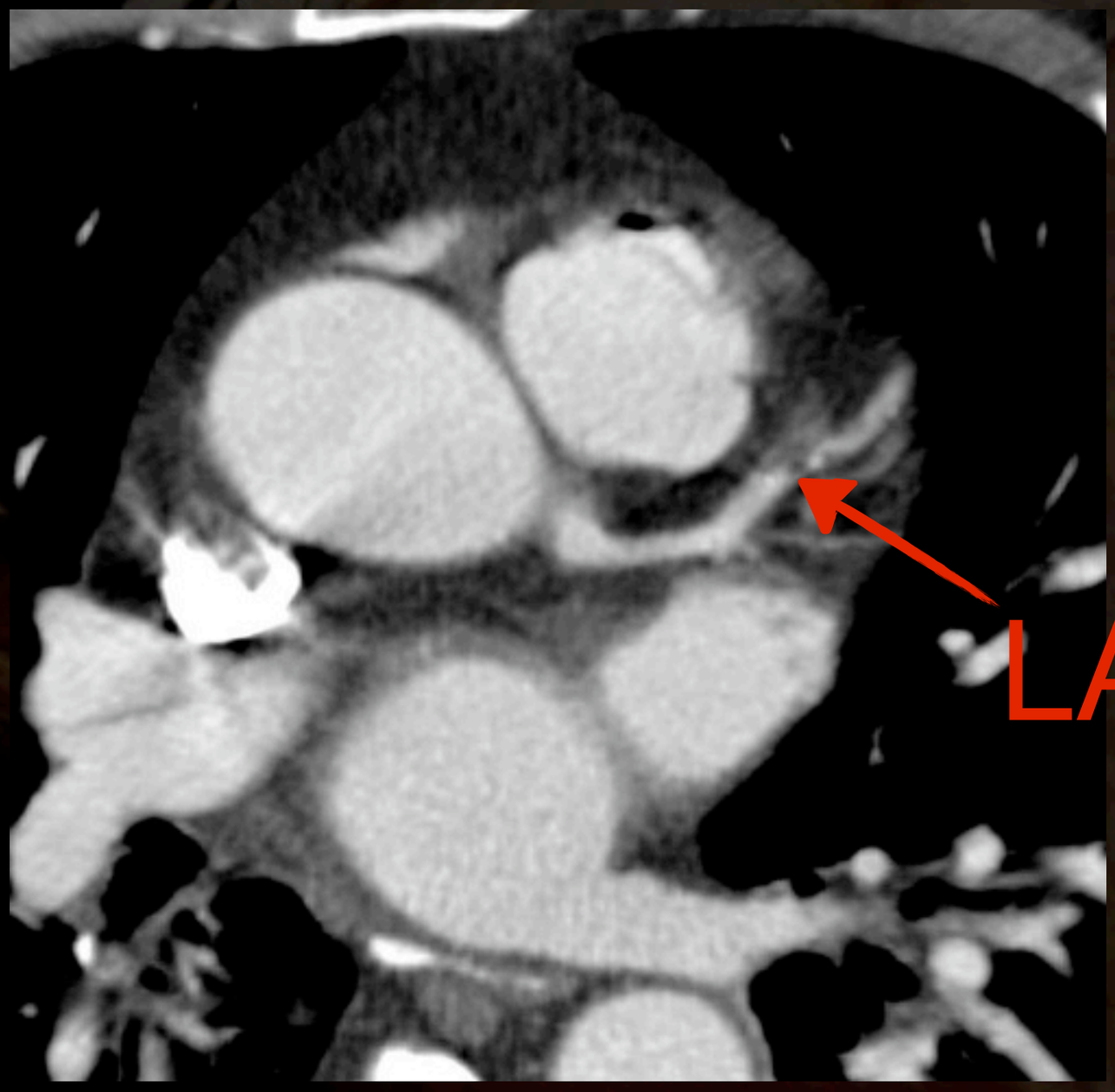
The RESULTS: High NPV for CCTA

Author	Scanner Type	No. of Patients	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Raff et al (67)	64-Section CT	70	86	95	66	98
Leschka et al (66)	64-Section CT	67	94	97	87	99
Mollet et al (69)	64-Section CT	51	99	95	76	99
Fine et al (68)	64-Section CT	66	95	96	97	92
Ropers et al (73)	64-Section CT	81	93	97	56	100
Ehara et al (70)	64-Section CT	69	90	94	89	95
Ong et al (72)	64-Section CT	134	82	96	79	96
Oncel et al (71)	64-Section CT	80	96	98	91	99
Meijboom et al (77)	64-Section CT	360	88	90	47	99
Weustink et al (76)	Dual-Source CT	100	95	95	75	99
Johnson et al (75)	Dual-Source CT	35	88	98	78	99
Leber et al (25)	Dual-Source CT	88	94	99	81	99
Ropers et al (26)	Dual-Source CT	100	92	97	68	99
Brodoefel et al (74)	Dual-Source CT	100	91	92	75	97

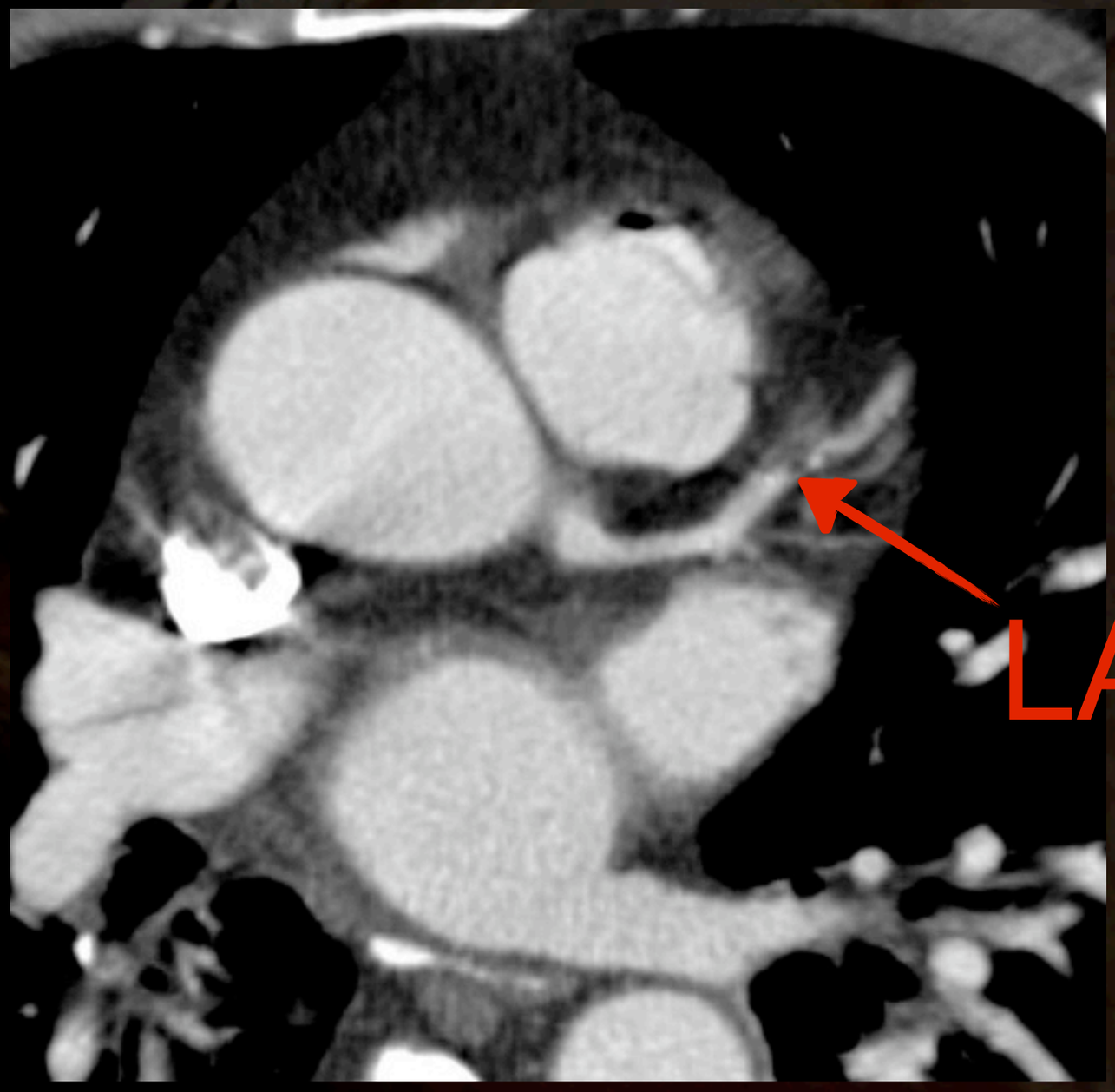
Bastarrika, G., Y. S. Lee, et al. (2009). "CT of coronary artery disease." Radiology **253**(2): 317-338.

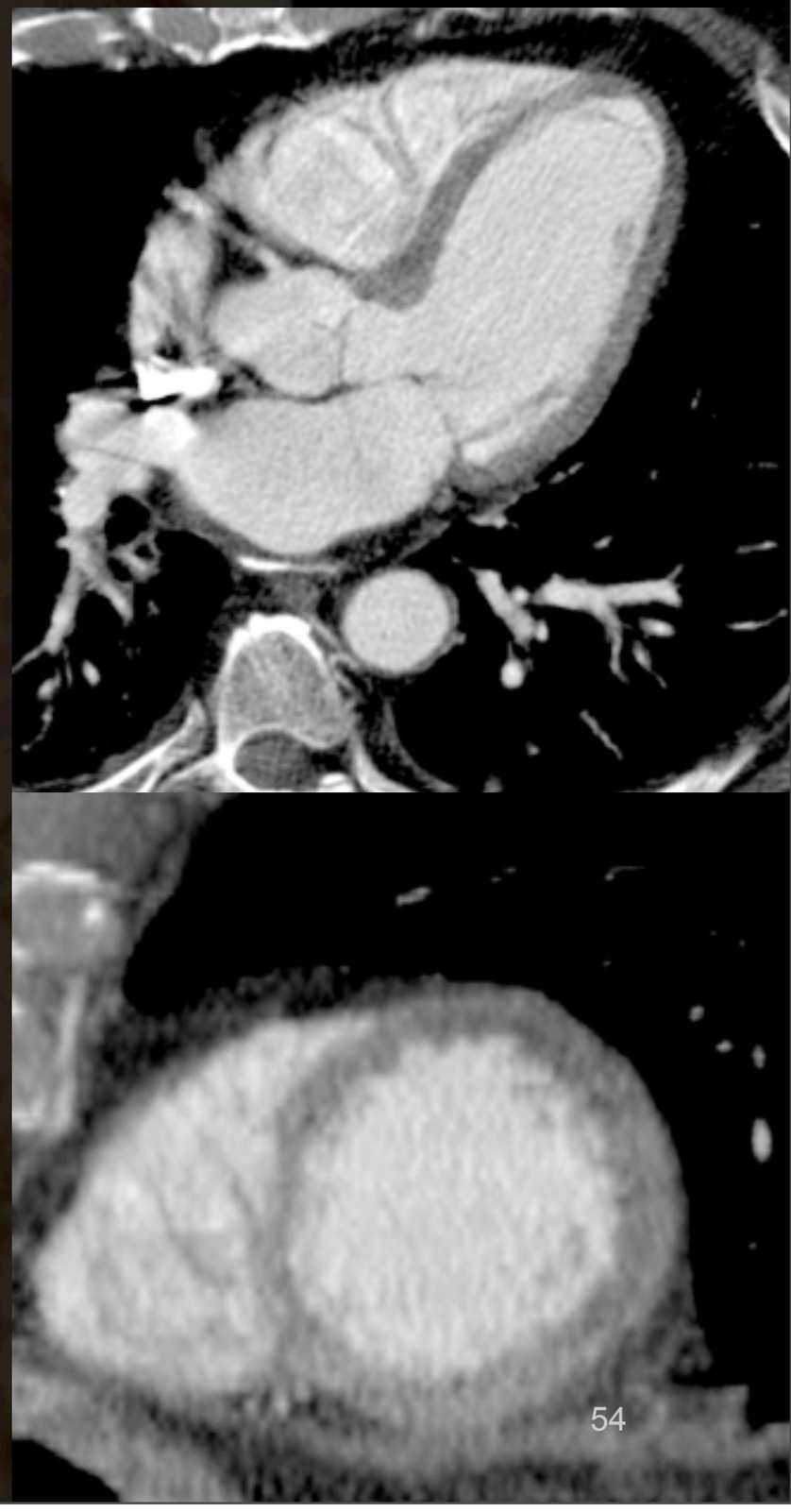
Examples:
CAD

ED - Chest pain

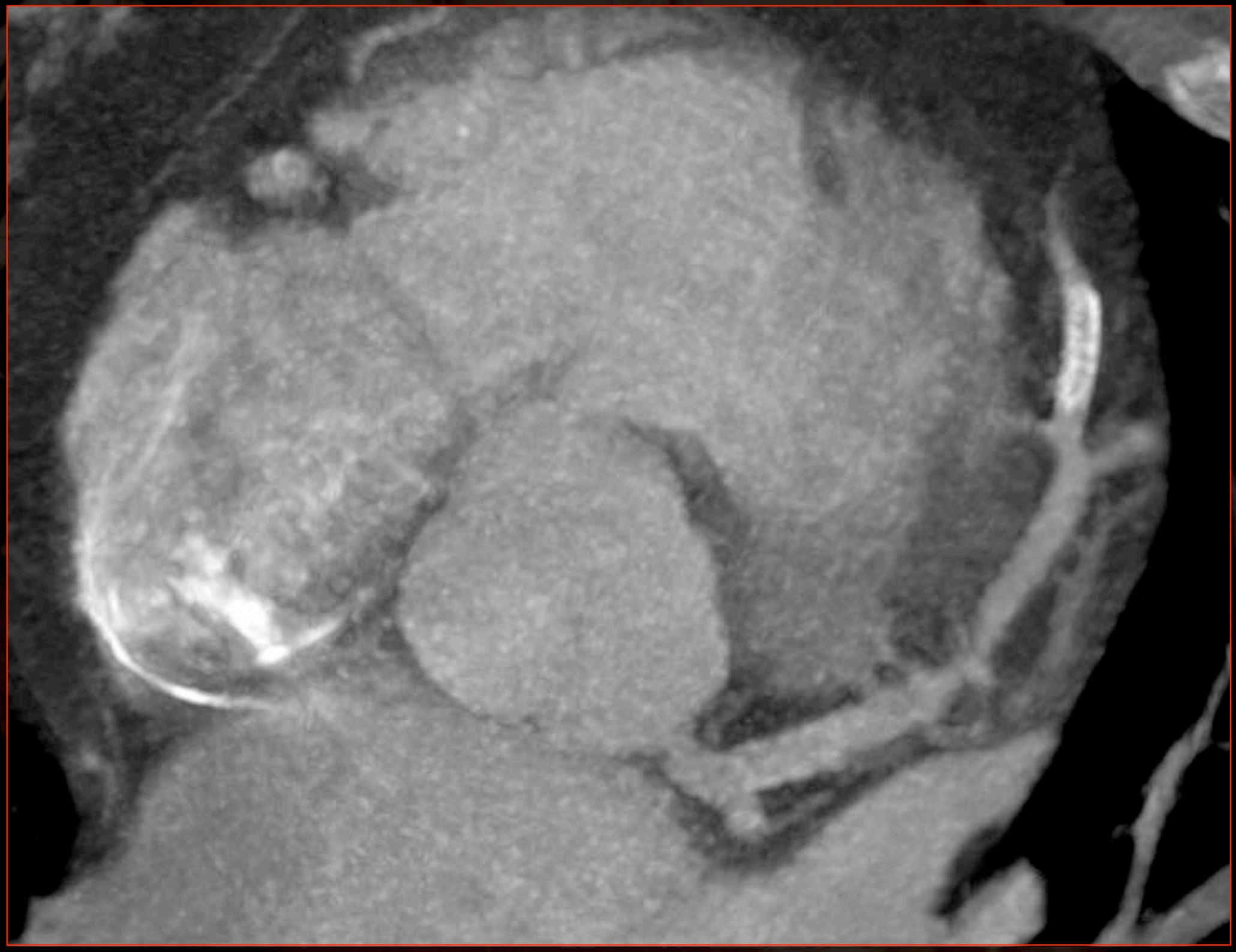


ED - Chest pain





38 yo post LAD stent



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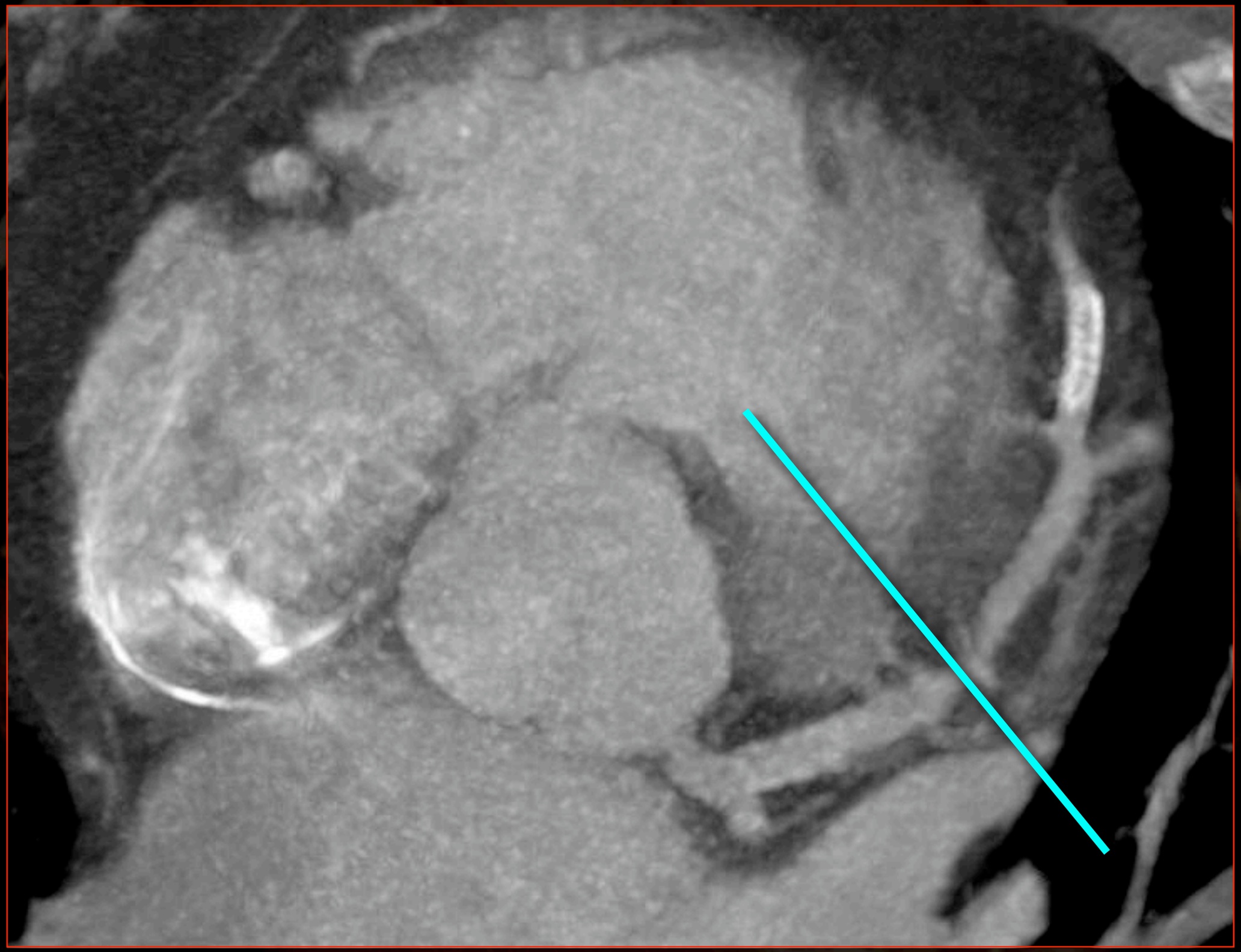
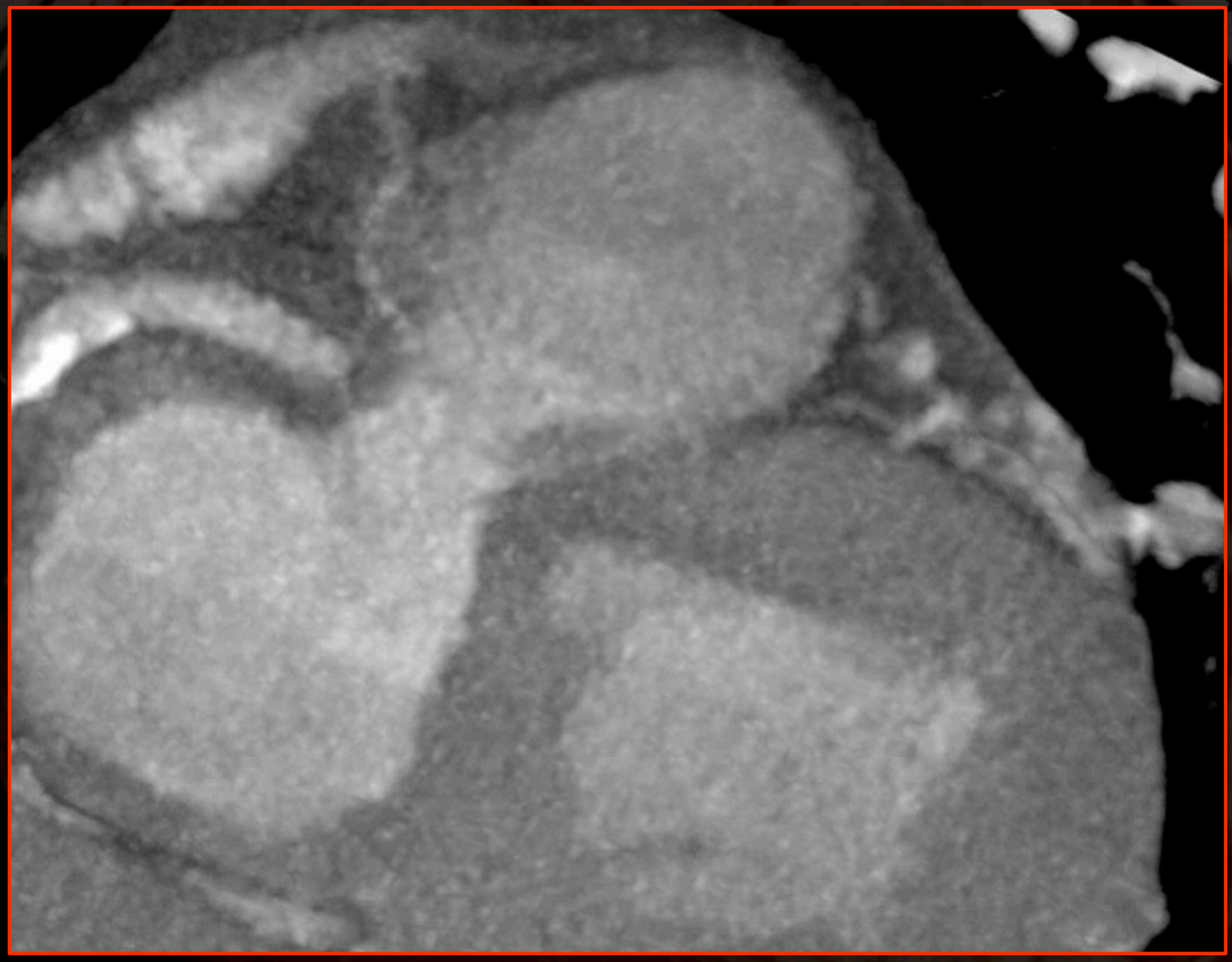


Soft Plaque in LAD (~ 40% stenosis)



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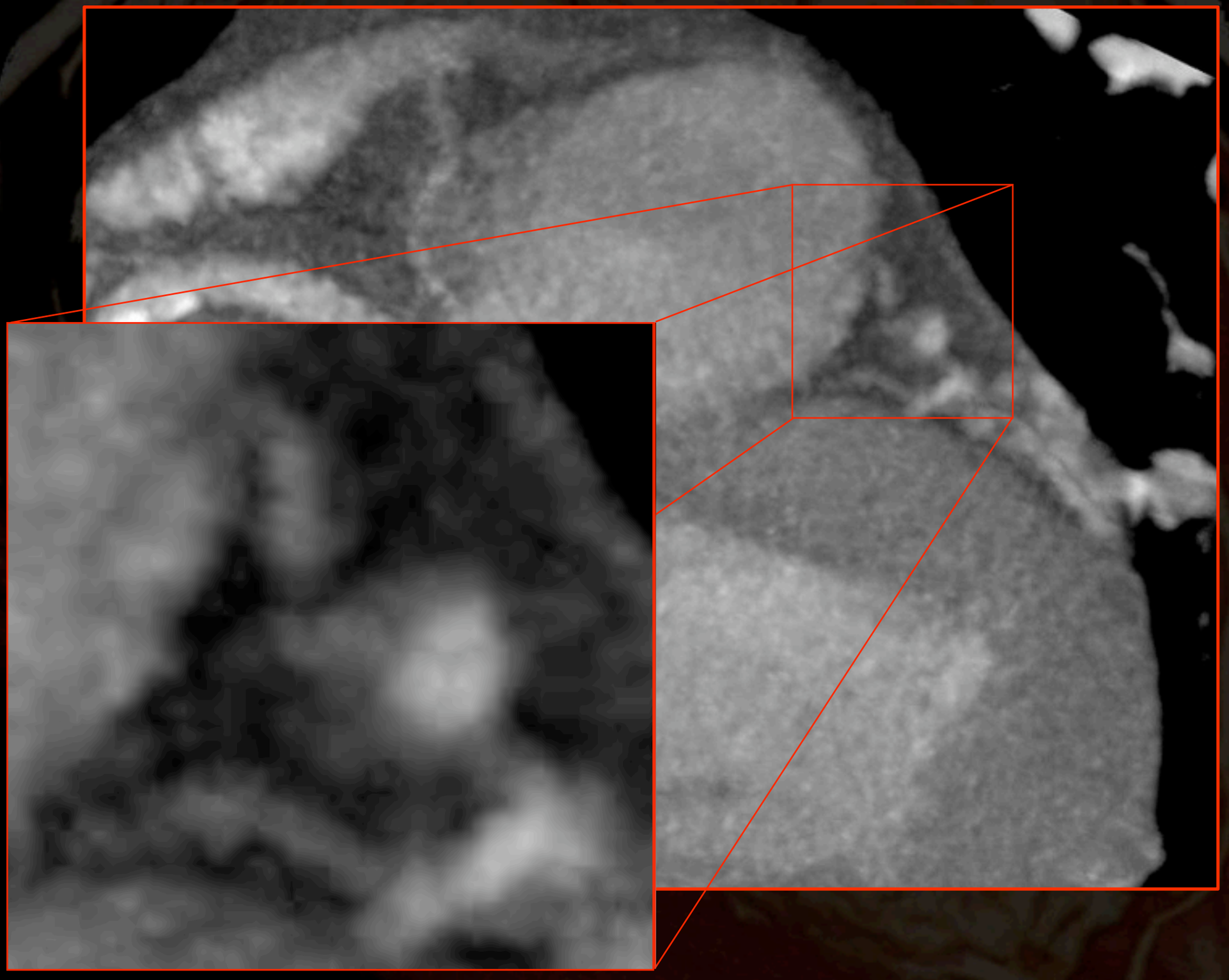
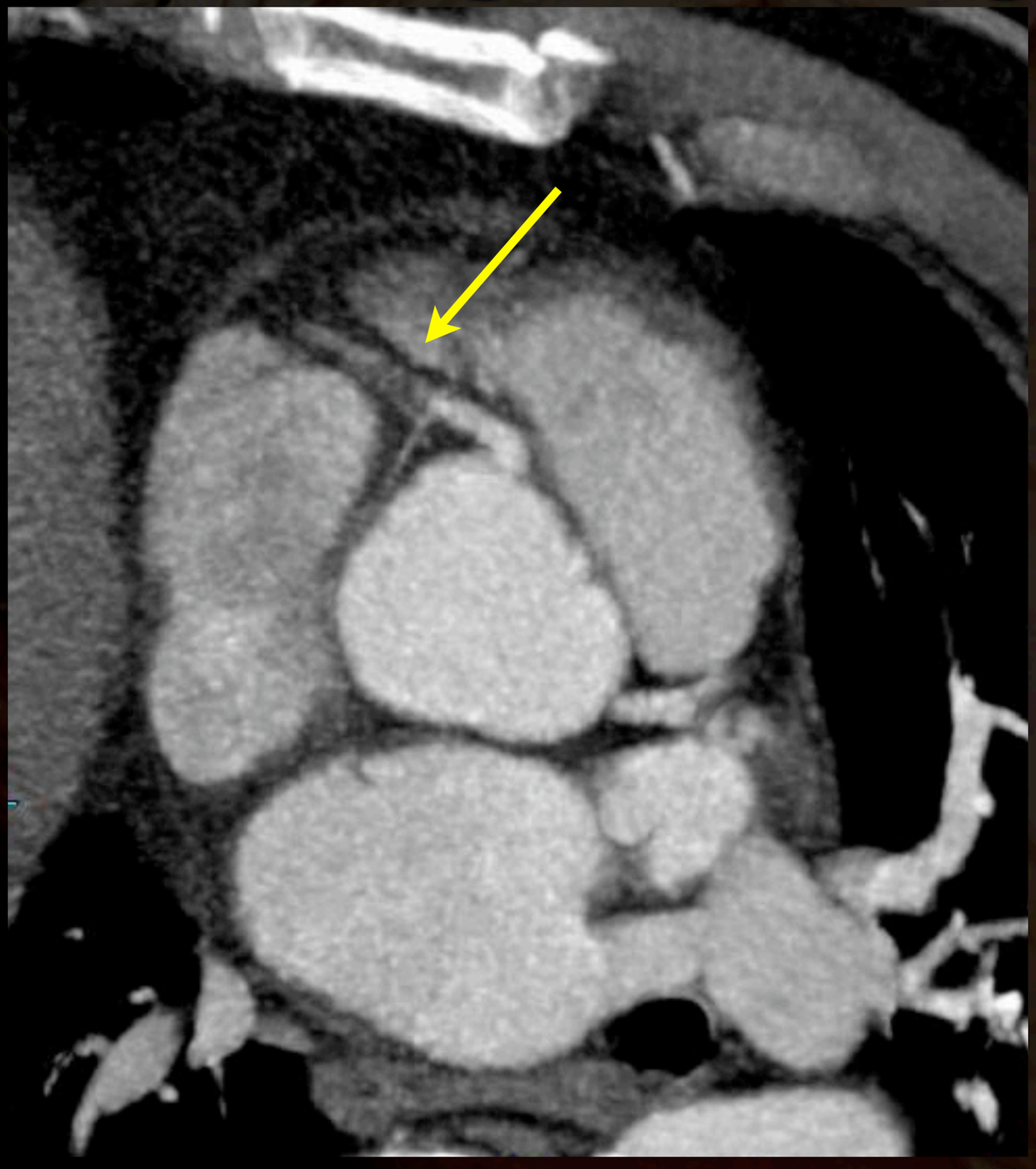
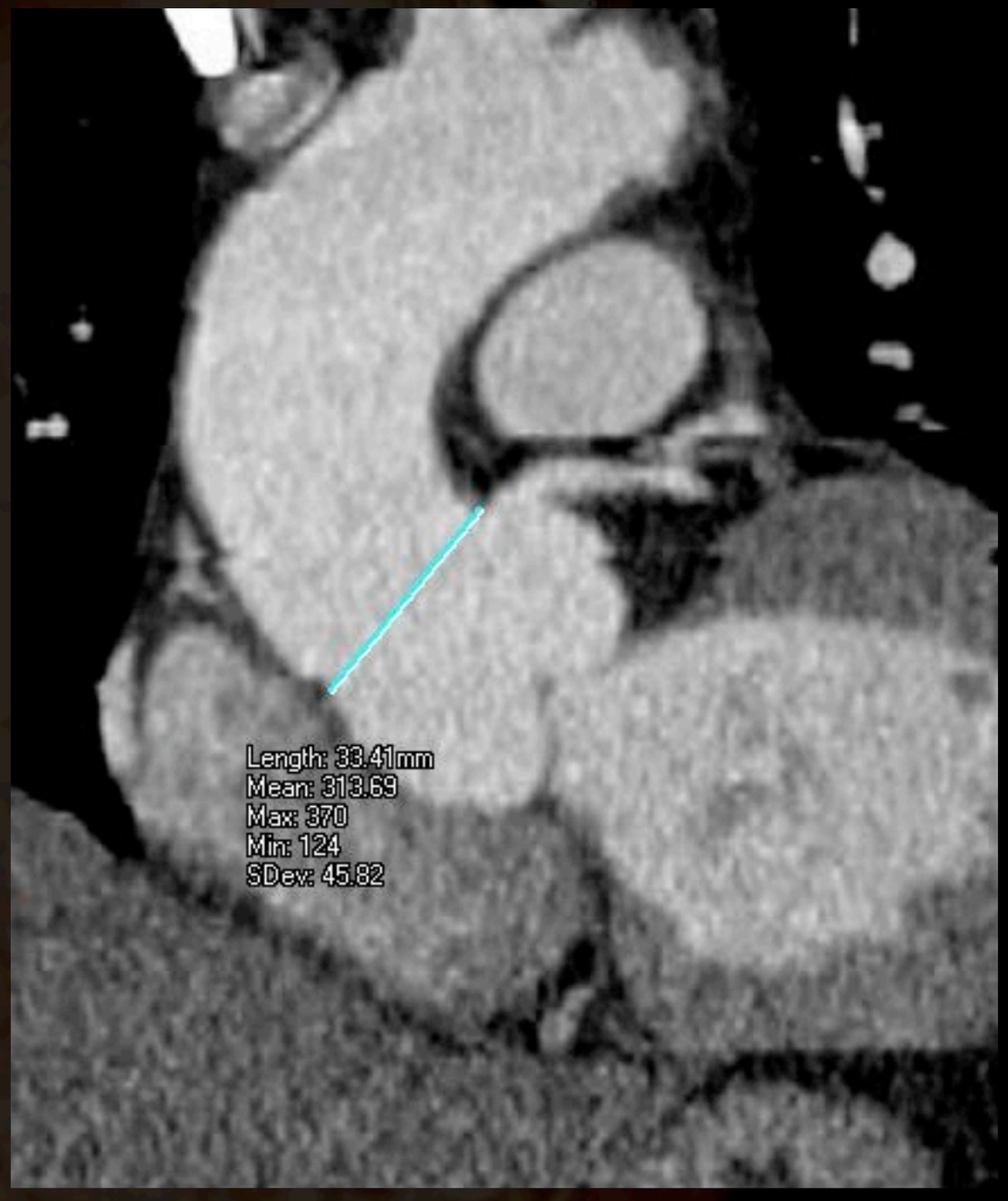


Proximal RCA Occlusion, High LM origin (at STJ)





SVG to RCA, native PDA disease

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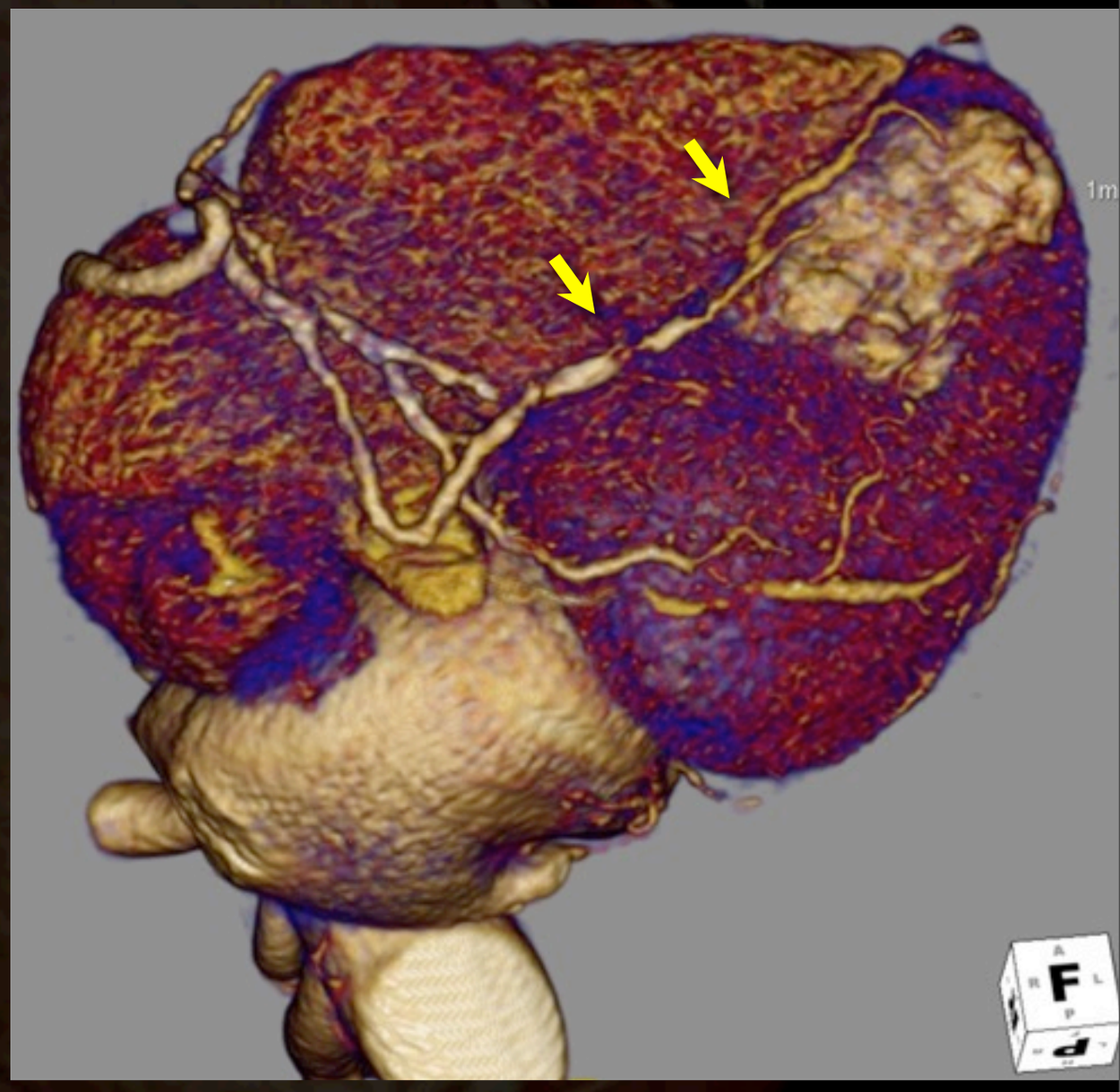

BPG Aneurysm

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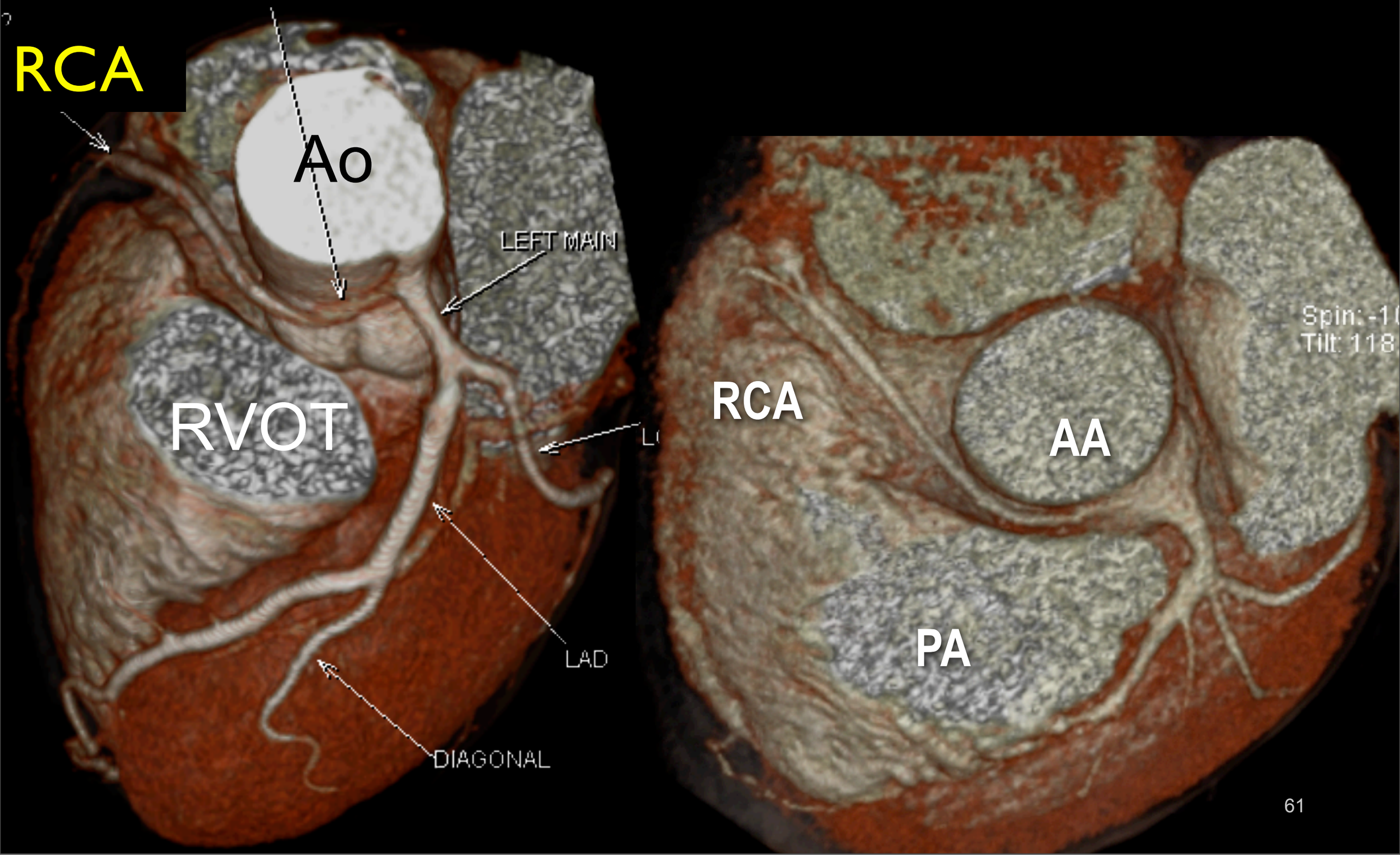
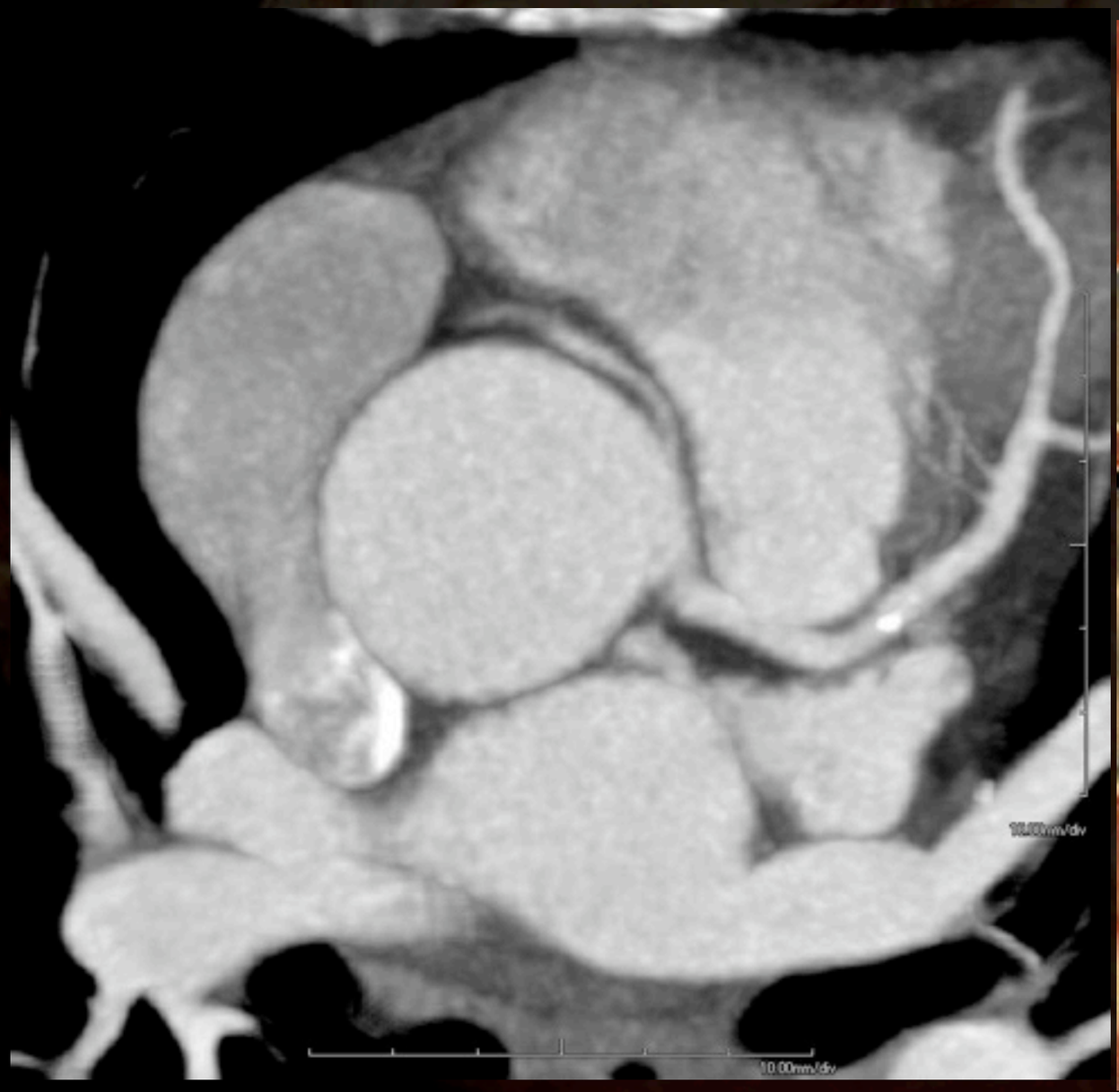
Examples:
Coronary Anomalies

Anomalous RCA - Malignant Course



Anomalous RCA - Malignant Course

Anomalous RCA above fused RL cusps in BAV



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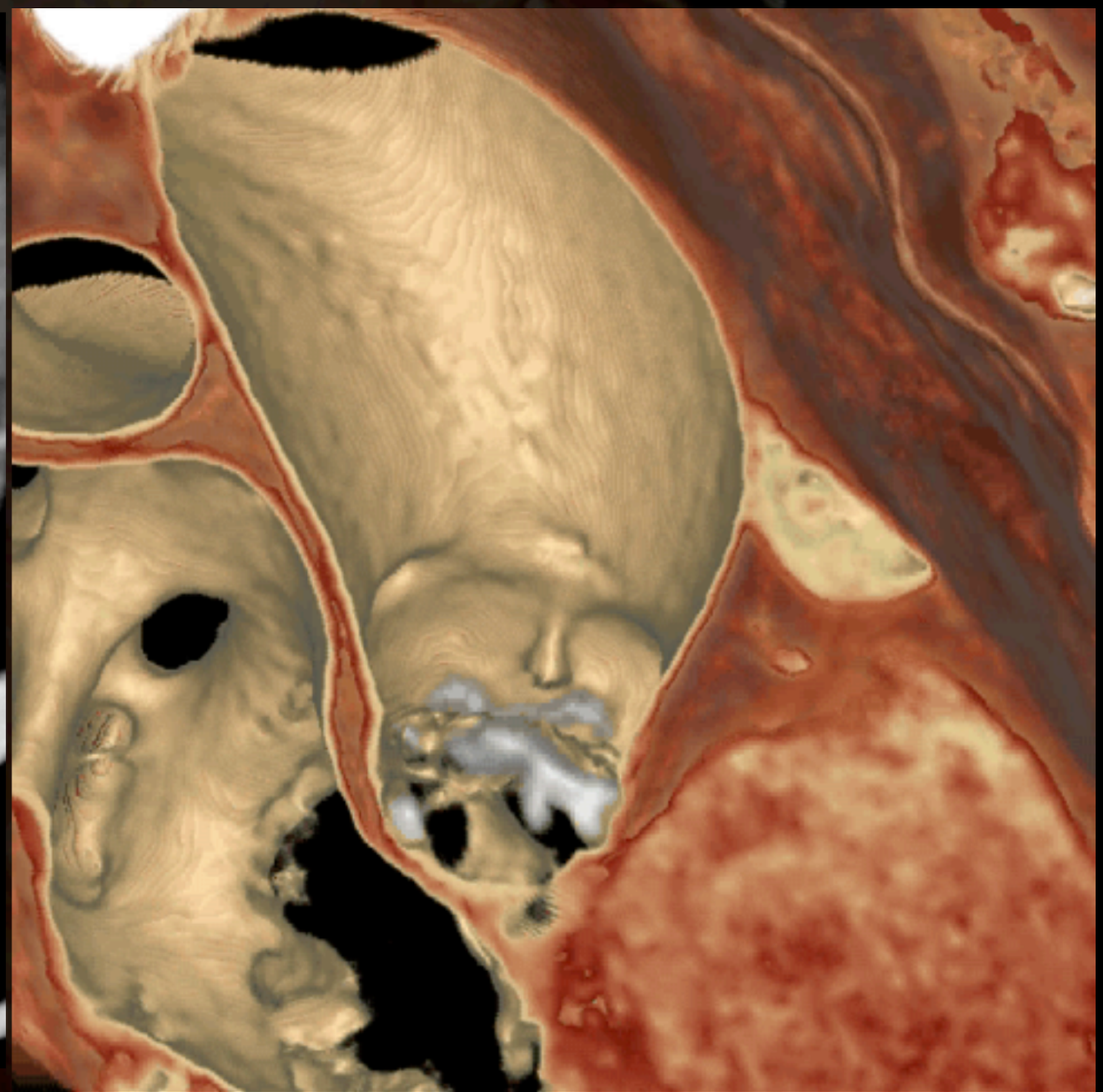

Intra-cavitary RCA

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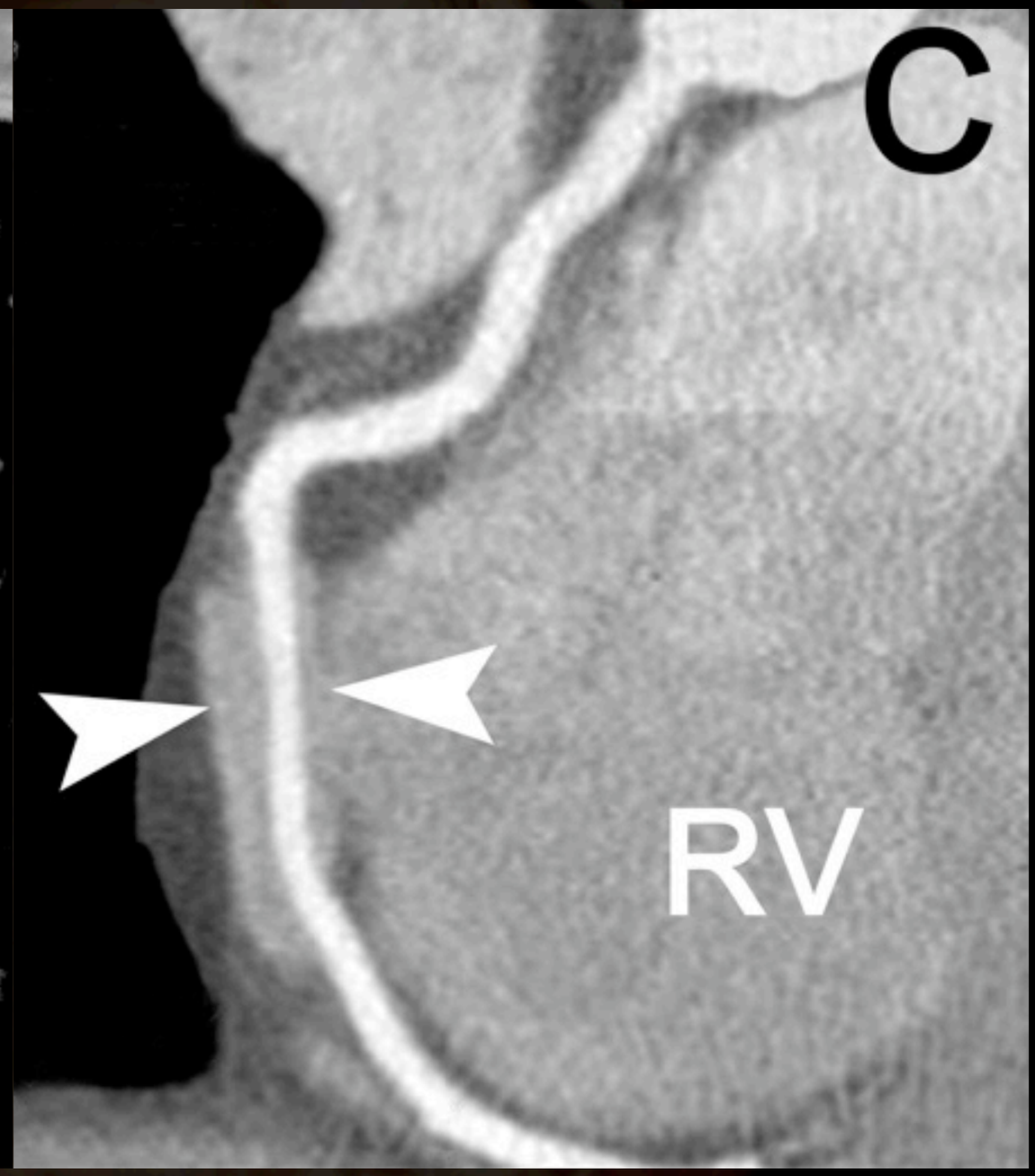
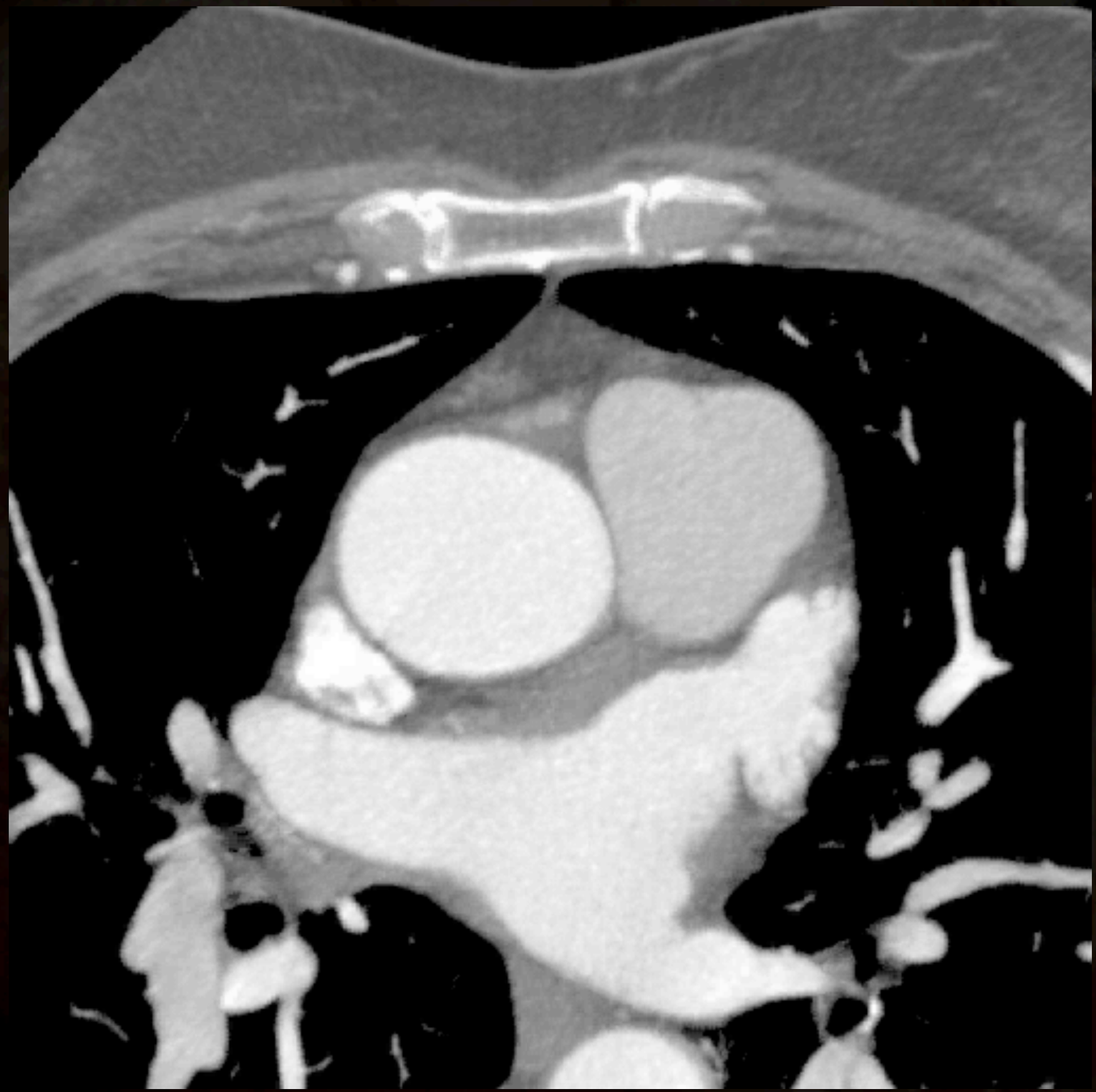
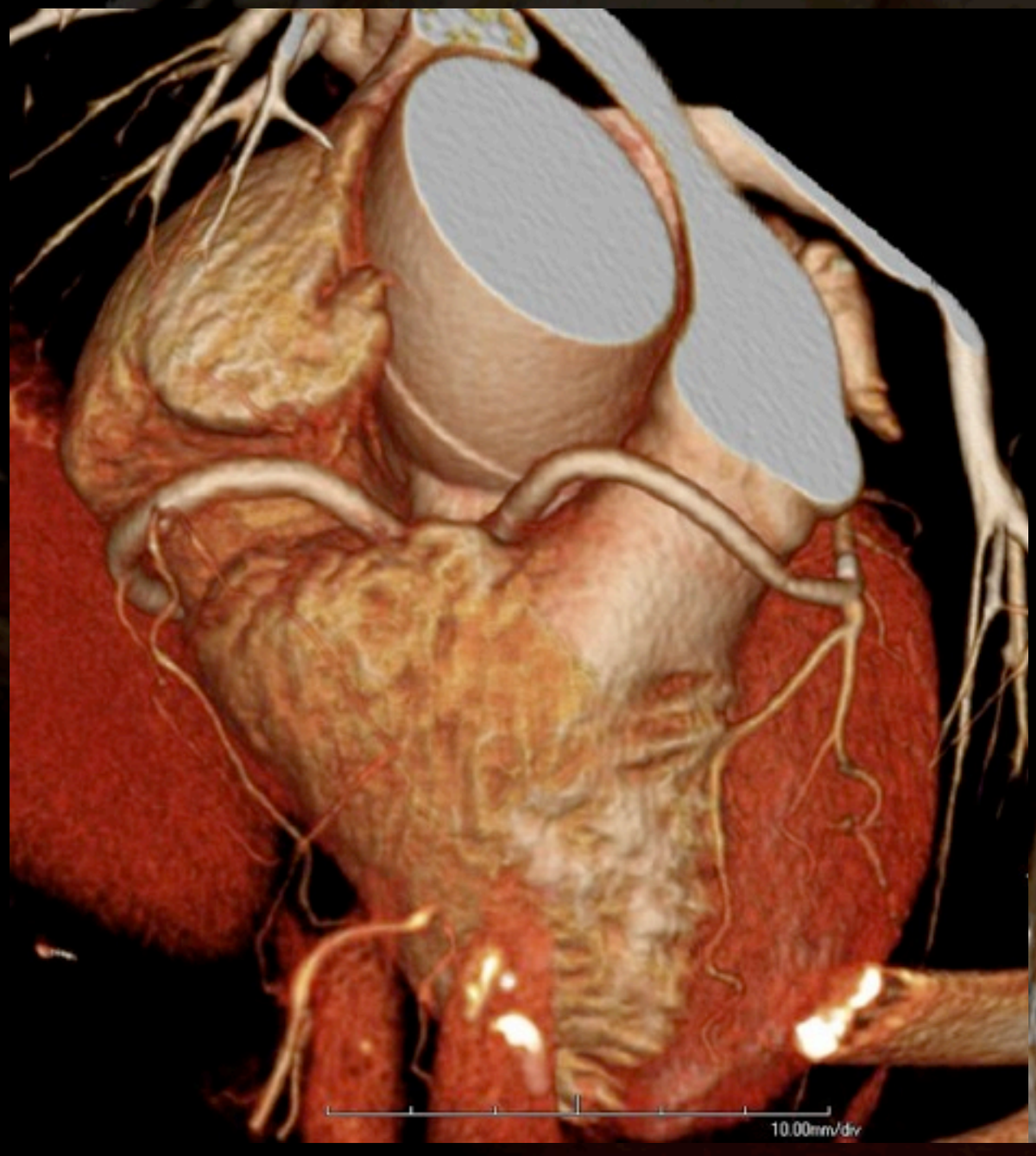
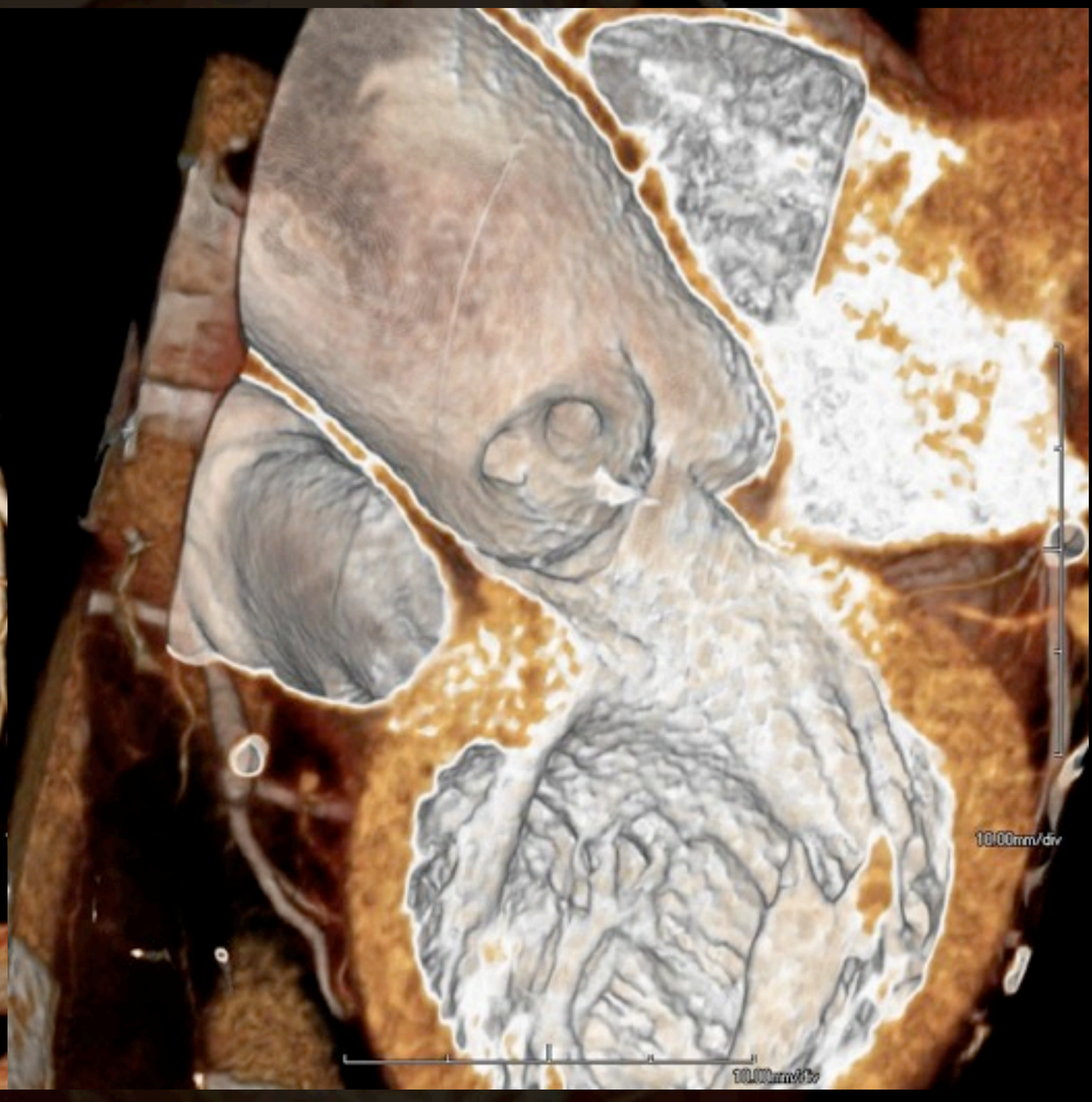


Anomalous Left Main - Septal course

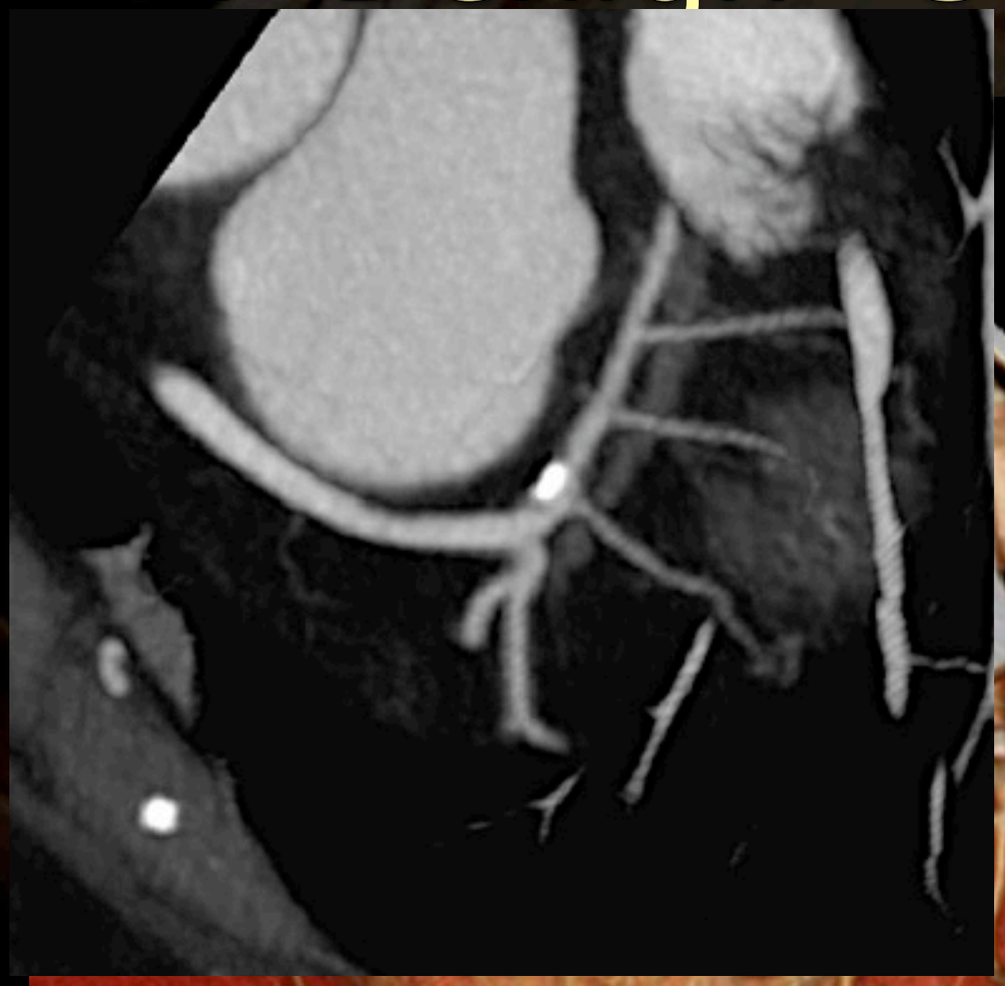


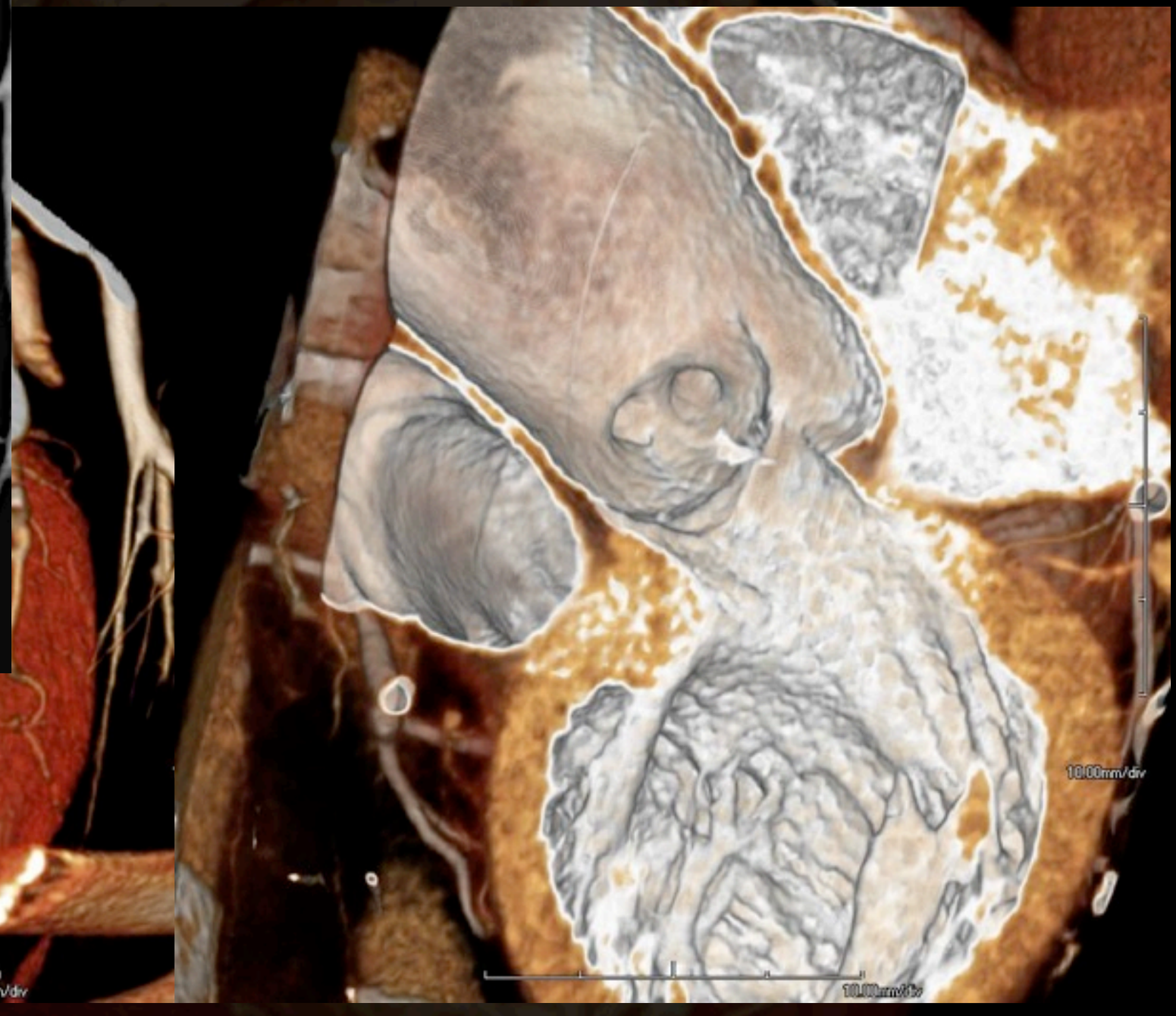
A “Benign” Coronary Anomaly (?)





A “Benign” Coronary Anomaly (?)





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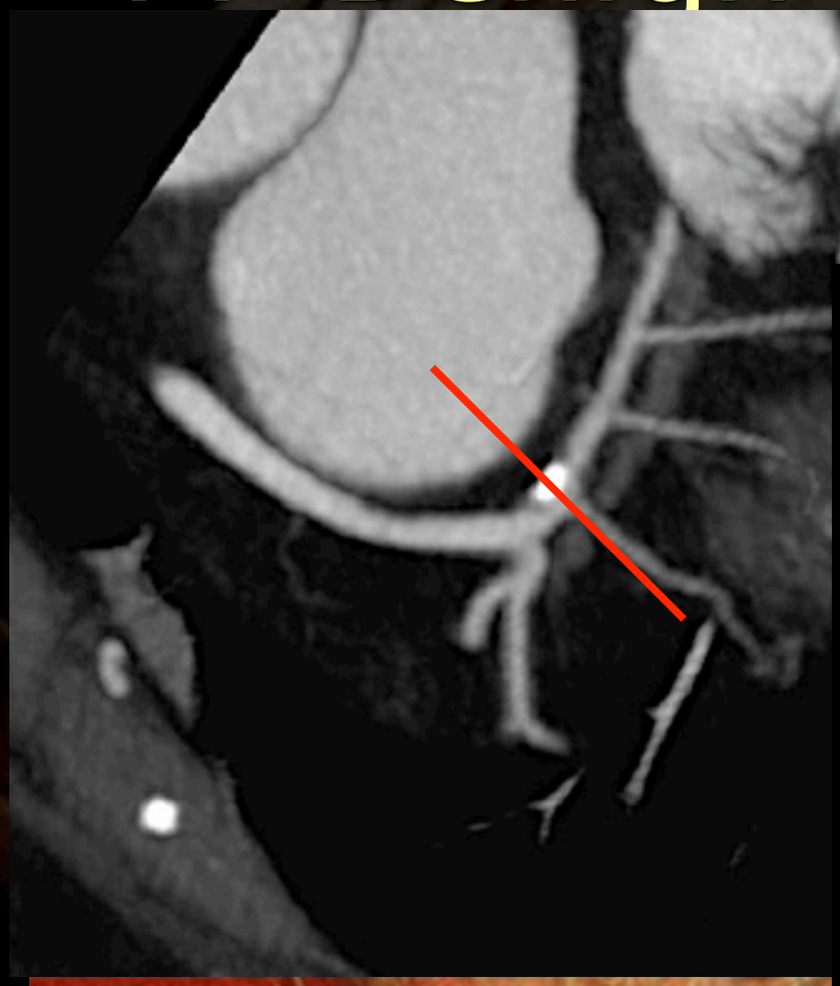
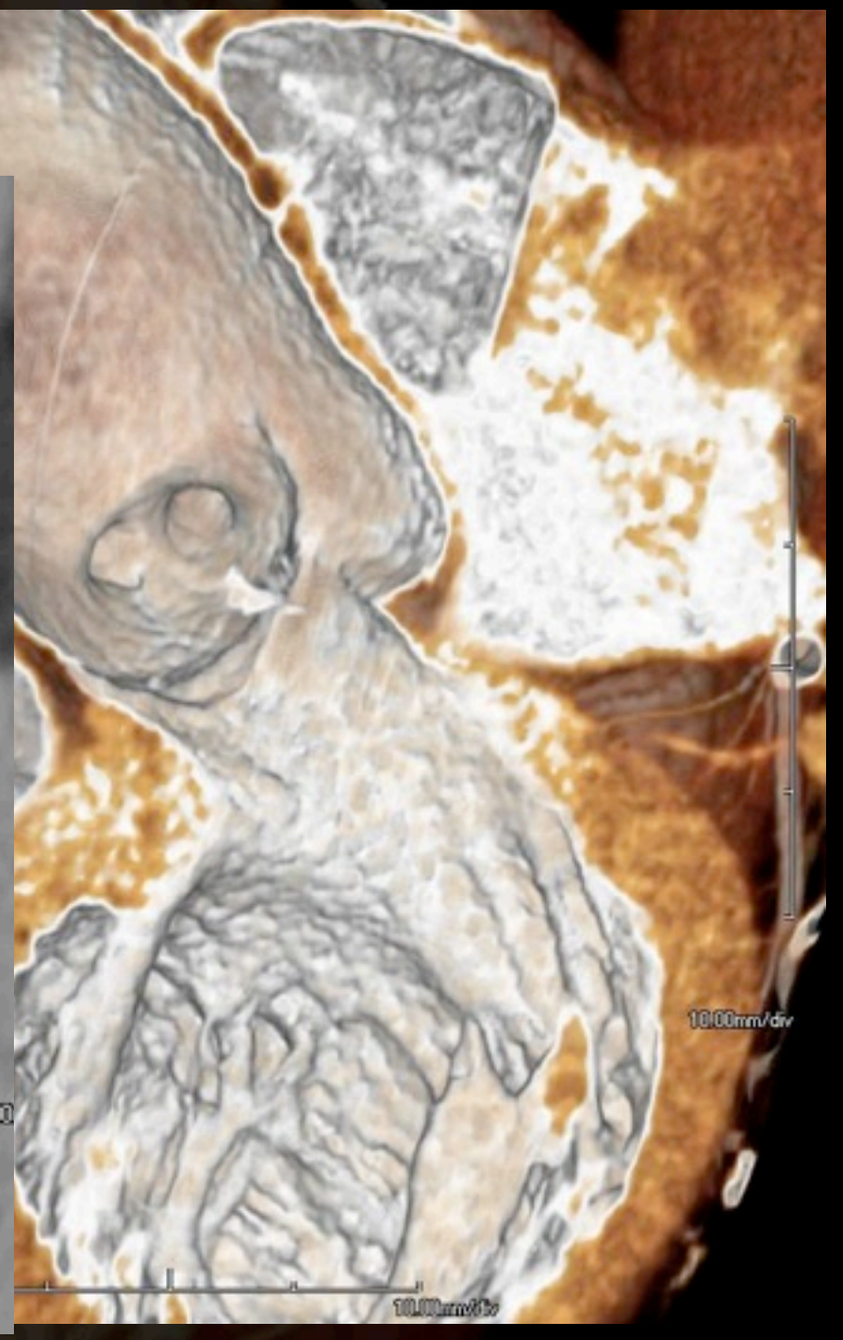
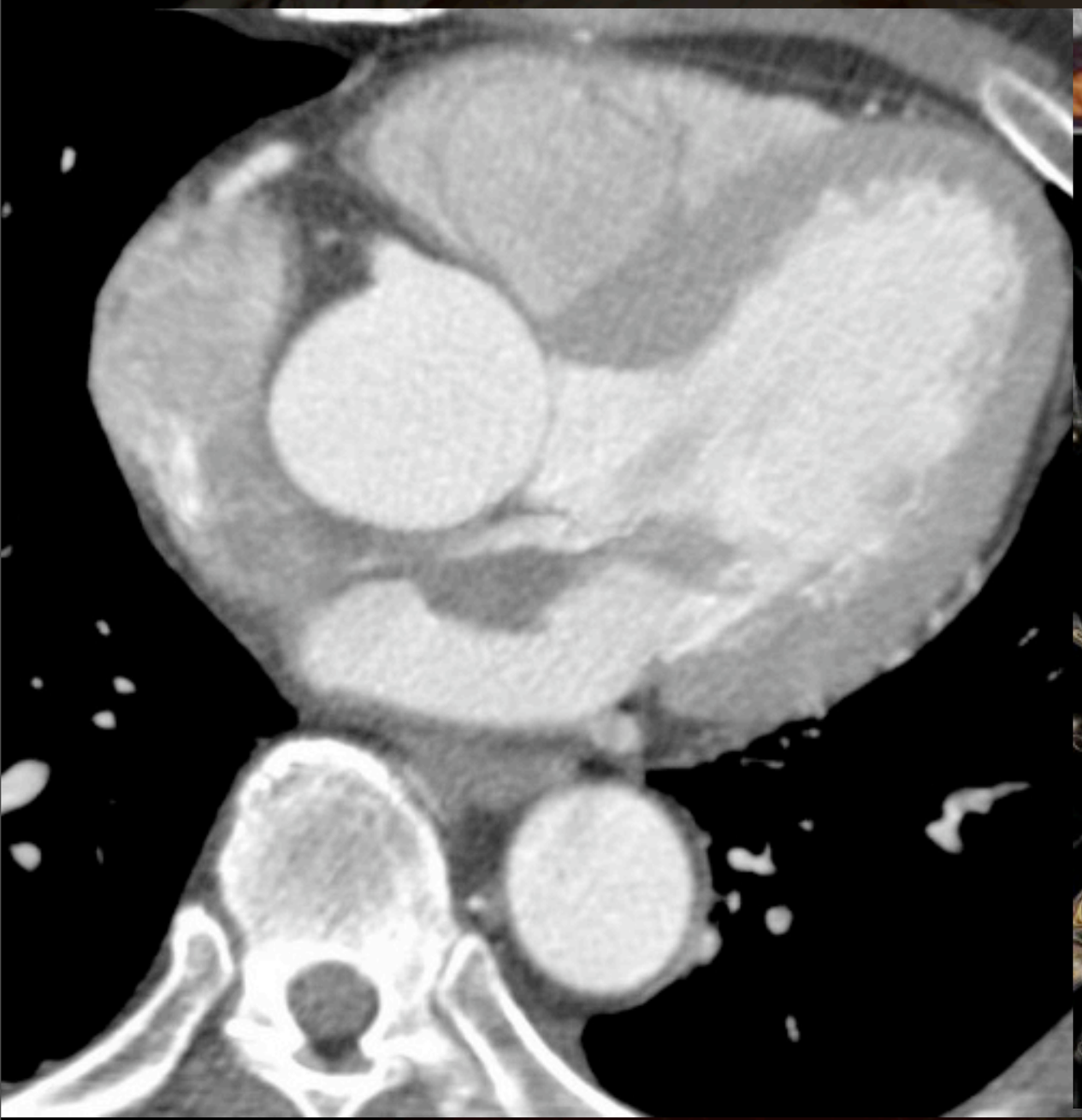
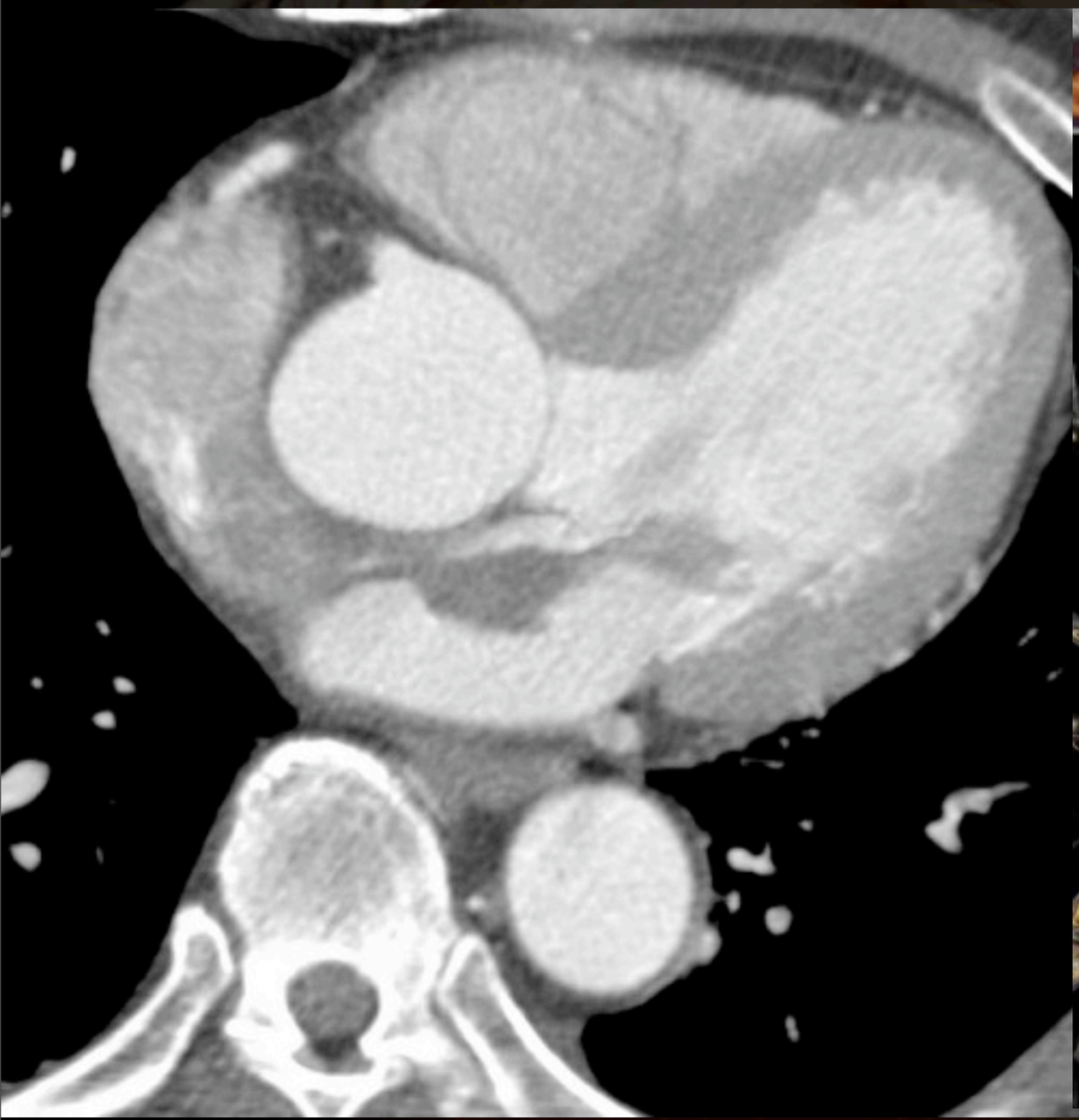




Example: Cardiac Tumor



Example: Cardiac Tumor



LA Myxoma

Conclusions

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Conclusions

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- Image Reconstruction:
  - Improve and troubleshoot image reconstruction (FOV, kernel, etc)
- Image Post-Processing
  - Remember inherent advantages, limitations, and differences in each type of image display
- Coronary CTA:
  - Robust technique for many (emerging) indications

Special Thanks to:

Geoff Rubin, MD
Dominik Fleischmann, MD
Jen Martin, RT (R)(CT)
Mina Thakur, RT (R)(CT)

Online Handouts from Lecture:

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Further Reading:

- Image Reconstruction:
  - Rubin GD, Sedat P, Wei JL: *Ch. 6. Postprocessing and Data Analysis.* In: Rubin GD and Rofsky N. CT and MR Angiography: Comprehensive Vascular Assessment Lippincott, Williams and Wilkins, 2008
  - Barrett JF, *RadioGraphics* 2004;24:1679-1691
  - Ch. 4: Image Reconstruction and Review. In: Lipson SA: MDCT and 3D Workstations. Springer, 2006.
  - Luccichenti G, et al. Eur Radiol 2005; 15: 2146 - 2156
  - Parrish FJ, AJR 2007; 189:528-534
  - Dalrymple NC, RadioGraphics 2005;25:1409-1428
  - Hara AK, et al. Am J Roentgenol. 2009;193(9):764-771
  - Roos JE, et al. Acad Radiol 2009; 16 (6) 646-653.

Further Reading

- CTA Interpretation Strategies:
  - Ferencik, M. Radiology 2007;243:696-702
  - Saba, et al. J Comput Assist Tomogr. 2007 Sep-Oct;31(5):712-6.
  - Maintz, D. et al. Am. J. Roentgenol. 2002;179:1319-1322
  - Pugliese, F. et al. Radiographics 2006;26:887-904

- OSIRIX (Free Image Viewer for MAC):
  - http://www.osirix-viewer.com/
  - WIKI: http://osirixmac.com/index.php/Main_Page