



Avoiding CT Pitfalls

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Biomedical Engineering³



- Tim Stick's Disclosures

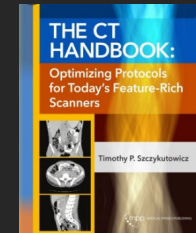
- Funds or equipment to UW-Madison

- Supplies CT protocols to GE Healthcare under a licensing agreement
 - Research support from GE Healthcare
 - Receives research support from Canon Medical Systems USA

No
personal \$
from
GE/Canon

- Personal

- Medical Advisory Board of iMAGLOGIX LLC
 - Consult to ALARA Imaging LLC.
 - Licensing Patent US10957444B2 (repeat rates) to Qaelum.
 - Royalties from Medical Physics Publishing
 - Founder of RadUnity Corp.



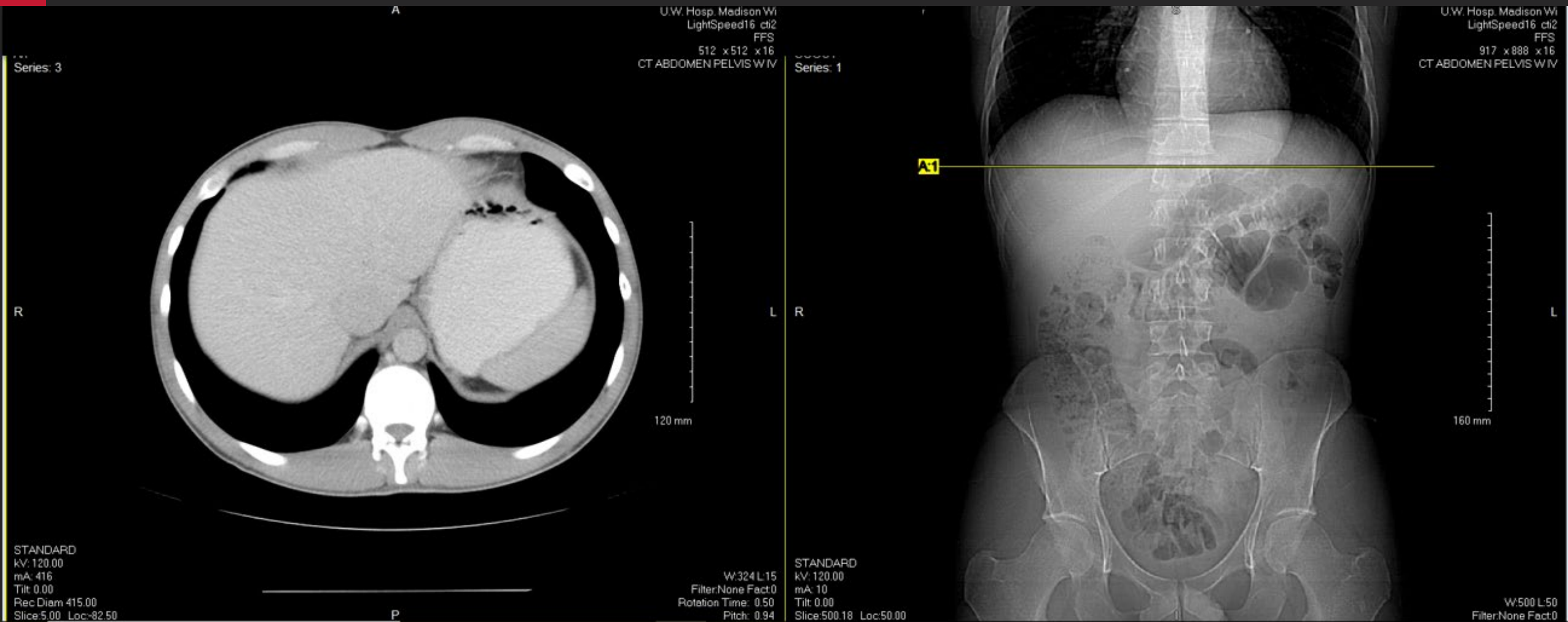
Learning Objectives

- Learn how evolving technology requires rethinking protocol design—legacy practices can reduce diagnostic utility.
- Understand how poor patient positioning, especially in MSK imaging, can degrade image quality.
- Identify and avoid well-meaning but misguided “dose reduction” decisions in pediatrics and pregnancy.

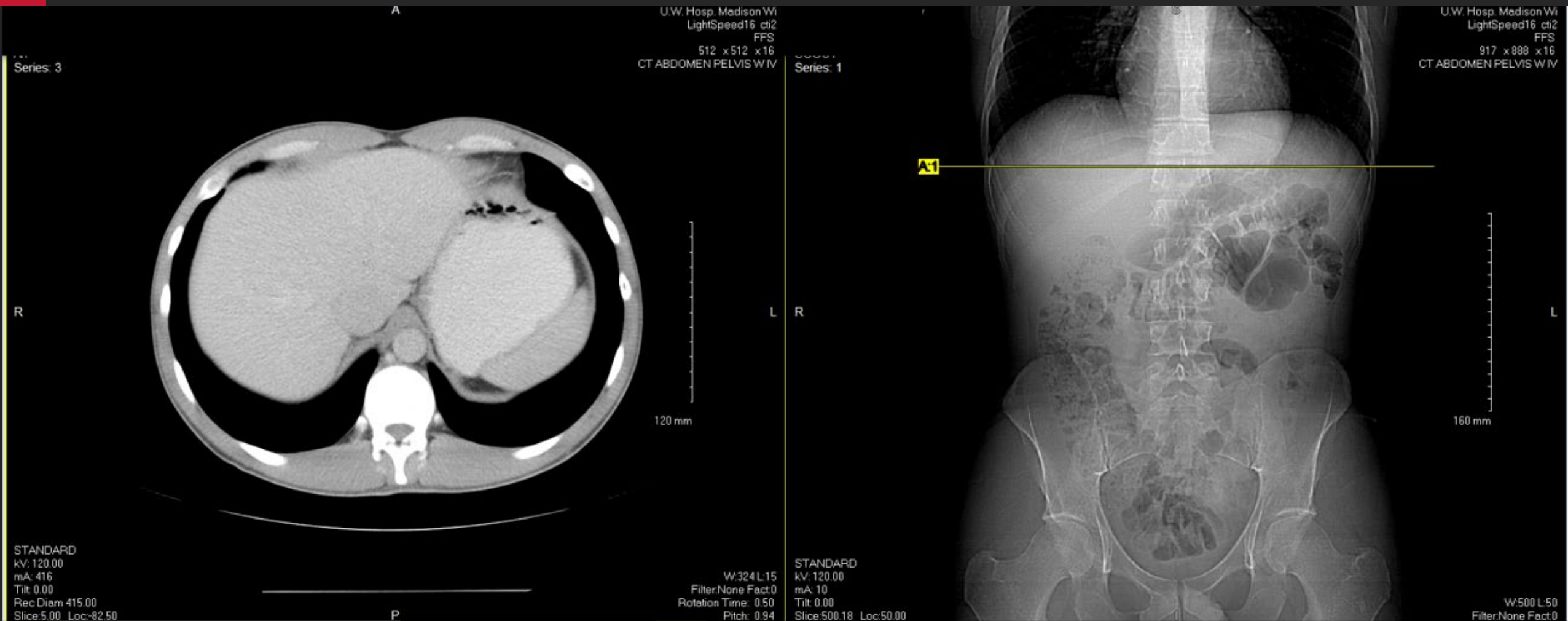


Poor protocol translation

~13 years ago... your truly got a CT scan (negative, dx was stress induced abdominal pains, post-doc/residency/baby...)



~12 years ago... your truly got a CT scan (negative, dx was stress induced abdominal pains, post-doc/residency/baby...)



GE Healthcare LS 16 (older scanner even at that time, 32 channel scanner when there were 320 slices...)
Collimation used here was 20 mm (the best this old scanner could do)
Rotation time was 0.5 seconds (not bad)
Pitch was 0.94:1

$$\text{Speed} = \frac{\text{pitch} * \text{collimation}}{\text{Rotation time}}$$

$$\text{Scan Duration} = \frac{\text{Scan Length}}{\text{Speed}}$$

$$\text{Speed} = 0.94:1 * 20 \text{ mm} / 0.5 \text{ s}$$

$$\text{Speed} = 37.6 \text{ mm/s}$$

Scan length was ~480 mm

So scan duration was $480 \text{ mm} / (37.6 \text{ mm/s}) = 12.8 \text{ seconds}$

Patient					
Accessi					
Patient					
Exam Description: CT ABDOMEN PELVIS W IV					
LightSpeed16					
Dose Report					
Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
200	Axial	168.750-168.750	20.83	20.80	Body 32
2	Helical	14.500-1475.125	17.57	879.96	Body 32
Total Exam DLP:				900.76	
1/1					

Highest tube
current was 440
mA over pelvis



Old Scanner Exam Settings and outcomes

Collimation: 20 mm

Rotation time: 0.5 s

Pitch: 0.94:1

Max tube current: 440 mA

Scan Duration: 12.8 seconds

CTDIvol: 17.57 mGy



(LightSpeed 16) Old Scanner Exam Settings and outcomes

Collimation: 20 mm

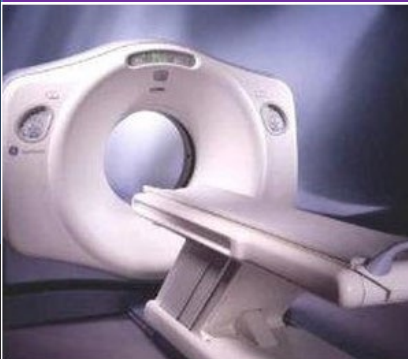
Rotation time: 0.5 s

Pitch: 0.94:1

Max tube current: 440 mA

Scan Duration: 12.8 seconds

CTDIvol: 17.57 mGy



(HD 750) New Scanner Exam Settings and possible outcomes

Collimation: 20 mm

Rotation time: 0.5 s

Pitch: 0.969:1

Max tube current: 440 mA

Scan Duration: ~12 seconds

CTDIvol: ~18 mGy



Direct Translation HD 750 Protocol

Collimation: 20 mm

Rotation time: 0.5 s

Pitch: 0.969:1

Max tube current: ~440 mA

Scan Duration: ~12 seconds

CTDIvol: ~18 mGy



Better HD 750 Protocol

Collimation: 40 mm

Rotation time: 0.4 s

Pitch: 0.984:1

Max tube current: 835 mA

Scan Duration: ~5 seconds

CTDIvol: ~18 mGy



Original Research | Cardiothoracic Imaging | February 25, 2025

Derivation of Best-Practice Scan Speeds and Excess Scan Durations for CT Pulmonary Angiography: Analysis Using Registry Data for 166,769 Examinations Across 121 Sites

Authors: Yifei Wang, PhD, Carly Stewart, MHA, Rebecca Smith-Bindman, MD, and Timothy P. Szczykutowicz, PhD

Volume 224, Issue 4 | <https://doi.org/10.2214/AJR.24.32323>

CME CLAIM CREDIT

221 / 3 GET ACCESS

I designed a study to see how often this kind of poor protocol translation is occurring

$$\text{Excess Scan Duration [s]} = \max \left(0, \frac{\text{Scan Length [mm]}}{\text{Observed Scan Speed [mm/s]}} - \frac{\text{Scan Length [mm]}}{\text{Best-Practice Scan Speed [mm/s]}} \right)$$

In this study, we used 166,769 CTPA examinations from an international dose registry to determine best-practice scan speeds for combinations of scanner model and radiation dose categories, based on actual 95th-percentile speeds. The scan speed was slower than the best-practice scan speed for 87% of acquisitions, and $\geq 20\%$ slower for 62% of acquisitions. Use of the best-practice scan speed could have saved a median of 1.2 seconds and a mean of 2.3 seconds in comparison with a median actual scan duration of 4.8 seconds.

Turns out it is occurring a lot



@Prof_TimStick's Actionable information

- You can get away with blindly copy/paste most CT protocol clinical instructions (patient prep, IV contrast, breathing instructions, oral contrast, etc.) but when switching to a new scanner almost always should involve a change to acquisition parameter



PE scanning in pregnancy (breast dose, PE CT vs VQ)



Ferrata Storti Foundation

Computed tomography pulmonary angiography versus ventilation-perfusion lung scanning for diagnosing pulmonary embolism during pregnancy: a systematic review and meta-analysis

Cécile Tromeur,^{1,2,3} Liselotte M. van der Pol,^{1,4} Pierre-Yves Le Roux,⁵ Yvonne Ende-Verhaar,¹ Pierre-Yves Salaun,⁵ Christophe Leroyer,^{2,3} Francis Couturaud,^{2,3} Lucia J.M. Kroft,⁶ Menno V. Huisman¹ and Frederikus A. Klok¹

Haematologica 2019

Volume 104(1):176-188

¹Department of Thrombosis and Hemostasis, Leiden University Medical Center, the Netherlands; ²Groupe d'Etude de la Thrombose de Bretagne Occidentale, University of Brest, Equipe d'Accueil 3878, Department of Internal Medicine and Chest Diseases, CHRU Brest, France; ³Centre d'Investigation Clinique INSERM 1412, University of Brest, France; ⁴Department of Internal Medicine, Haga Teaching Hospital, the Hague, the Netherlands;

rently used. The higher breast radiation exposure with CTPA partly explains the recommendation of V-Q lung scans by international guidelines for pregnant patients with suspected PE. The Society of Thoracic Radiology clinical practice guidelines have presented comparable radiation exposure doses to our findings.⁷⁴ However, since

along the studies prevents a solid evaluation of the sensitivity. Moreover, radiation doses associated with CTPA and V-Q lung scanning are well below the safety threshold.



Ferrata Storti Foundation

Computed tomography pulmonary angiography versus ventilation-perfusion lung scanning for diagnosing pulmonary embolism during pregnancy: a systematic review and meta-analysis

Cécile Tromeur,^{1,2,3} Liselotte M. van der Pol,^{1,4} Pierre-Yves Le Roux,⁵ Yvonne Ende-Verhaar,¹ Pierre-Yves Salaun,⁵ Christophe Leroyer,^{2,3} Francis Couturaud,^{2,3} Lucia J.M. Kroft,⁶ Menno V. Huisman¹ and Frederikus A. Klok¹

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Haematologica 2019
Volume 104(1):176-188

An Official American Thoracic Society/Society of Thoracic Radiology Clinical Practice Guideline: Evaluation of Suspected Pulmonary Embolism In Pregnancy

[Ann N. Leung](#), [Todd M. Bull](#), [Roman Jaeschke](#), [Charles J. Lockwood](#), [Phillip M. Boiselle](#), [Lynne M. Hurwitz](#), [Andra H. James](#), [Laurence B. McCullough](#), [Yusuf Menda](#), [Michael J. Paidas](#) ... [Show more](#)

American Journal of Respiratory and Critical Care Medicine, Volume 184, Issue 10, November 2011, Pages 1200–1208, <https://doi.org/10.1164/rccm.201108-1575ST>

Published: 15 November 2011

Dose Metric	CTPA	V-Q
Maternal Effective dose (mSv)	0.23-9.7	0.9-5.85
Fetal absorbed dose (mGy)	0.002-0.51	0.2-0.7
DLP (mGy*cm)	69-397	n/a
Breast dose Mother (mGy)	10-60	~1

Fetus	No data	There is no data from humans on a dose threshold for prenatal death, microcephaly, or childhood cancer. ICRP Publication 90 [24] discusses these effects in more detail; some have been shown in animal models.
Fetus	0.3 Gy delivered 8–15 weeks post conception	During this window of cortical sensitivity, severe mental retardation was found in atomic bomb survivors. A radiation dose of 1 Gy would increase the risk for severe mental retardation by 40%.
Fetus	25 IQ point reduction per 1 Gy during weeks 8–15 post conception	Linear trend observed with atomic bomb survivors, but below 0.1 Gy the IQ reduction was not statistically significant.
Fetus	0.2 Gy delivered 1–8 weeks post conception	Atomic bomb survivors receiving more than this level of dose were smaller (2–3 cm in height and 1 cm head circumference) and lighter (3 kg) relative to controls. Note: this finding was not reported in the executive summary of ICRP Publication 90, but was in the report body.
Fetus	0.25 Gy delivered 2–8 weeks post conception	Organ malformation

“The CT Handbook: Optimizing Protocols for Today’s feature-rich scanners”

By Tim Szczykutowicz. Medical Physics Publishing 2020

The last slide says fetal dose is < 1 mGy from CTPA and V-Q

So we just need to give 200+ scans to reach the smallest threshold observed in atomic bomb survivors

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Incremental radiation risk is small and theoretical, whereas delayed dx of PE has a real and immediate established clinical risk to both mom and the fetus



Practice guideline from 2011, American Thoracic Society of Thoracic Radiology → V-Q favored only when chest radiograph is negative. Panel felt in this situation, extra time is okay for small dose advantage to the mother's breasts.

Pregnant PE patient things to avoid

Doing any of these things limits diagnostic utility or limits the robustness of the protocol.

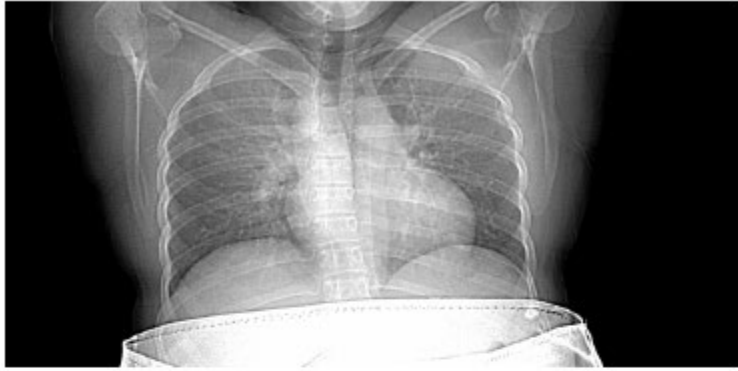
PE is the leading cause of maternal death!

1. Don't limit scan coverage to not include the lung bases.
2. Don't reduce dose (lower mAs).
3. Don't skip doing timing bolus/bolus tracking.
4. Don't put a shield on unless you have to by law or the patient asks (peace of mind).
 1. If you put a shield on, put it FAR away from the lung bases.
 2. Watch to make sure the shield doesn't slip down over the lungs.
5. Don't have them drink barium! Why waste time? The fetus does is already hundreds of times below any level where data shows there could be an issue.

Question the literature. Methods producing huge fetal dose reductions don't really mean anything when the starting dose is already a hundred times below limits we care about...



Yuck, IQ resulting from a shield slipping down into scan range ☹



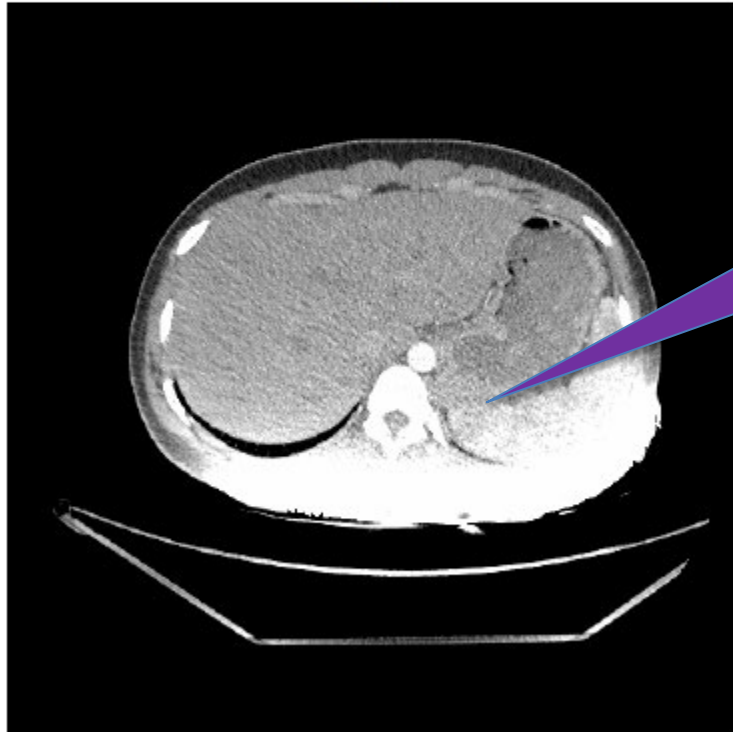
(a)



(b)



(c)



(d)

Tech included lead apron in scan range (or apron slipped during scan)



April 2019, Volume 212, Number 4

FOCUS ON: Medical Physics and Informatics
Clinical Perspective

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Patient Shielding in Diagnostic Imaging: Discontinuing a Legacy Practice

Rebecca M. Marsh¹ and Michael Silosky¹

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Citation: American Journal of Roentgenology. 2019;212: 755-757. 10.2214/AJR.18.20508

Abstract | Full Text | References | PDF | PDF Plus | Add to Favorites | Permissions | Download Citation

Examples of Radiation-Based Superheroes:

The Hulk:

Bruce Banner becomes the Hulk after being caught in a gamma bomb explosion.

Captain Atom:

In the DC Comics universe, Captain Atom was vaporized by a thermonuclear explosion, only to be rebuilt as a being of pure energy.

Firestorm:

This character's powers are linked to a nuclear accident, allowing him to manipulate matter and energy.

Daredevil:

In some versions, Daredevil's blindness and enhanced senses result from an accident involving radioactive waste.

Spider-Man:

A radioactive spider bite gives Spider-Man his powers, including super strength, agility, and the ability to stick to walls.

Black Canary:

Some comic book storylines give her the "Super-Scream" ability due to radiation exposure. 

We thought

US law in 1976 → we thought x-rays caused hereditary risks

Now we know

Shields cause increases in repeated imaging

Shields decrease diagnostic utility of images via artifacts

Shields cause increases in patient dose in some cases



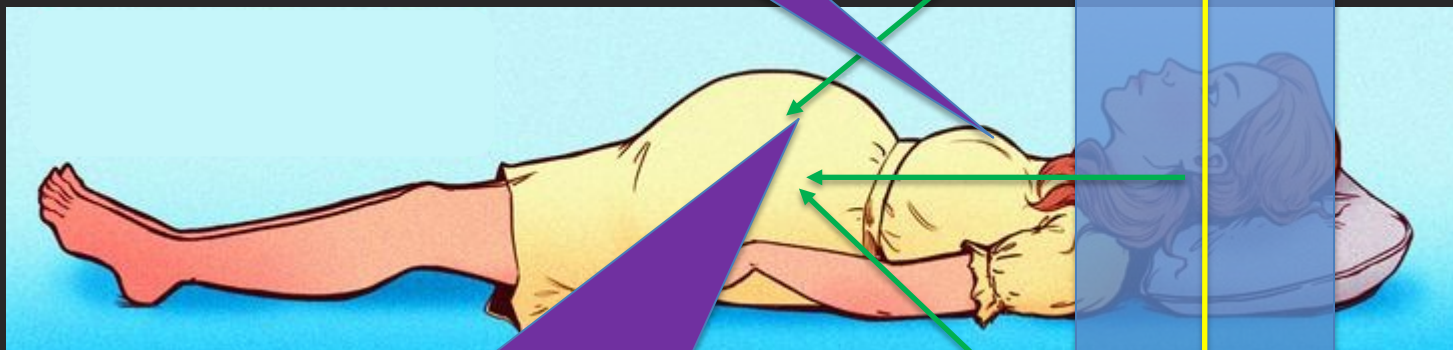
Head scanning in pregnancy, fetal dose

Scan Region	CTDI _{vol} (mGy) Required to Give Uterus Dose of 50–100 mGy	Median Dose for This Scan Type	Number of Scans Needed to Exceed 50/100 mGy Threshold	Scan Range Limits
Abdominal and thoracic Imaging				
Abdomen	36/72	12	3/6	Top of diaphragm to pubic symphysis
Pelvis				
Pelvis	36/72	13	3/5.5	Top of iliac crests to pubic symphysis
Chest	>100	11	>100	Lung apices to lung bases
Neuro Imaging				
Brain	>100	49	>100	
Neck	>100	15	>100	
Thoracic Spine	>100	23	>100	Top of C7 to the bottom of L1
Lumbar Spine	38/76	25	1.5/3	Top of T12 to the bottom of S2

CT scanner

X-Ray Tube

This scatter is almost entirely attenuated by the patient



The tube leakage and collimator/detector scatter are less than an operator in a CTF procedure gets from a single tap (micro gray range)

Scattered Photon

Primary Photon

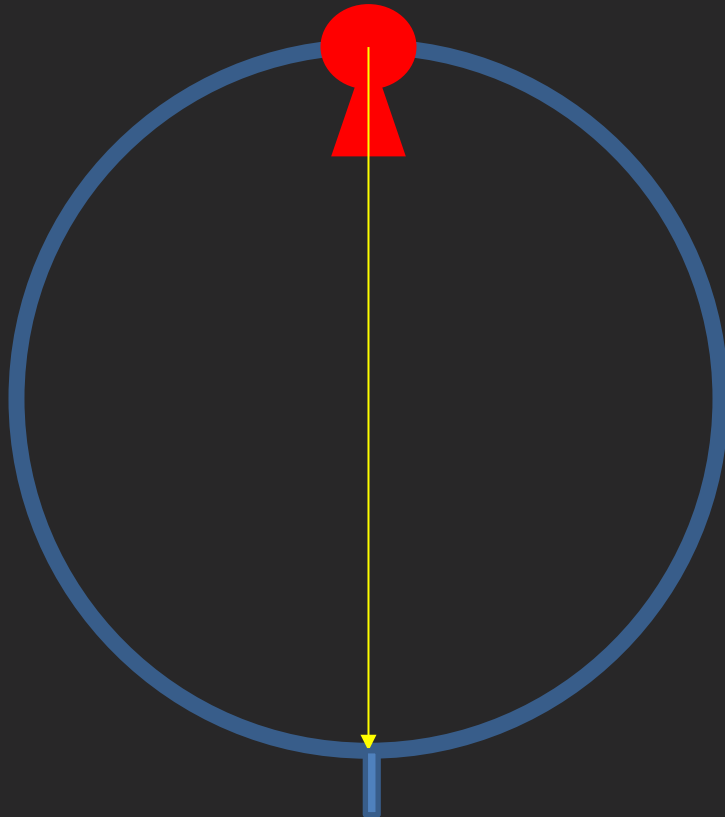
Detector

- If lead is used over the torso during a head scan, it may
 - Interfere with a bolus tracking scan if the head scan is a CTA
 - E.g., our Head CTA performs bolus tracking over the arch
 - Take time to place. Where minutes count in the setting of acute stroke, explain why a Pb apron is being used and placing/removing takes time.
 - Slide up the patient (given their pregnant body habitus) and interfere with any head scanning that includes the neck region

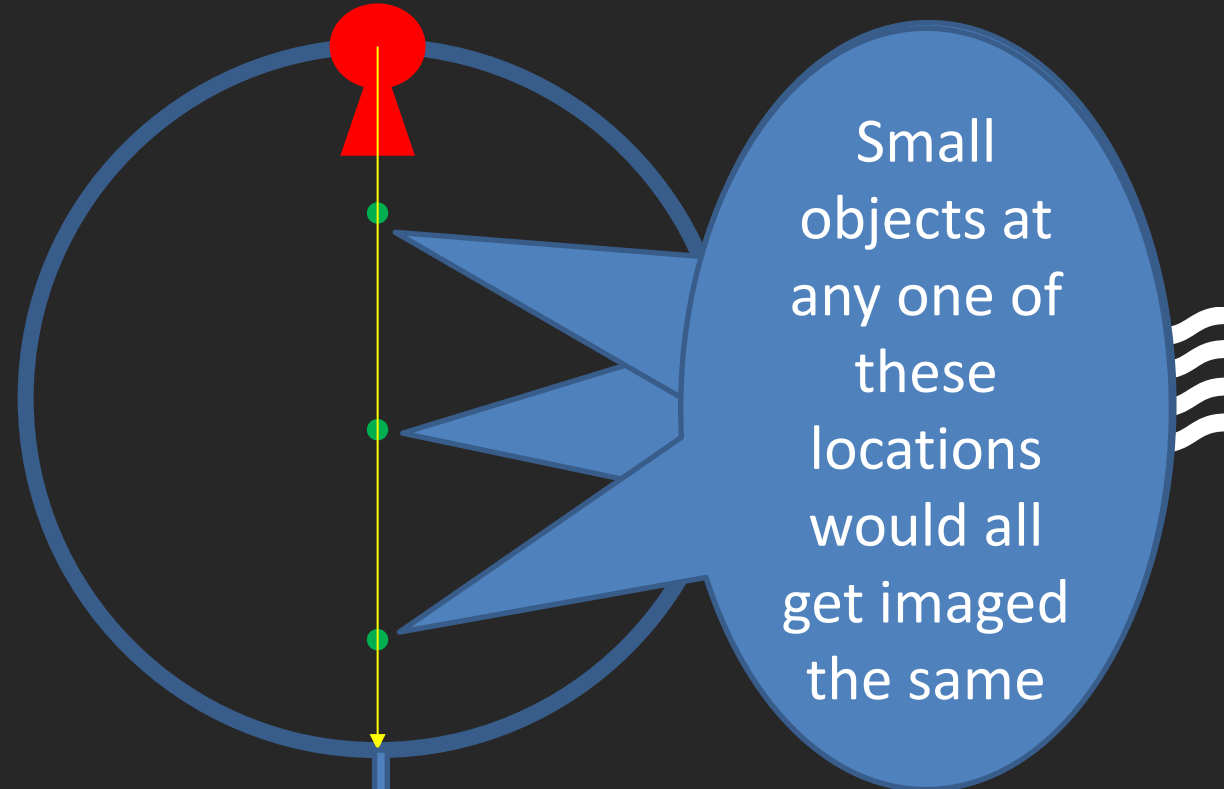


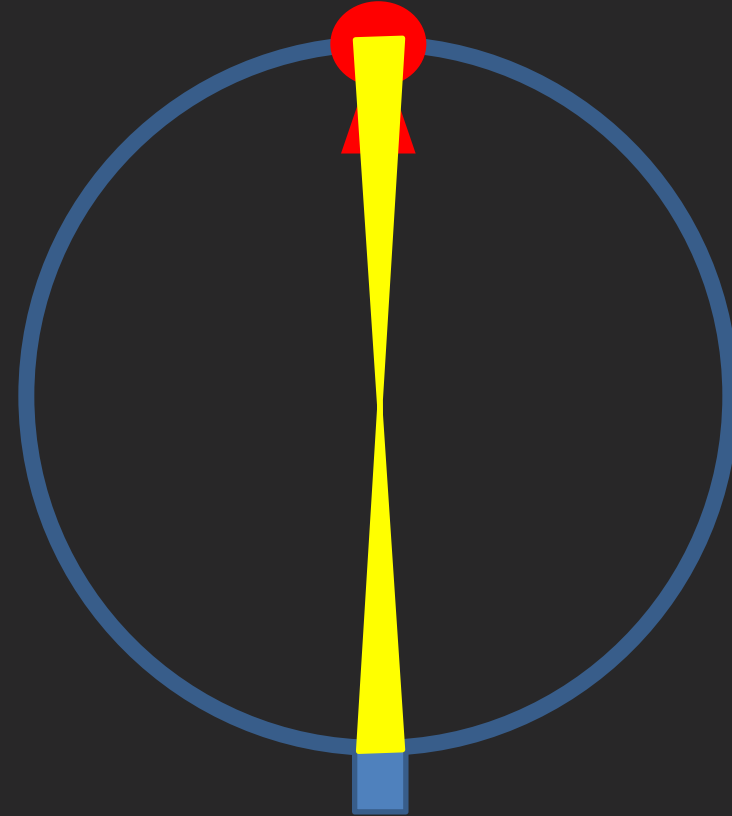
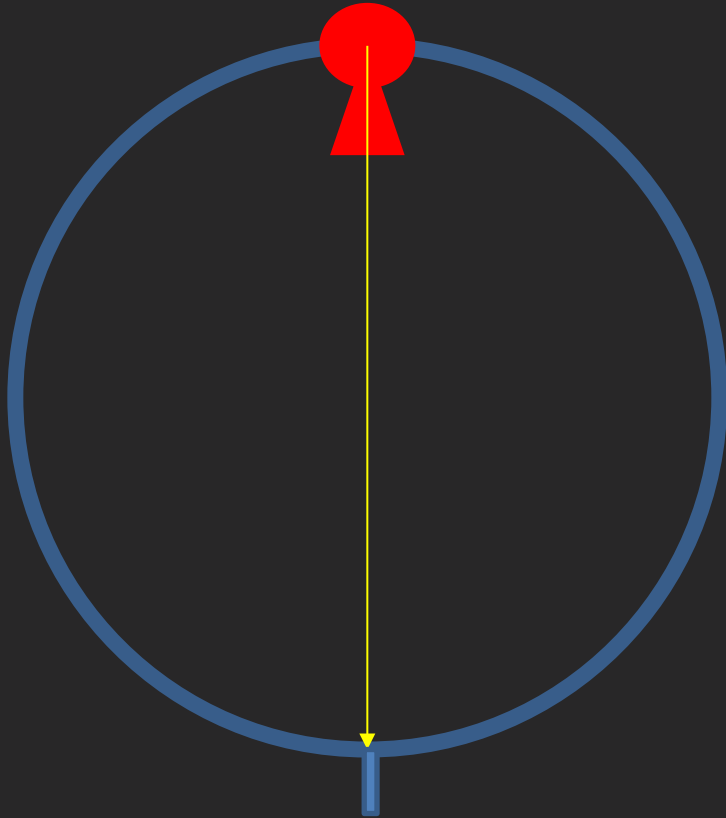
Patient positioning for high spatial resolution



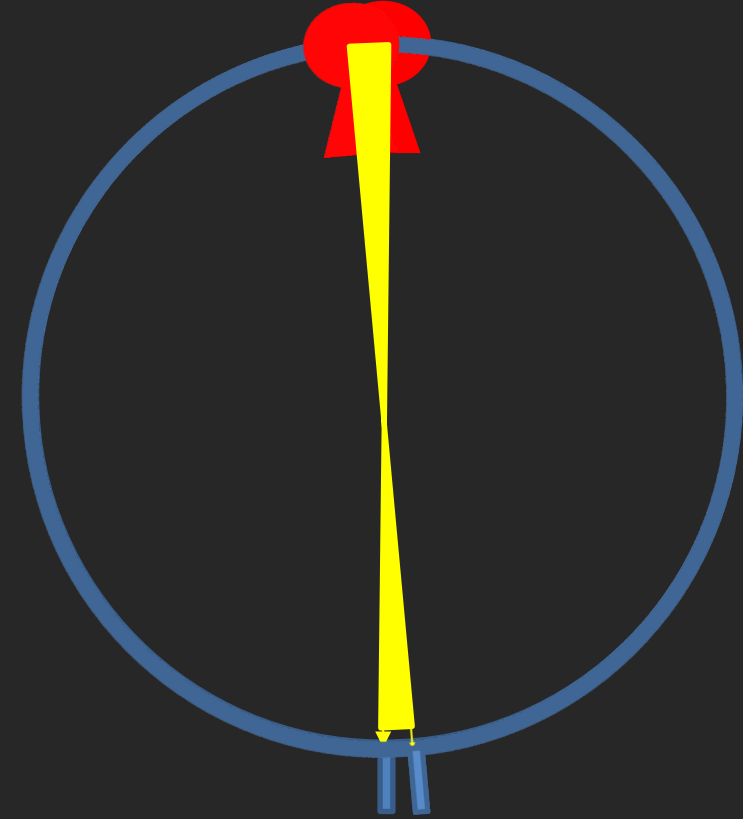
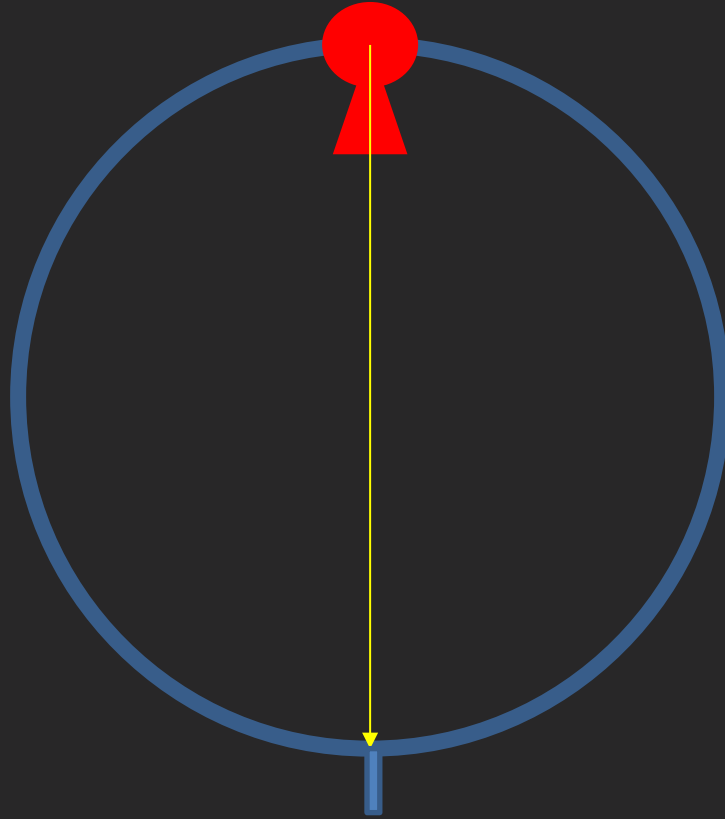


Ideally we would have a focal spot size of zero, a detector size of zero, and a data acquisition time of zero



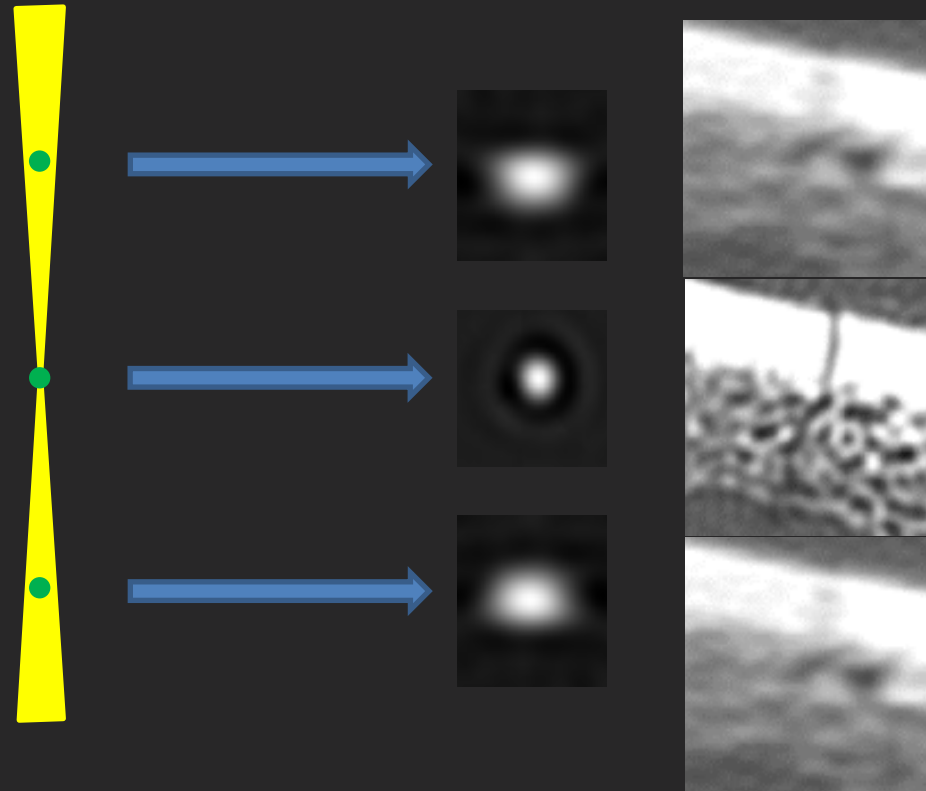


The finite size of the focal spot and detector element work together to blur our images when one moves closer to the focal spot or detector



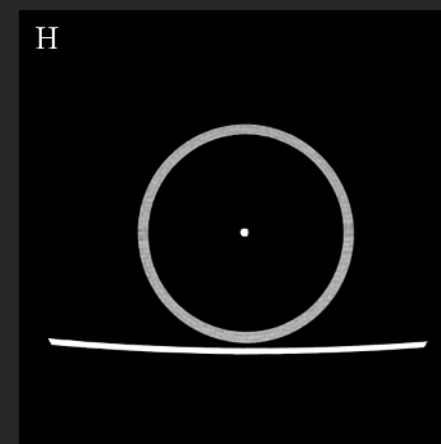
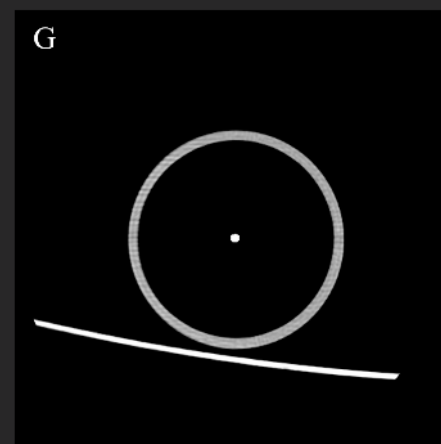
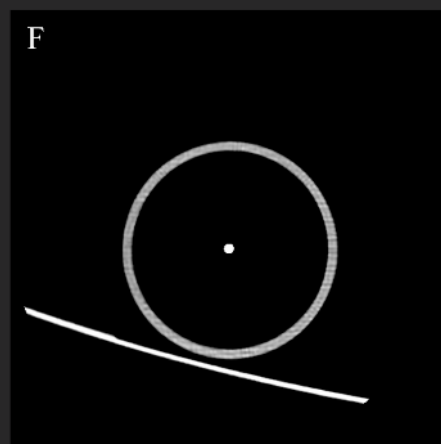
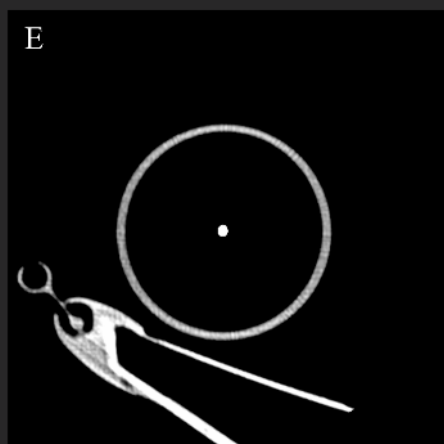
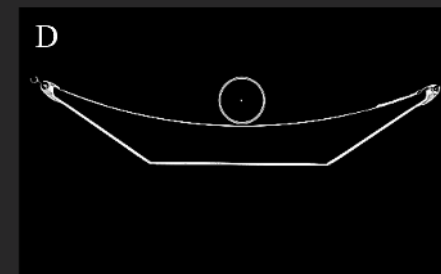
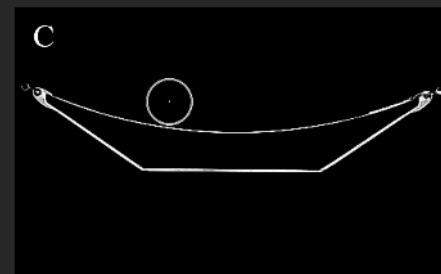
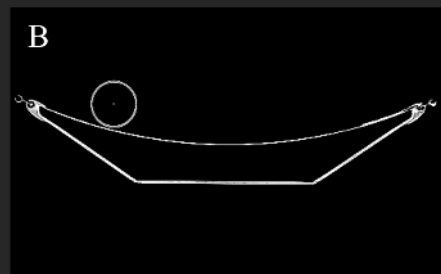
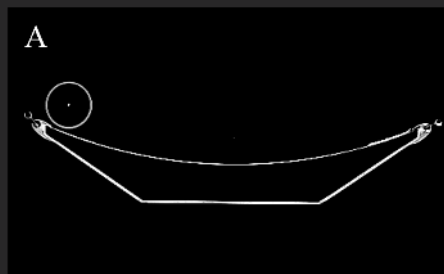
In reality, each view angle represents a finite angular range since the gantry is always moving and data acquisition time is finite

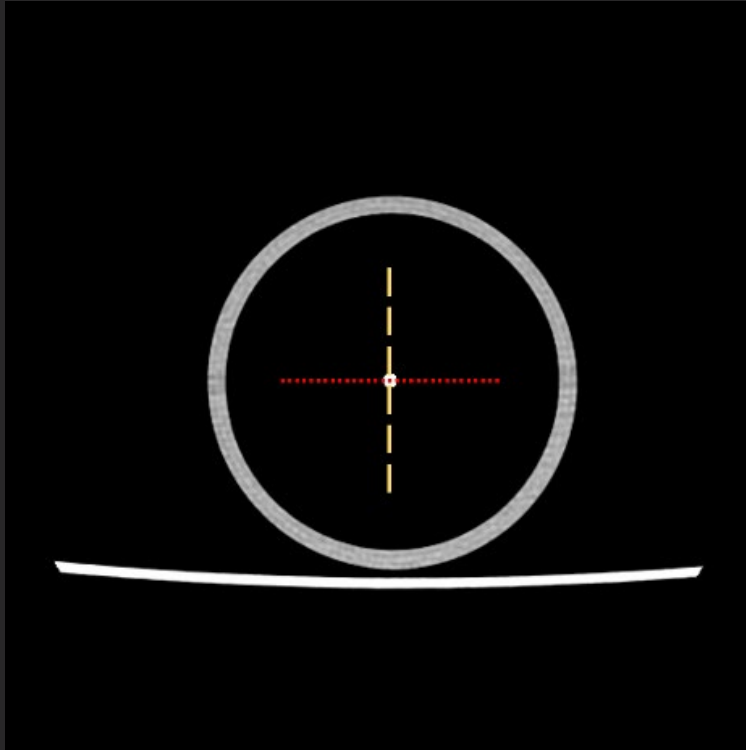
Position and Spatial Resolution



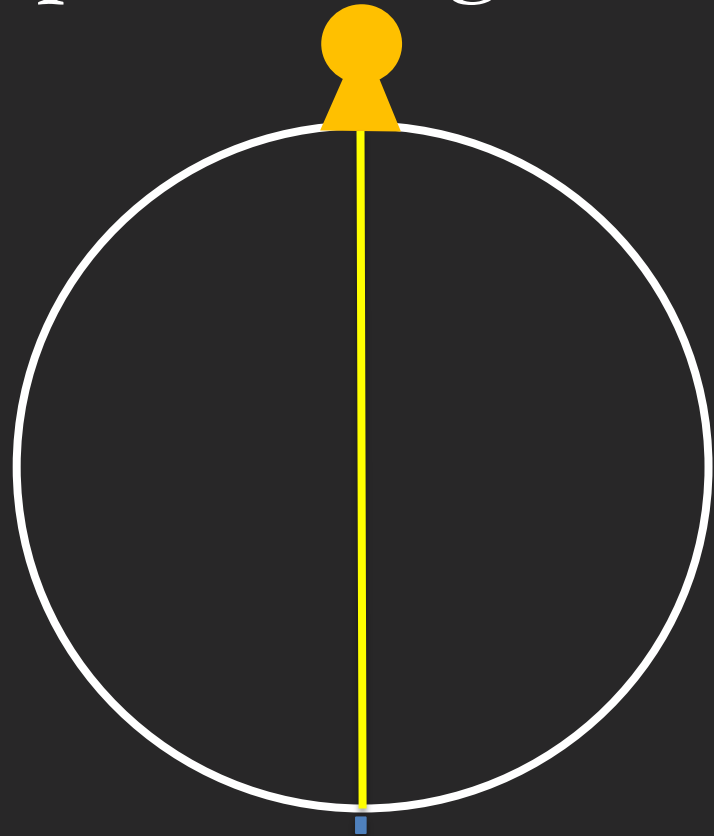
Rubert, N., Szczykutowicz, T., & Ranallo, F. (2016). Improvement in CT image resolution due to the use of focal spot deflection and increased sampling. *Journal of applied clinical medical physics*, 17(3), 452-466.



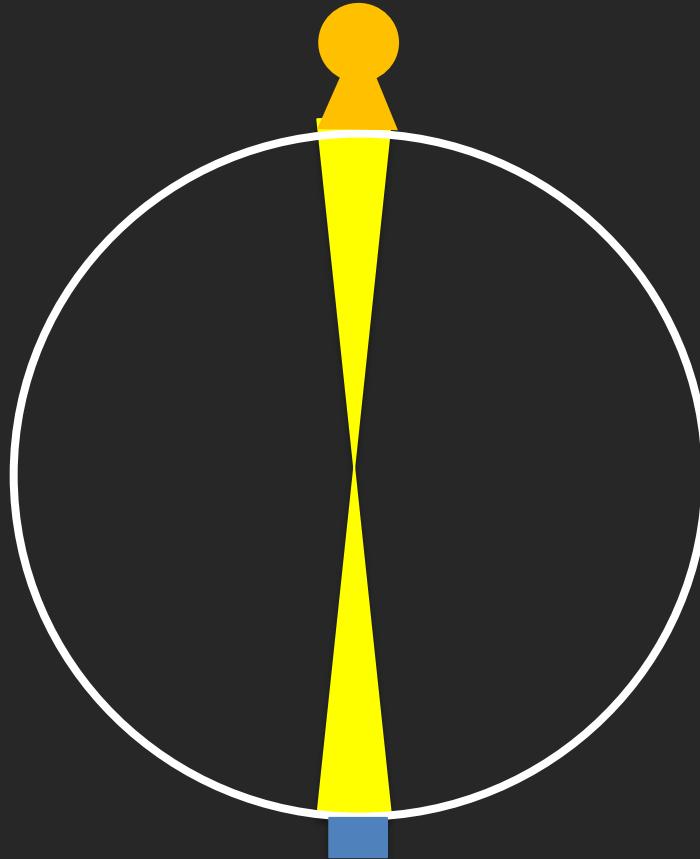




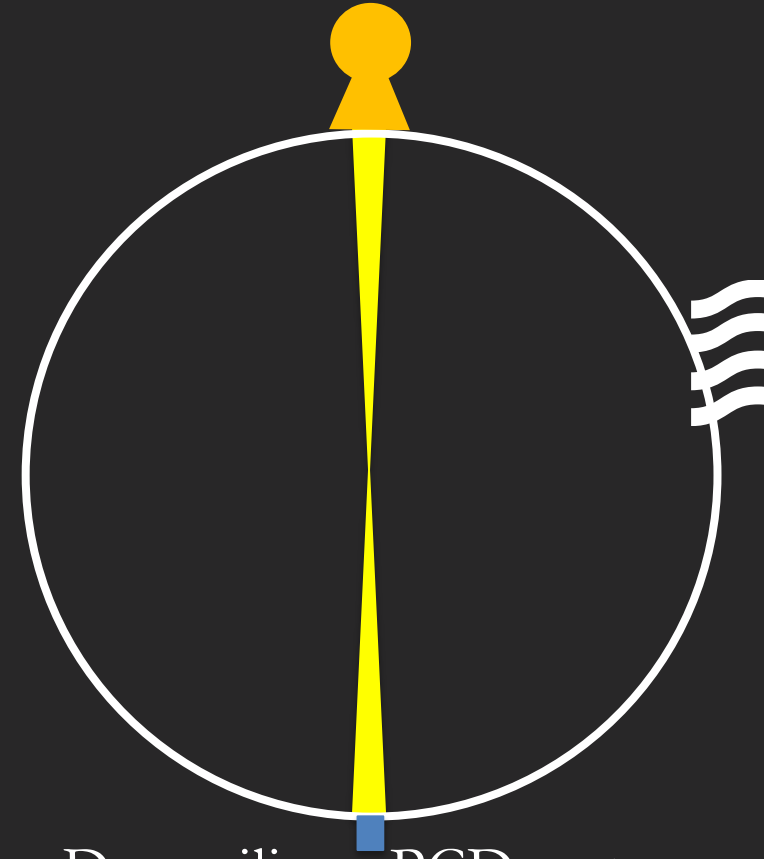
How is spatial resolution affected by patient positioning?



Ideal system



EID system: ~1k projection



Deep silicon PCD system:
>4k projection

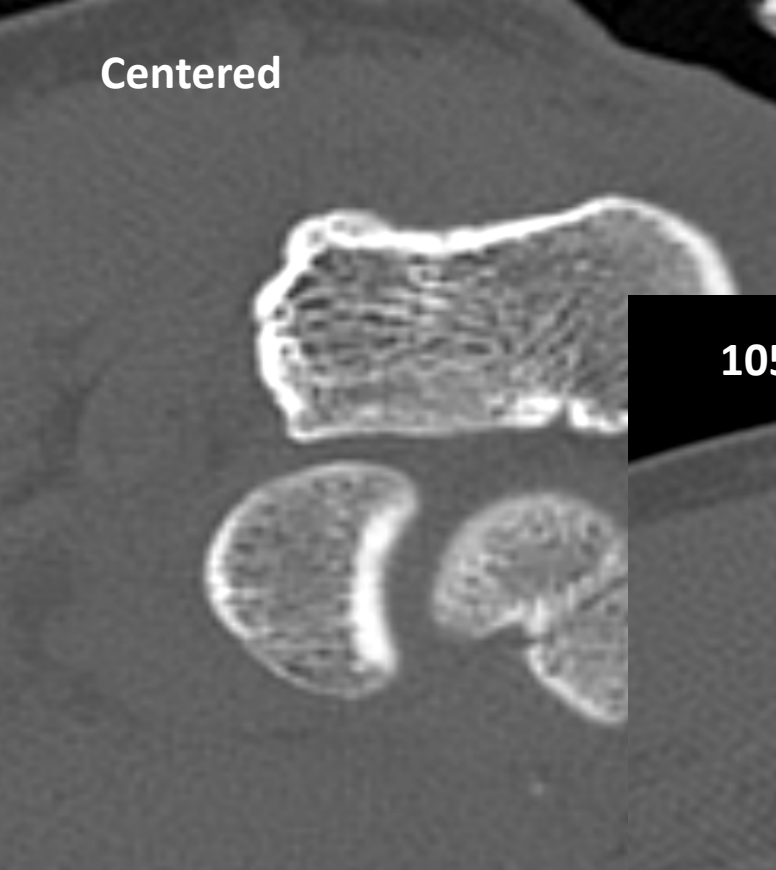
Position	Regular EID			HD EID			PCD		
	Ratio	% Diff	p	Ratio	% Diff	p	Ratio	% Diff	p
AZ 6.7 cm	1.00±0.01	0	0.39	0.99±0.02	1	<.001*	1.00±0.08	0	0.38
AZ 11.8 cm	1.16±0.01	16	<.001*	1.01±0.01	1	<.001*	0.99±0.08	1	0.80
AZ 17.1 cm	1.36 ± 0.01	36	<.001*	1.12 ± 0.01	12	<.001*	0.99 ± 0.08	1	0.82

GE high definition
mode is better than
regular mode

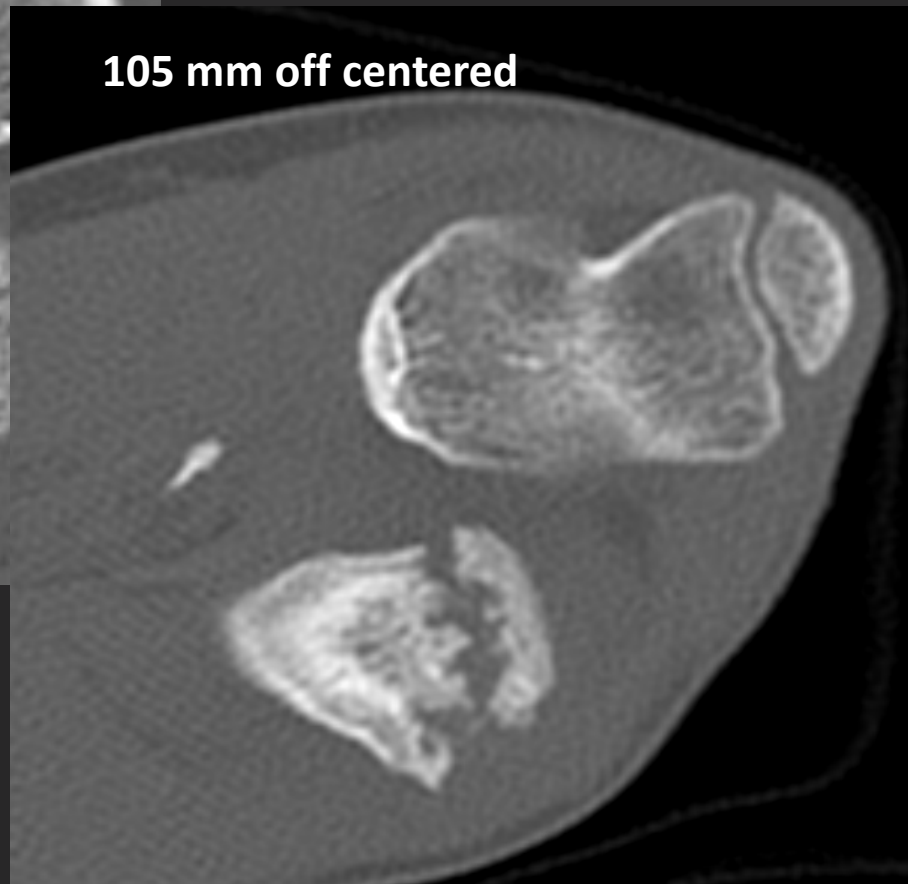
GE Deep Silicon PC is
better than HD
mode

GE Deep Silicon PC is better than regular mode

Centered



105 mm off centered



207.2 mm off centered



Centered

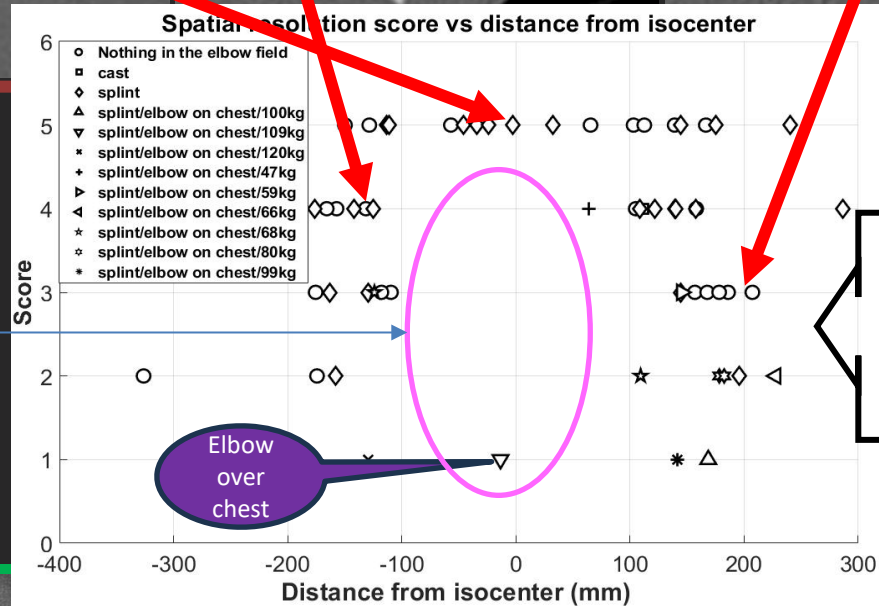
105 mm off centered

207.2 mm off centered

EID CT

“sweet spot”
of scanner is
evident for
EID

PCD CT



Spatial resolution scored by
Rads vs distance from
isocenter (mm) for EID CT

Centered

102.5 mm off centered

202.5 mm off centered

Reader scores not significantly changed with distance from
iso-center for Photon Counting

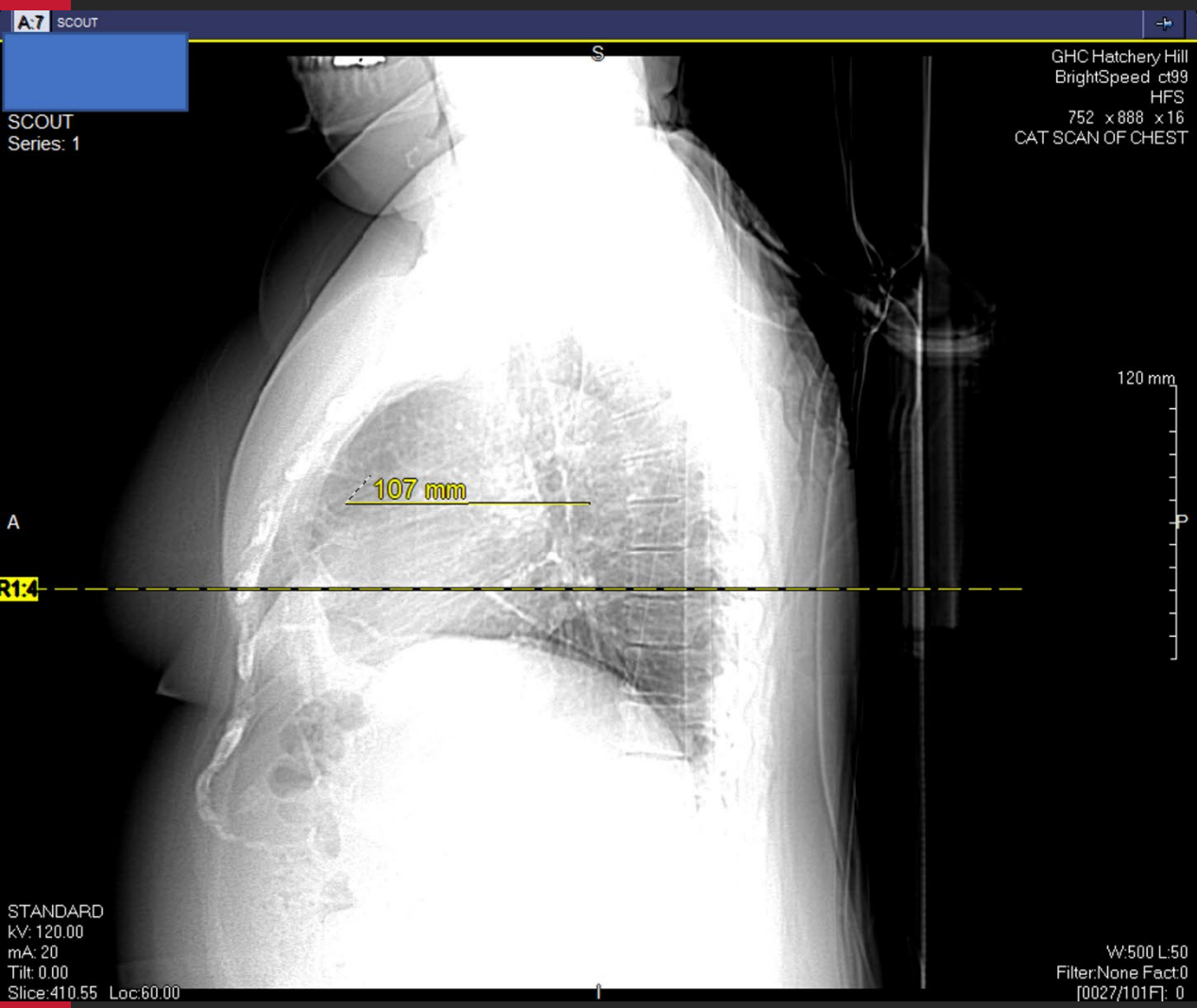


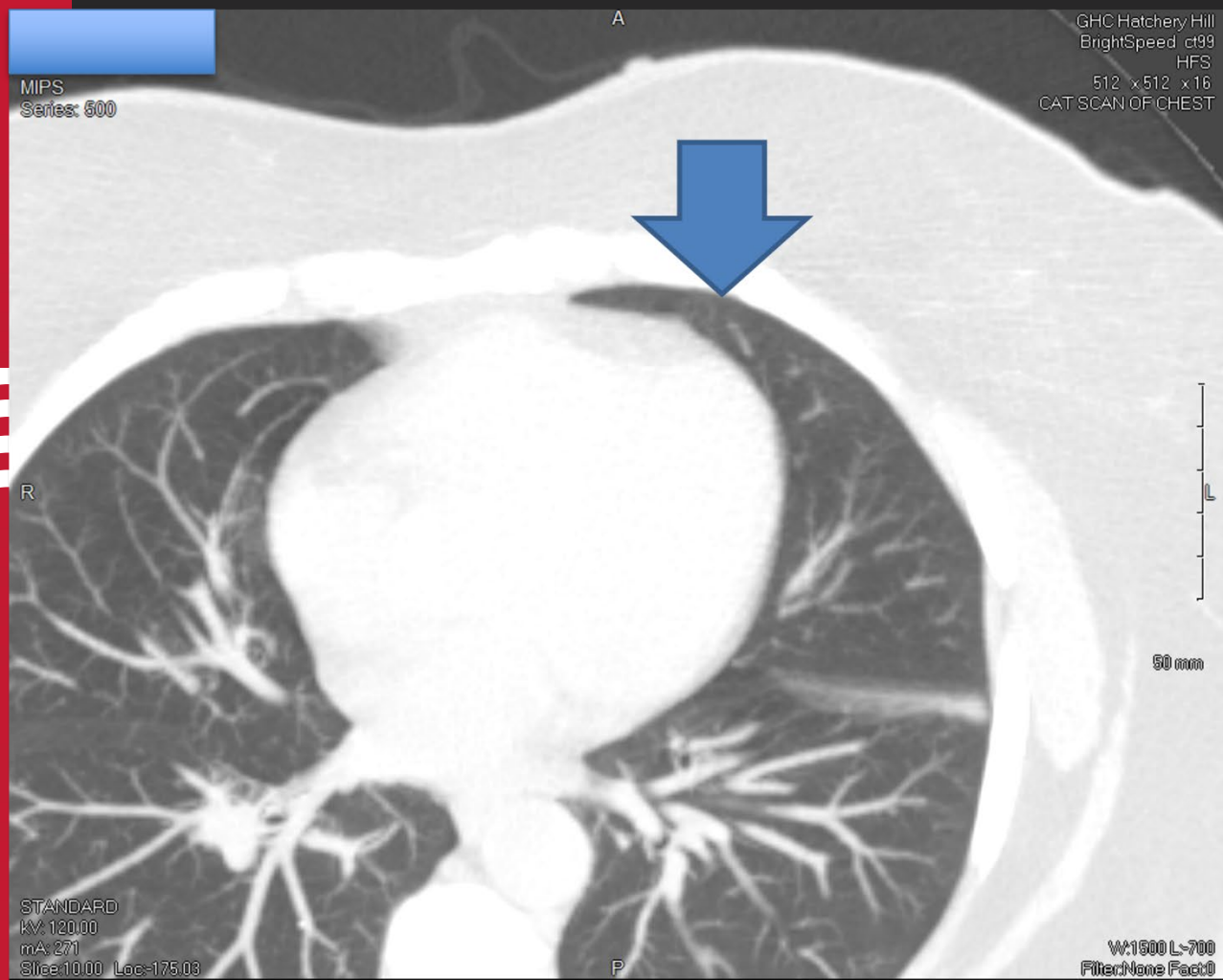
Issues with mis-positioning and spatial resolution: Clinical Example



Anterior portion of lung far
from iso-center

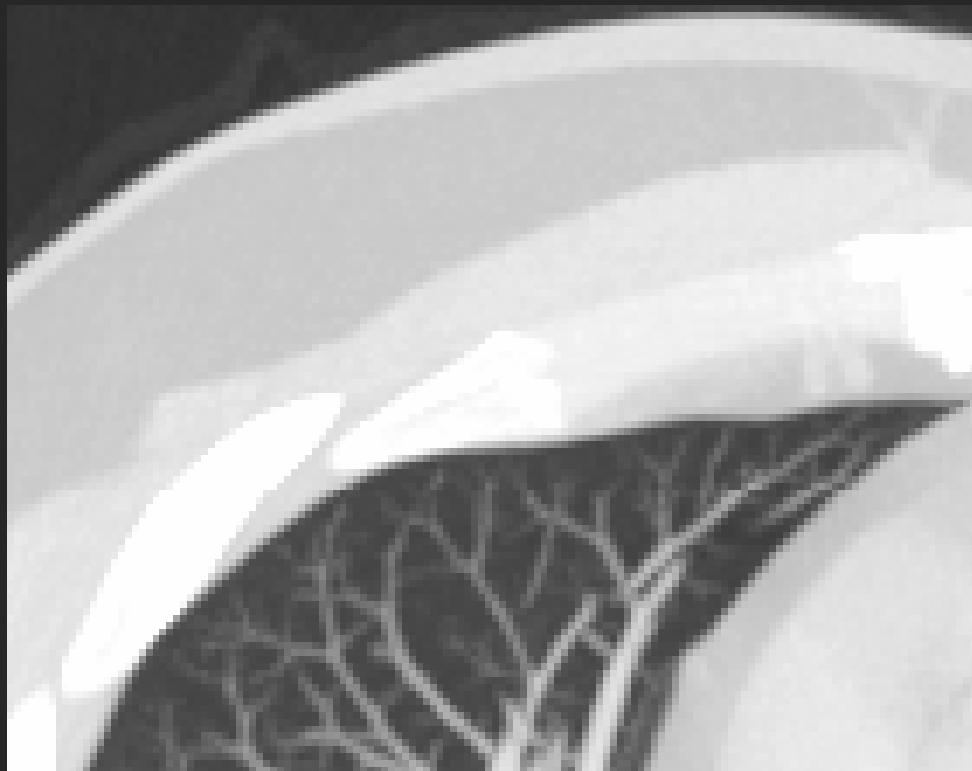
Anterior portion of lung close from iso-center





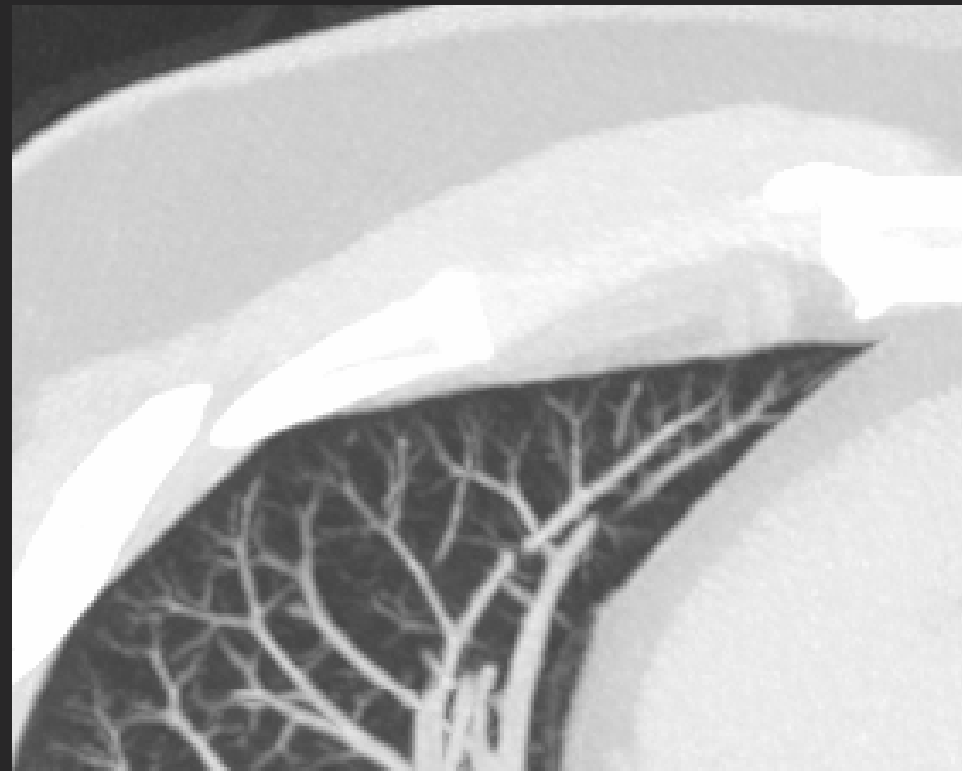
10 mm MIP
14.07 mGy
120 kV
GE standard kernel

EID prior



10 mm MIP
14.89 mGy
120 kV
Pluto standard kernel

Deep Silicon





Kernel RFOV mismatch

➤ Med Phys. 2026 May;53(5):e70505. doi: 10.1002/mp.70505.

Technical Note: Efficacy of CT spatial resolution metrics in clinical settings

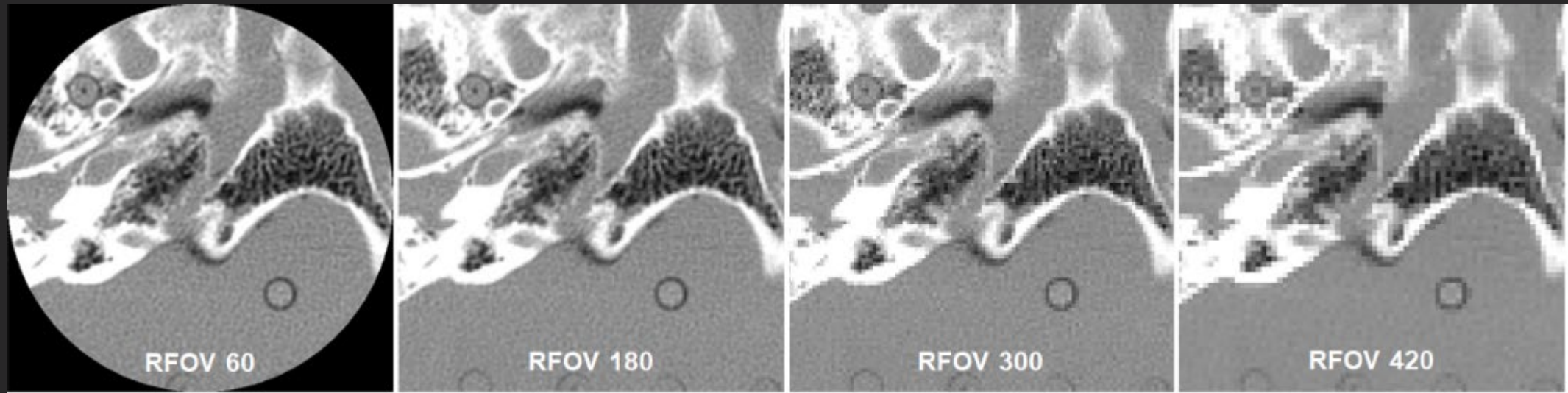
Hiroki Kawashima¹, Aria M Salyapongse², Giuseppe V Toia², Katsuhiro Ichikawa¹,
Timothy P Szczykutowicz²

Affiliations + expand

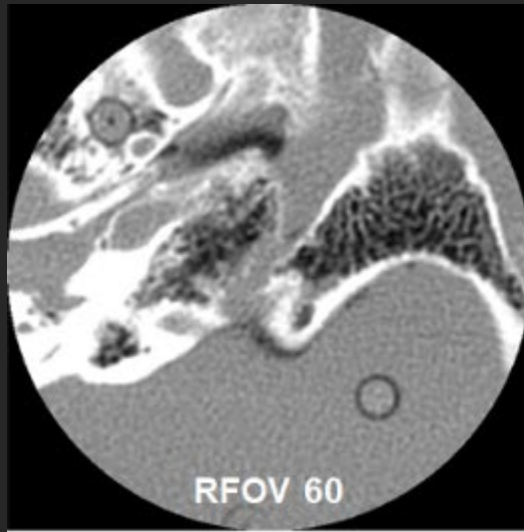
PMID: 42186124 DOI: [10.1002/mp.70505](https://doi.org/10.1002/mp.70505) 



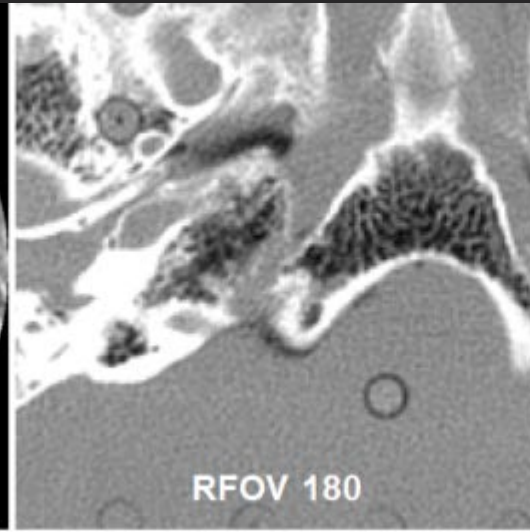
Same scan data,
reconstructed at different
field of views, with the same
number of pixels



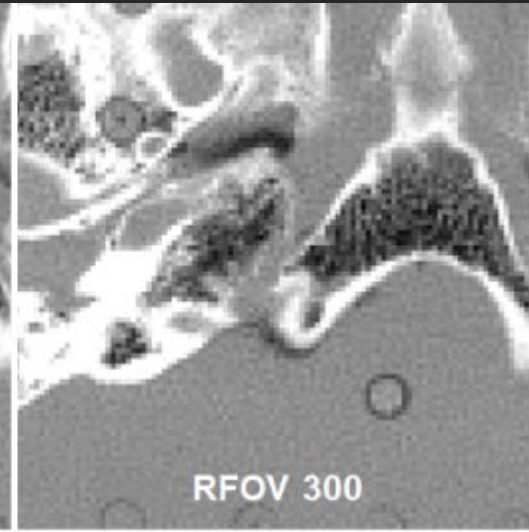
Same scan data,
reconstructed at different
field of views, with the same
number of pixels



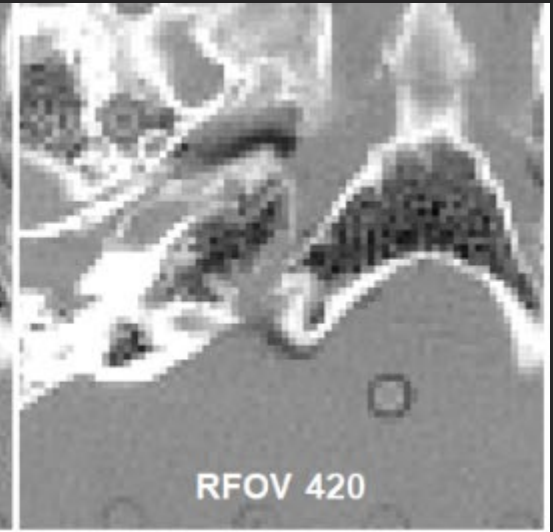
0.12 mm
pixel size



0.35 mm
pixel size



0.59 mm
pixel size

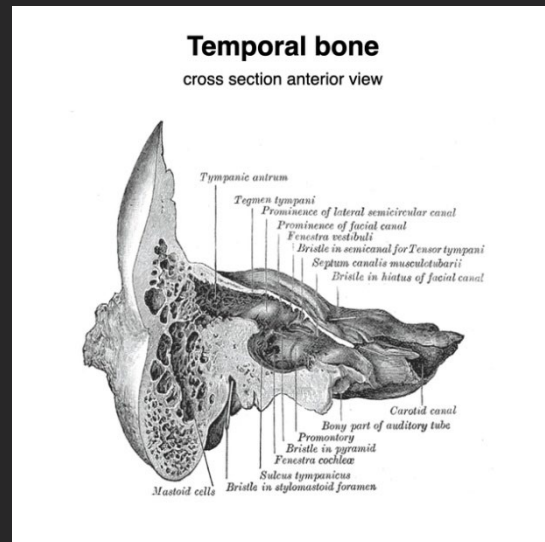


0.82 mm
pixel size

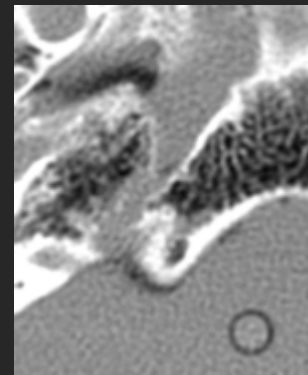
Real object, with
infinite spatial
frequencies

CT scanner can pass
through frequencies
up to ~13-20 line pairs
for most “high
resolution” exams
types

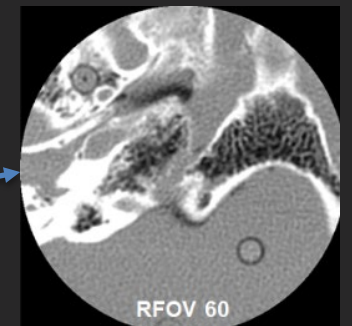
But depending on how
we sample (i.e.,
display) the image to a
radiologist, the
resolution can be
preserved or lost



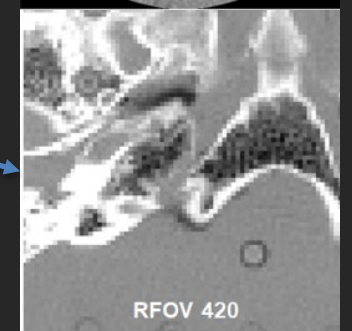
Gray's

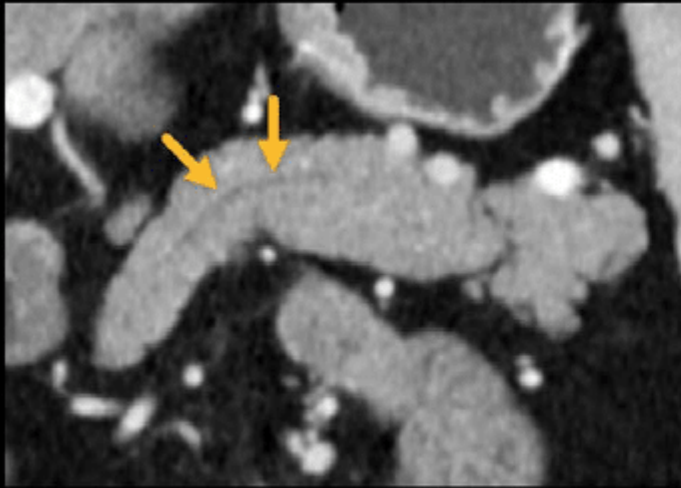


Sampling that
preserves what
the CT scanner
can measure



Sampling that
destroys what
the CT scanner
can measure

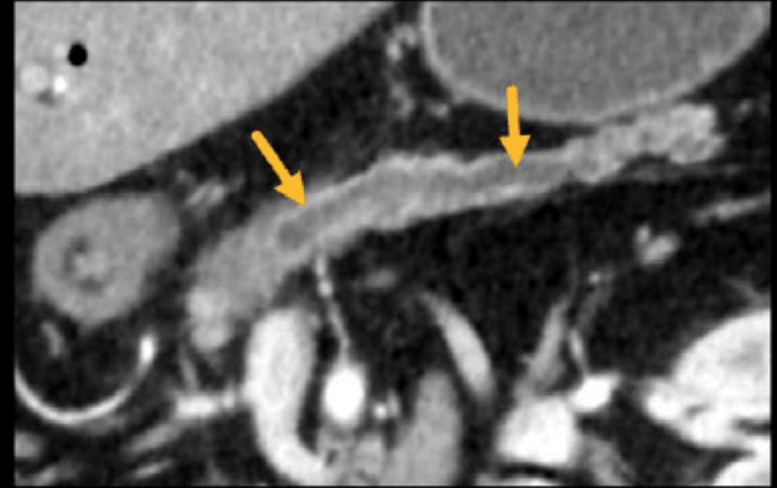




Normal



Mild dilation



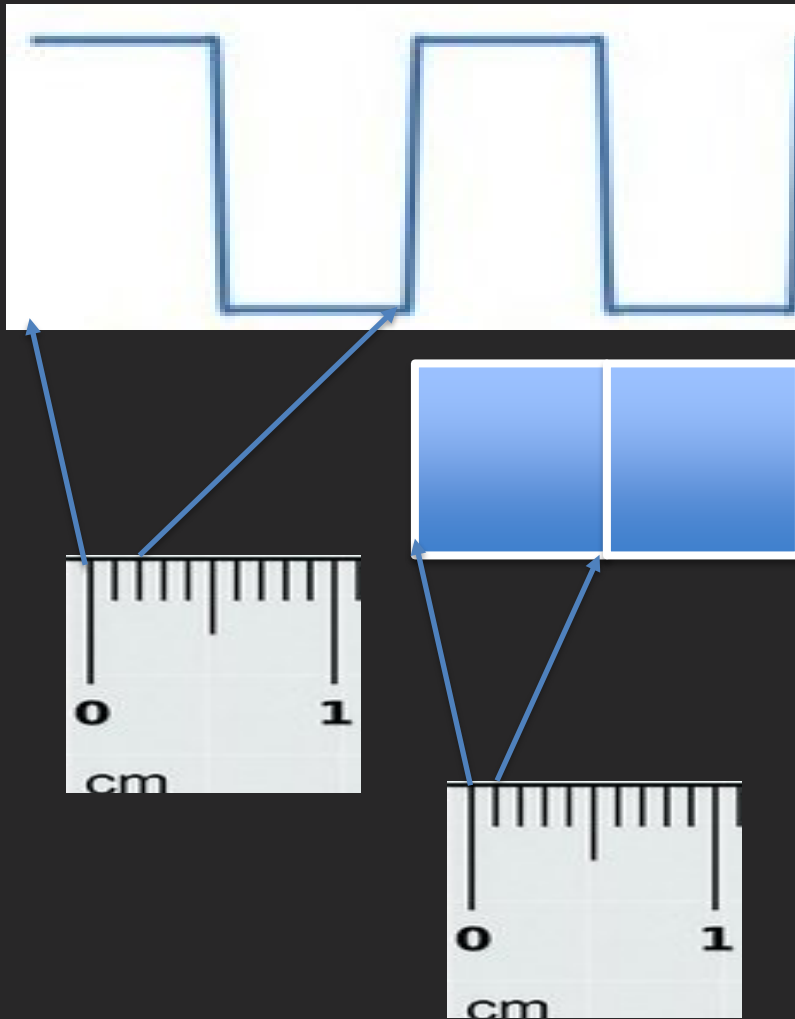
Severe dilation

Pancreatic duct varies in width from ~4 to 2 mm from head to tail

This is currently a “hot topic” in photon counting CT, “Can I see this duct with PC CT?”

What kind of pixel matrix would I need to support 2 mm resolution?

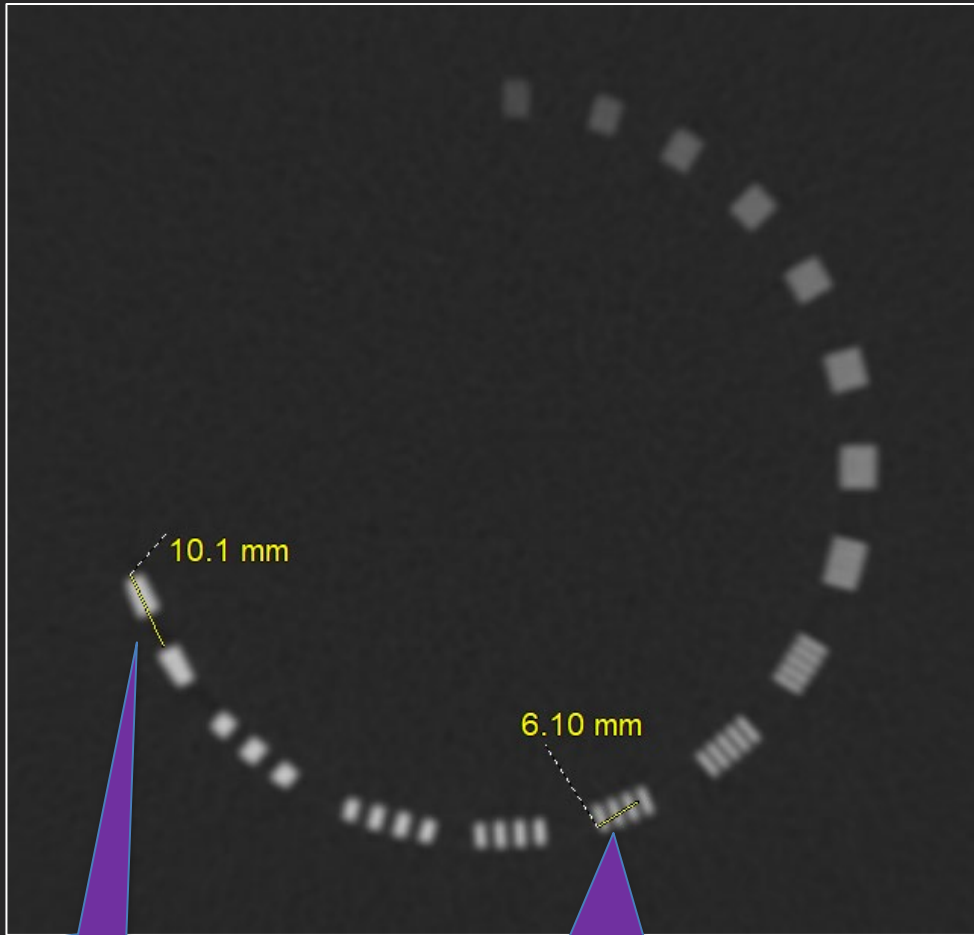
Stolen from <https://litfl.com/abdominal-ct-biliary-system-and-pancreas/>



1. So we have a function who repeats every 2 mm (2 mm periodicity)

2. Therefore we need to sample this at with pixels with a size $\frac{1}{2}$ the period, to 2x the frequency of the input signal. So each pixel needs to be 1 mm. (This is common sense based on picture above, called Nyquist Sampling Theorem)

For the electrical engineering aficionados among you: this example is illustrative but not strictly correct. A square wave contains many higher-frequency harmonics above its fundamental, which would of course be aliased if we sampled at only twice the fundamental frequency.



1 line
pair
per cm

5 line pairs per cm (~6
mm measured,
containing 3 pairs, that is
2 mm period)

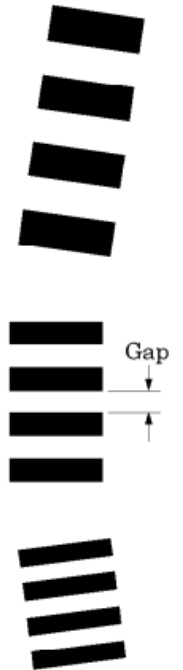
21 Line pair per centimeter high resolution gauge

The 21 line pair/cm gauge has resolution tests for visual evaluation of high resolution ranging from 1 through 21 line pair/cm. The gauge accuracy is ± 0.5 line pair at the 21 line pair test and even better at lower line pair tests.

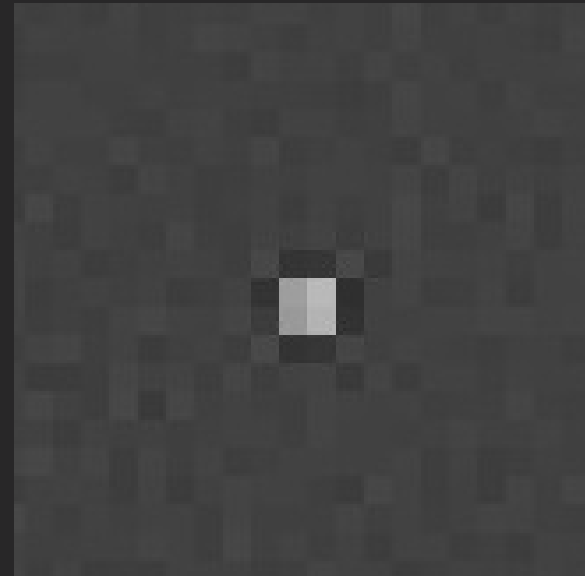
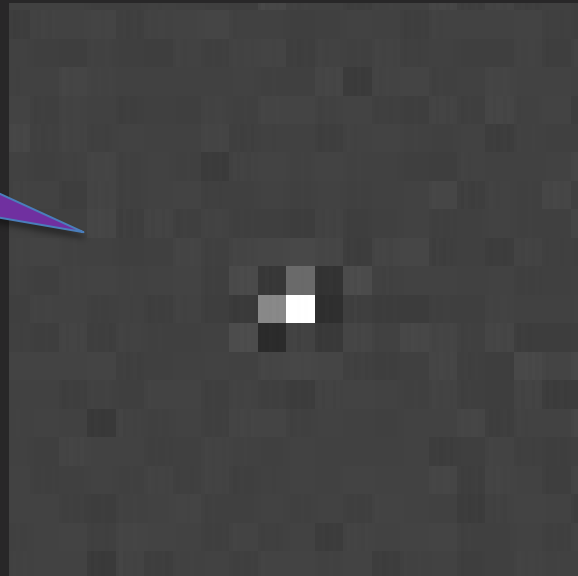
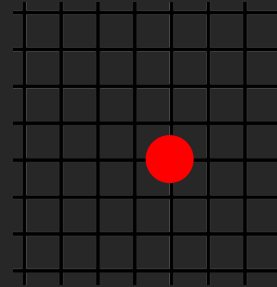
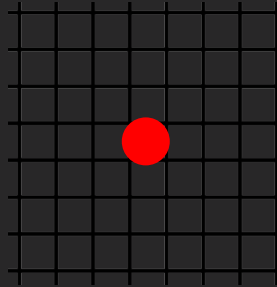
The gauge is cut from 2mm thick aluminum sheets and cast into epoxy. Depending on the choice of slice thickness, the contrast levels will vary due to volume averaging.

Line Pair/cm	Gap Size
1	0.500 cm
2	0.250 cm
3	0.167 cm
4	0.125 cm
5	0.100 cm
6	0.083 cm
7	0.071 cm
8	0.063 cm
9	0.056 cm
10	0.050 cm

Line Pair/cm	Gap Size
11	0.045 cm
12	0.042 cm
13	0.038 cm
14	0.036 cm
15	0.033 cm
16	0.031 cm
17	0.029 cm
18	0.028 cm
19	0.026 cm
20	0.025 cm
21	0.024 cm



When we start to flirt with the Nyquist limit, we get these situations where the specific locations of objects with respect to the pixel matrix matter



Both CT images are of a thin metal wire

- 
- 
- This is all why we do zoomed in reconstructions for temporal bone
 - This is why we do zoomed in reconstructions for spines
 - This is why it doesn't make sense thoracic rads like “chest” kernels on full RFOV lung images...



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CT1 Temporal Bone 2.11

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Clinical Instructions

Indication

Oral Contrast

Pre-Scan Instructions

Select IV Contrast Option 1 or 2 - based on concentration available at your site

Option 1: IV Contrast Parameters 350 mgI/mL

Option 2: IV Contrast Parameters 300 mgI/mL

Field of View

Scan Description

Protocols

[UWHC TOC](#)

[UWHC Ped TOC](#)

[EMC/EMH TOC](#)

[EMC/EMH PED TOC](#)

[Community TOC](#)

[Community PED TOC](#)

[PETCT/Ablation/Biopsy](#)

[3D Lab TOC](#)

Tech Resources

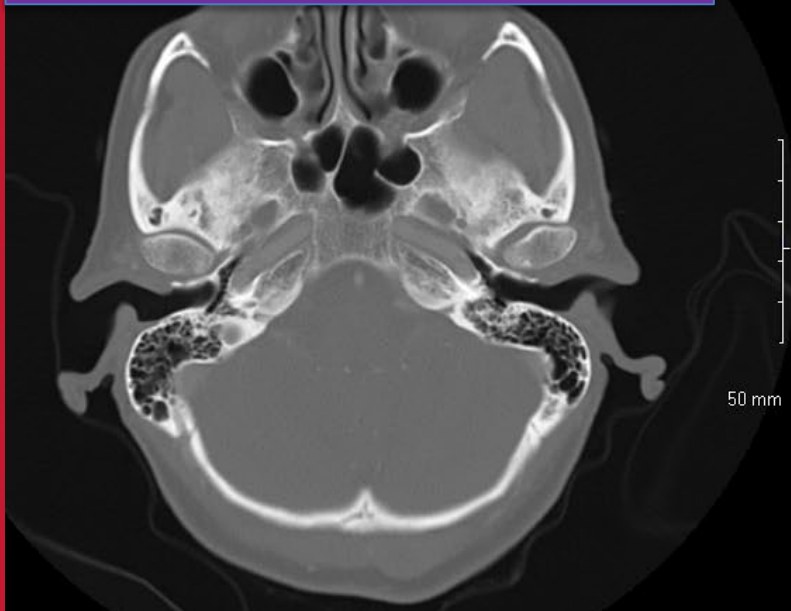
Recon 1 (BONE)

DFOV	22
Recon Type	Bone Plus
WW/WL	2500/350
Recon Option	Plus
Recon Option	
ASIR/ASIR256/DLIR	None
Slice Thickness (mm)	2.5
Interval (mm)	1.5

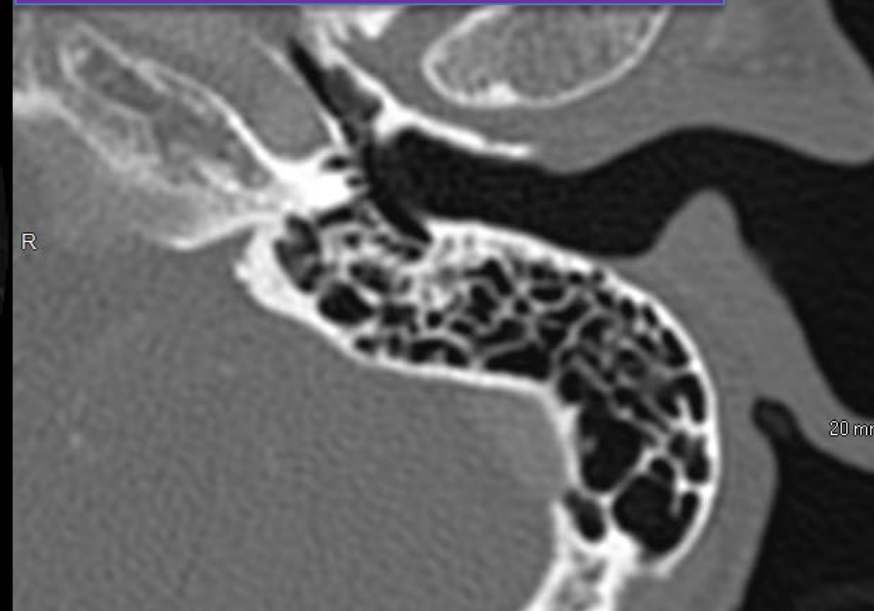
Recon 2 (THIN BONE RT)

DFOV	9.6
Recon Type	Bone Plus
WW/WL	2500/350
Recon Option	Plus
Recon Option	IQ Enhance
ASIR/ASIR256/DLIR	None
Slice Thickness (mm)	0.625
Interval (mm)	0.312

Full RFOV high resolution head



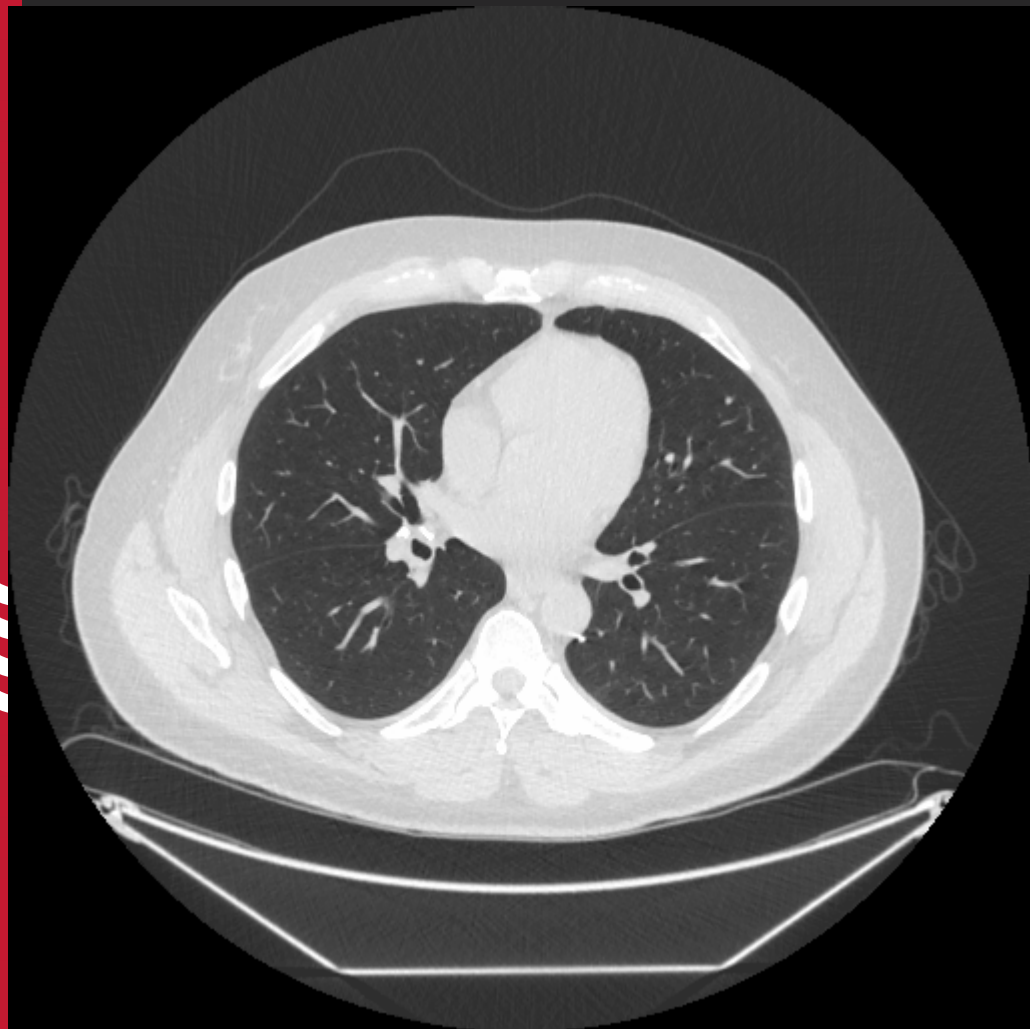
Zoomed in reconstruction (9.6 cm) high resolution head



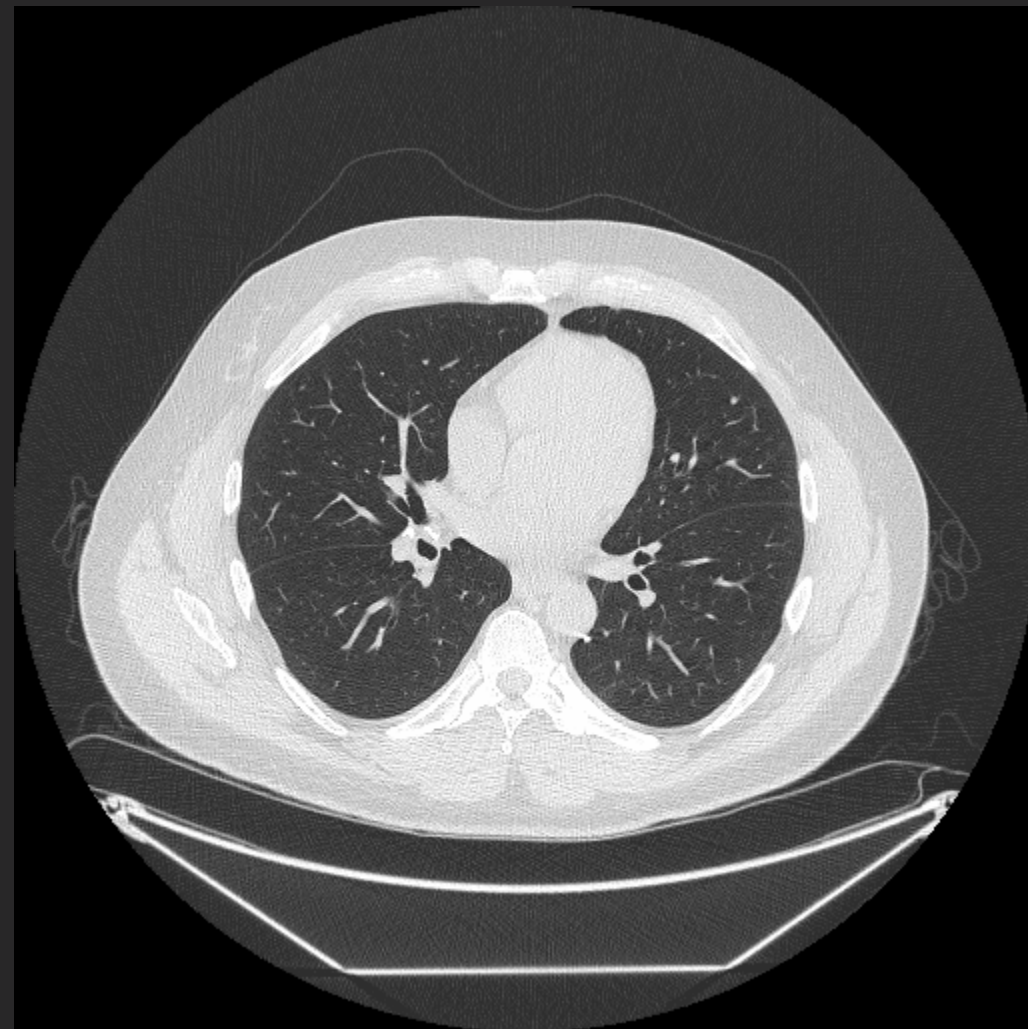
Full RFOV high resolution head zoomed in to match a zoomed in reconstruction



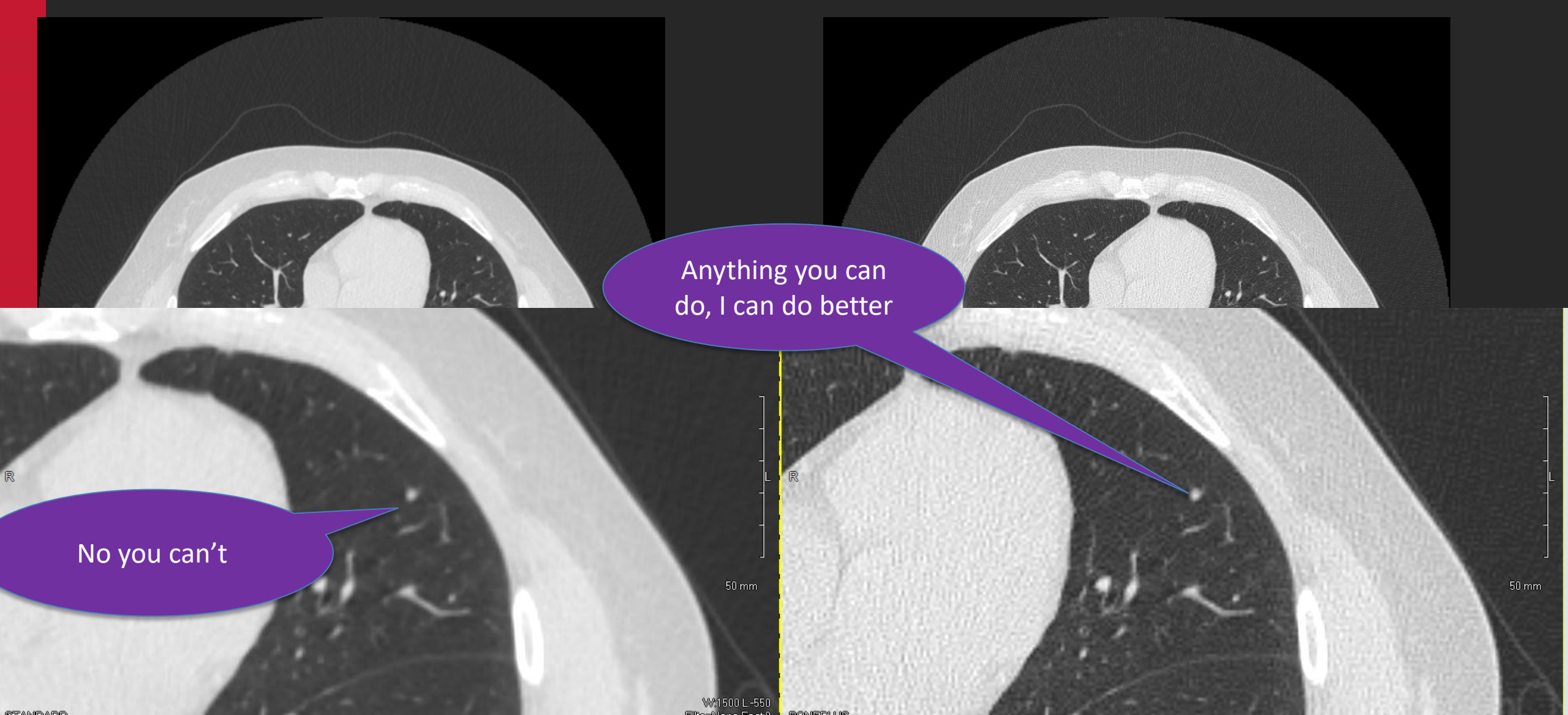
Zooming in on a full RFOV images clearly is blurrier than performing a zoomed in reconstruction



500 mm RFOV
512 pixels soft
tissue kernel



500 mm RFOV 512
pixels high resolution
kernel

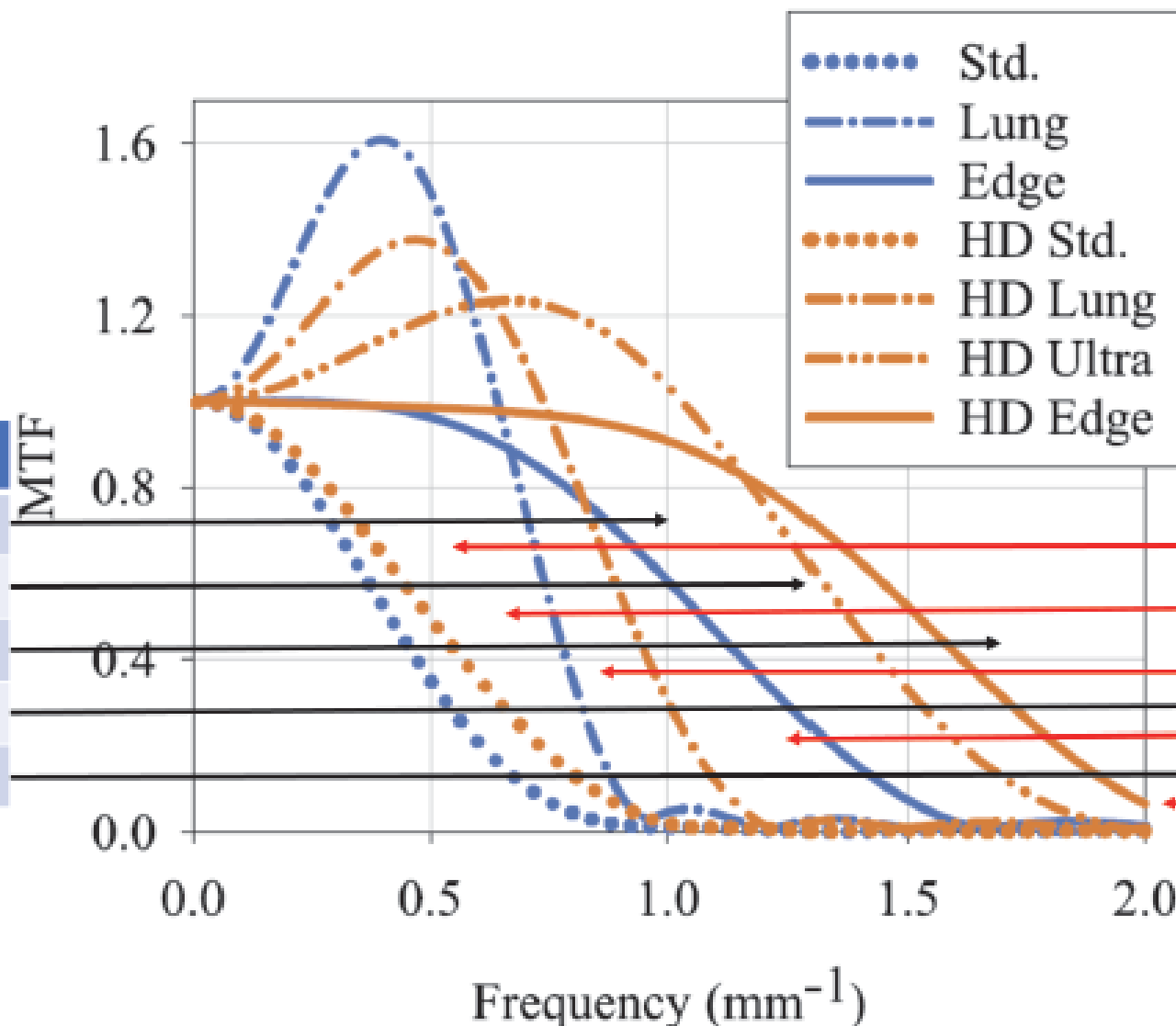


The only benefit we get from high resolution kernel at this RFOV is noise and aliasing

Voxel limiting RFOV
pixels/(2*RFOV)

1024 pixel Image

500 mm	1.02 lp/mm
400 mm	1.28 lp/mm
300 mm	1.71 lp/mm
200 mm	2.56 lp/mm
100 mm	5.12 lp/mm



Voxel limiting RFOV
pixels/(2*RFOV)

512 pixel Image

500 mm	0.51 lp/mm
400 mm	0.64 lp/mm
300 mm	0.85 lp/mm
200 mm	1.28 lp/mm
100 mm	2.56 lp/mm



Thanks!

Feel free to contact me at
tszczykutowicz@uwhealth.org

