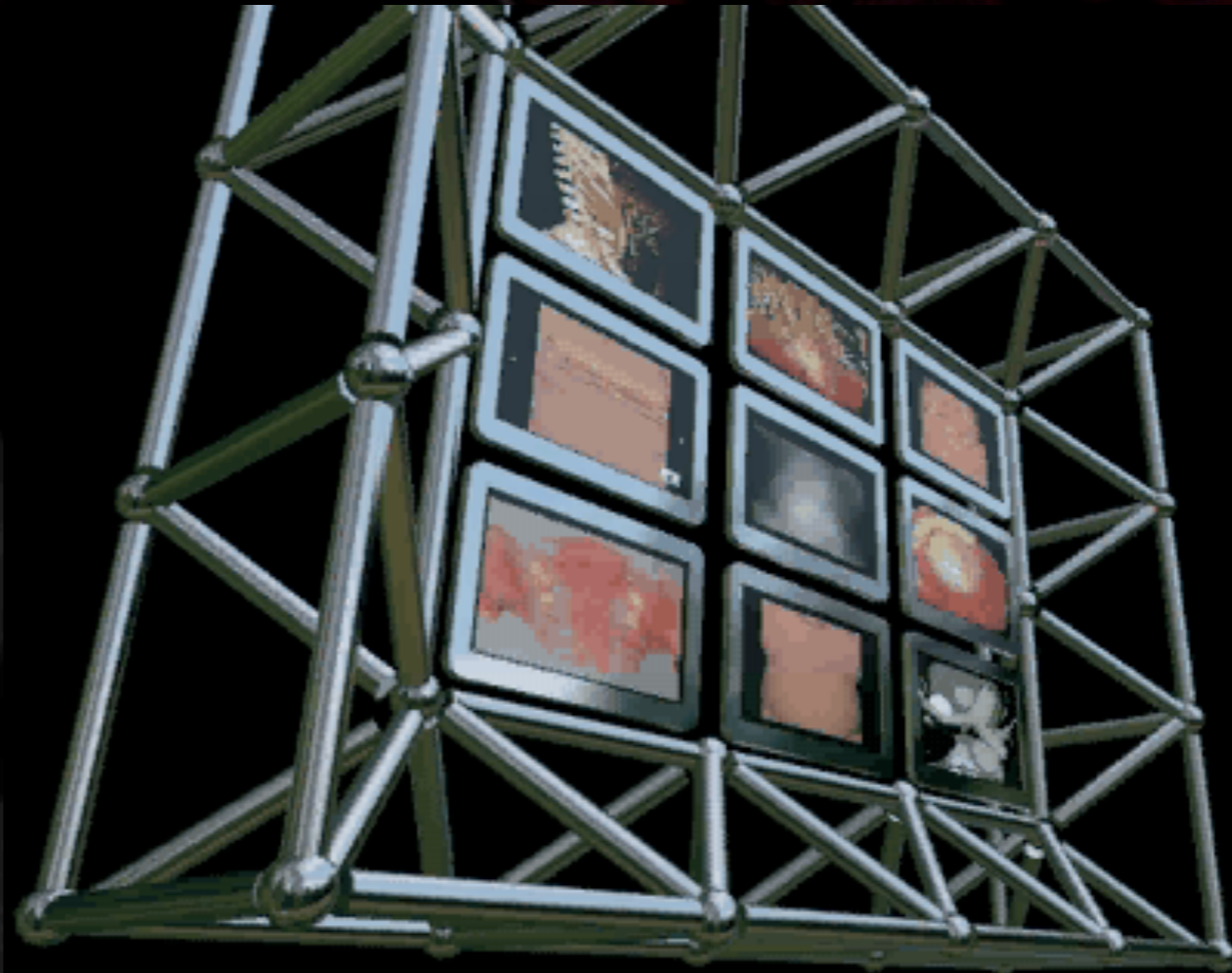


# 3D Image Post-Processing Techniques

**Richard L. Hallett, MD**

*Chief, Cardiovascular Imaging  
Northwest Radiology Network  
Indianapolis, IN*

*Adjunct Assistant Professor  
Stanford University  
Stanford, CA*



NMCSD 10 July 2011 0830-0900

Saturday, July 9, 2011



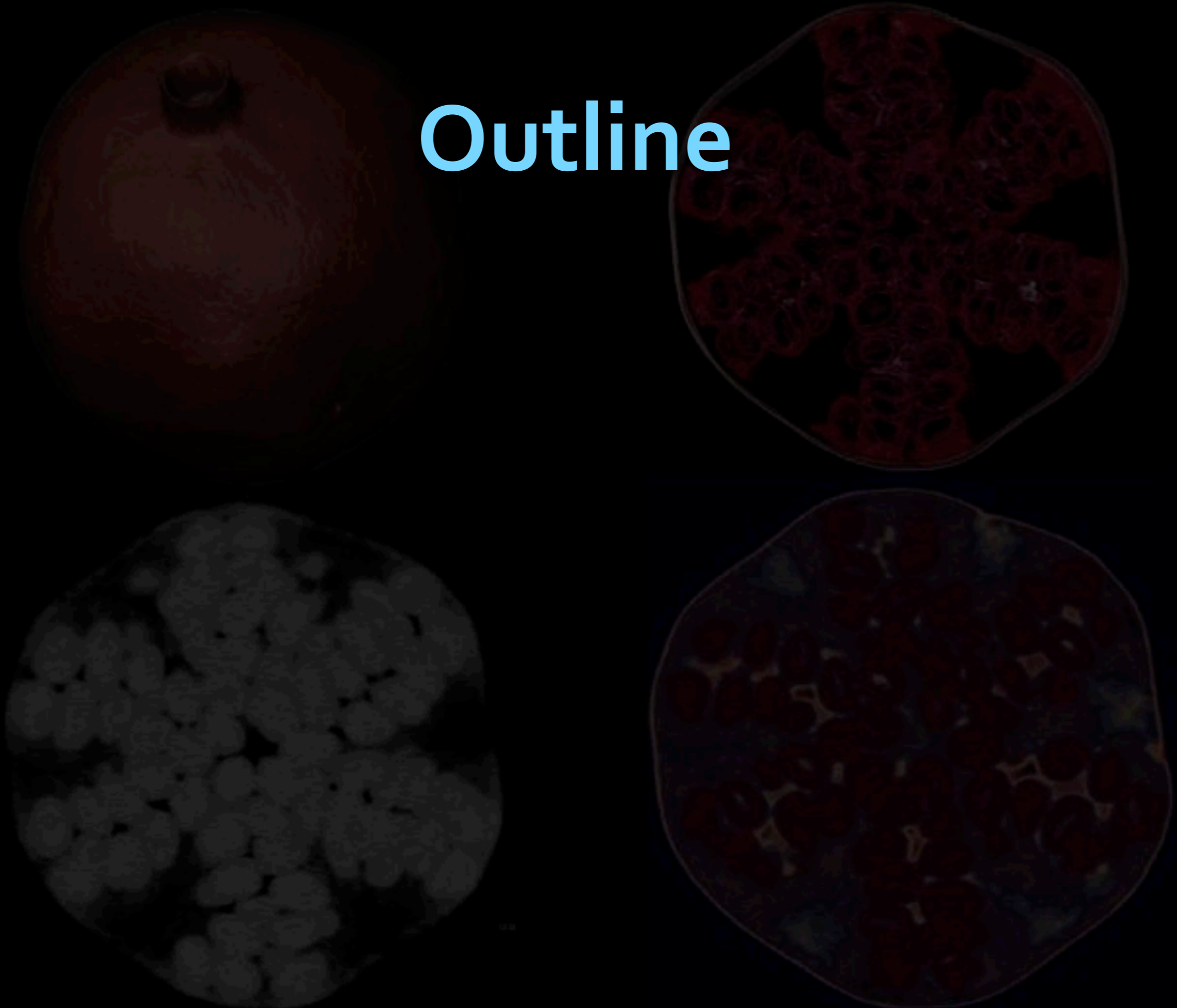
Disclosures: None

*Online Handouts from Lecture:*

[www.stanford.edu/~hallett](http://www.stanford.edu/~hallett)

*Choose “NMCSD”*

# Outline



# Outline

The background of the slide features several medical images. At the top, there are two axial CT slices of a brain. The left slice shows a normal brain structure, while the right slice shows a brain with a dark, irregularly shaped region, likely representing a tumor or lesion. Below these, there is a 3D reconstruction of a brain slice, showing a white, textured surface. In the center-right area, there are two small, bright, circular objects, possibly representing a tumor or a specific anatomical feature. The overall background is dark, with the images appearing as lighter, semi-transparent overlays.

I. CT Image reconstruction

II. Post-processing techniques

# Outline

- I. CT Image reconstruction
- II. Post-processing techniques



# Outline

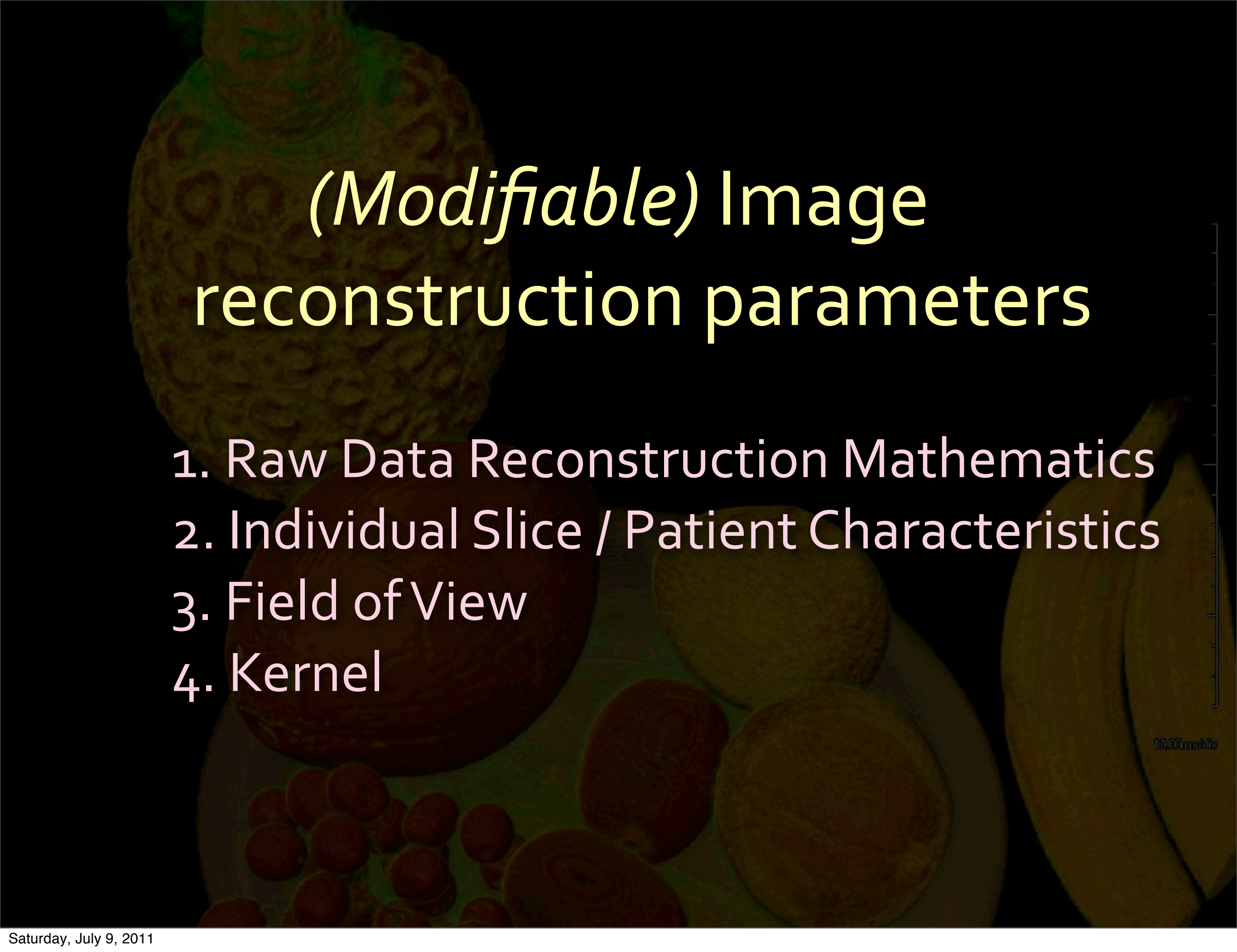
- I. CT Image rec
- II. Post-process



# Image reconstruction parameters



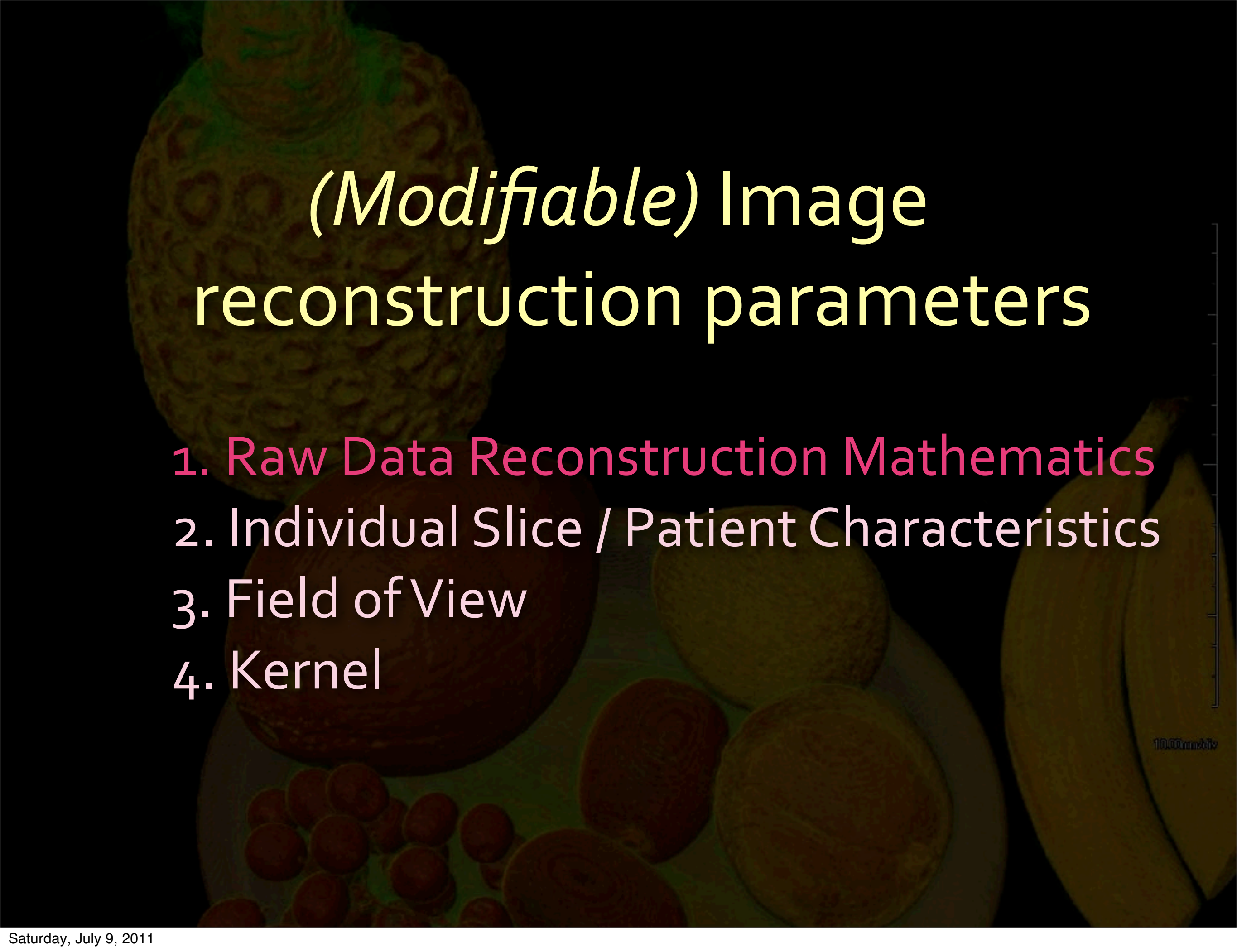
1000mbiv



# *(Modifiable)* Image reconstruction parameters

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

1000mm/s



# *(Modifiable)* Image reconstruction parameters

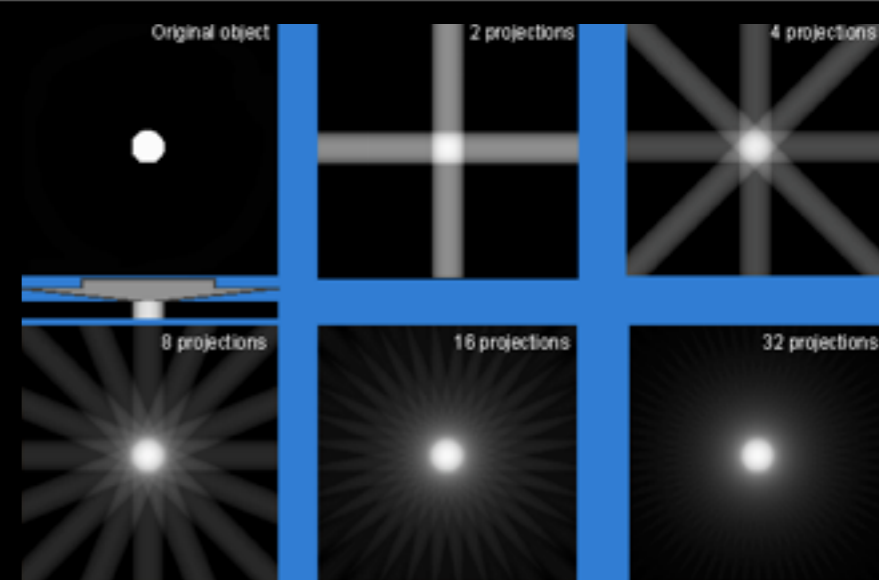
1. Raw Data Reconstruction Mathematics
2. Individual Slice / Patient Characteristics
3. Field of View
4. Kernel

100mm/s

# TRADITIONAL

## Raw Data Reconstruction

- Traditionally reconstructed using Filtered Back Projection (FBP)
- Necessary ASSUMPTIONS:
  - Focal spot infinitely small
  - Detector is single point in center of detector cell
  - Reconstructed voxel - no shape or size
  - Measured signal has no error from photon statistics or image noise



# “New” Data Reconstruction

- Iterative Reconstruction (IR)
  - Used in SPECT and PET years ago.....
  - Models CT system optics (geometric information) as well as statistics (noise)
    - ➔ Compares model to real raw data, correct, repeat
    - ➔ Model can be *iterated* over and over until image is essentially constant
  - Computationally expensive

Hara AK, et al. Am J Roentgenol. 2009;193(9):764-771

# Conventional FBP

# vs. Iterative Reconstruction

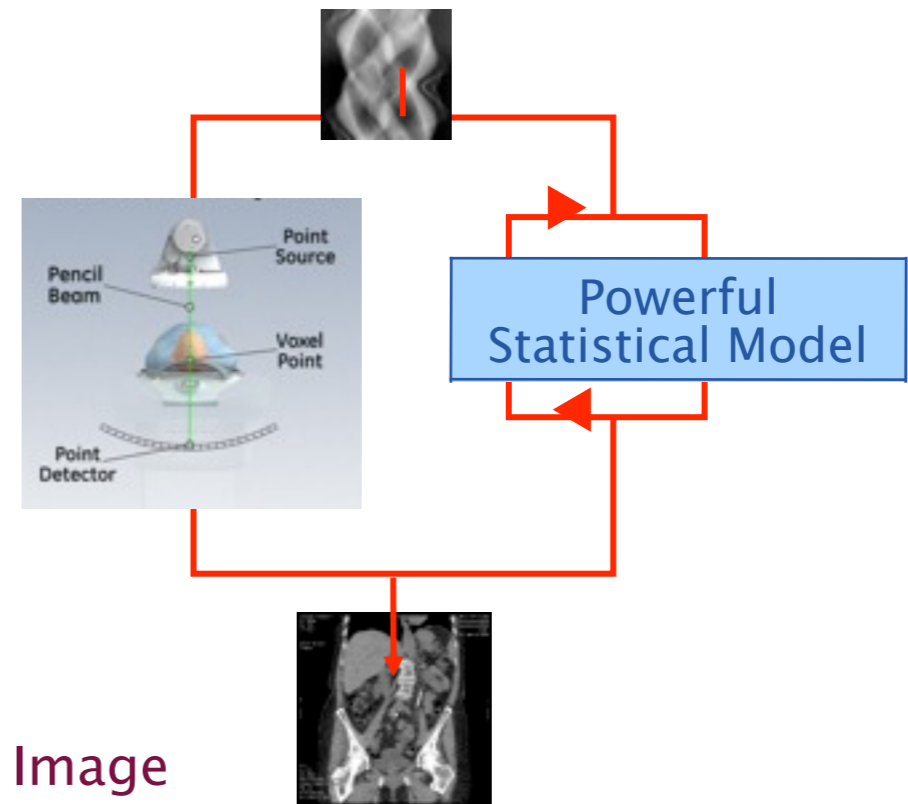
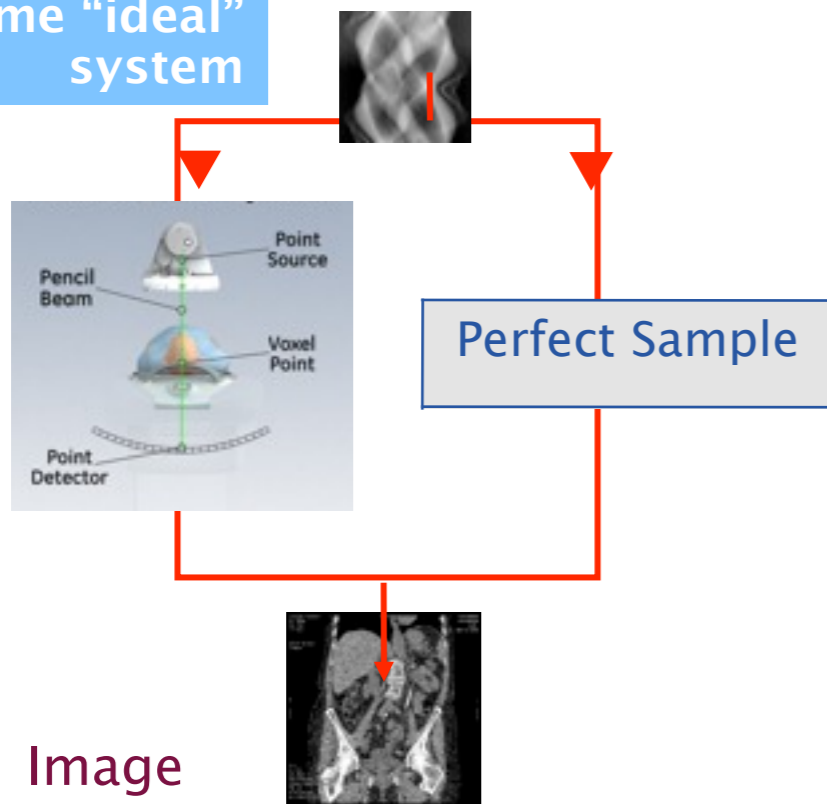
## FBP Reconstruction

## Iterative Reconstruction

Raw Data

Raw Data

Assume "ideal" system



Image

Image



CPU  
required

Simple  
Fast reconstruction  
High Noise



CPU  
required

Better Image Quality  
Low Noise  
Lower Dose

# Conventional FBP

# vs. Iterative Reconstruction

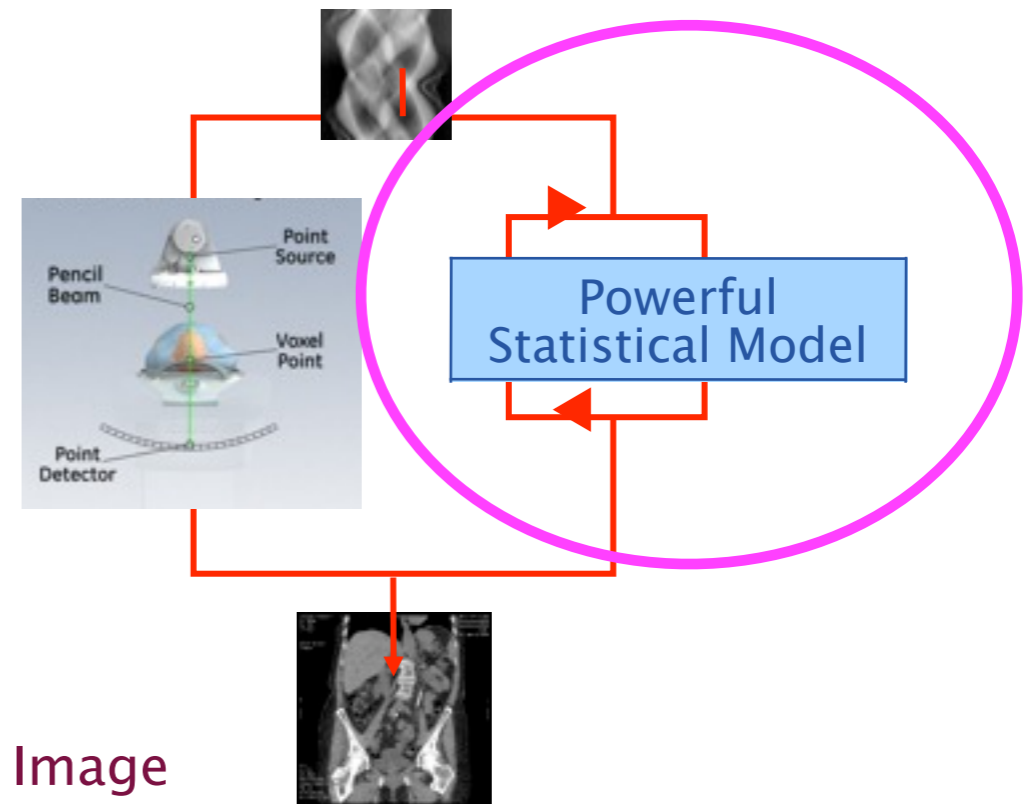
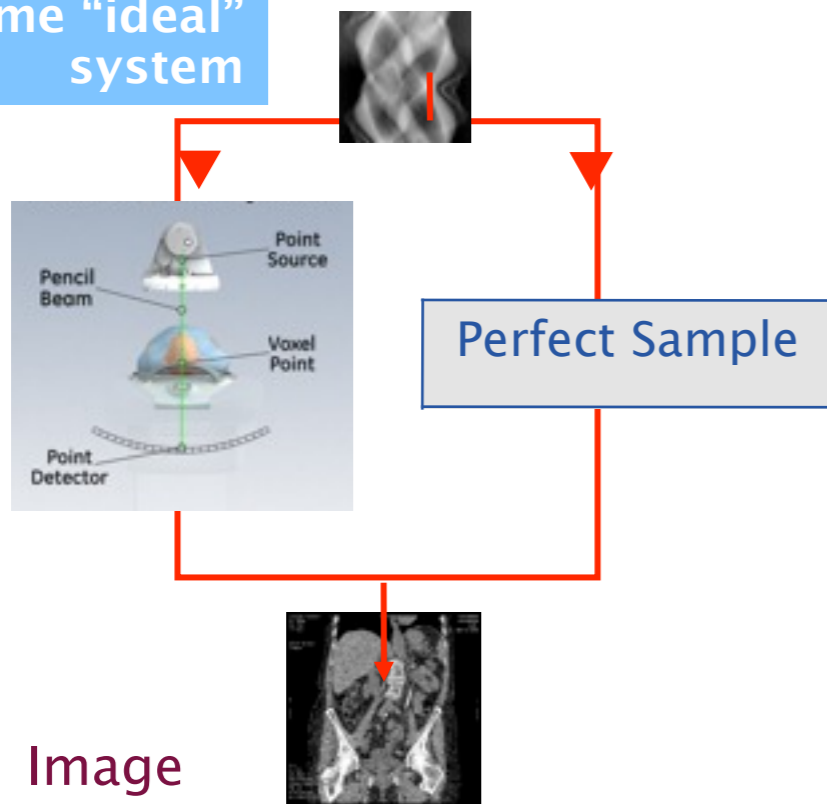
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# Conventional FBP

# vs. Iterative Reconstruction

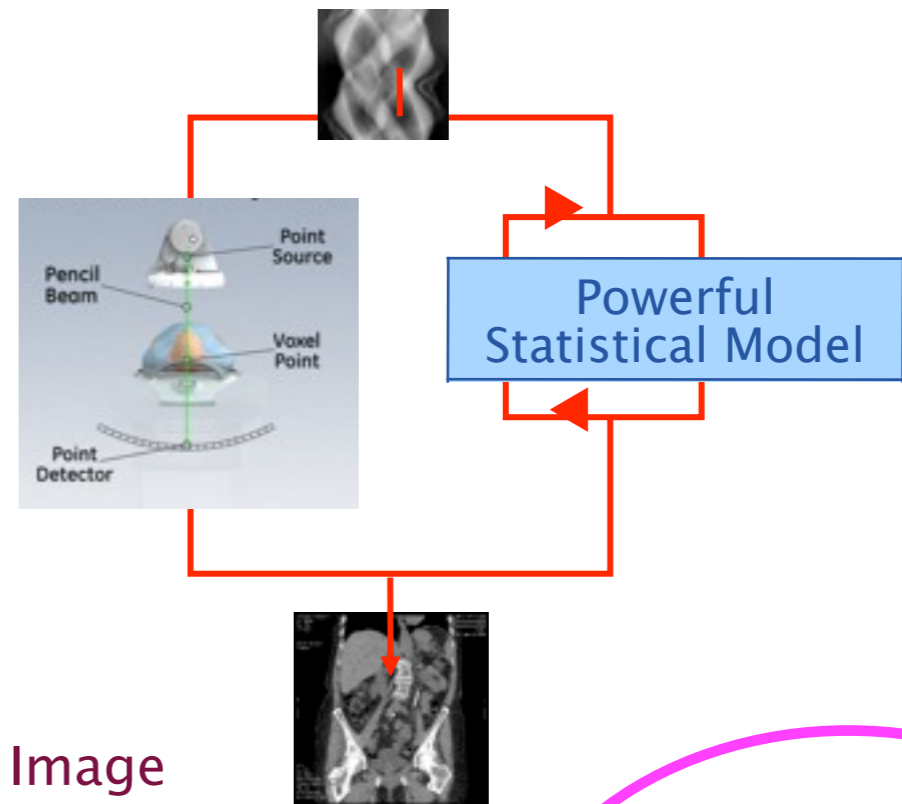
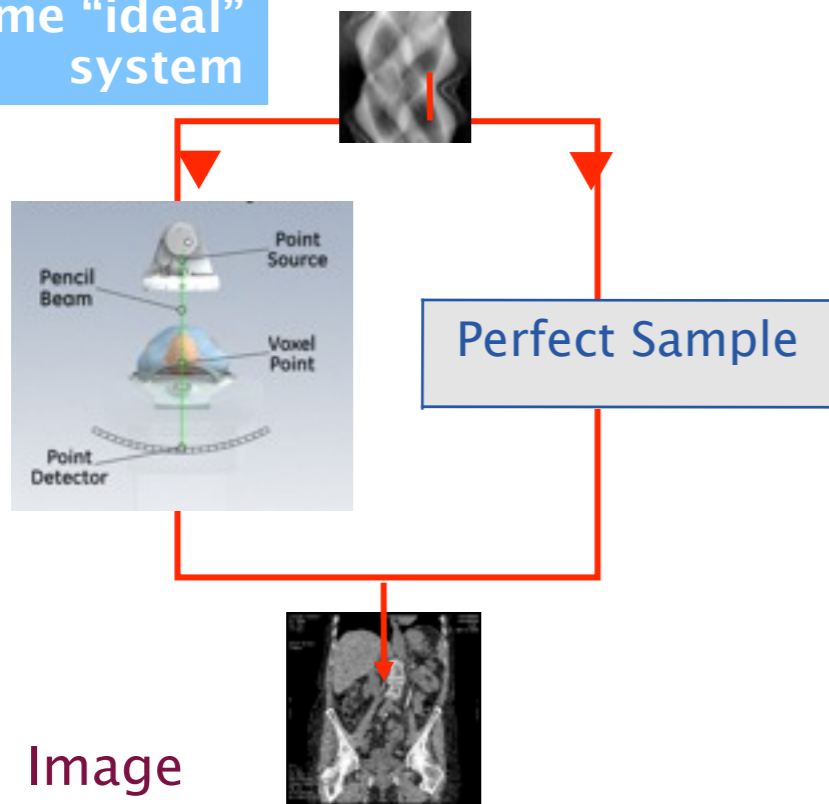
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Raw Data

Assume "ideal"  
system



Image

Image



CPU  
required

Simple  
Fast reconstruction  
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CPU  
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Better Image Quality  
Low Noise  
Lower Dose

# Benefits of Iterative Reconstruction

- Up to 50% dose reduction is possible at same image noise

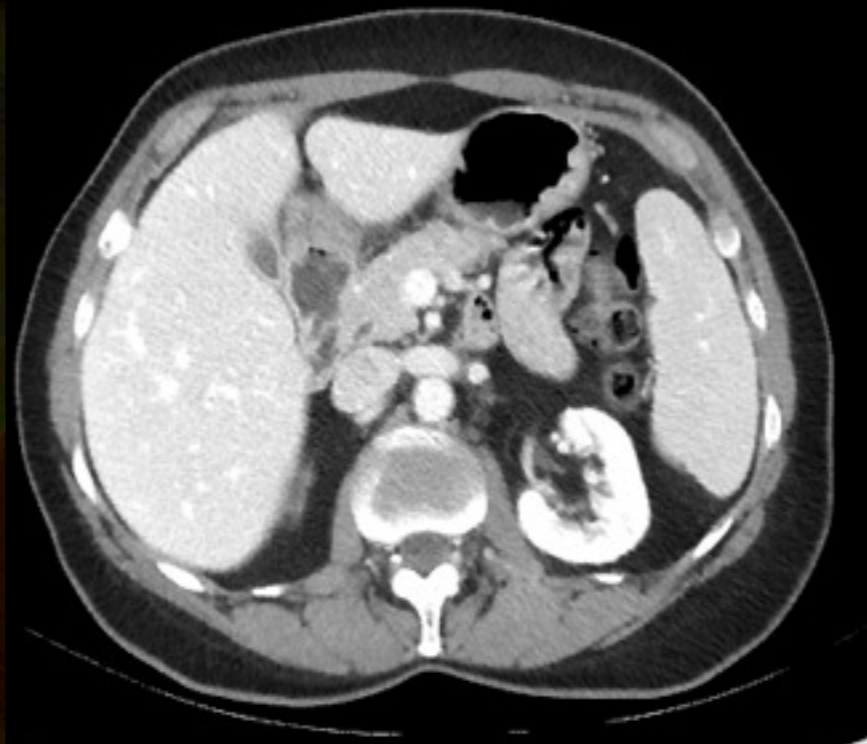
OR:

Improved image quality at same dose

- 40% improvement in low contrast detectability



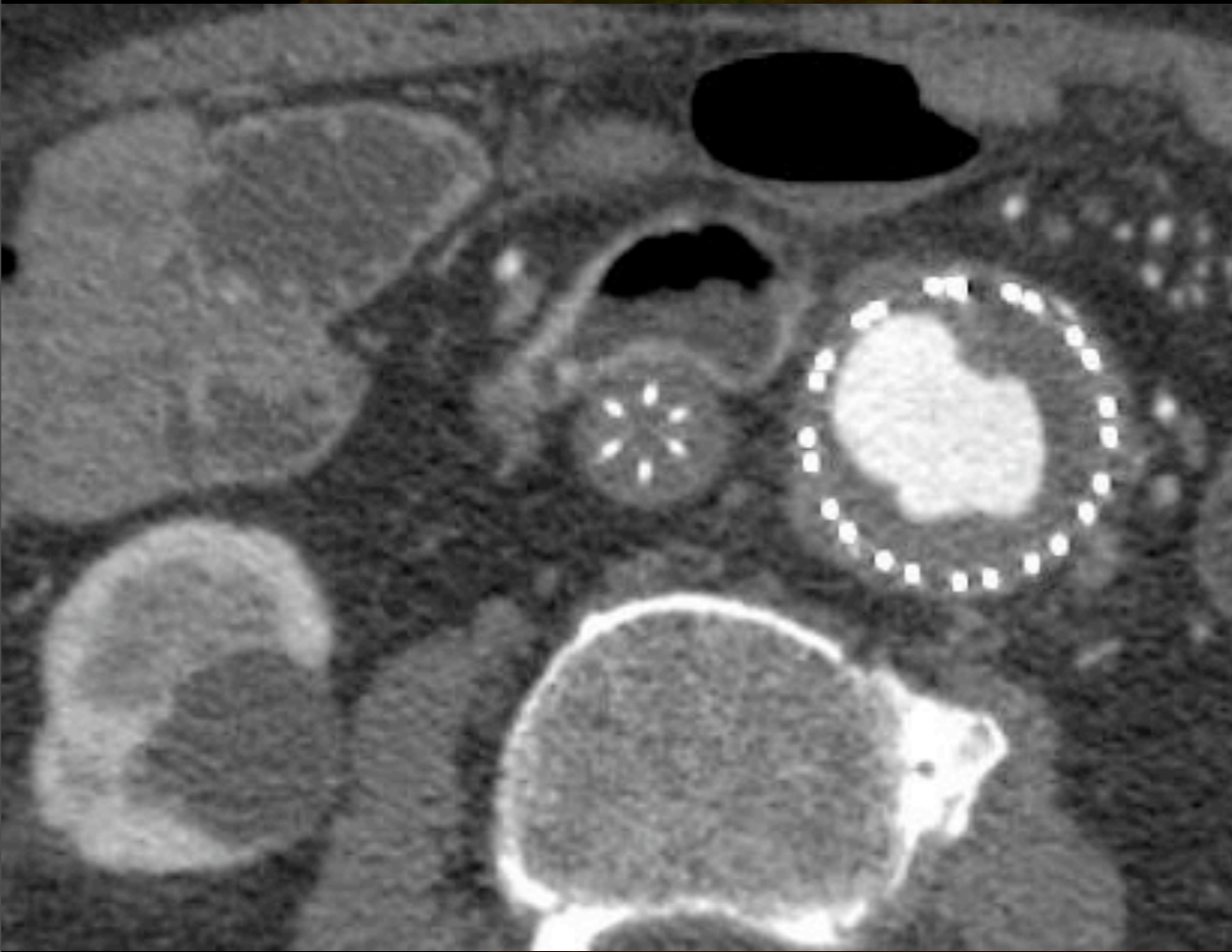
2007, Std.  
Technique  
CTDI=19



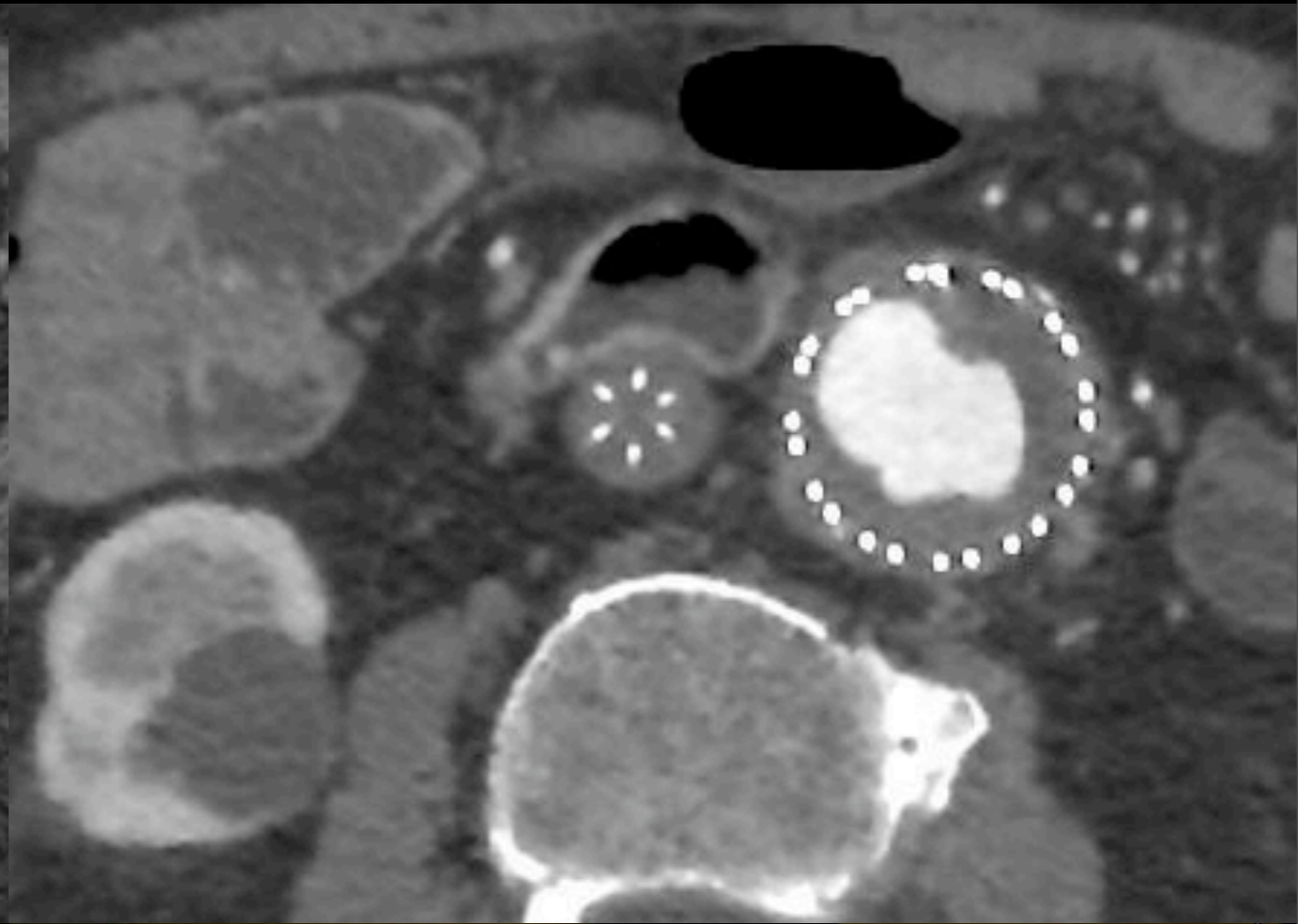
2008  
ASiR  
CTDI=9

Images courtesy of Mayo Clinic Arizona

# Iterative Reconstruction: Appearance



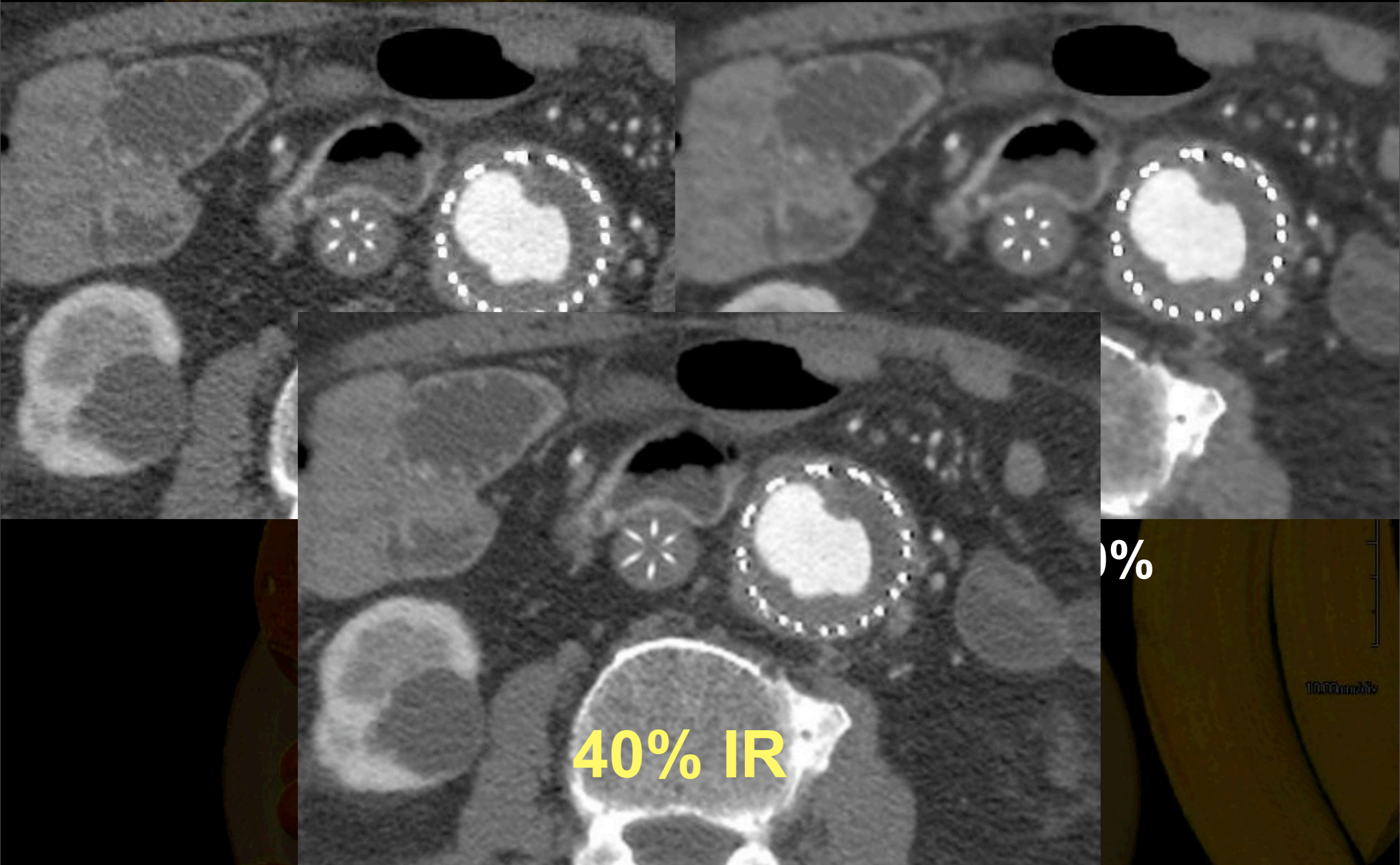
**0% IR**



**100%  
IR**

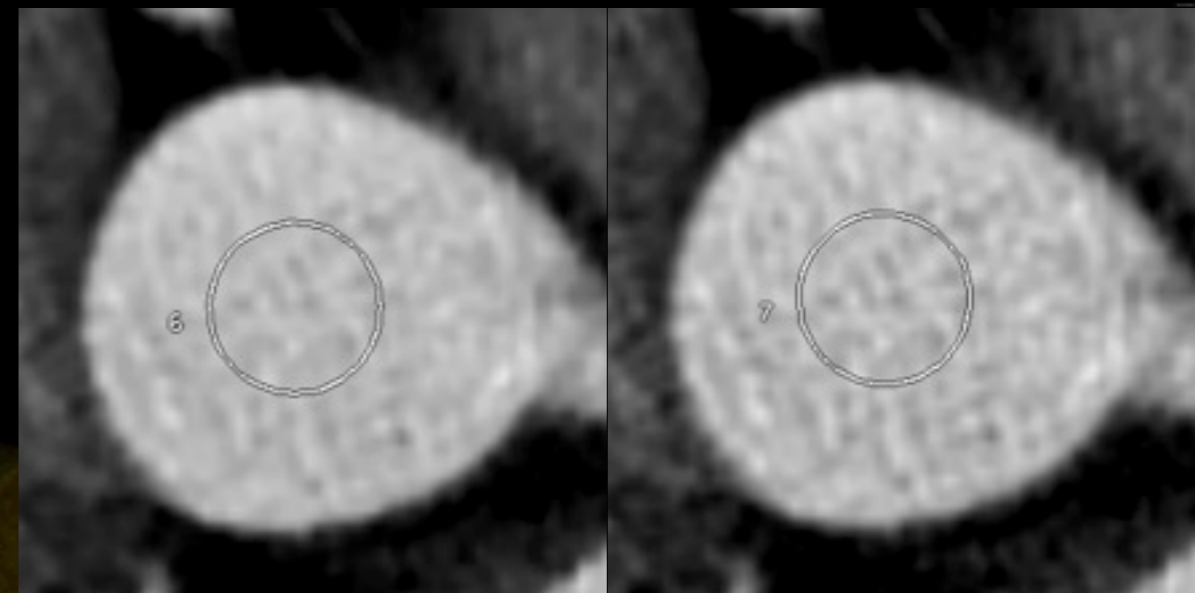
100mm/div

# Iterative Reconstruction: Appearance



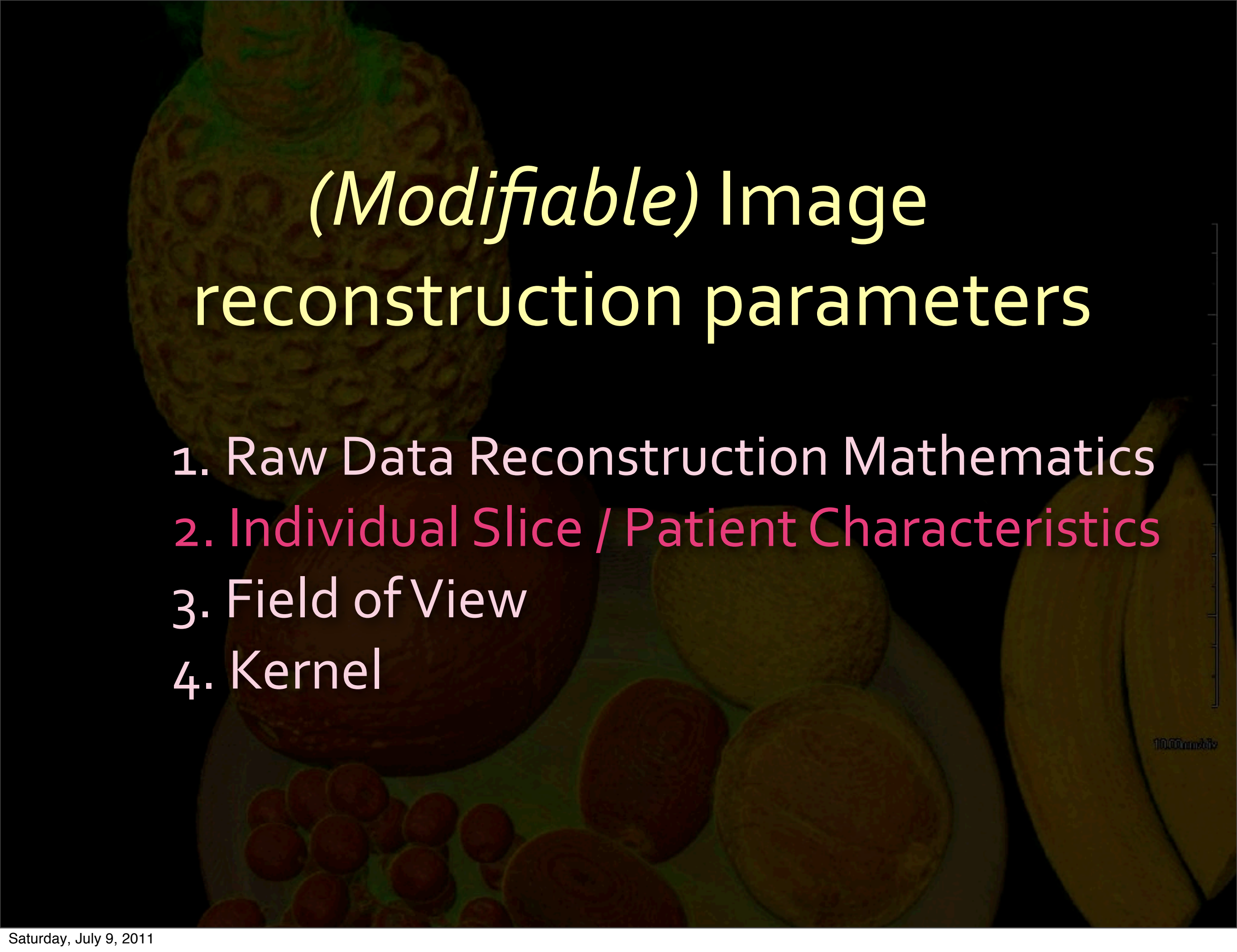
# Iterative Recon for CCTA: the ERASIR STUDY

- 574 consecutive pts at 3 sites referred for CCTA: FBP vs. 40% ASiR blend
- 27% dose reduction from IR utilization, without increased image noise or non-evaluatable segments
- 45% total reduction including other scan parameters (100 kV, etc)



	FBP	40% ASIR
Density, HU	718.6	719.3
SD (noise)	52.3	38.5

Leipsic J, et al. AJR 2010; 195:655-660



# *(Modifiable)* Image reconstruction parameters

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

100mm/s

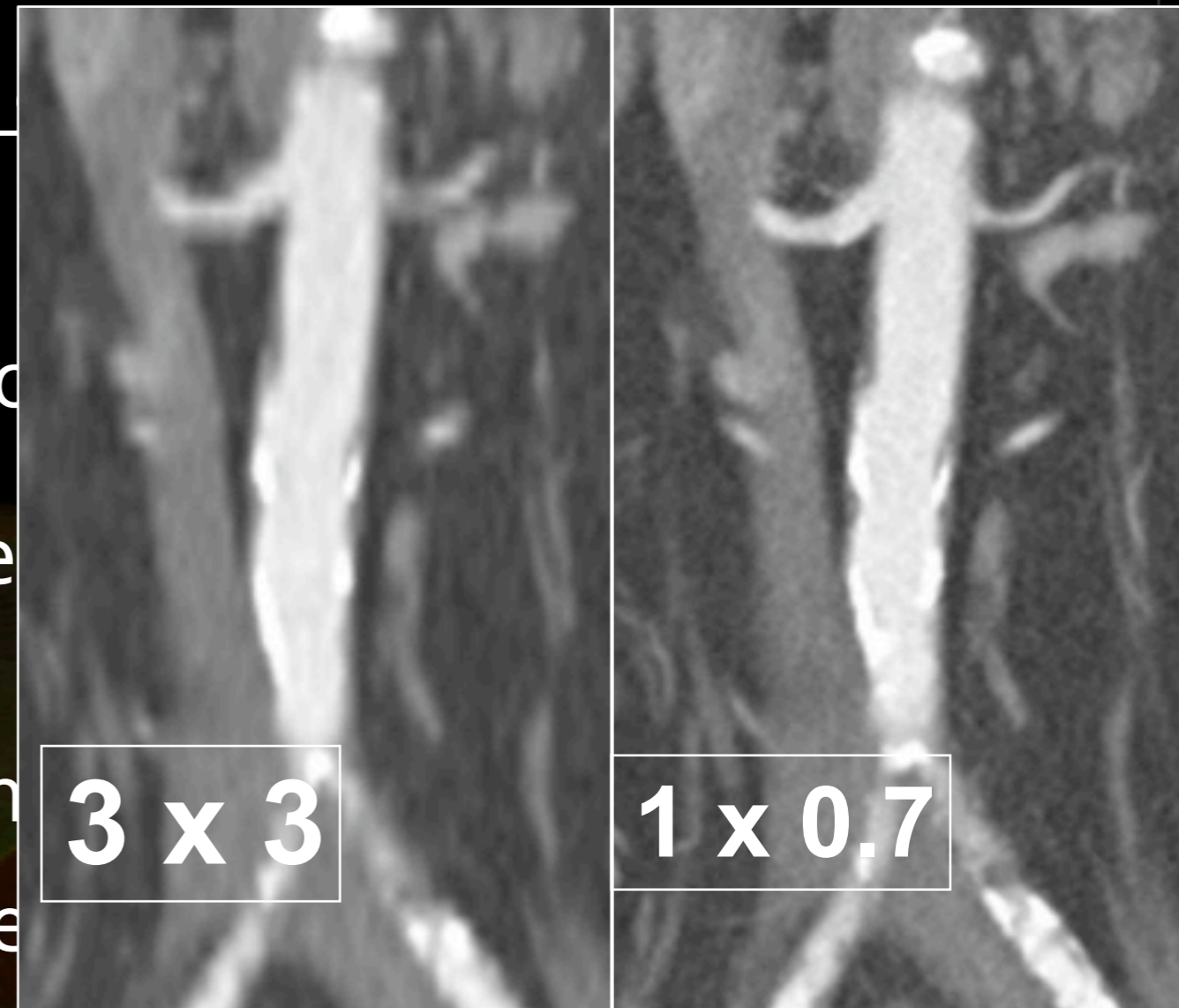
# CT “slice” Characteristics...

- “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)

1000mm/s

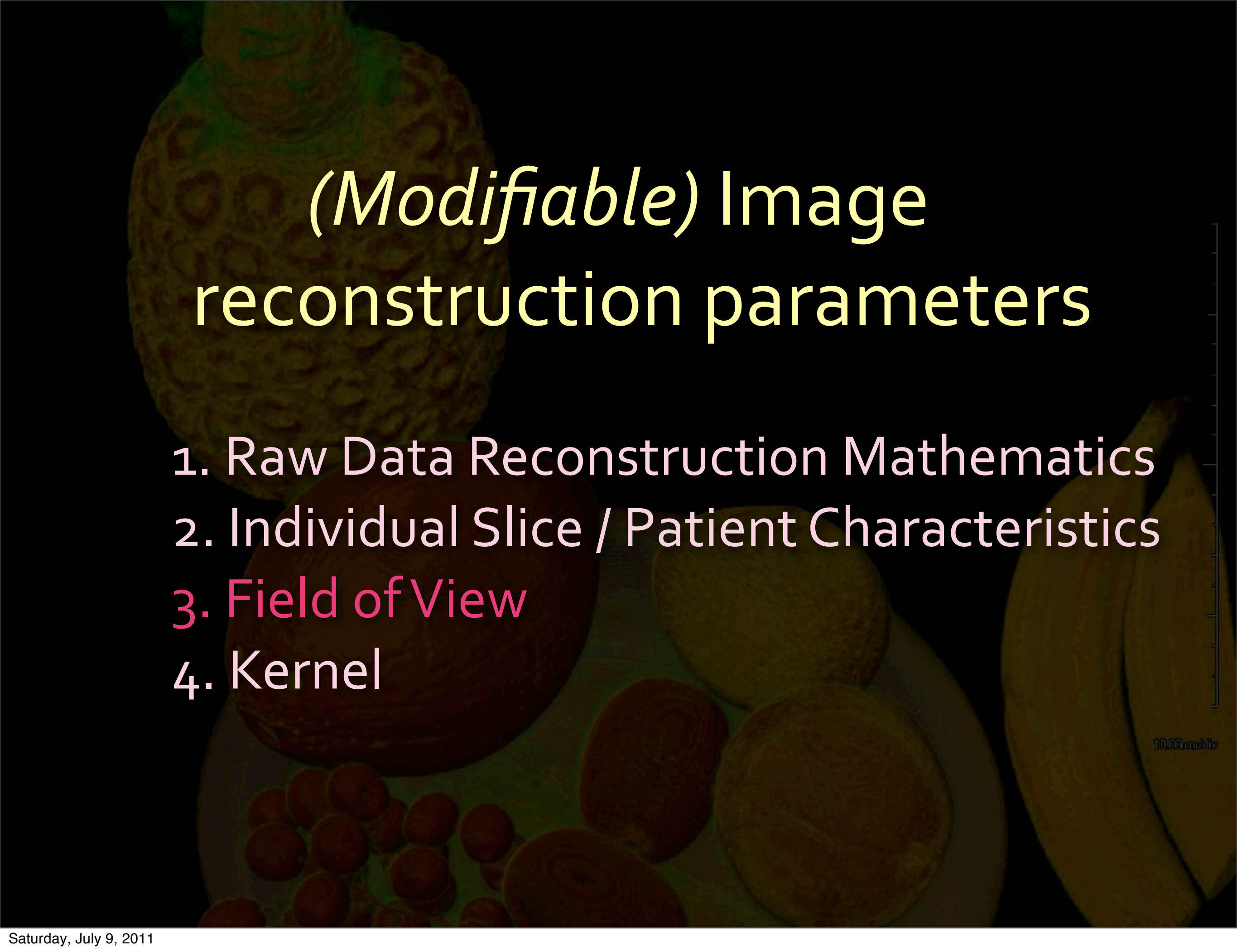
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during scan acquisition
- Thicker (but not thinner) reco
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overlapped by ~ 30%
  - e.g. 1mm ST at 0.7 mm
  - Less "aliasing" (stairste



# 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



# *(Modifiable)* Image reconstruction parameters

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

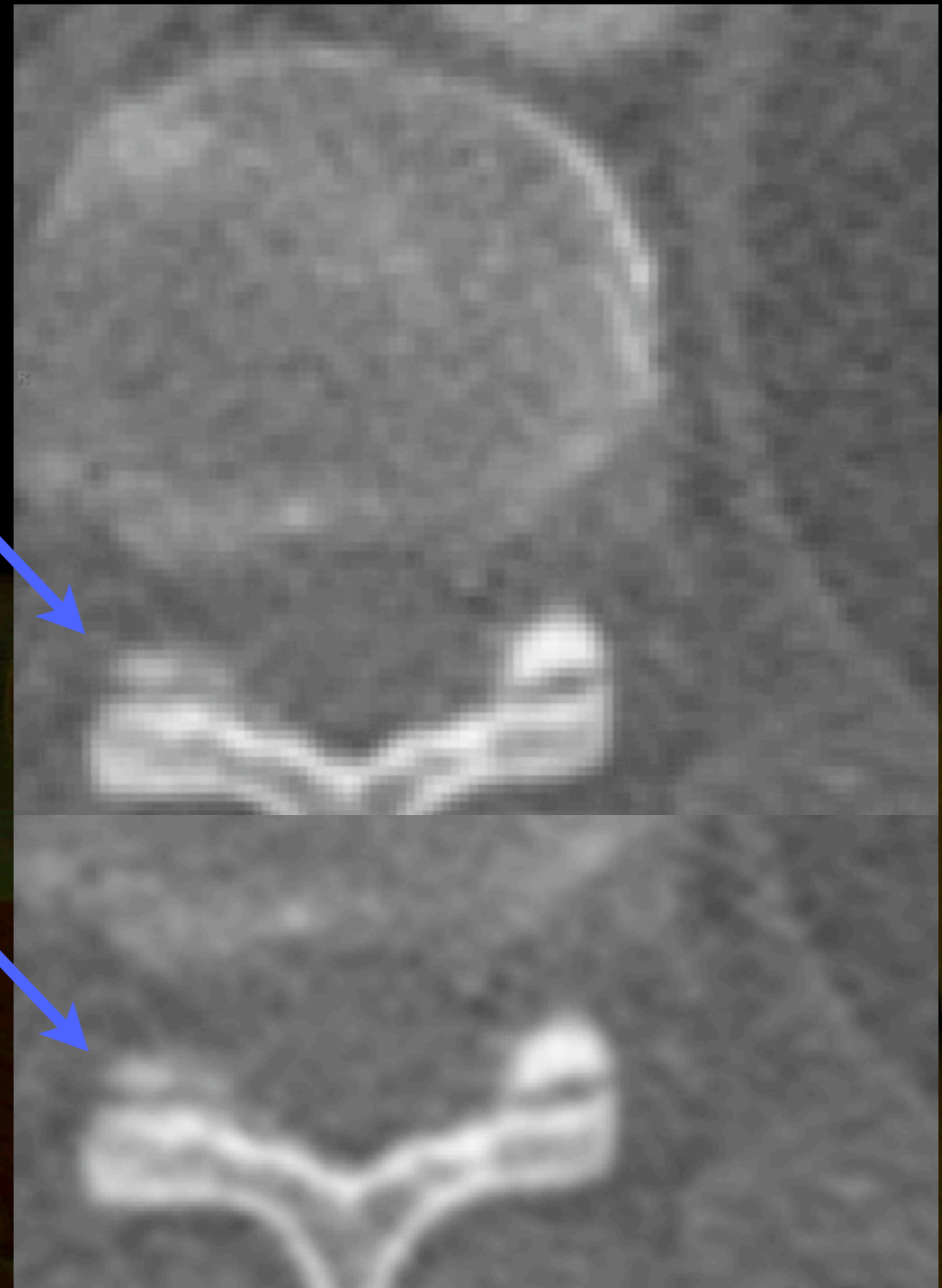
# Effect of changing FOV

- Standard CT image:
  - 512x512, FOV = 30 cm
  - Pixel size ~ 0.35 mm<sup>2</sup>
- Small FOV:
  - 512x512, FOV = 15 cm
  - Pixel size ~ 0.10 mm<sup>2</sup>
- BUT: "Isotropic" voxels easier to obtain at thicker slice / larger FOV

100mm/div

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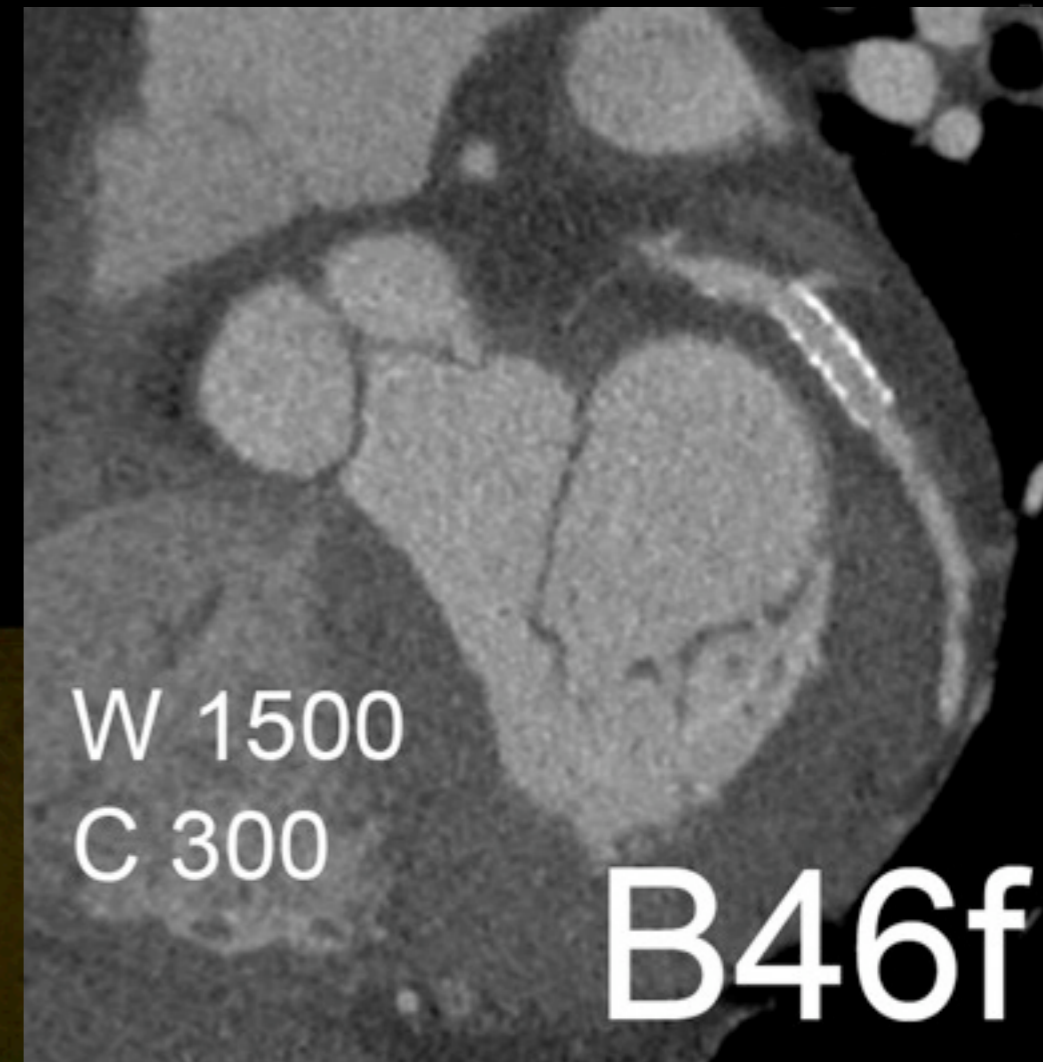


# *(Modifiable)* Image reconstruction

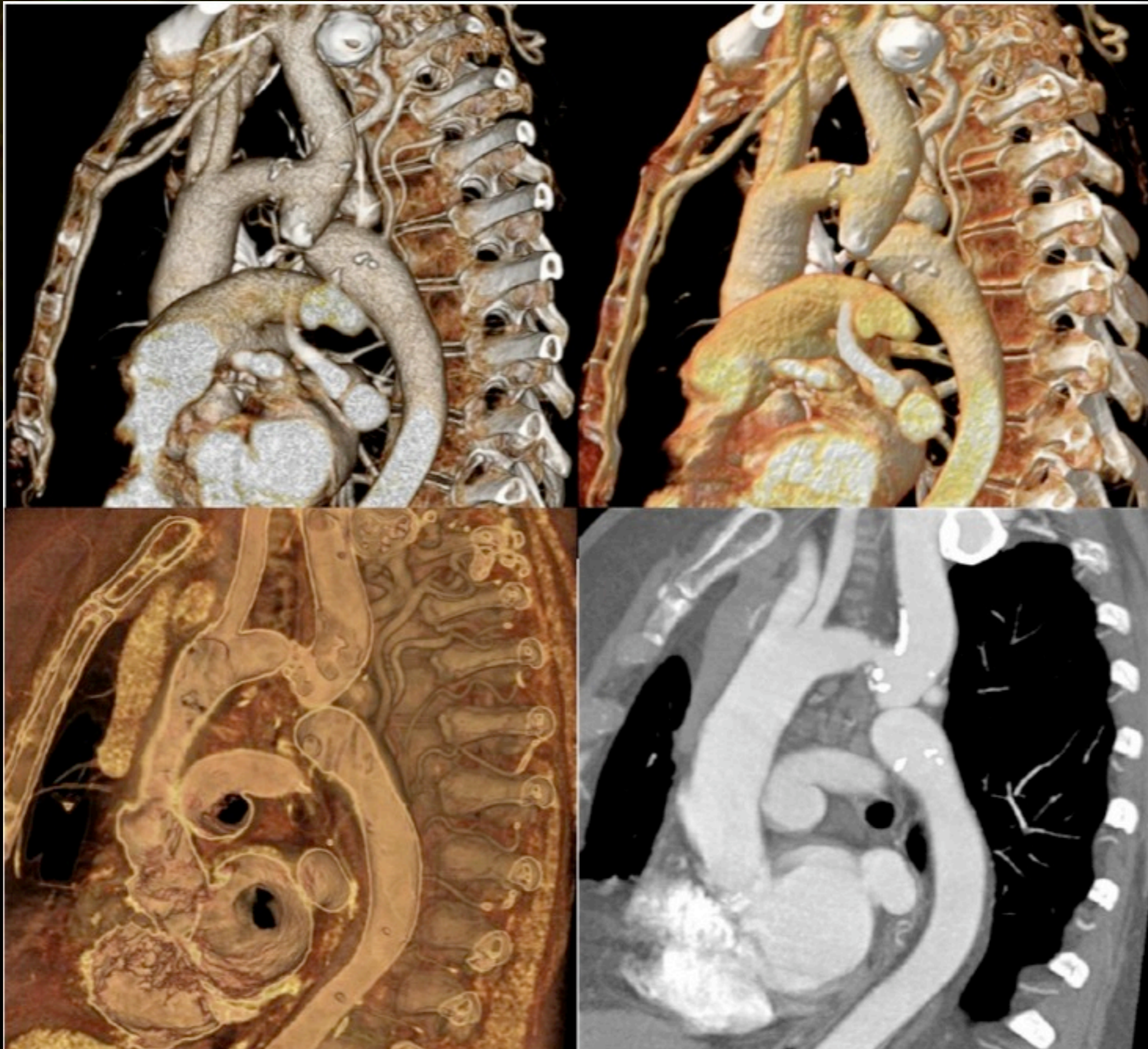
1. Raw Data Reconstruction Mathematics
2. Individual Slice / Patient Characteristics
3. Field of View
4. Kernel

# 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

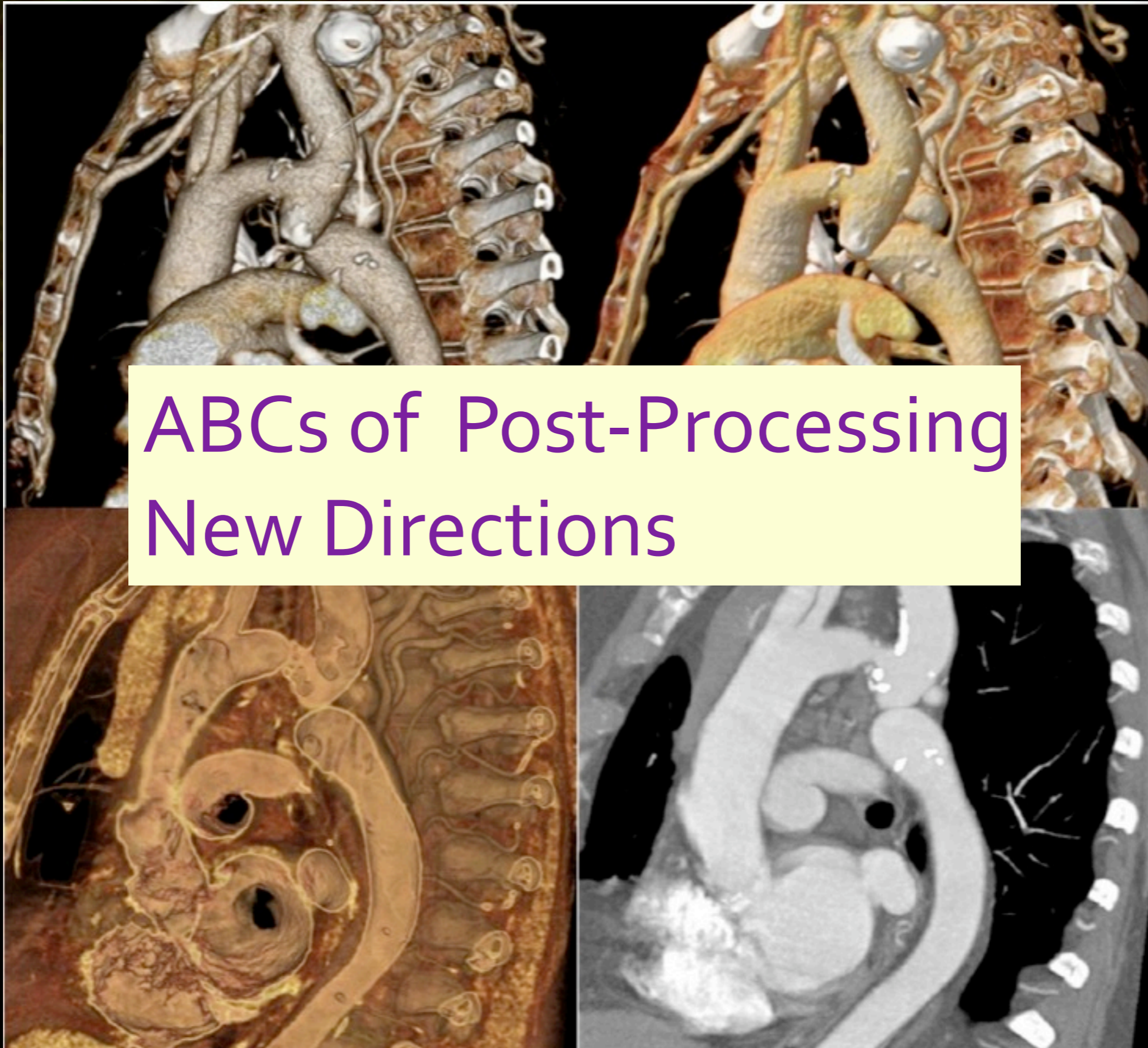


# Image Post-Processing



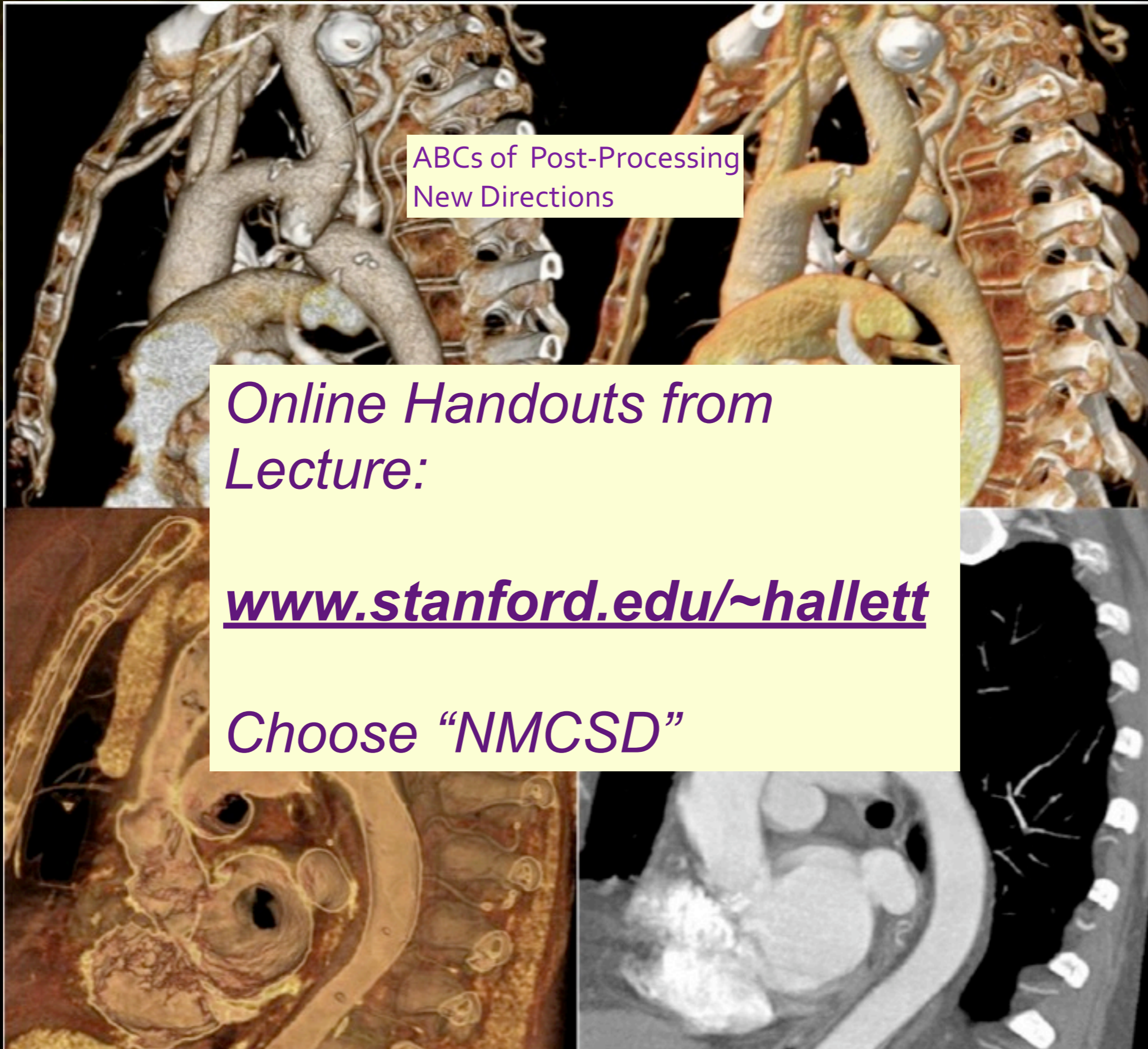
1000mm/div

# Image Post-Processing



1000mm/s

# Image Post-Processing



ABCs of Post-Processing  
New Directions

*Online Handouts from  
Lecture:*

**[www.stanford.edu/~hallett](http://www.stanford.edu/~hallett)**

**Choose “NMCSD”**

# Post-Processing "Alphabet Soup"



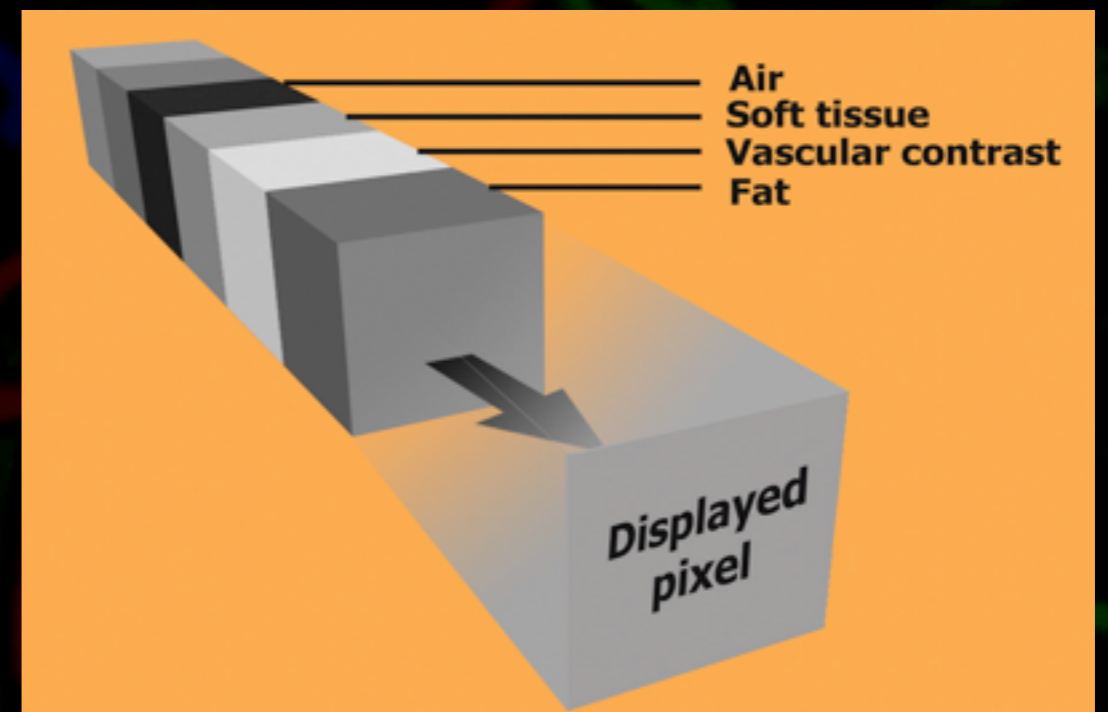
# Post-Processing "Alphabet Soup"

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



# 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



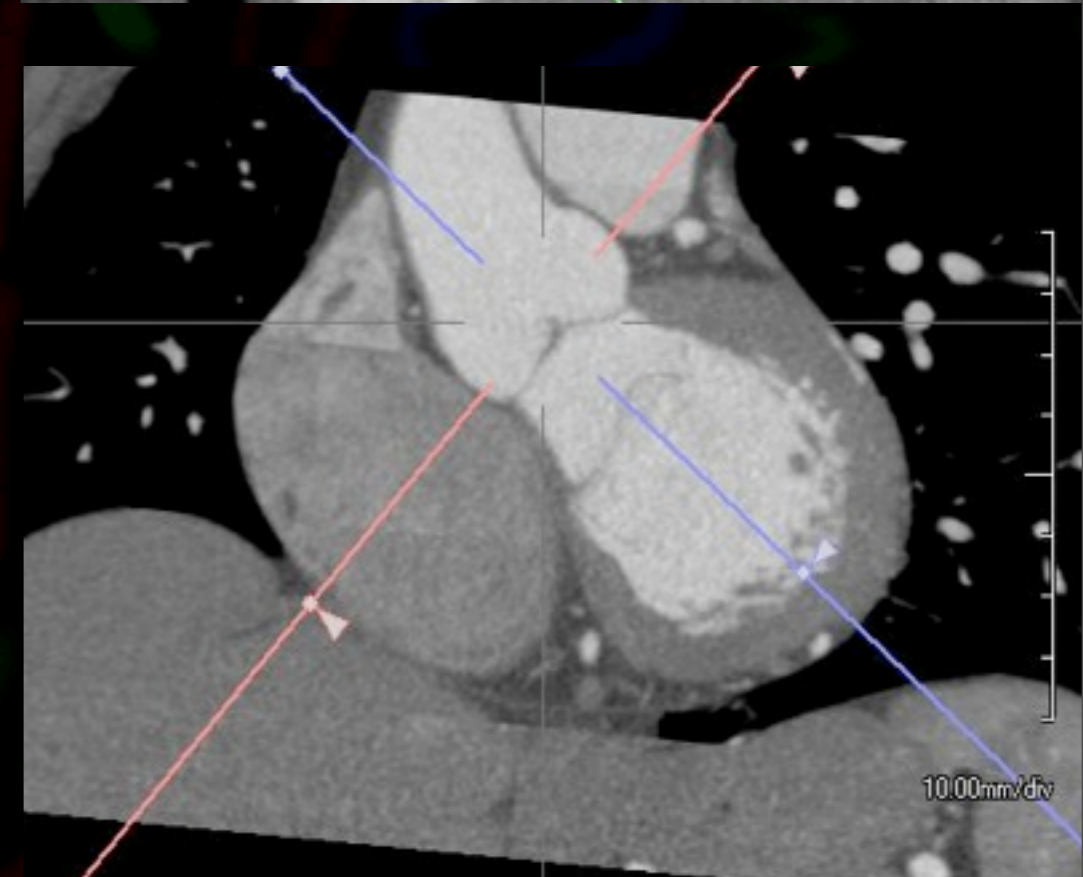
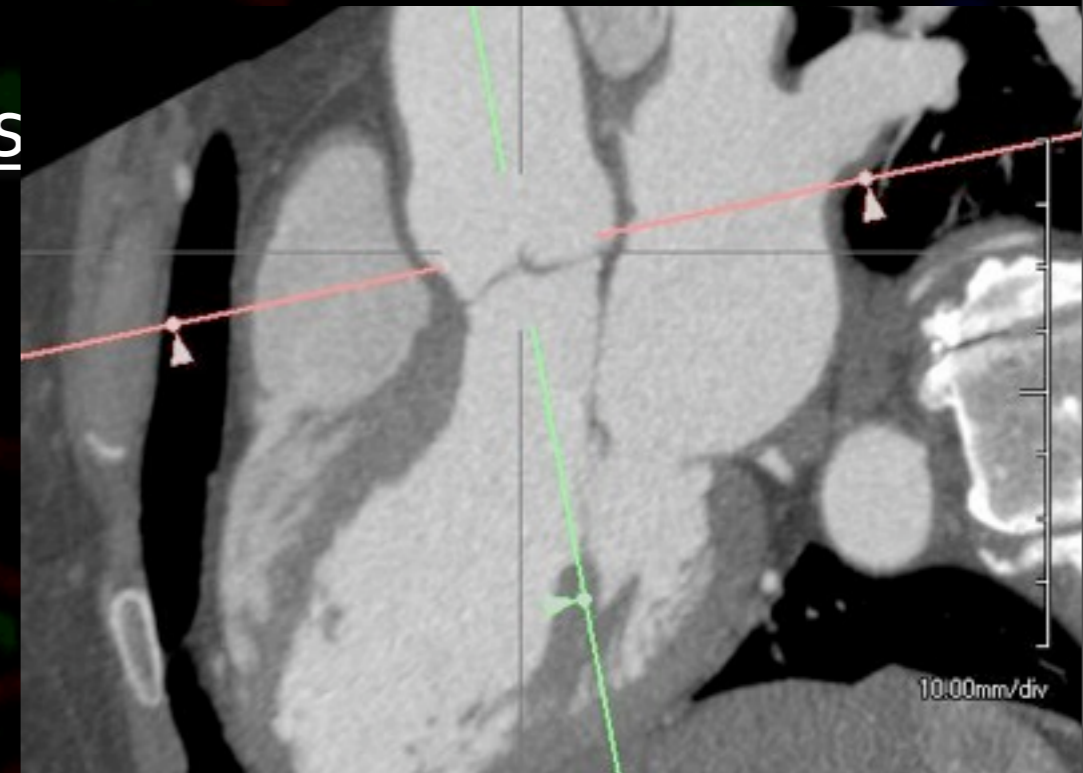
# EXAMPLE: MPR - Orthogonal Measurements

- Axial measurements not as precise nor as reproducible as orthogonal measurements
- **TIP: Rotate crosshairs perpendicular in 2 planes  $\rightarrow$  3<sup>rd</sup> is orthogonal!!**
  - Can also auto generate from centerlines



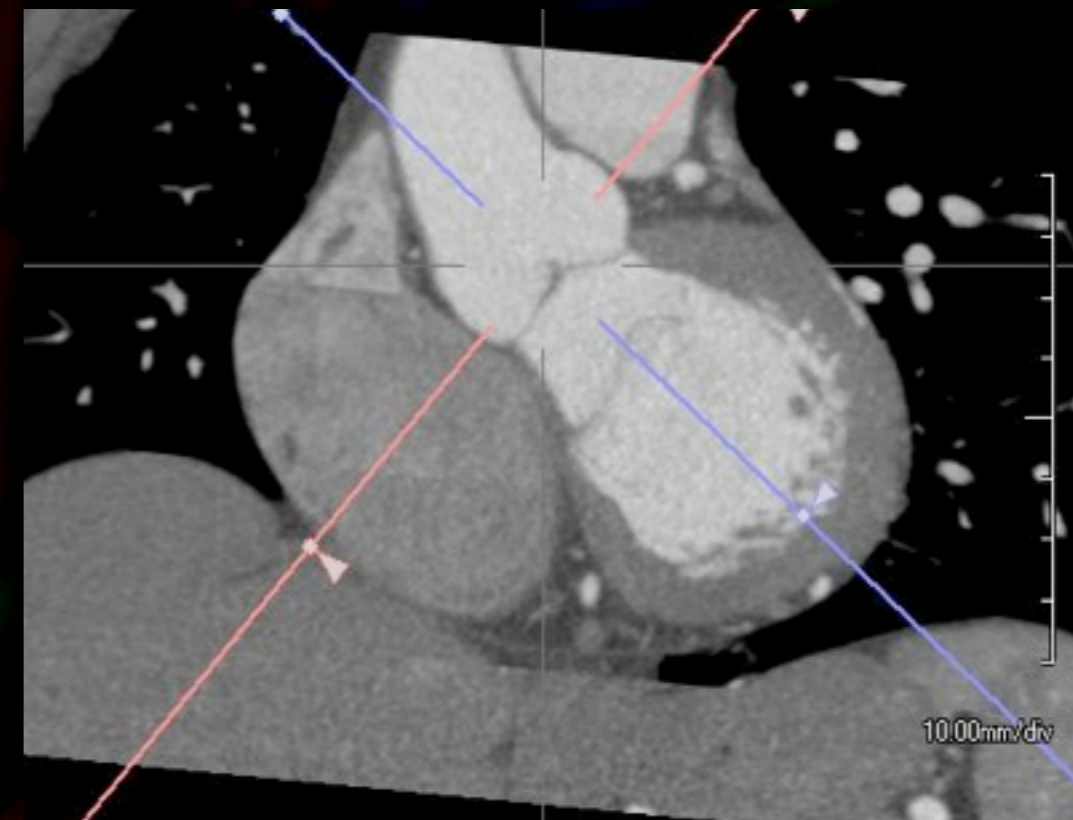
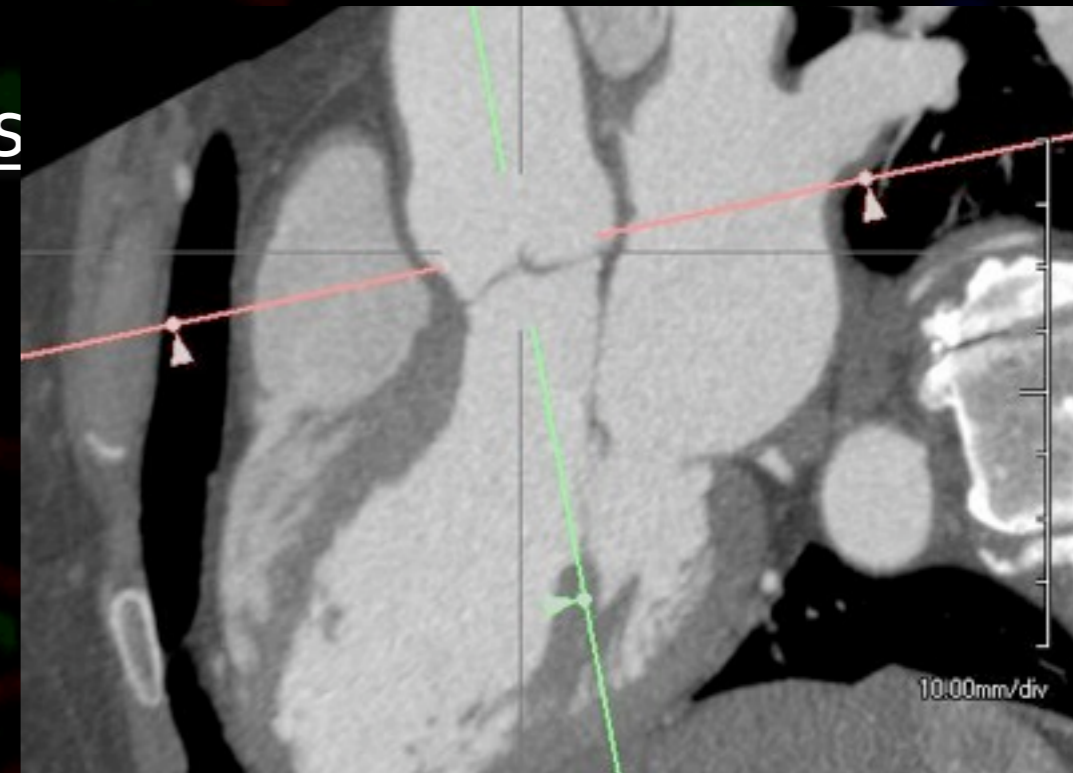
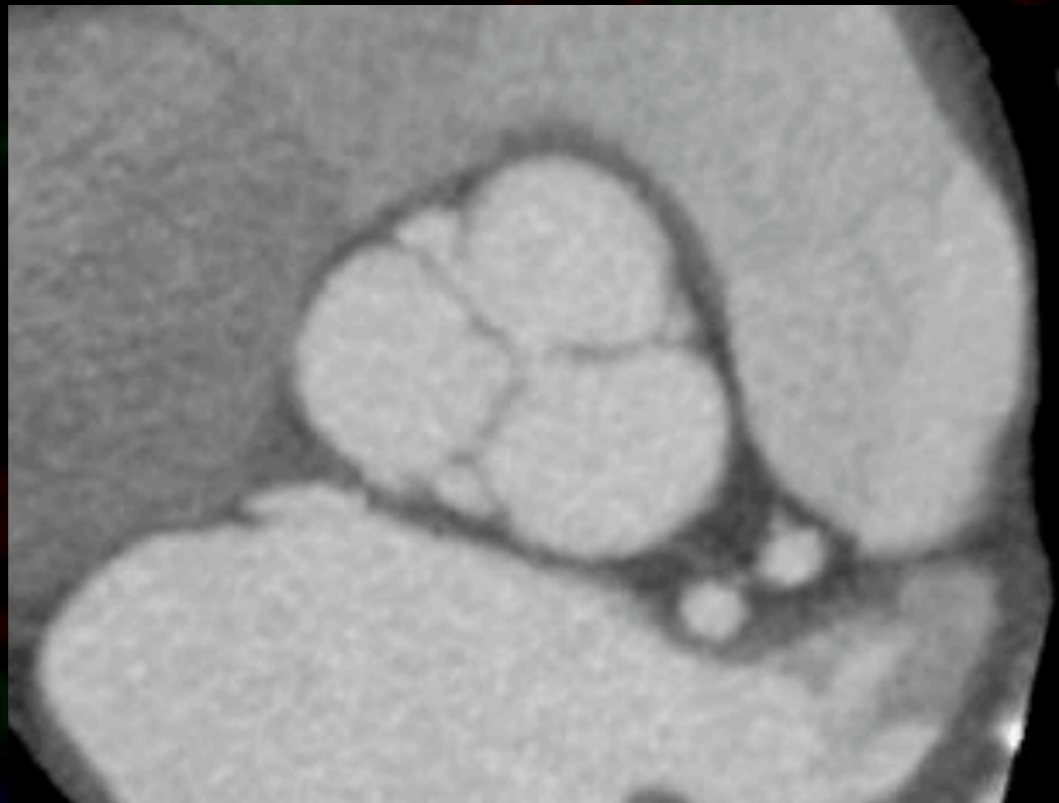
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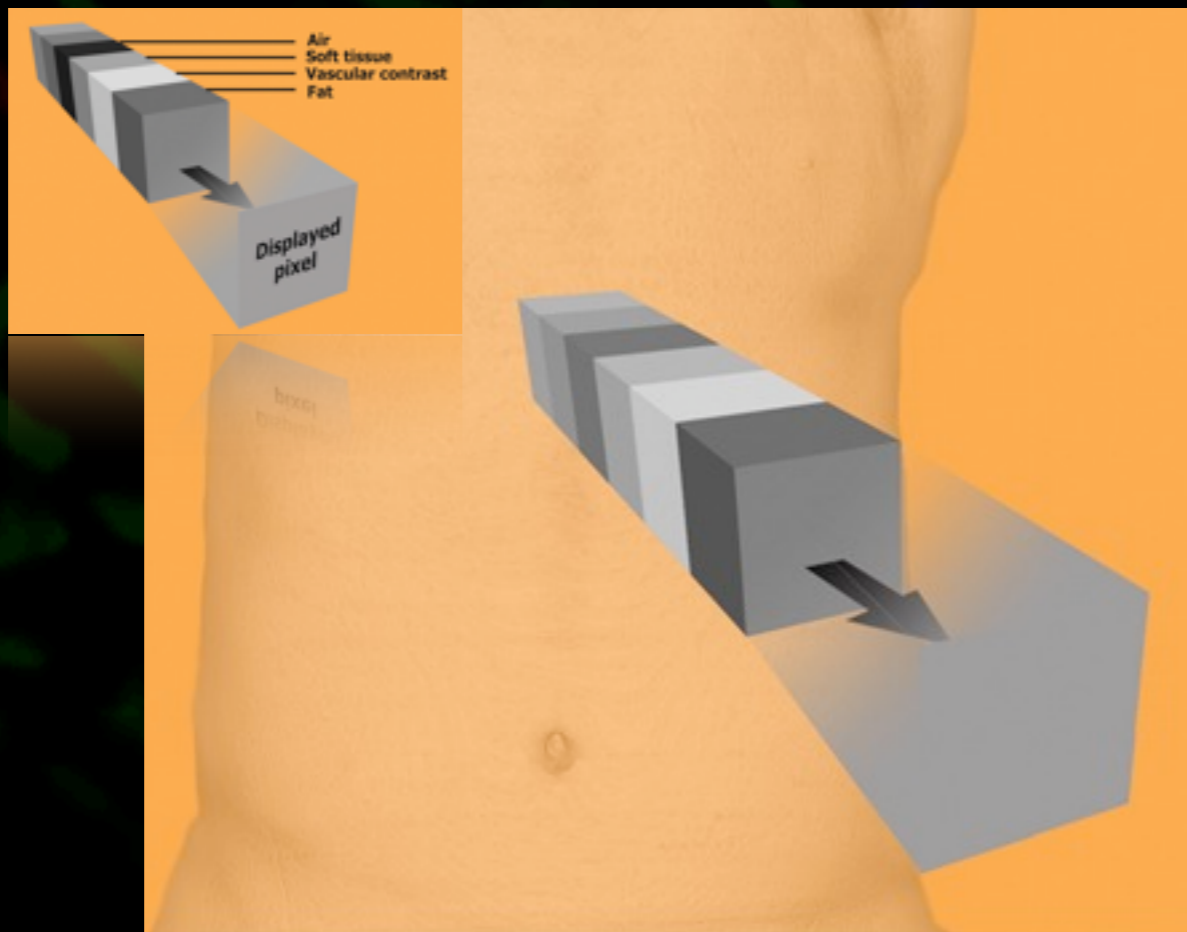
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# Average Intensity Projection (AIP)

= “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



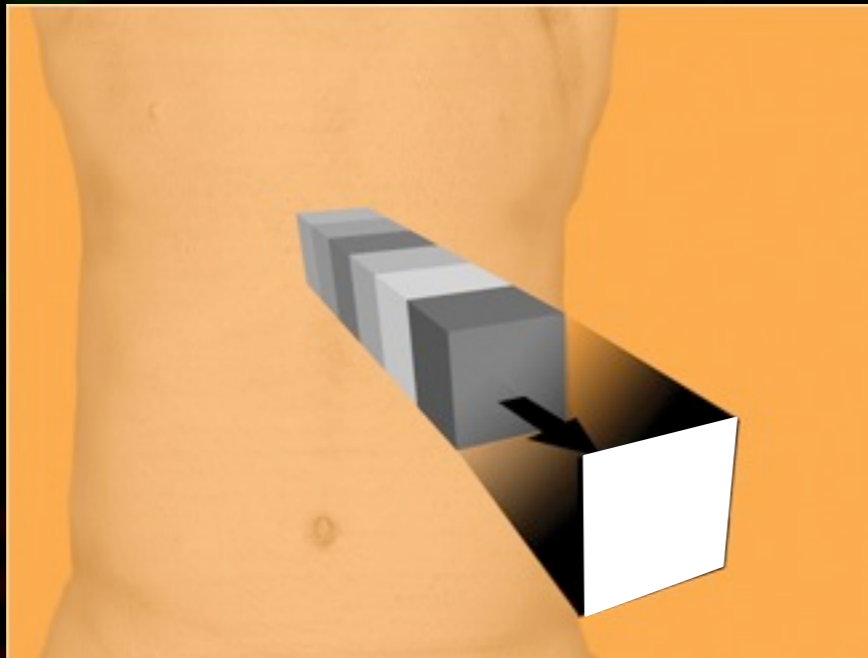
# 360 lb patient, non-Dx Echo Thick MPR Cine 4D

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



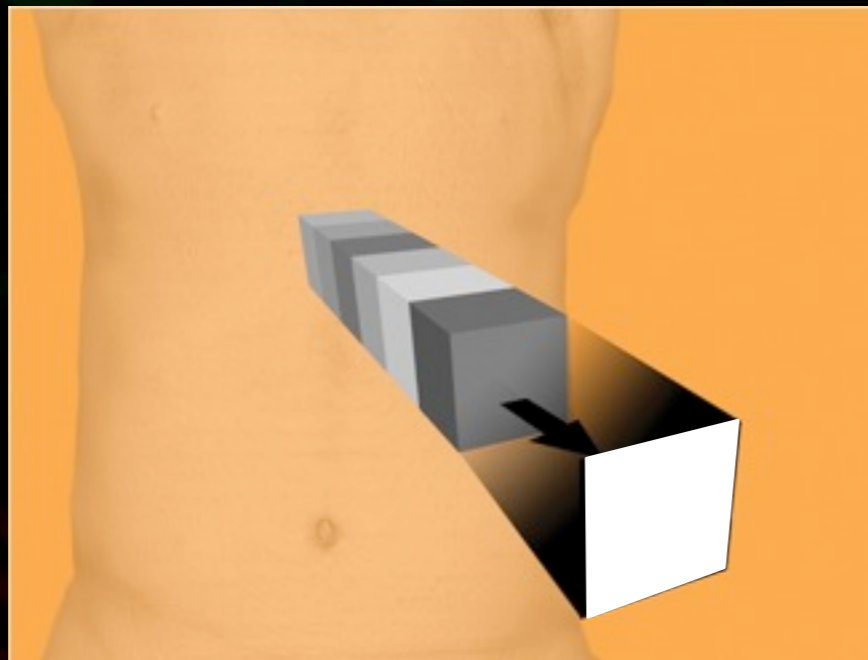
# Maximum Intensity Projection (MIP)

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

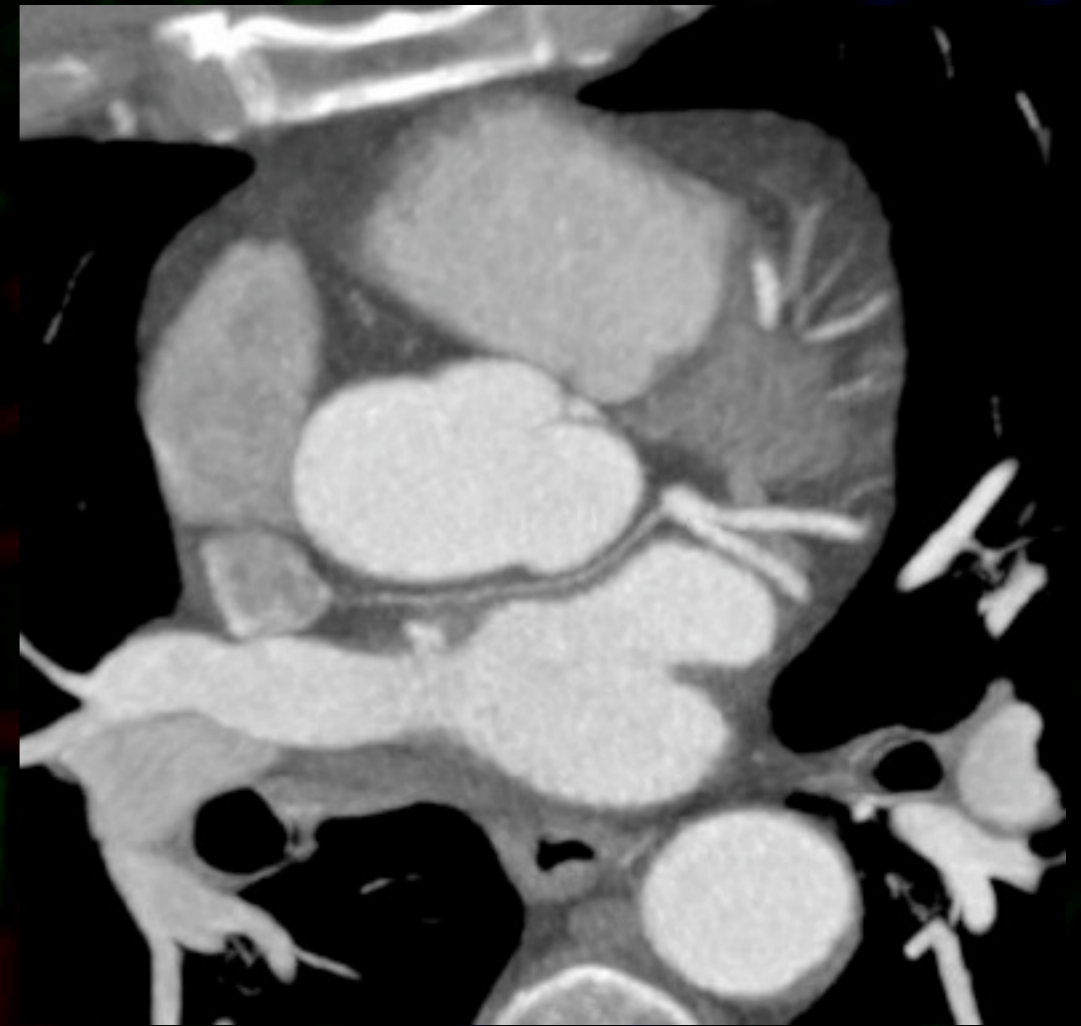


# Maximum Intensity Projection (MIP)

- Voxel along ray with maximal HU value displayed
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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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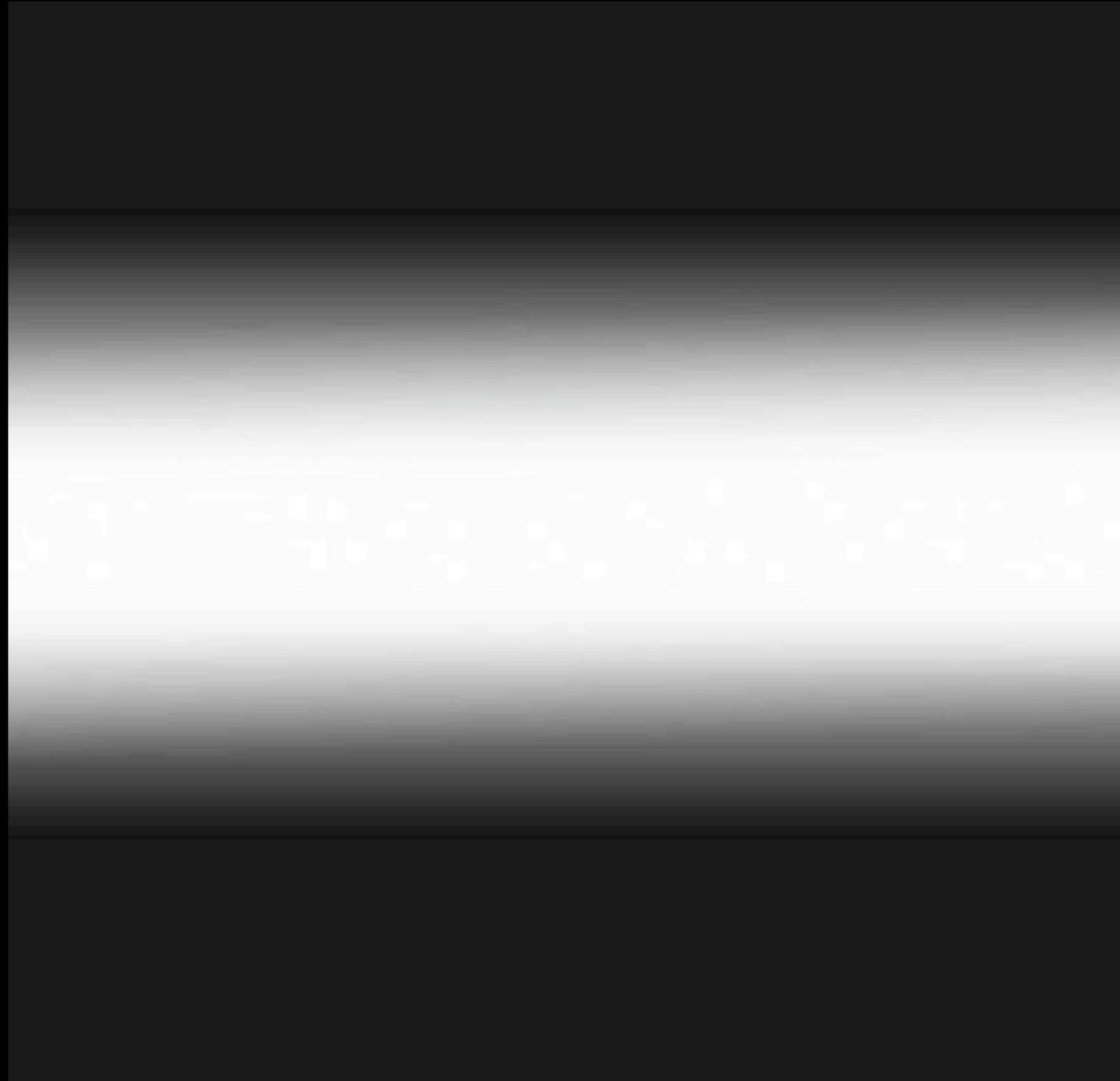


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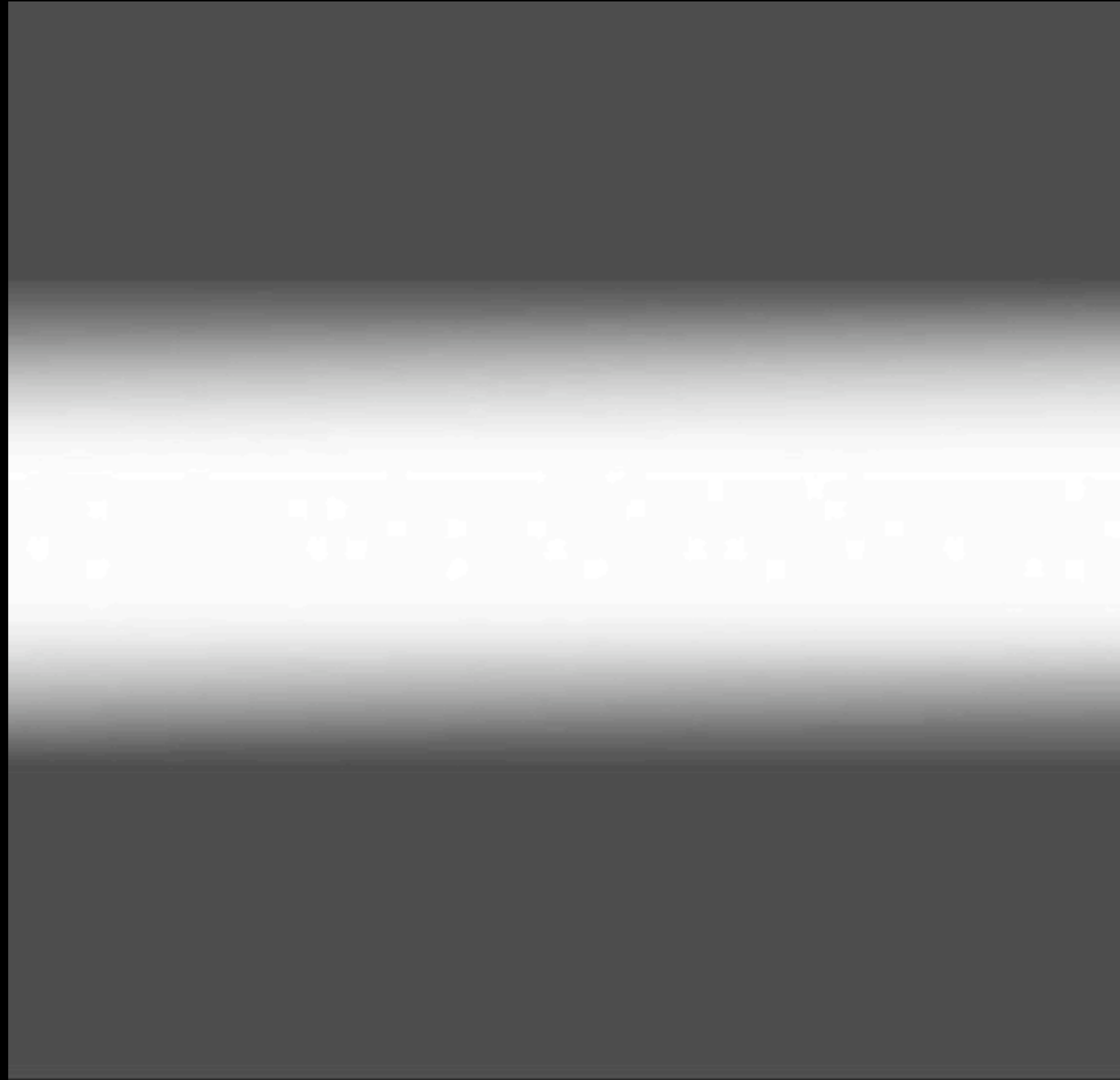
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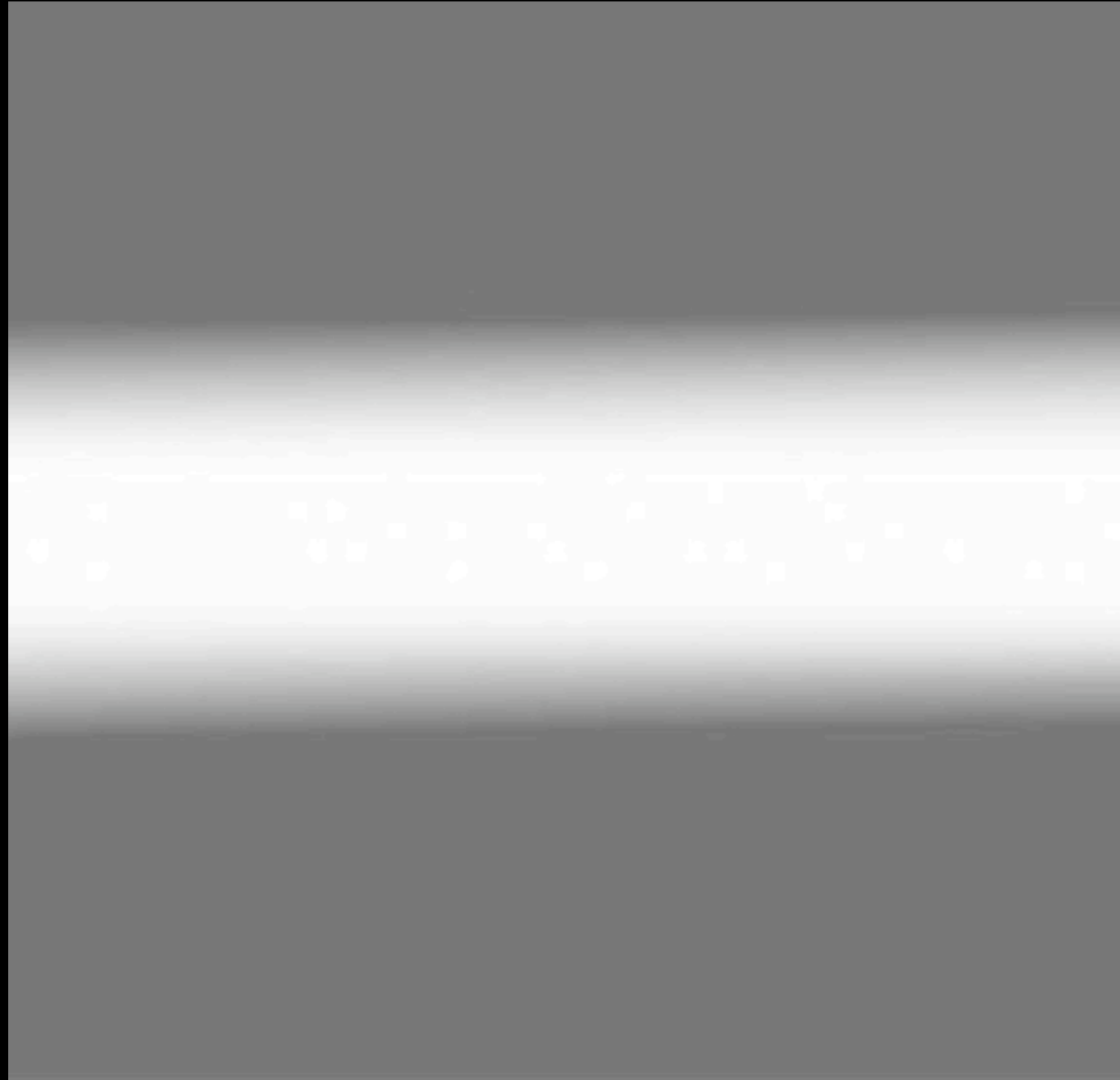
# Caveat for MIP: Effect of Background Noise on apparent stenosis



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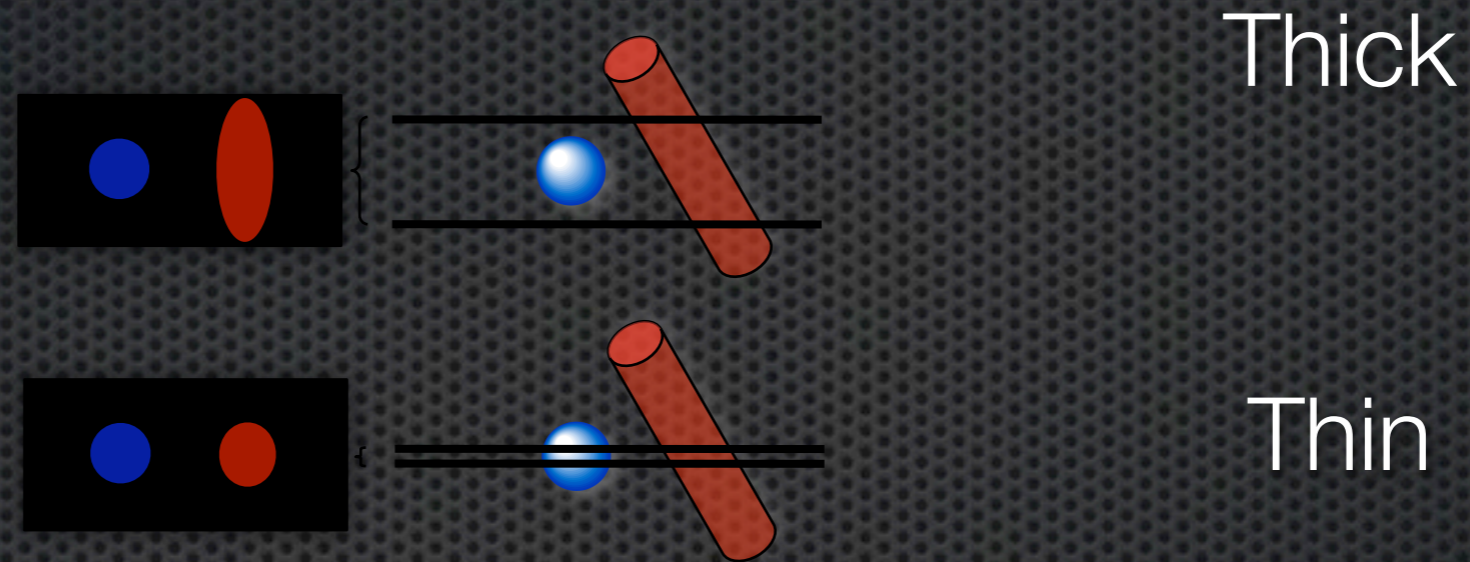


# Another Use for MIP: Lung Nodules

## “Sliding” Thin Slab MIP

- no additional cost
- generated by CT scanner
- *increases conspicuity and apparent size of lesion*  
(measurements always on original data)
- error rate ↓ 40-55% / speed ↑ 1.5 to 5x

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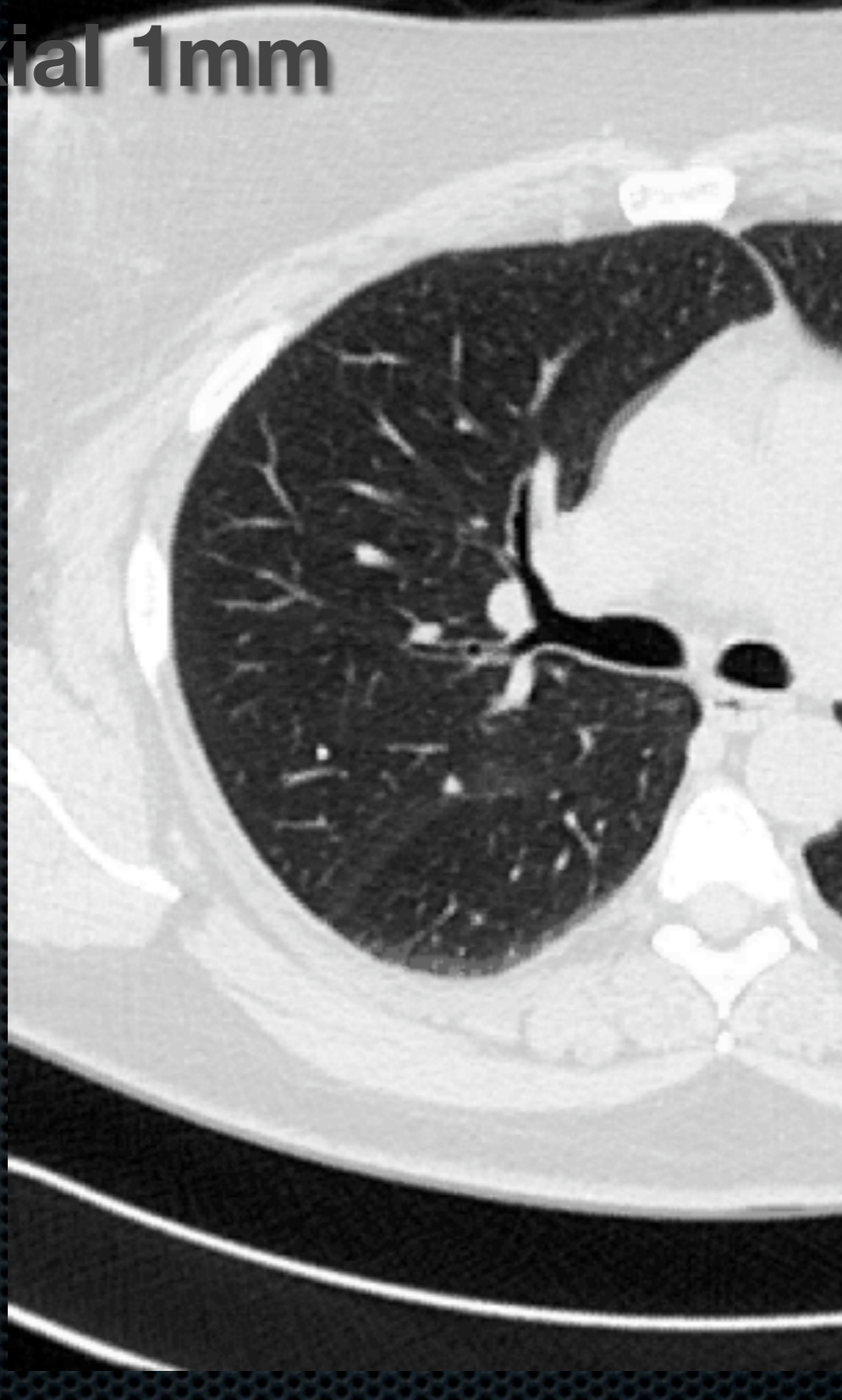
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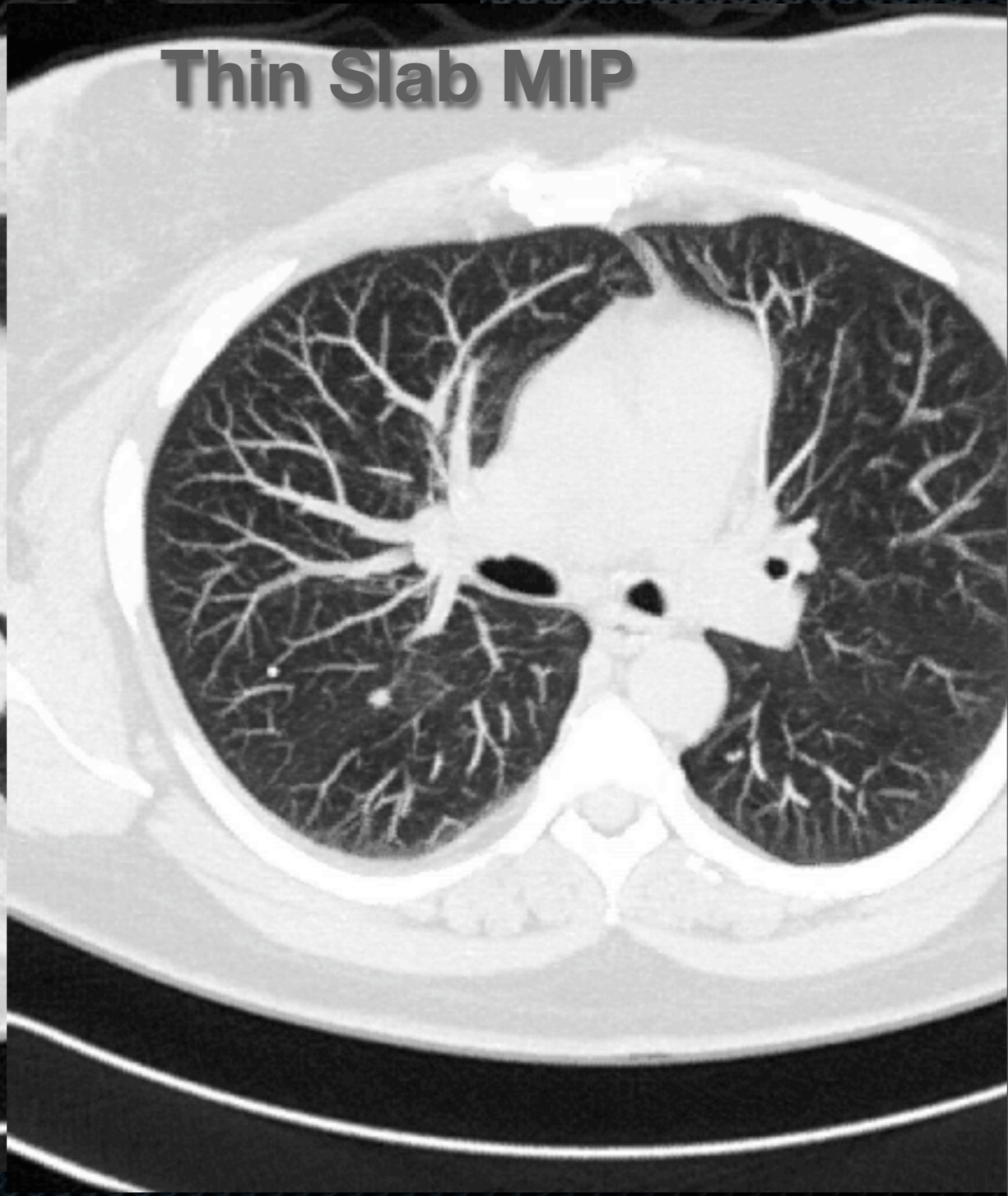
# Sliding Thin Slab MIP for Nodules

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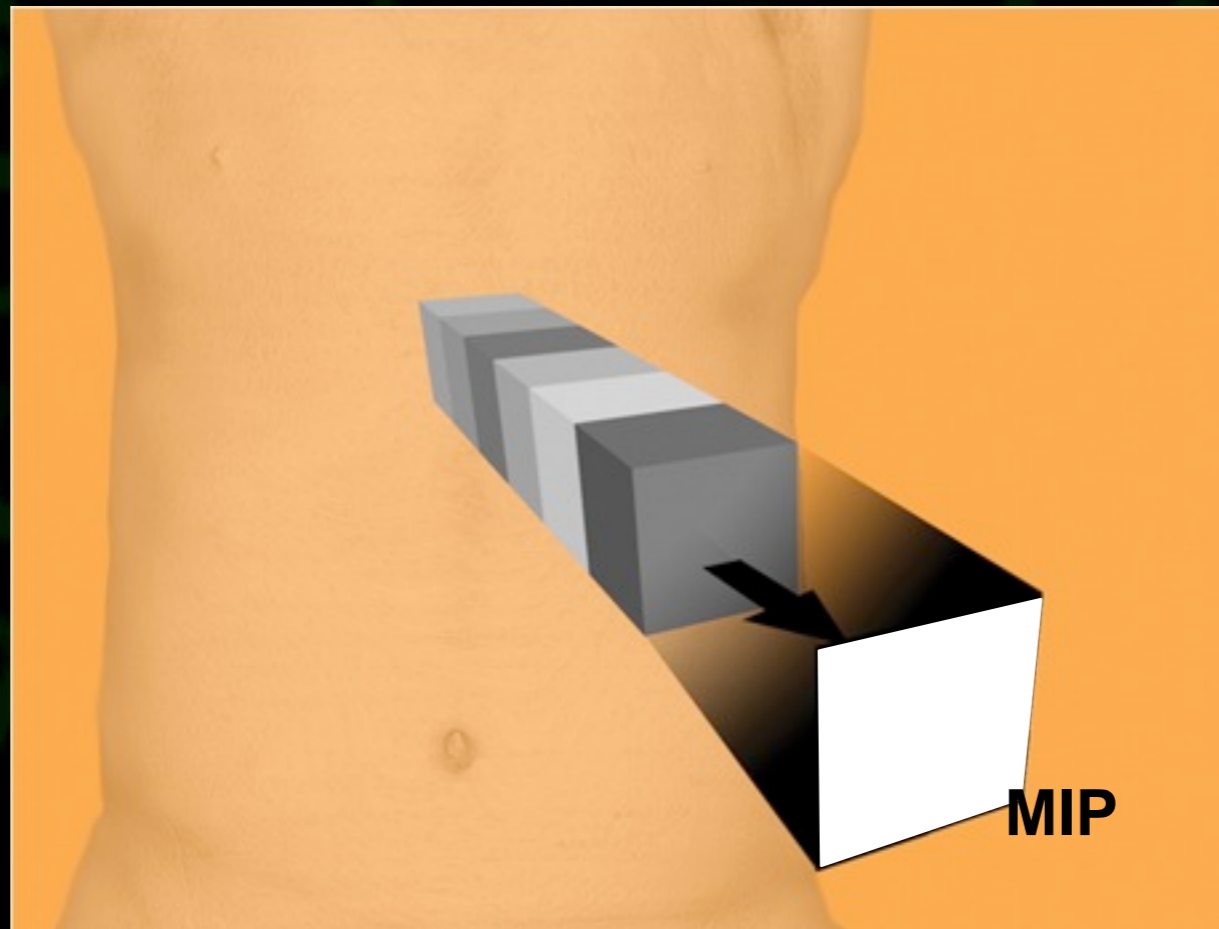
**Axial 1mm**



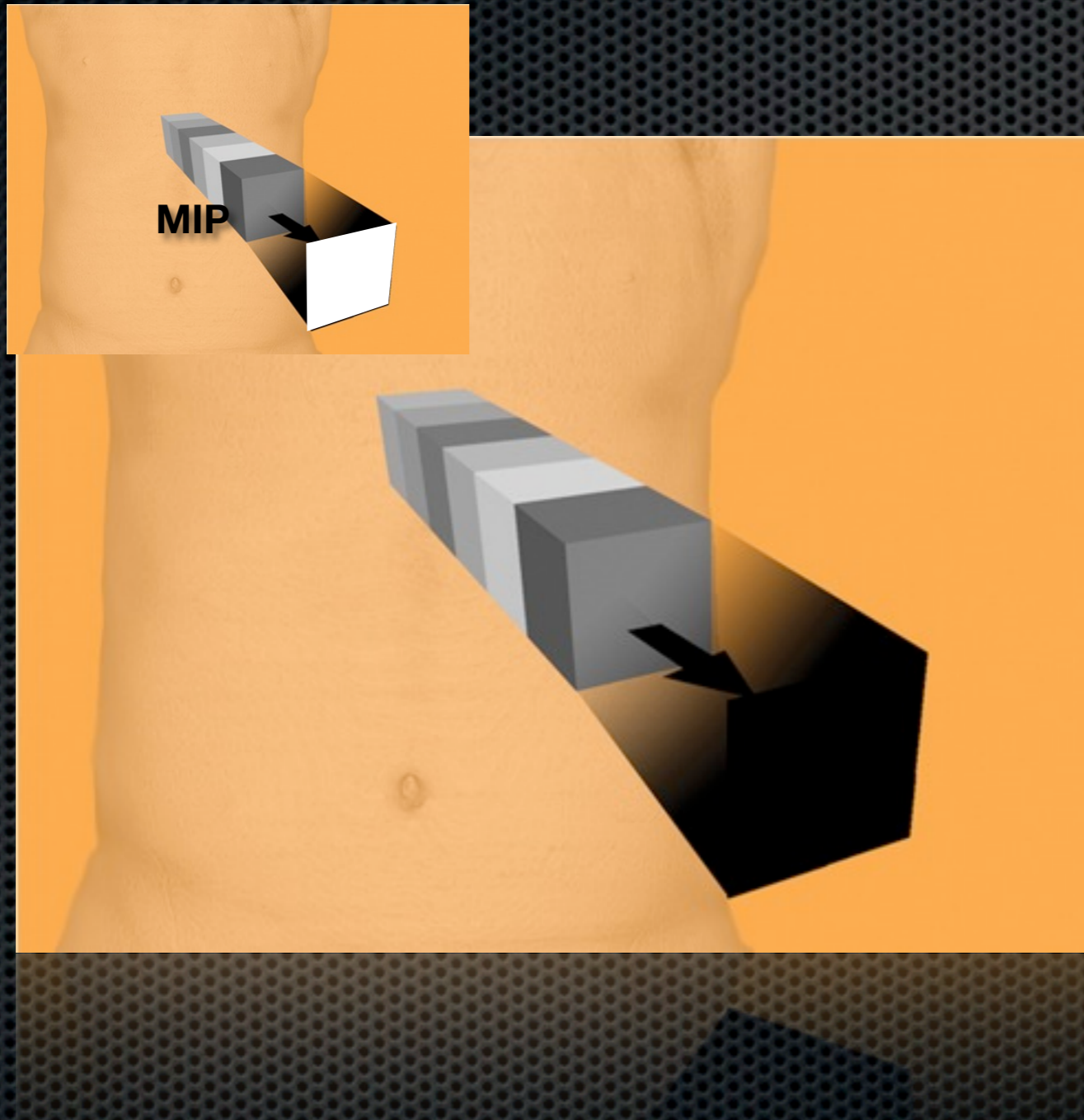
**Thin Slab MIP**



# MIP has a sibling.....

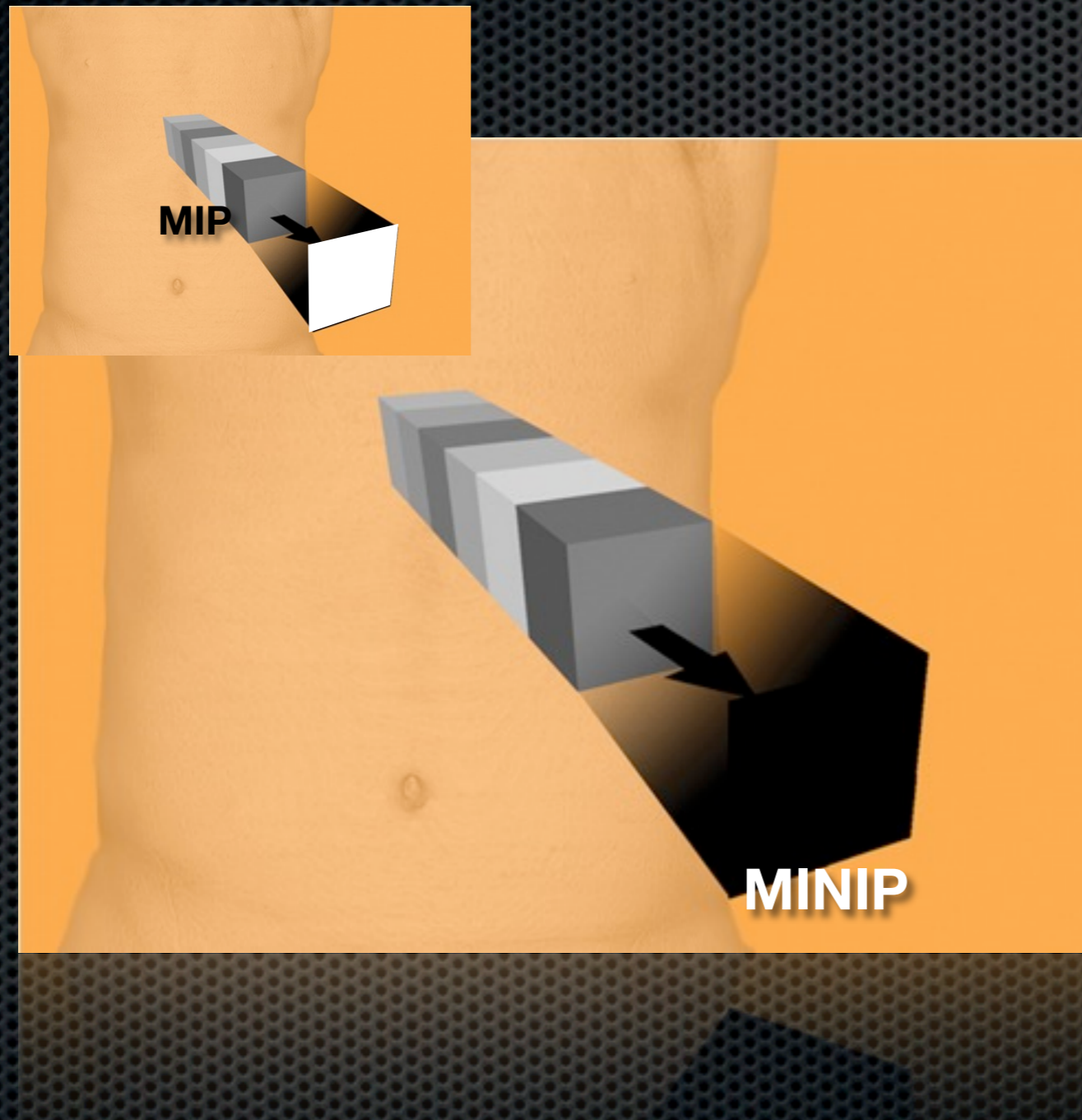


# Minimum Intensity Projection (MinIP)



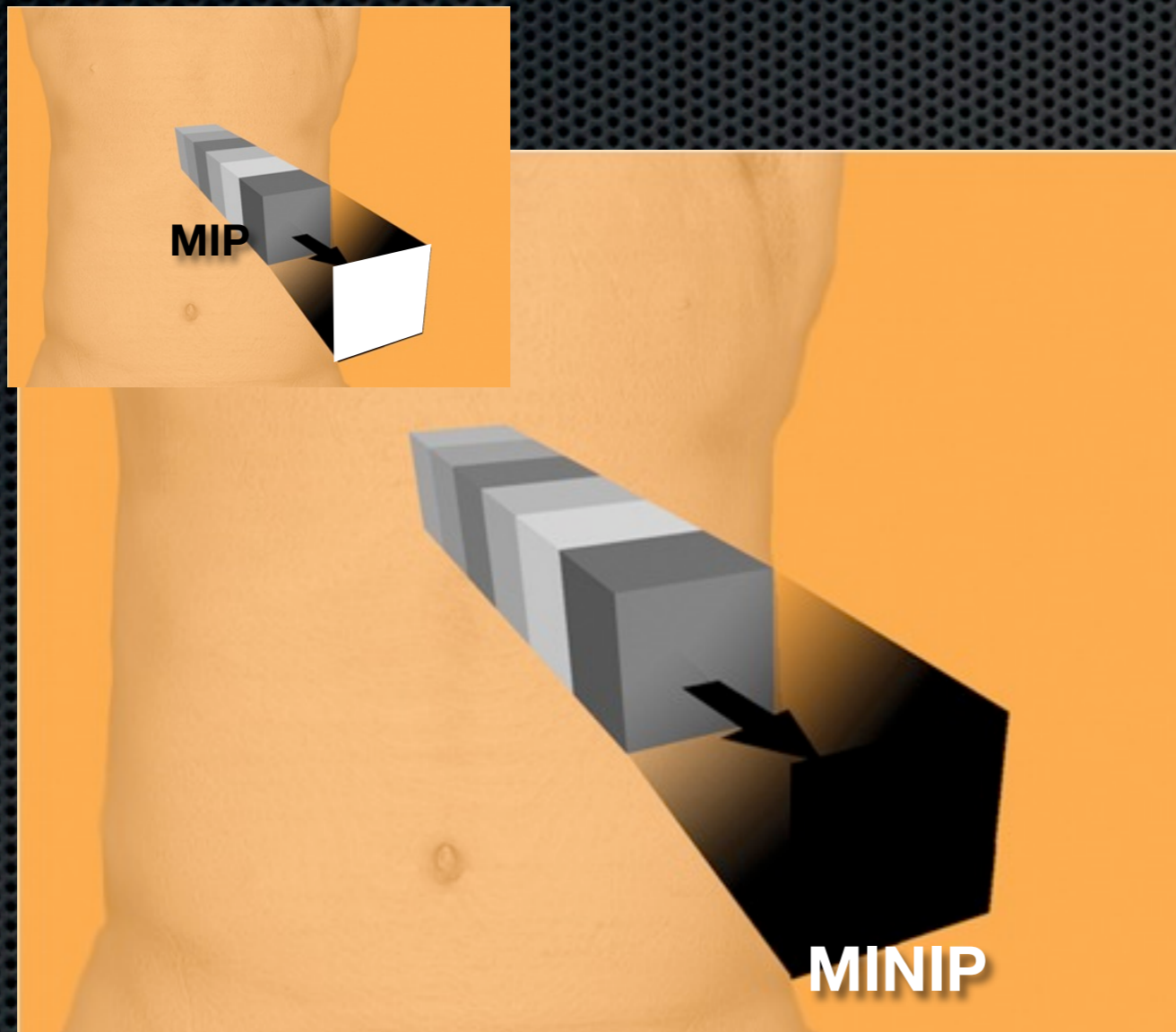
Like MIP, but  
minimum voxel  
value along ray  
depicted

# Minimum Intensity Projection (MinIP)



Like MIP, but minimum voxel value along ray depicted

# Minimum Intensity Projection (MinIP)



Uses:

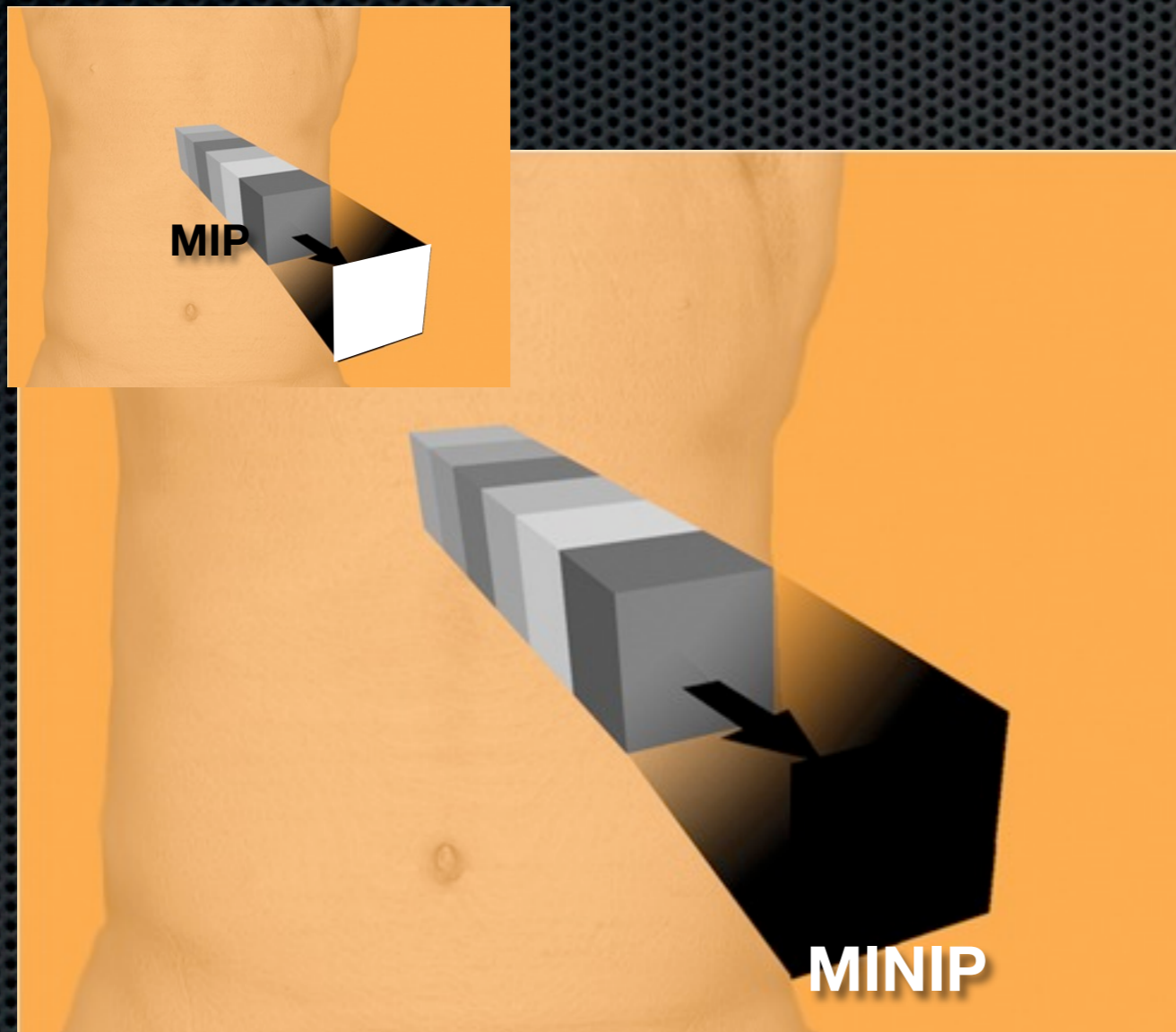
Lungs

Central airways, air trapping

Cardiac Valves

≤5 mm slab; 4D review

# Minimum Intensity Projection (MinIP)



Uses:

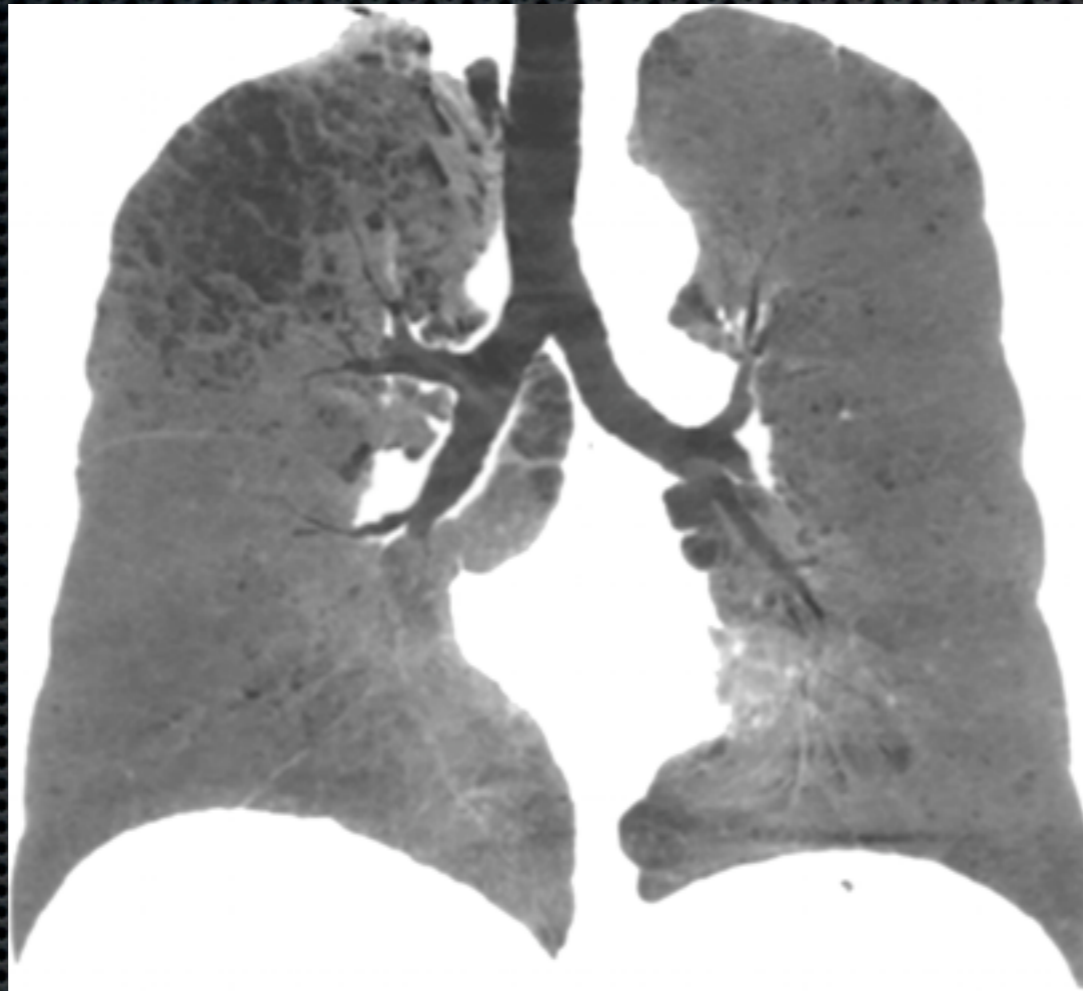
Lungs

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$\leq 5$  mm slab; 4D review

# Minimum Intensity Projection (MinIP)



20 mm MINIP

Uses:

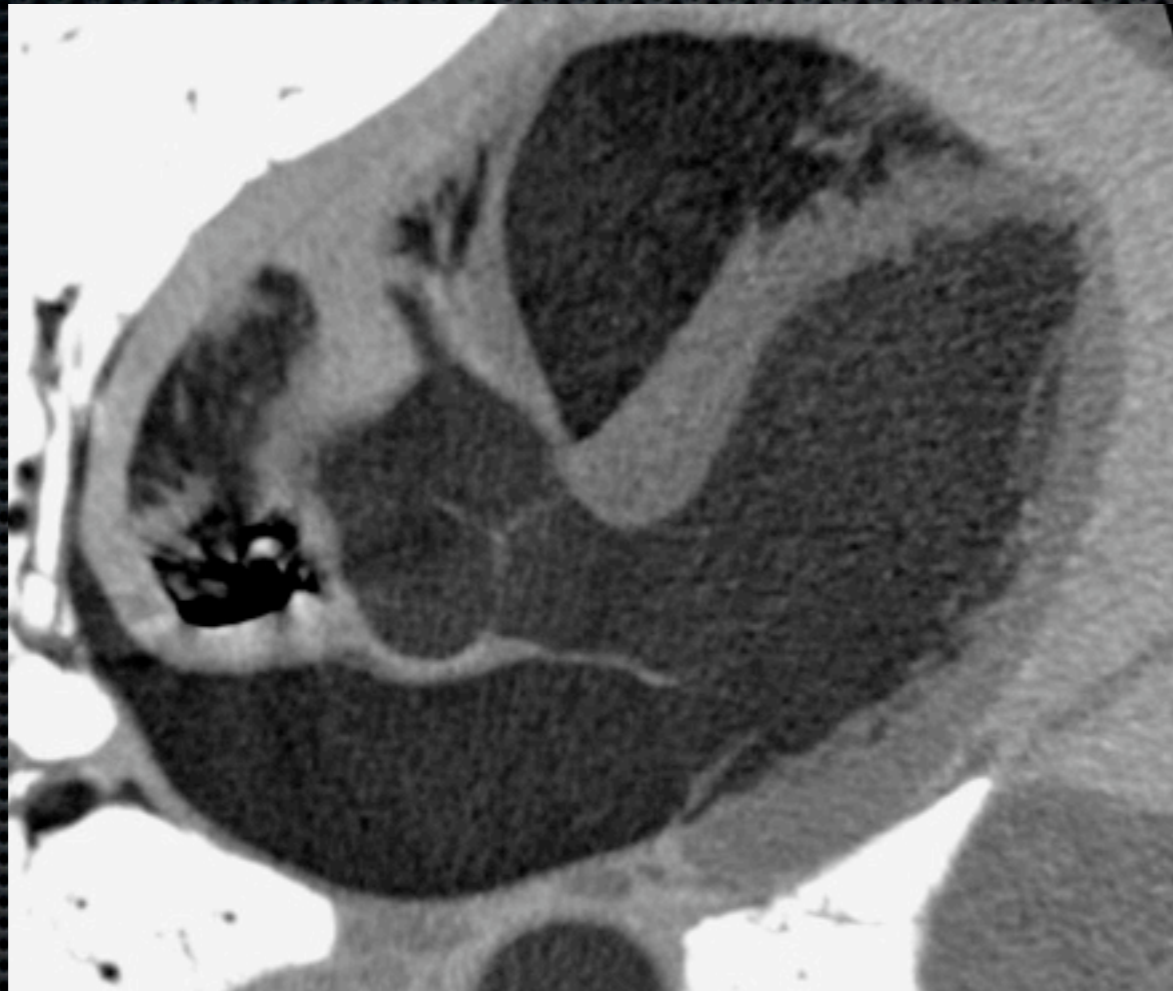
Lungs

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Cardiac Valves

≤5 mm slab; 4D review

# Minimum Intensity Projection (MinIP)



**2 mm MINIP INVERSE**

Uses:

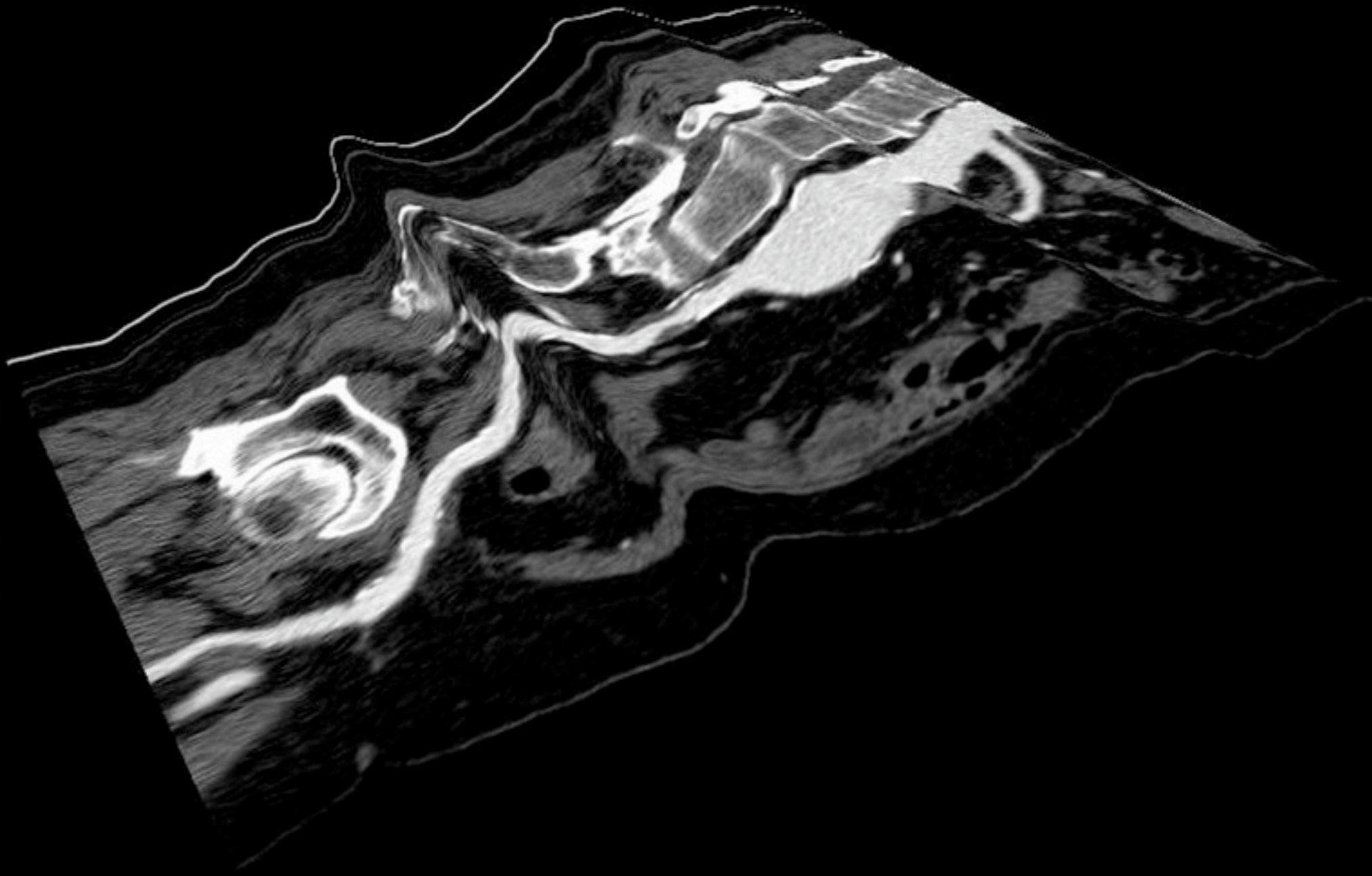
Lungs

Central airways, air trapping

Cardiac Valves

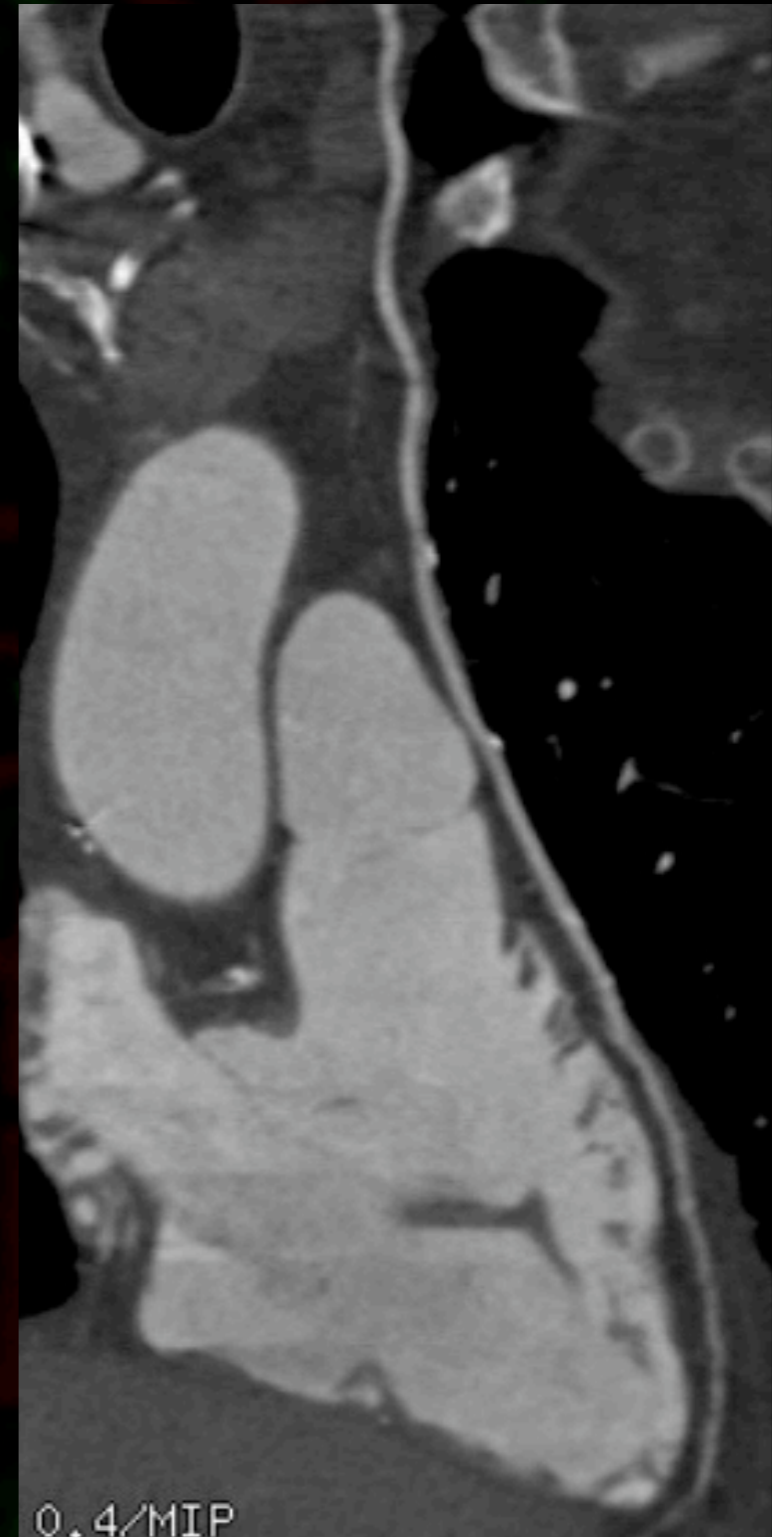
≤5 mm slab; 4D review

# Curved Planar Reformation (CPR)



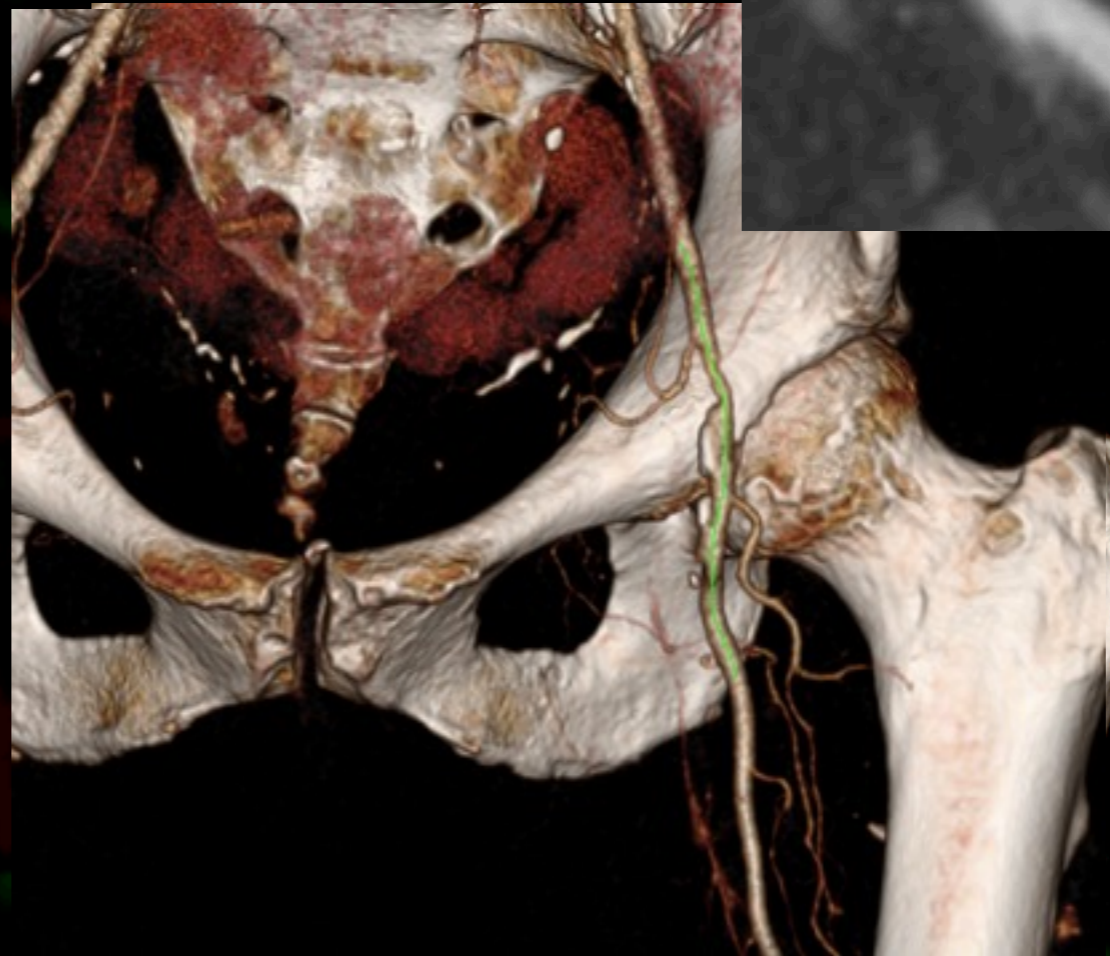
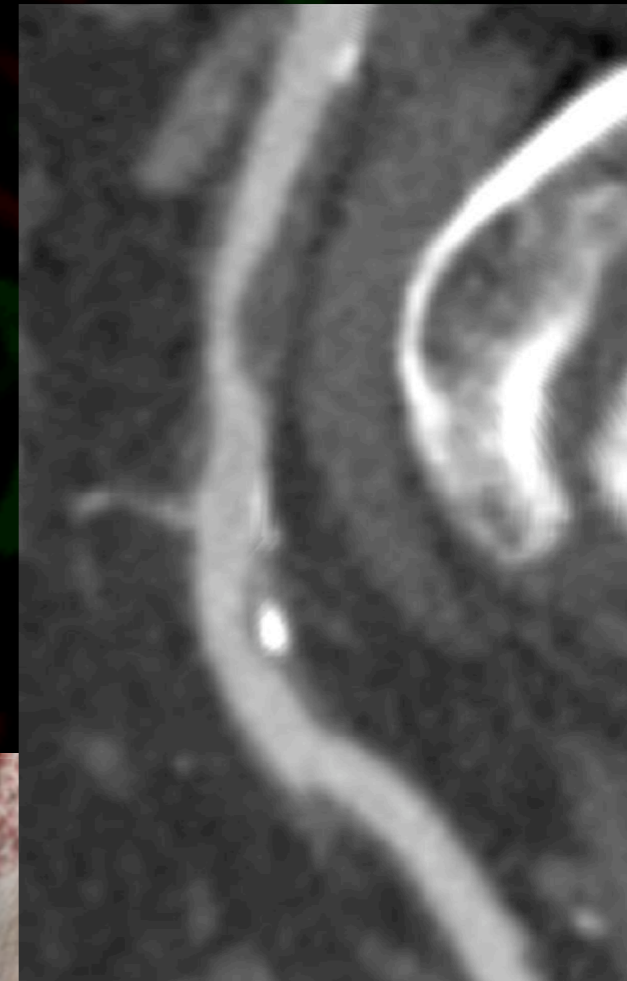
# CPR = Curved MPR

- 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



# CPR = Curved MPR

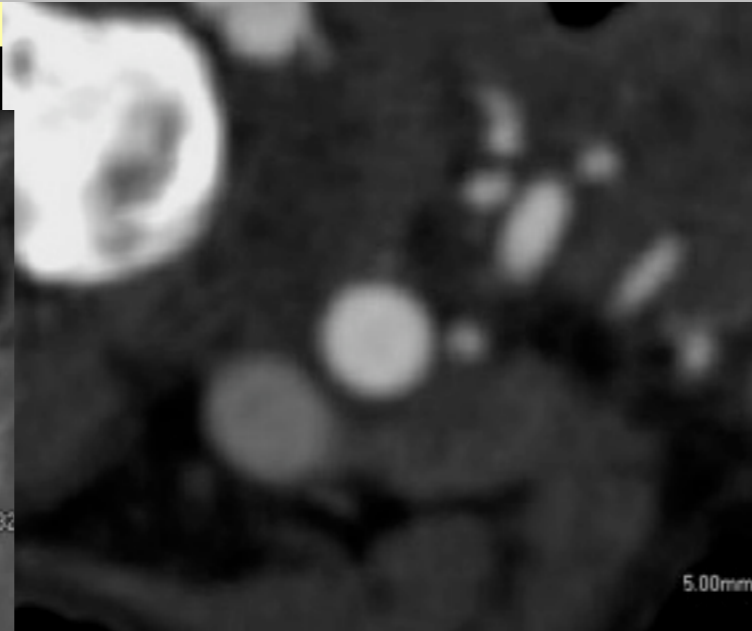
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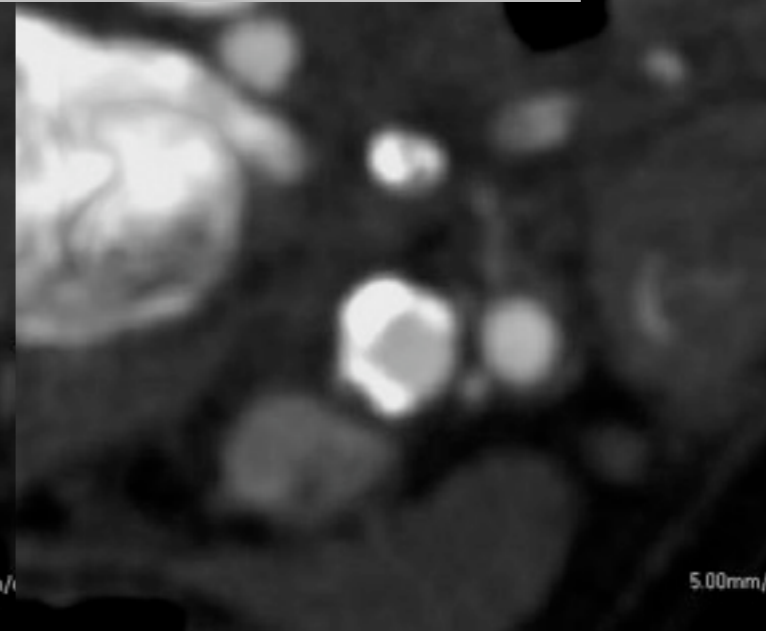
# CPR - Orthogonal Measurements (slice through display)



% Stenosis (Minimum): 53.53%  
% Stenosis (Average): 34.39%  
% Area Stenosis: 54.97%

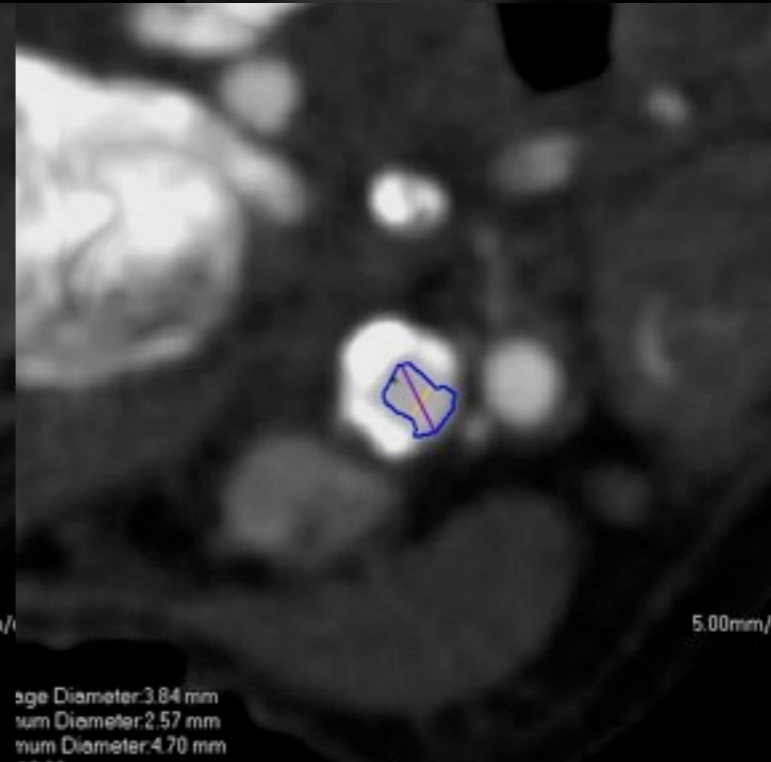
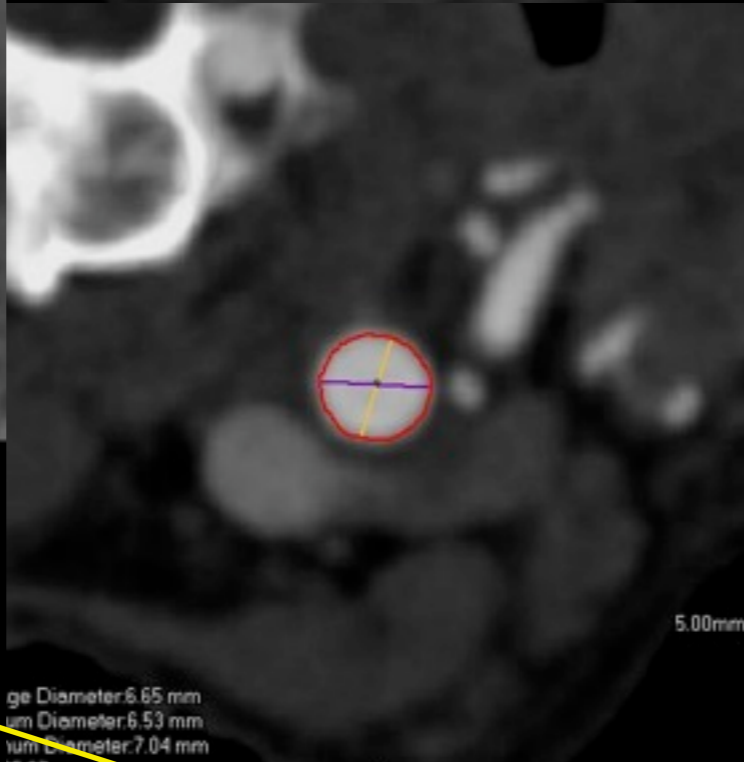
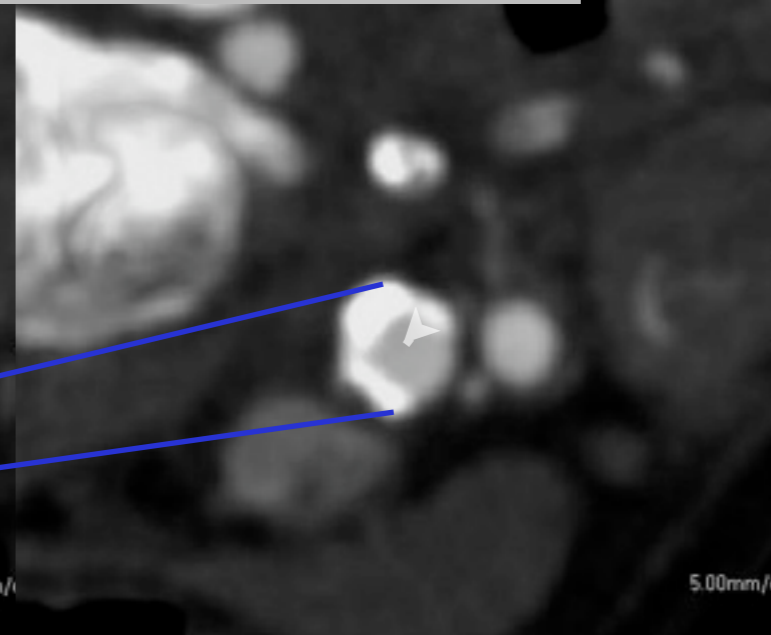
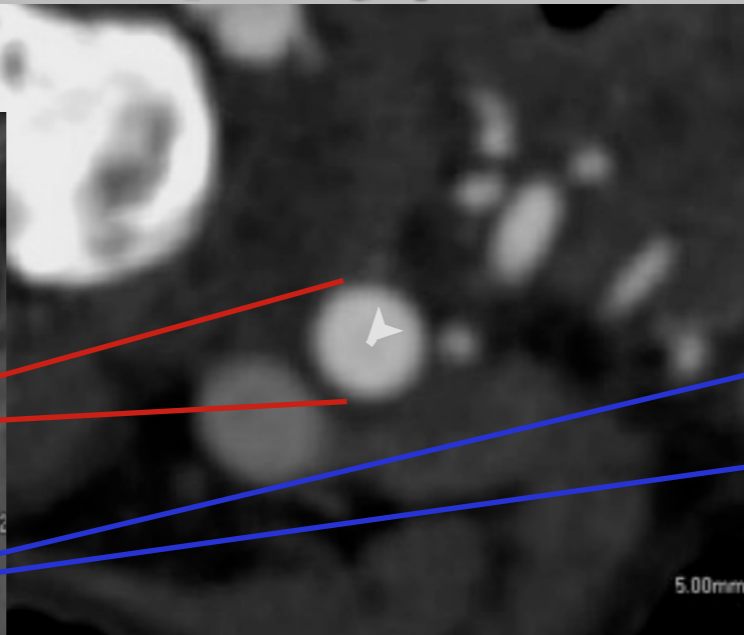
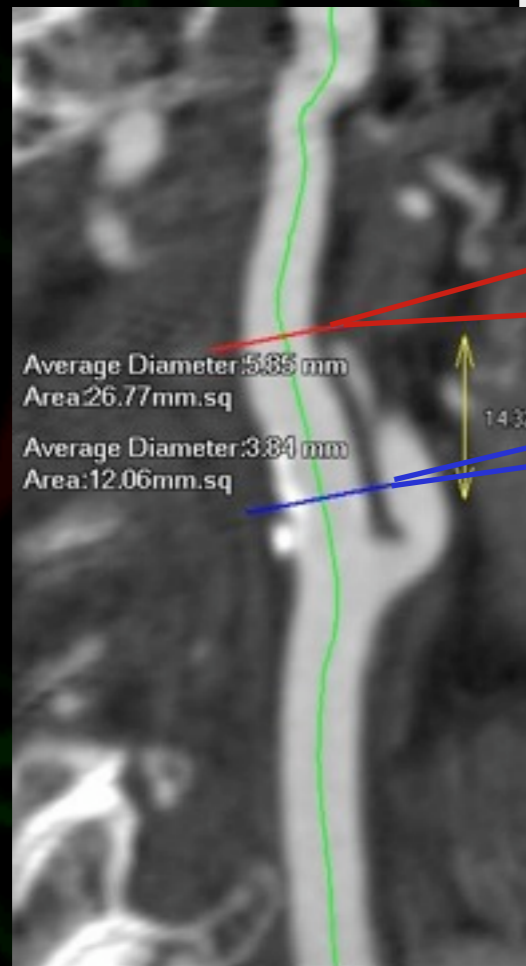


Normal Diameter: 6.65 mm  
Stenosis Diameter: 6.53 mm  
Reference Diameter: 7.04 mm



Normal Diameter: 3.84 mm  
Stenosis Diameter: 2.57 mm  
Reference Diameter: 4.70 mm

# CPR - Orthogonal Measurements (slice through display)



% Stenosis (Minimum): 53.53%  
% Stenosis (Average): 34.30%  
% Area Stenosis: 54.97%

ge Diameter: 6.65 mm  
um Diameter: 6.53 mm  
um Diameter: 7.04 mm

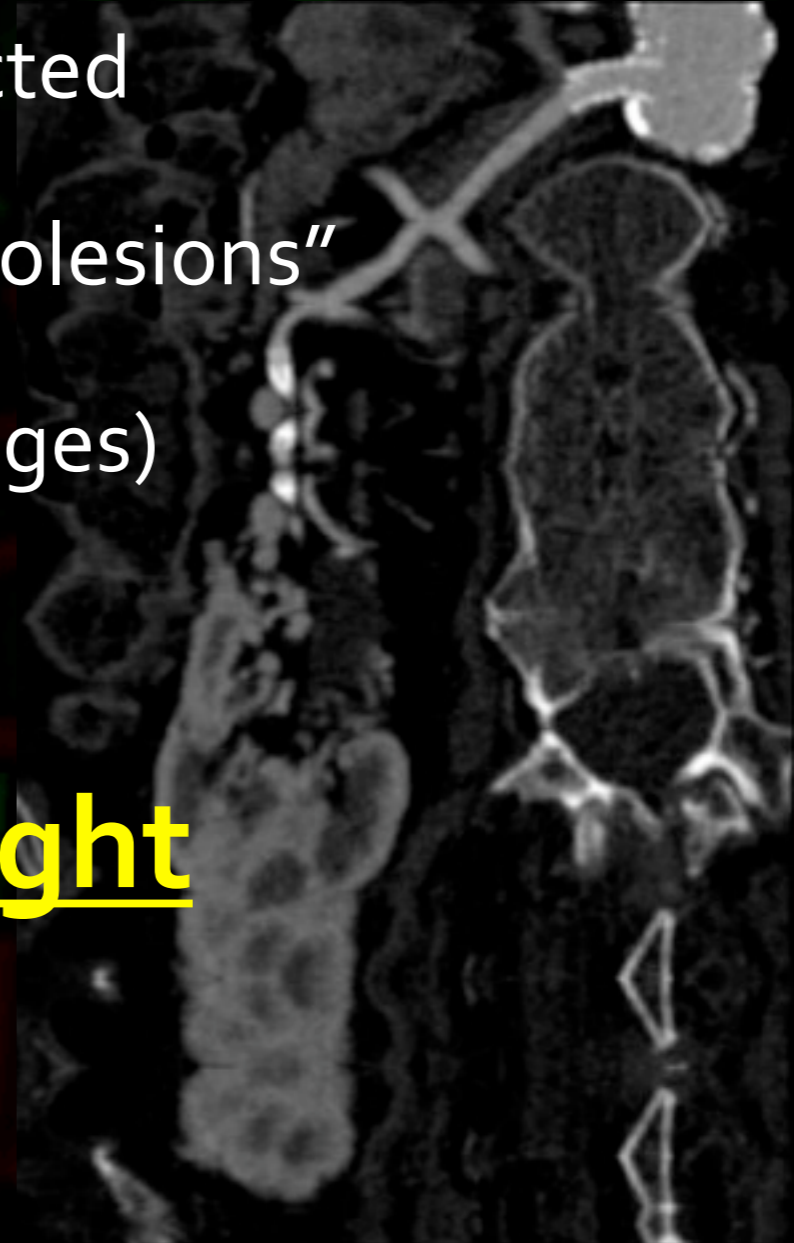
age Diameter: 3.84 mm  
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**NASCET ~ 53% stenosis**

# Curved MPR Limitations

- Information limited to plane reconstructed
- Bizarre anatomic relationships , “pseudolesions”
- Cannot be used alone (need source images)
- Time consuming if manual generation

- Still needs RT / MD oversight



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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)

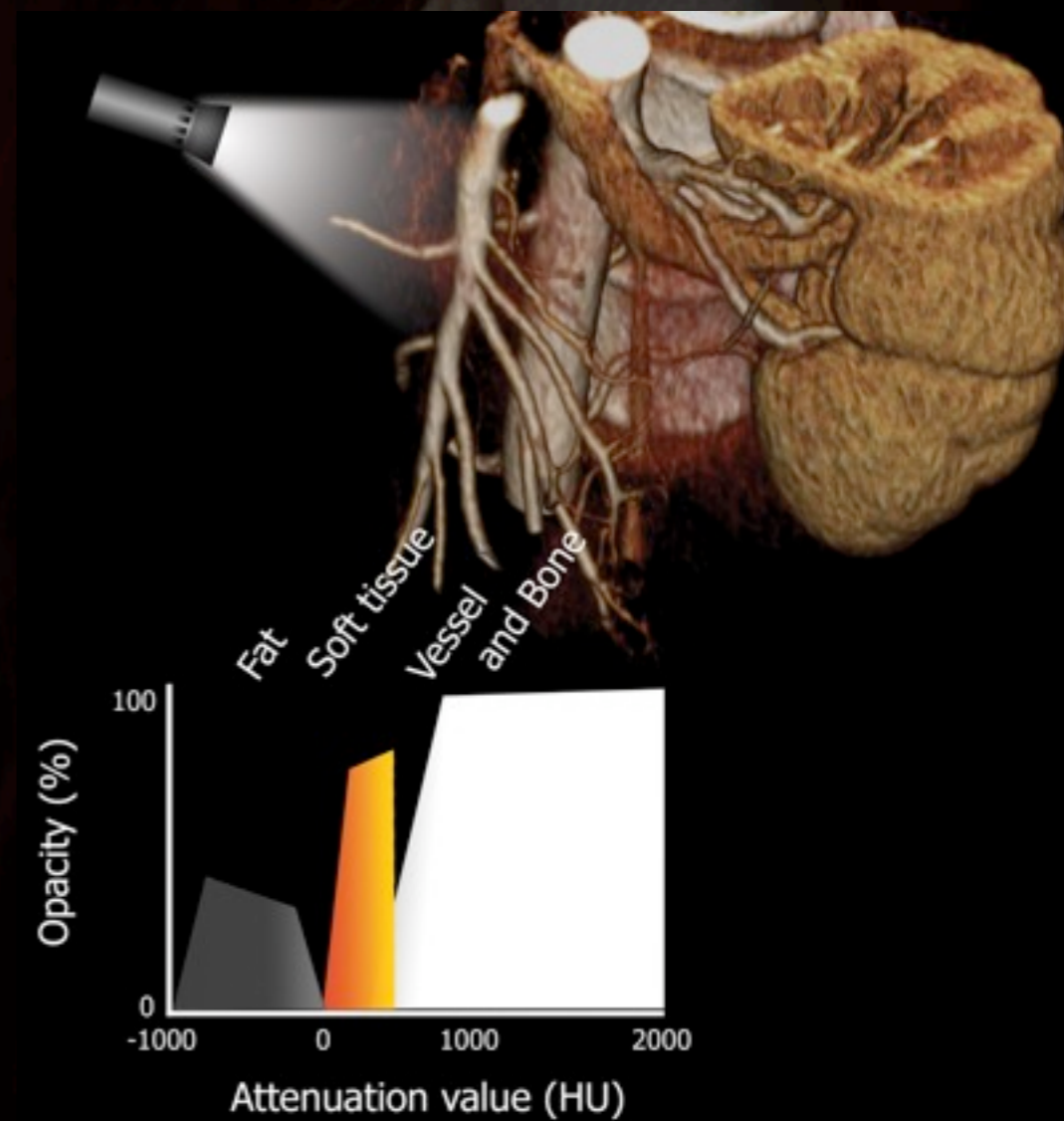


# ◆ “Opacity Transfer Function”: curve that describes relative opacities and colors

◆ Changing the OTF

P changes displayed tissues

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



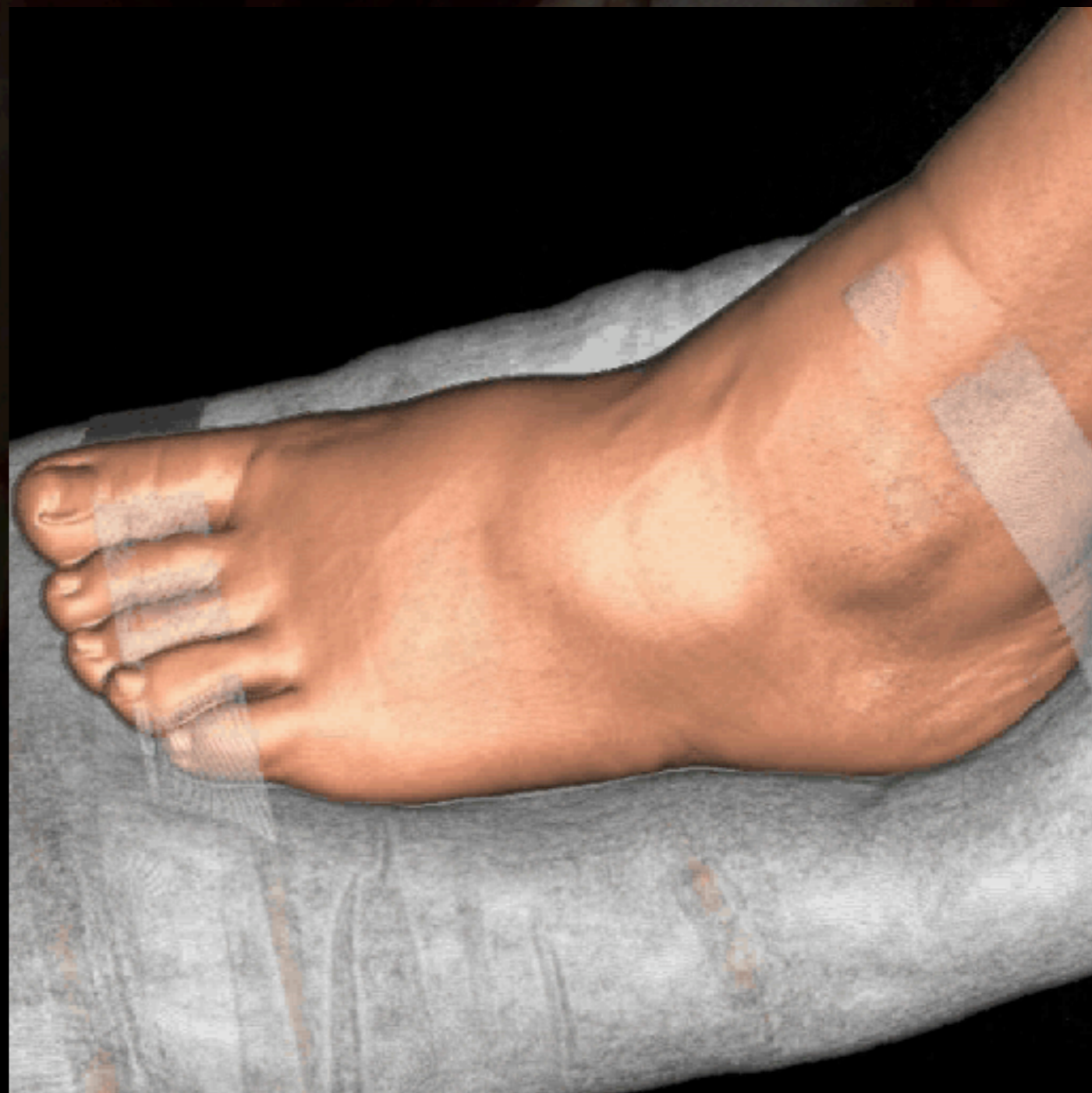
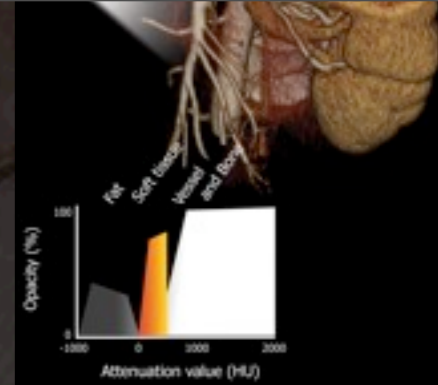
Dalrymple, N. C. et al. Radiographics 2005;25:1409-1428

◆ “Opacity Transfer Function”: curve that describes relative opacities and colors

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# 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

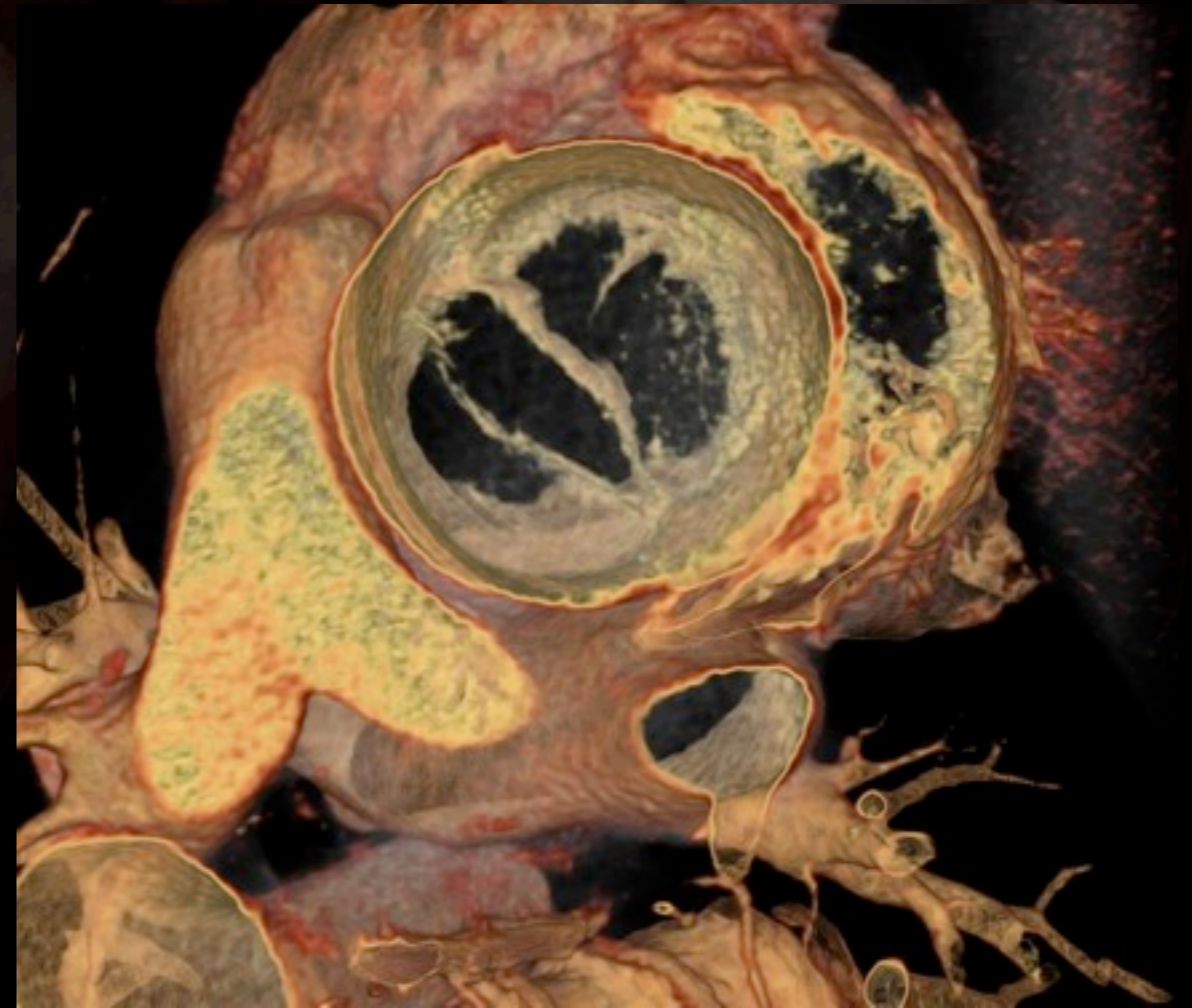
P

A



# BPI - Volume Rendering (VR)

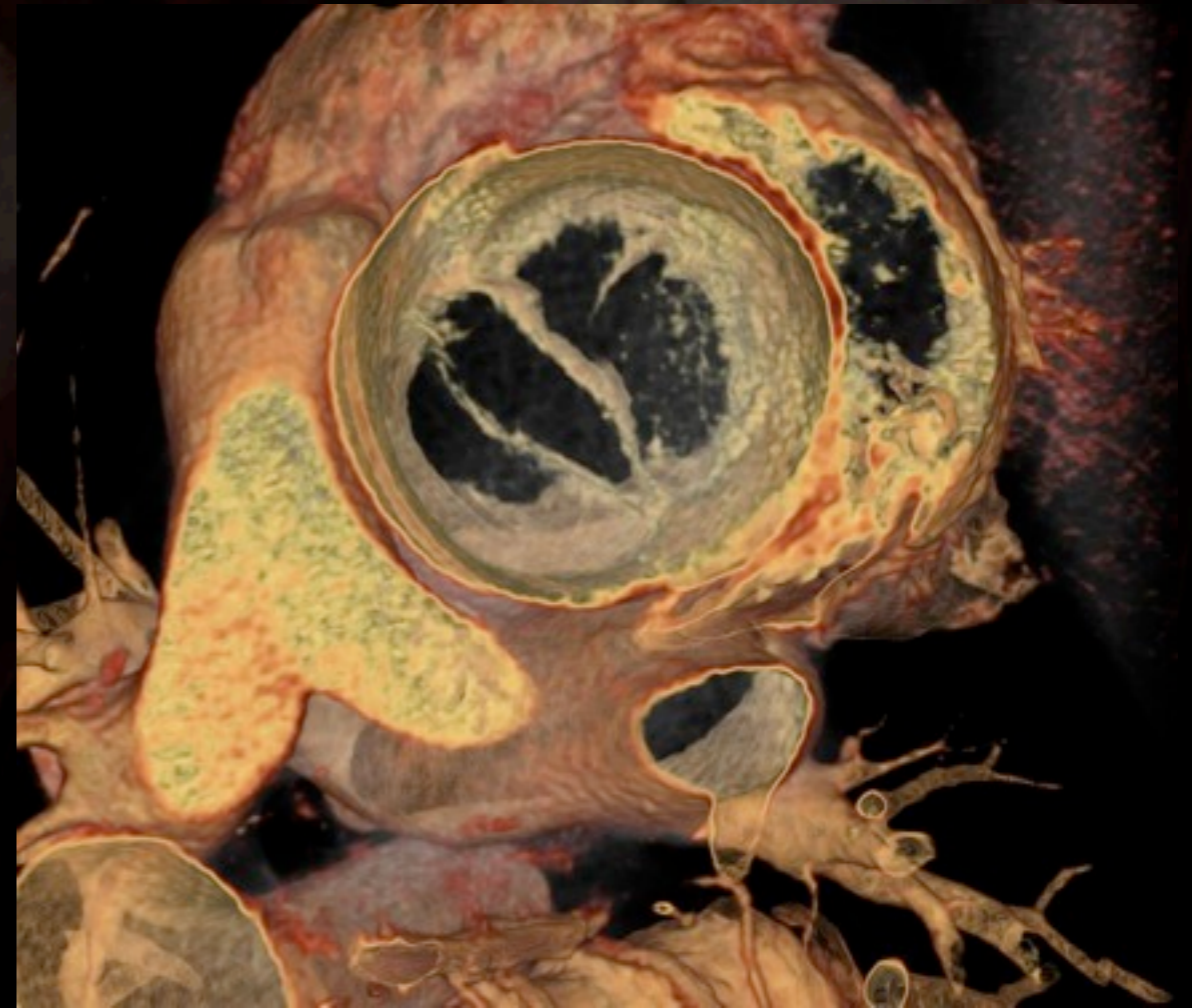
- ◆ Can use mirror image of opacity ramp to render lumen transparent → **endoluminal views**
- ◆ aka “Blood Pool Inversion” VR



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

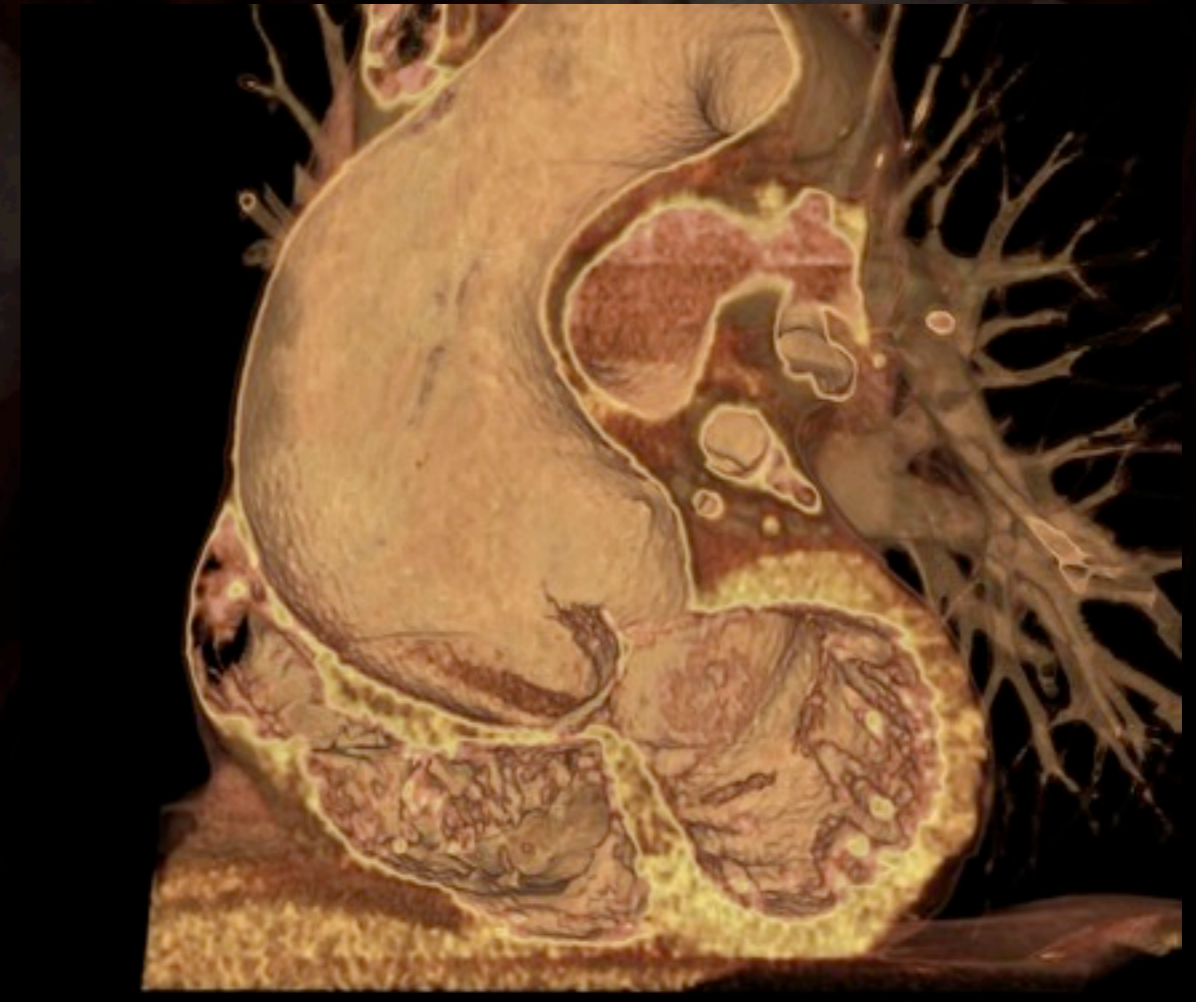
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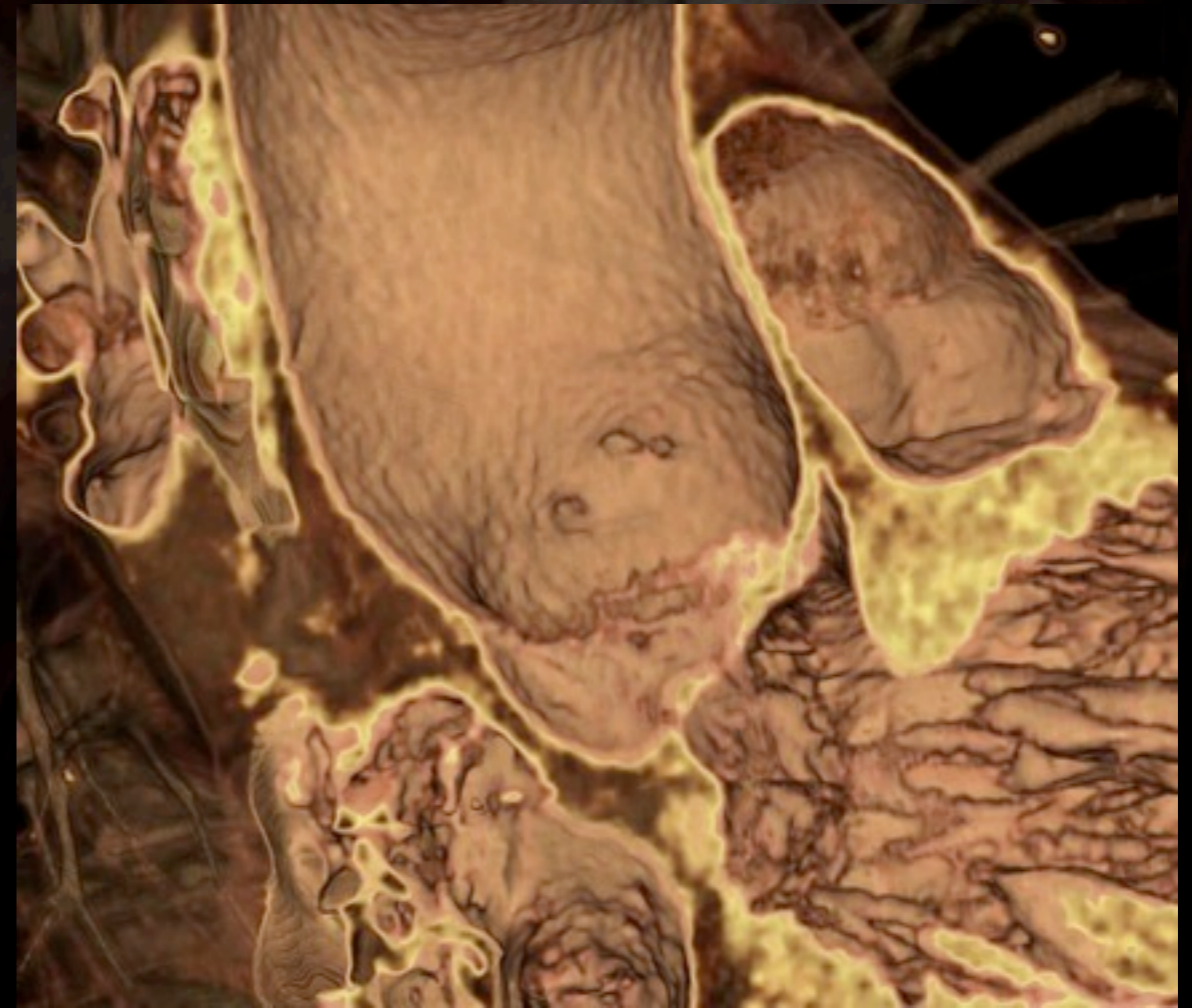
# BPI - Volume Rendering (VR)

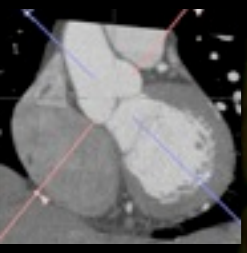
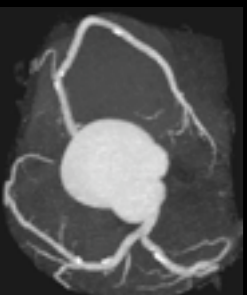

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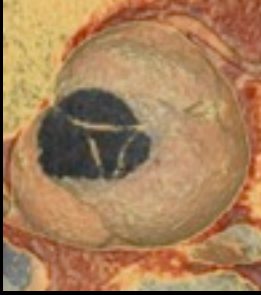


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	Major Uses	Advantages	Disadvantages
<b>MPR</b> 	Stenosis, vessel wall analysis Lung nodule measurement Orthogonal Measurements	Accurate for stenosis, nodule, orthogonal measurements Calcification, stent evaluation <b>"Thick MPR": salvage noisy datasets</b>	Limited spatial relationships (so stack review) <b>Limited display if curving vessel</b>
<b>MIP</b> <b>(MINIP)</b> 	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 <b>Stenosis Overestimation</b> <b>NOISE IS ADDITIVE!!</b>
<b>CPR</b> 	Flow lumen, vessel wall analysis Curved Objects	Best for mural stenosis, occlusions, calcifications, stents <b>Slice through display (perpendicular to CPR)</b>	Distortion of extra-vascular structures <b>Dependent on accurate centerline (Needs Oversight)</b>

	Major Uses	Advantages	Disadvantages
<p><b>VR</b></p> 	<p>Angiographic overview, contextual with adjacent structures</p> <p>Pre-procedural planning</p>	<ul style="list-style-type: none"> <li>• Best for complex relationship display</li> <li>• Valves</li> <li>• Vessel Origins</li> <li>• EVAR, DSX, etc</li> </ul>	<p><b>Opacity transfer function and operator dependent</b></p> <p>No accurate measurements</p>
<p><b>BPI-VR</b></p> 	<p>Valves, vessel orifices, DSX flaps</p>	<p><b>WOW</b> factor</p>	

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# Recent Postprocessing Advances

- ◆ Automatic Segmentation
- ◆ Multipath - CPR (MP-CPR):
  - ◆ Simultaneous CPRs of all LE vessels at once
- ◆ Partial Vector Shape Projection (PVSP)
  - ◆ Knowledge-based extrapolation of centerlines for SFA occlusions
  - ◆ Independent of local density and gradient information

*Roos JE, et al. Radiology 2007; 244 (1) 281-90.  
Rakshe T, et al. Med Image Analysis 2007; 11 (2) 157-68.*

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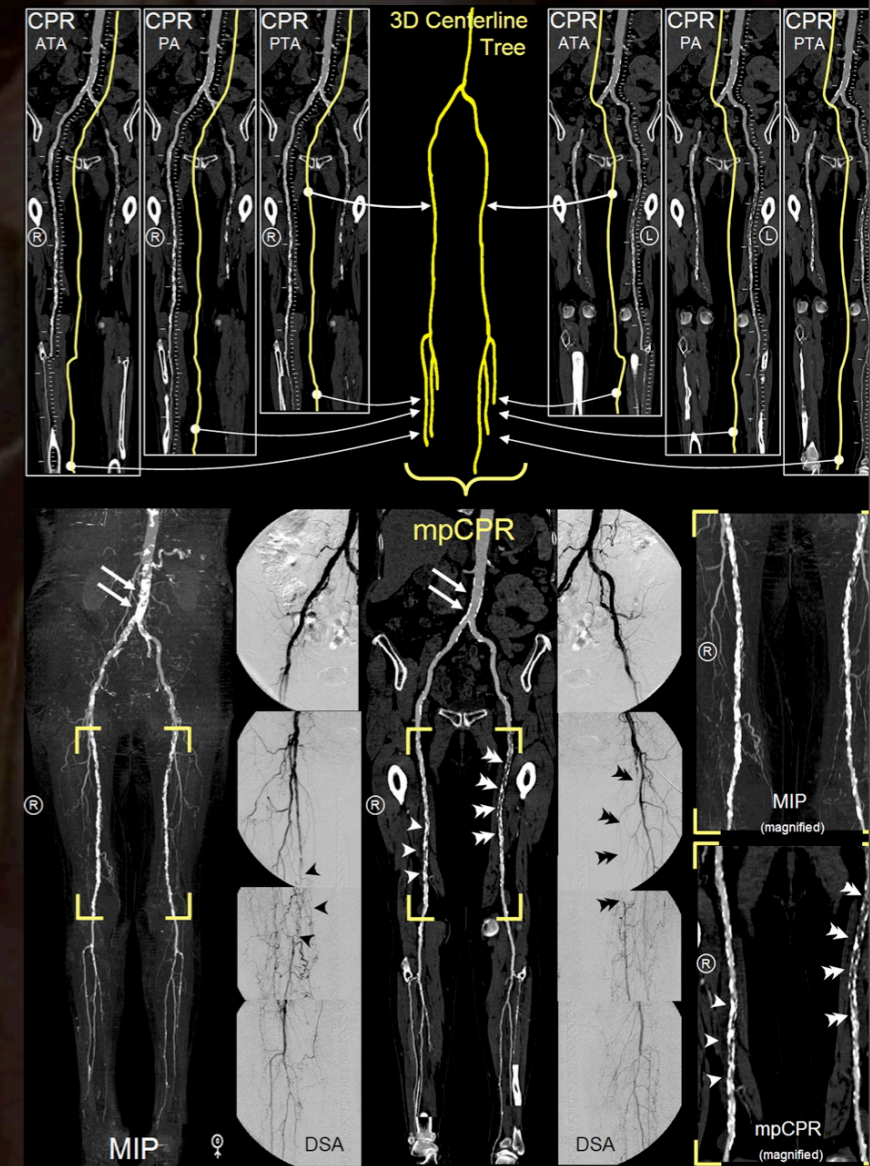
## ◆ Automatic Segmentation

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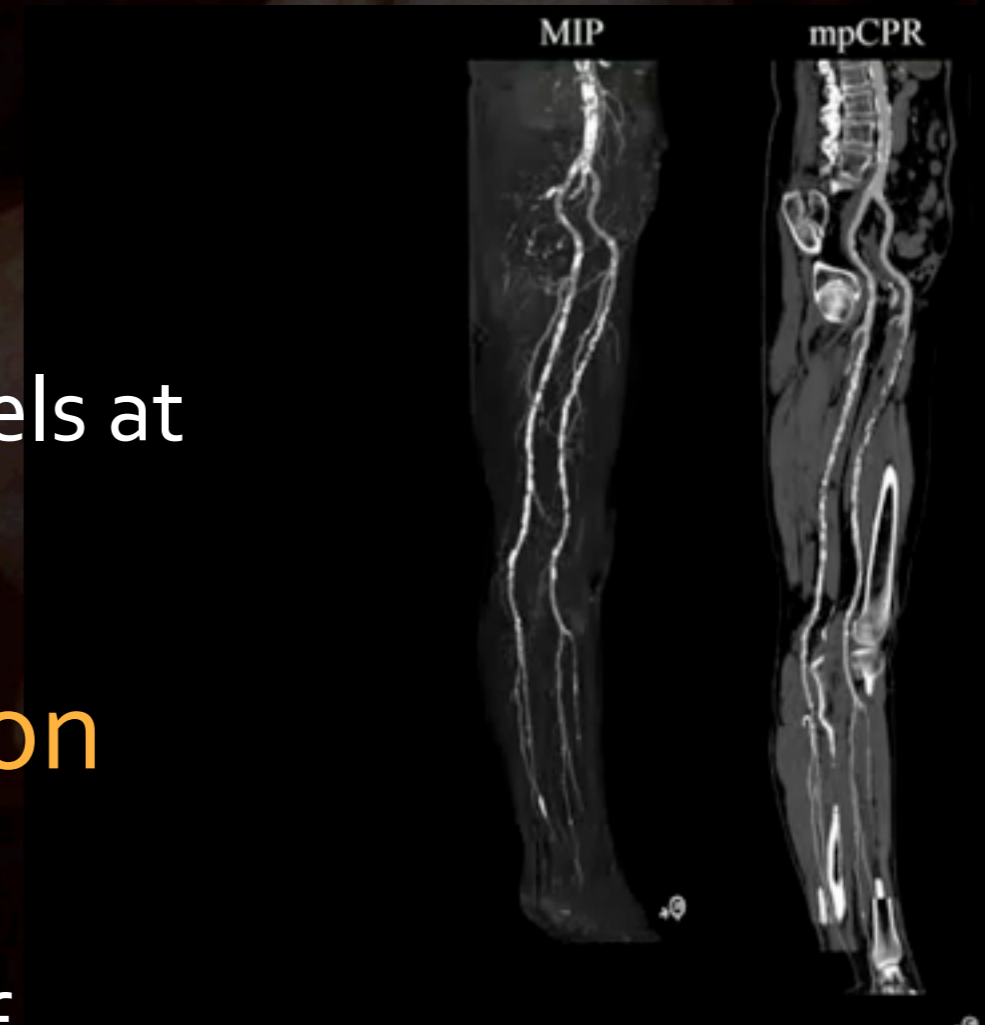
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# Conclusions



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- Image Reconstruction:
  - Use iterative reconstruction- save dose and/or improve quality
  - Improve and troubleshoot image reconstruction (FOV, kernel, etc)

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# Conclusions

- Image Reconstruction:
  - Use iterative reconstruction- save dose and/or improve quality
  - Improve and troubleshoot image reconstruction (FOV, kernel, etc)
- Image Post-Processing
  - Remember inherent advantages, limitations, and differences in each type of image display
  - Review the axial source data
  - Consider adding thin slab MIPs for lung review

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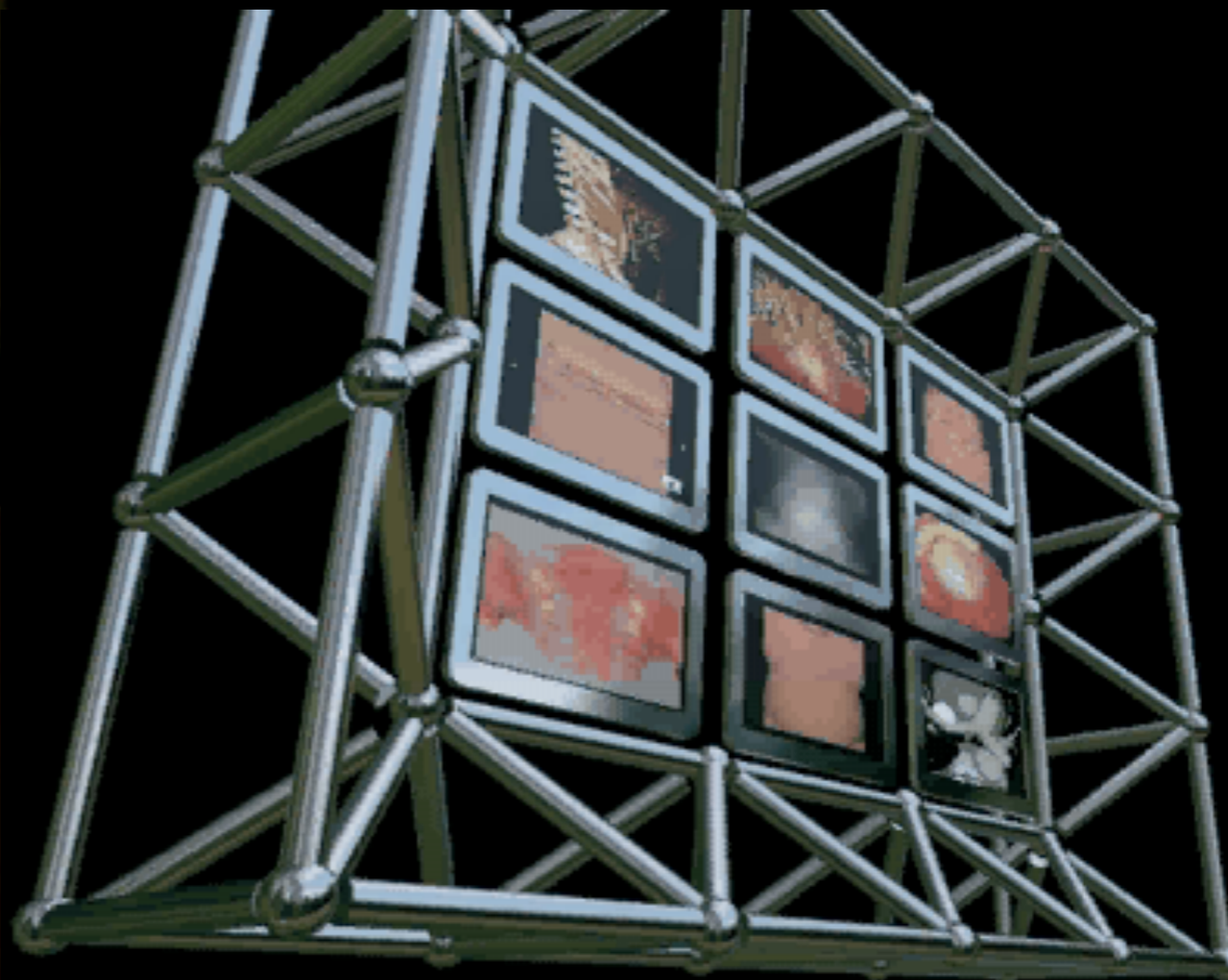
# *Special Thanks to:*

Scott Alexander, MD  
Geoff Rubin, MD  
Justus Roos, MD  
Mina Thakur, RT (R)(CT)

*Online Handouts from  
Lecture:*

[www.stanford.edu/~hallett](http://www.stanford.edu/~hallett)

*Choose “NMCSD”*



# 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.

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