Imaging Artifacts - CT, MRI, and Mammography

Physicists toolkit for CT artifact identification

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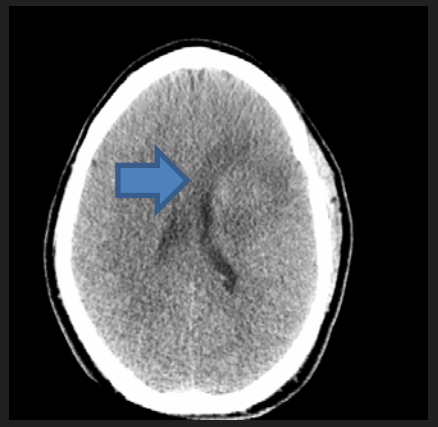
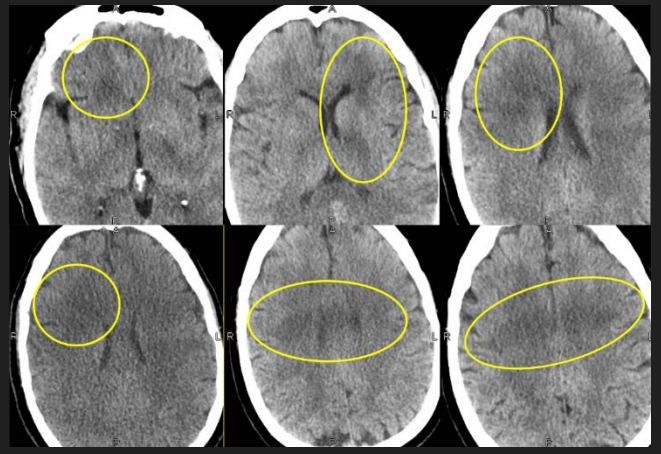
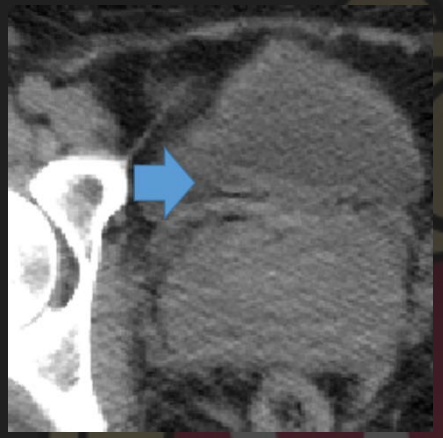
Disclosures/COI

- TPS Equipment Grant and Consultant GE HealthCare; supplies CT protocols to GE HealthCare under a licensing agreement; the founder of protocolshare.org, MAB of iMALOGIX LLC, co-owner LiteRay Medical LLC

Pathology or artifact…?







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Talk Goals

- As a CT physicist, I find myself applying a similar image review method when I get a complaint of artifacts in CT
  - I want to teach you how to perform an image review to diagnosis a scanner artifact issue
  - We will also learn how to differentiate the various types of CT artifacts and classify them into two major groups
  - We will also review the operation of our CT scanners to understand how the failure of the various components leads to image artifacts

Outline

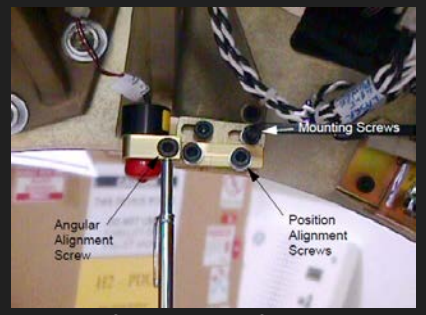
- Overview of CT Scanner Parts (what can break ☺)
- Iso-centric Artifacts
- Iso-centric Artifacts: how to find isocenter
- Non Iso-centric Artifacts
- General tips for troubleshooting Artifacts
- QA for Artifact Detection

Overview of CT Scanner Parts (what can break ☺)

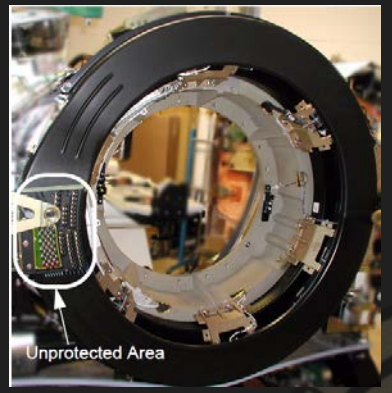
- Let's imagine everything that happens from the x-ray generator to the image being displayed
- Along the way we will consider what happens if something goes wrong…will it cause an artifact?

Overview of CT Scanner Parts (what can break ☺)

lasers



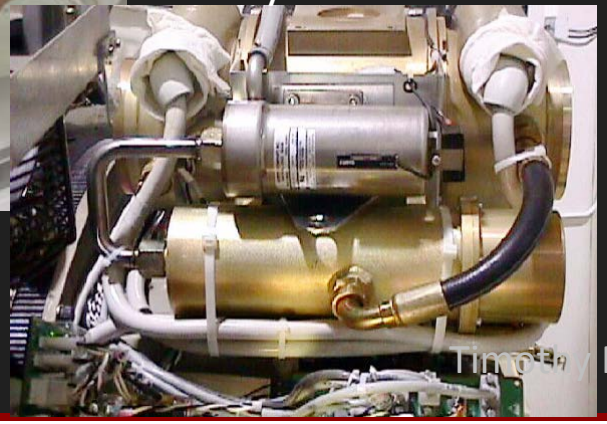
Slip ring



Slip ring brushes

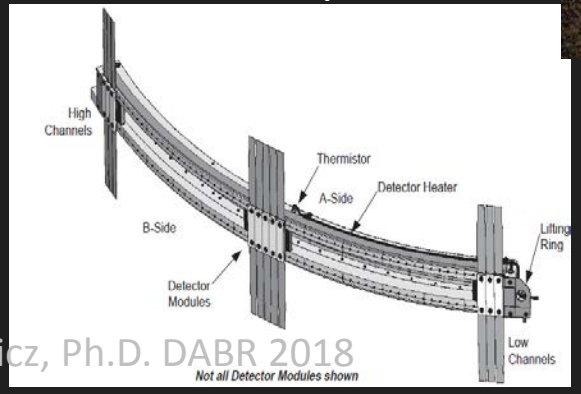
Mylar window

HV system and tube



Detector module

Detector array



Bowtie filter

Data acquisition system

Process	Failure Mode
X-ray generator builds up needed potential	Signal is not uniform/constant over time, not at the requested potential
High voltage transferred to tube housing from generator	HV line insulation failure
Voltage potential applied inside tube	HV/tube connection issue
Electrons boiled off cathode	Cathode can break for one or more sizes
Electrons accelerated towards anode	Electrons strike inside tube housing somewhere other than anode
Electrons strike anode	Electrons melt anode/create pit, electrons hit target in wrong place
X-rays crated inside anode	If created from pitted anode, many x-rays get trapped inside anode, tube not mechanically stable during gantry rotation

Process	Failure Mode
X-rays travel through tube assembly	Dirt on assembly, oil bubble in tube cooling oil
X-rays leave tube and go through filter packs (bowtie) and collimators (beam limiters)	Filters fail to move properly, dirt on filters, filters are not mechanically stable during rotation, collimators are not in correct location
X-rays go through Mylar window and hit air around patient	Contrast agent on window, chaser on window, patient fluids on window, window is displaced during exam (something pushes window out of place)
X-rays go through patient	A plethora of patient induced artifacts can occur…too many to list
X-rays go through patient support structures (table, head holder, etc.)	Support structure creates excessive beam hardening or beam attenuation

Process	Failure Mode
X-rays goes through Mylar window again	Contrast agent on window, chaser on window, patient fluids on window, window is displaced during exam (something pushes window out of place)
X-rays go through anti-scatter grid	Grid is dirty, grid is not mechanically stable during gantry rotation
X-rays hit detector	Detector surface dirty, detector assembly is not at the correct temperature, detector assembly is not mechanically stable
Analog signal created in detector	Signal corrupted by interferences from HV lines or other electro magnetic source within room or gantry
Analog signal travels to and is converted to a digital signal in DAS	DAS malfunctions, DAS not in good connection with the rest of the detector module

Process	Failure Mode
Digital detector signal is compressed from all channels and read off gantry through slip ring	Slip ring connections are dirty, compression step malfunctions
Detector data is sent to recon computer and reconstructed	Data loss during transfer, recon computer failure
Reconstructed data is sent to scanner image screen for review	Workstation computer issue, workstation monitor failure
Reconstructed data is sent to PACS for radiologist review	PACS display issue, PACS display monitor failure

Process	Failure Mode
Patient positioned inside scanner via couch	Couch not indexing correctly (axial scanning)
Patient translated inside scanner via couch	Couch belts loose, couch rollers dirty causing couch jumping
Patient ECG signal recorded	Signal noisy, signal drop out, signals contaminated with other electro magnetic signals

Overview of CT Scanner Parts (what can break ☺)

- List of failure codes for the x-ray tube from 1 CT vendor

FAILURE CODE	FAILURE CODE
AI: Image Artifact	OH: Other-Housing Related
BG: Broken Glass	OL: Generator Overload
CA: Casing Arcing	OR: Other-Rotor Related
CB: Casing Bubbles/Particles Seen	PF: Overheat/Pump Failure
CL: Casing Oil Leak	PT: Pulled Tube (No Failure)
GS: Grid Short	RF: Frozen Rotor
OC: Other-Cathode Related	RN: Noisy Rotor
OE: Tube Loss Due to Failure Elsewhere	SD: Shipping Damage/Error
OF: Open Filament	SS: Stator Open/Stator Short
OG: Arcing	XL: Low X-Ray Output

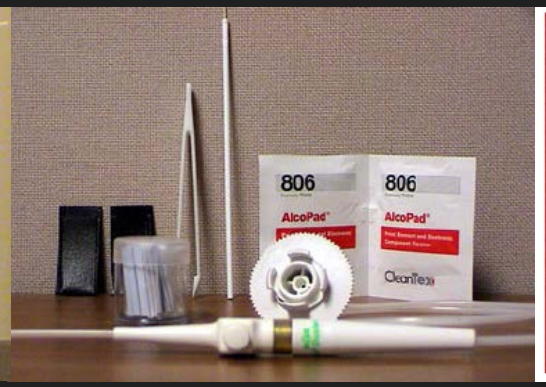
Table 9-44 Tube Failure Codes

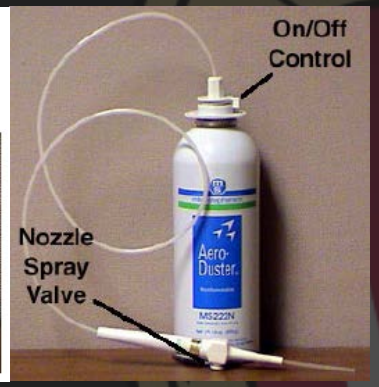
Overview of CT Scanner Parts (what can break ☺)

- Murphy's Law
  - Anything that can go wrong, will go wrong
- Basically any component on your scanner can and may fail leading to an image artifact
- Major culprits
  - Detectors (odds are, one is going to fail)
    - Typical scanner has ~60,000 of them!
  - Tube
    - filament
    - Anode
  - Couch movement
  - Geometric calibration (isocenter location)
  - "gunk" debris present in x-ray beam path either at the tube side or at the detector side
    - This is 1 reason the field engineers come and vacuum out the scanners and wipe down important components on a routine basis

Overview of CT Scanner Parts (what can break ☺)

- Cleaning the scanner is one of the most important things the FE does for both preventative maintenance and fixing issues (all these images are from a CT scanner service manual…)





Outline

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Iso-centric Artifacts

- We can think of CT artifacts as belonging to two major groups
  - Iso-centric
    - Any artifact that presents in a manner which demonstrates the circular data collection of CT
  - Non iso-centric
    - Any artifact that presents in a manner which does not represent the circular data collection nature of CT

Iso-centric Artifacts

2 camps for CT artifacts

Artifacts that look like:

Rings

Arcs

Bands

Lines/bands emanating from source to detector array

Iso-centeric

Artifacts that do not seem related to the circular system geometry of the CT scanner:

Beam hardening

Partial volume

Aliasing

Cone beam

Display/PACs issues

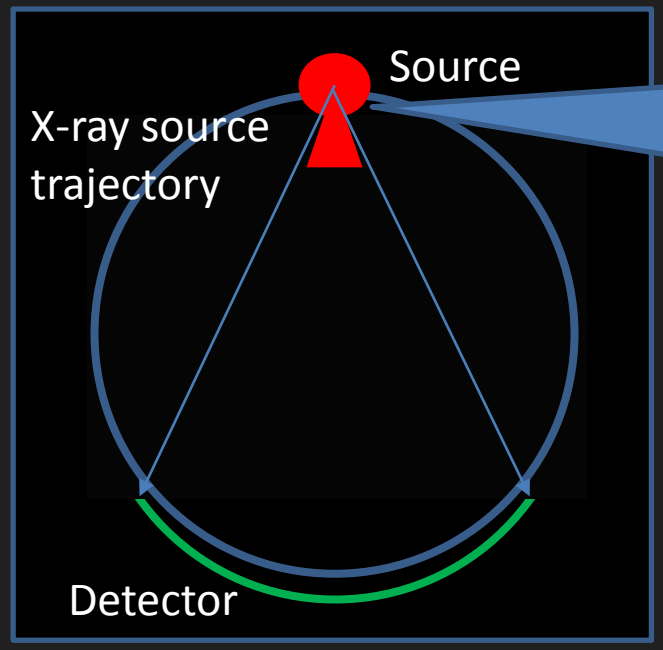
Recon computer trouble

Geometric calibration

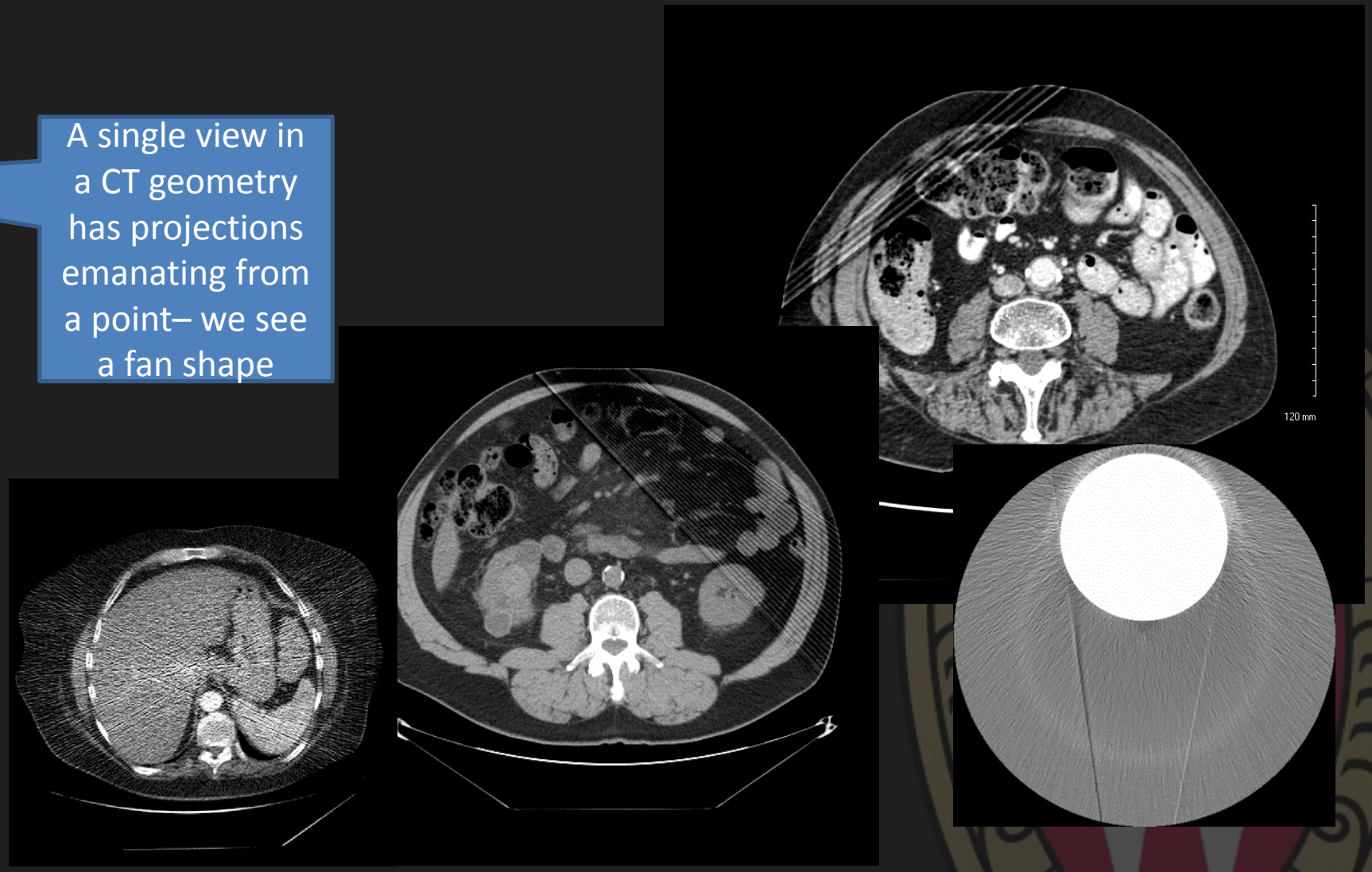
truncation

Non Iso-centeric

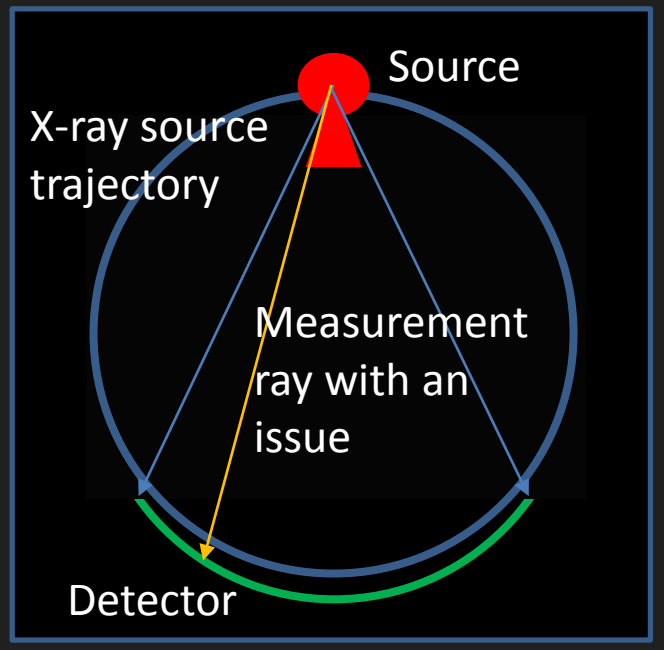
Iso-centric Artifacts

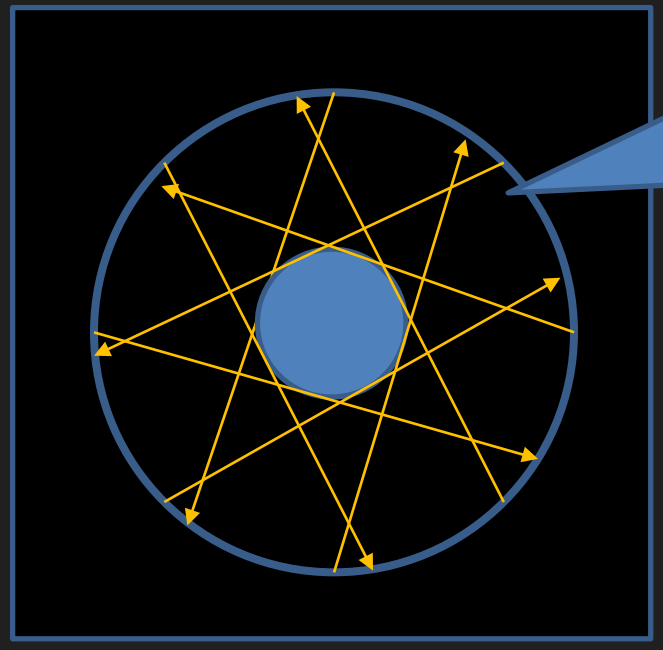


A single view in a CT geometry has projections emanating from a point– we see a fan shape

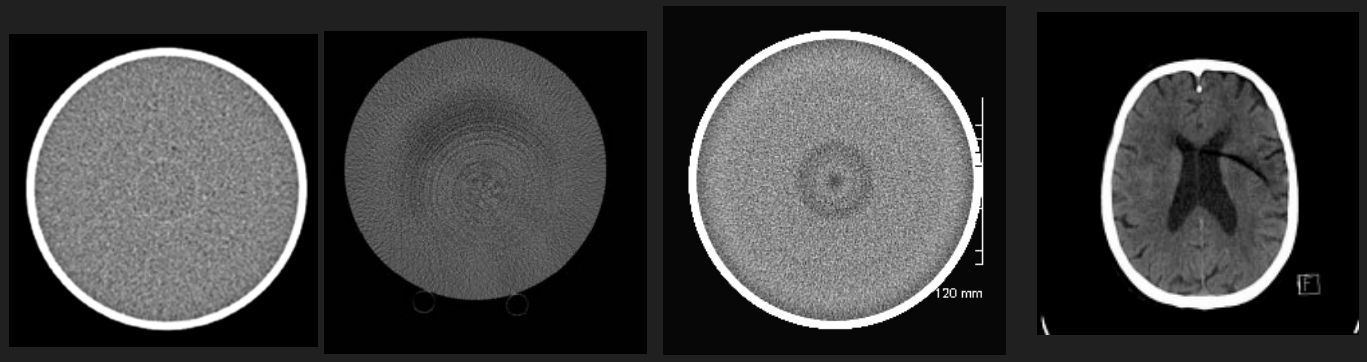


Iso-centric Artifacts





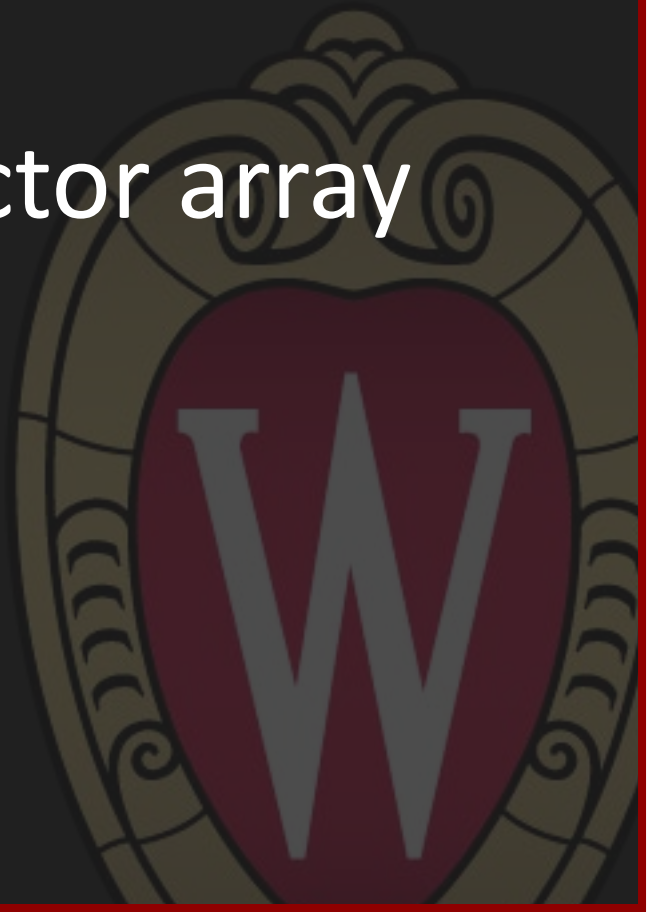
If there is an issue at the same fan angle for multiple view angles, we get an arc or ring or a circle all centered at the scanner's iso-center



Yes, for any given view the artifact is a line, but when we sum up all the views we get a re-enforcement of the artifact only along a circle of a diameter equal to the place where the artifact ray is tangential to a circle centered at iso-center for all views

Iso-centric Artifacts

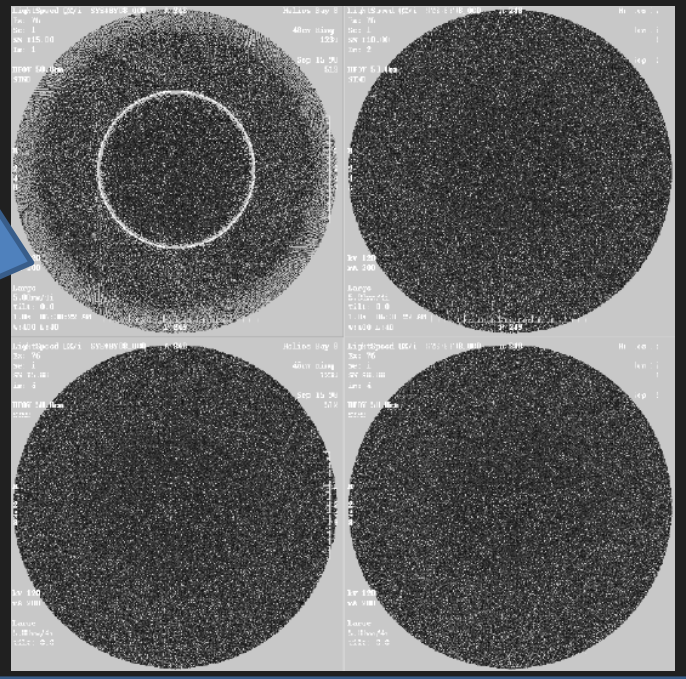
- Rings centered on iso-center
- Arcs centered on iso-center
- Lines emanating from source to detector array spreading from source to detector



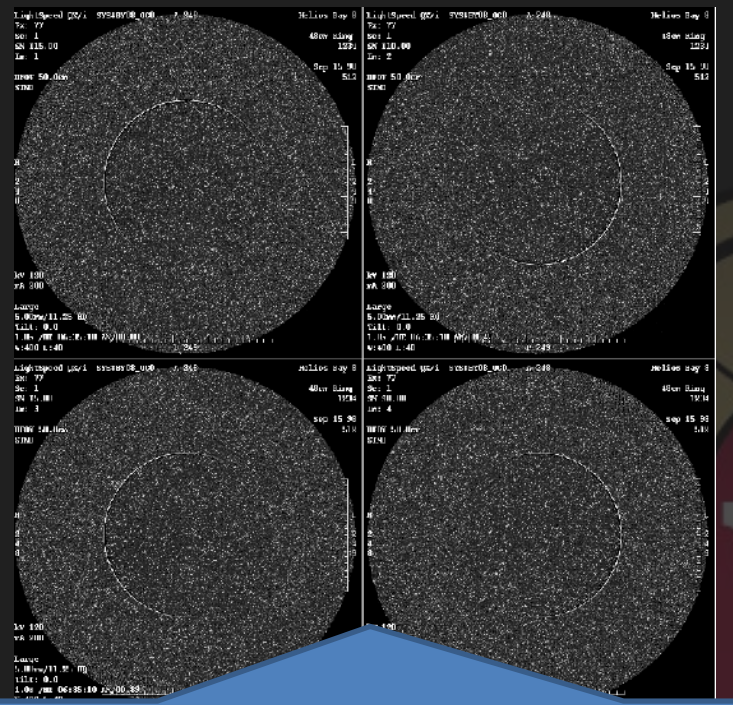
Iso-centric Artifacts: Axial versus helical

These images are from the same scanner all with the detector issue. On the left are axial images, on the right are helical images.

Axial



Helical

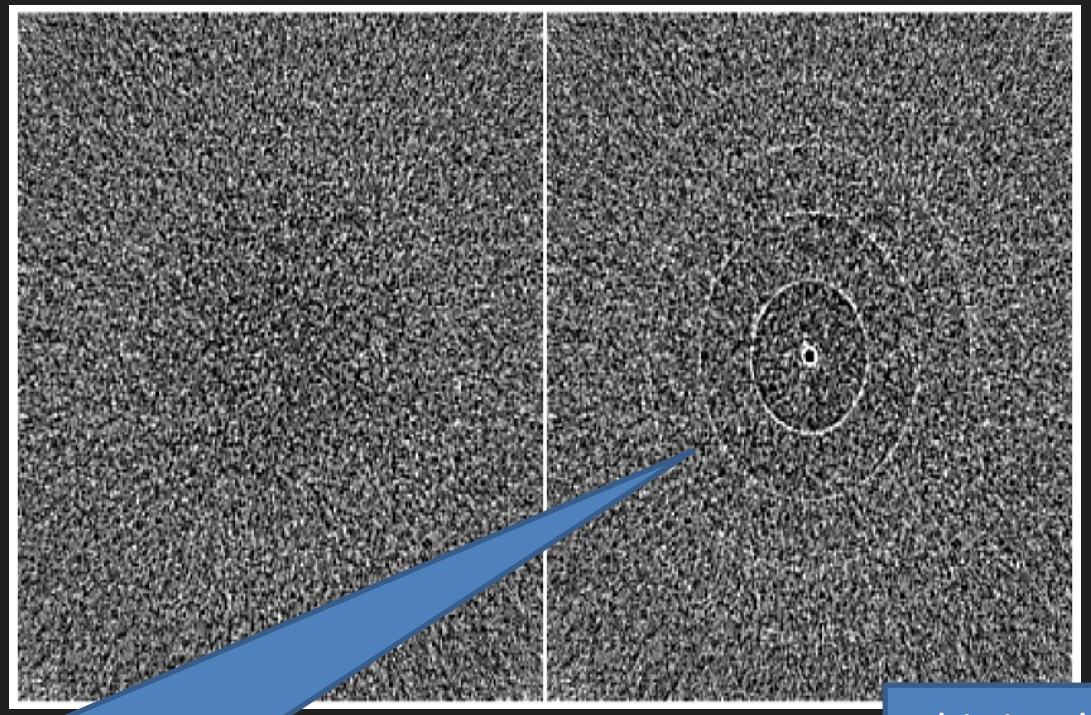


Each one of these images represents data from one part of the detector, → only one part of the detector is messed up (detector used to make the top left image)

In helical image reconstruction, data from multiple rows of the detector is used to reconstruct a single slice…so we see the bad detector artifact getting spread out over multiple z positions and appearing in arcs. The arcs correspond to the parts of the image when the bad detector row was closest to that slice.

Iso-centric Artifacts: Artifact strength

Image on the right has a offset error of 1%. Offset issues are usually a problem at low dose. Gain issues are a problem at high dose.

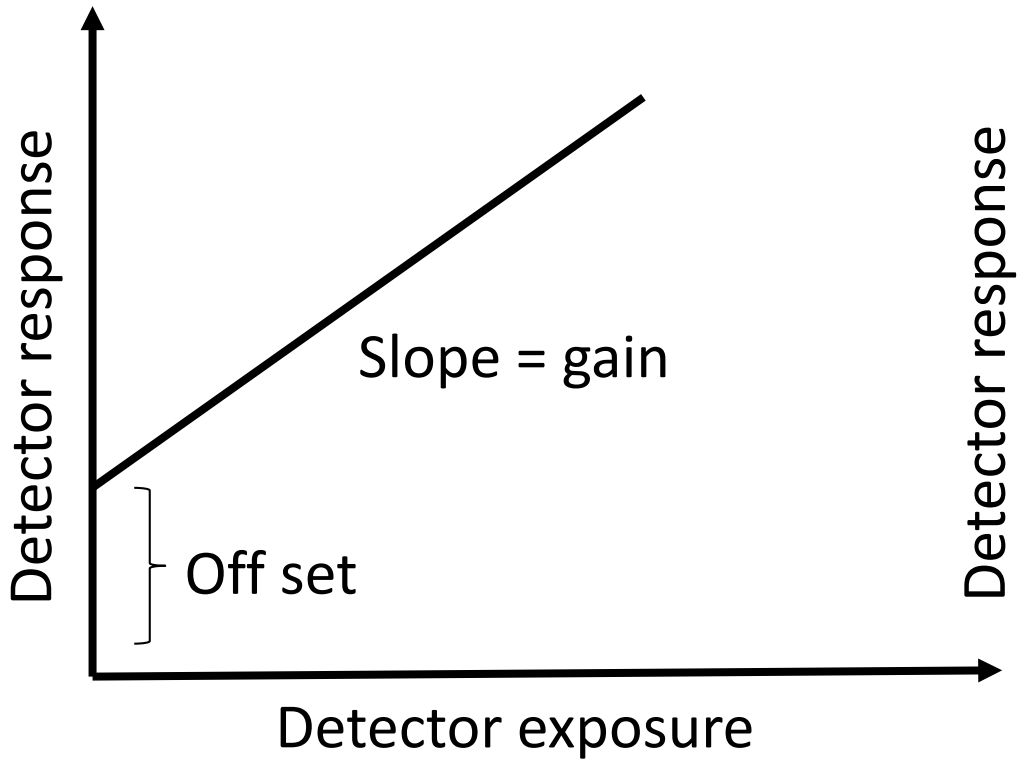


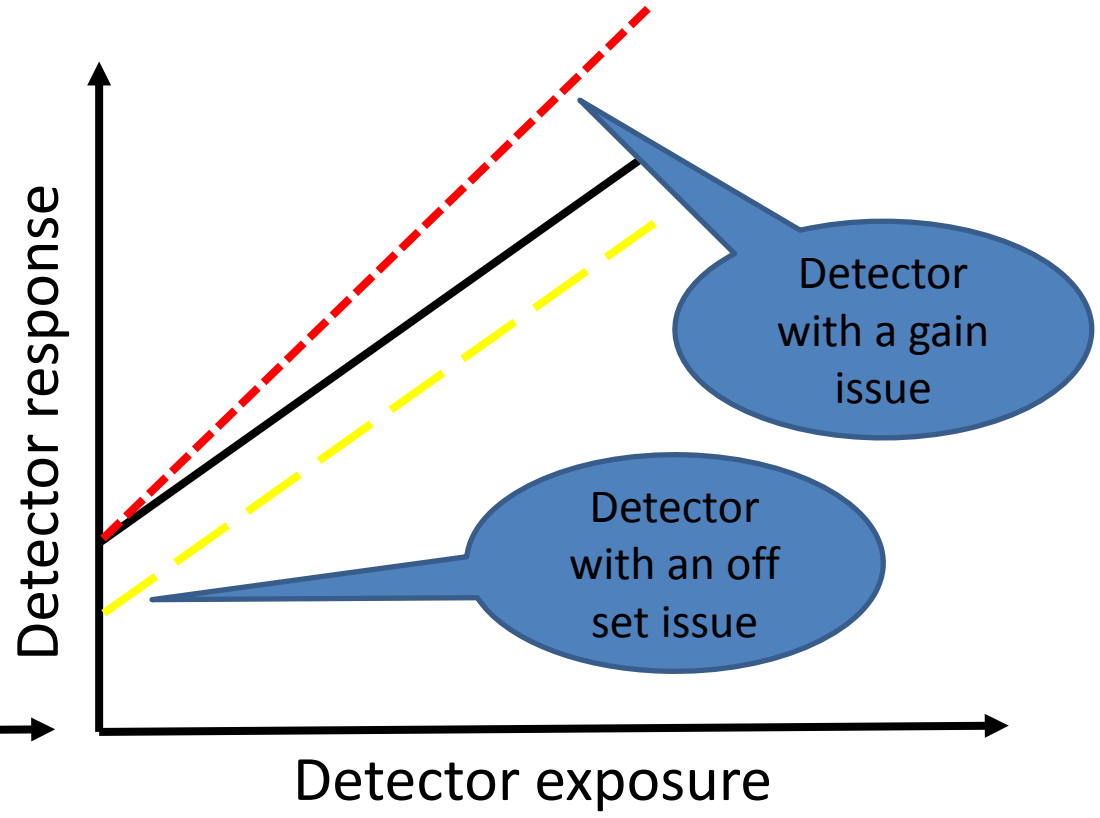
Hsieh, Jiang. "Computed tomography: principles, design, artifacts, and recent advances." Bellingham, WA: SPIE, 2009.

Artifact "strength" increases as we move closer to iso-center→ we can think of the artifact as having a finite amount of total signal, when we distribute that signal over a big circumference it doesn't appear so bad.

This is why the CT vendors put their best detectors closest to iso-center! Any small issues with the detectors closest to iso-center will have a much bigger chance of messing up the image relative to detectors at the edges of the FOV

Iso-centric Artifacts: Detector Problems

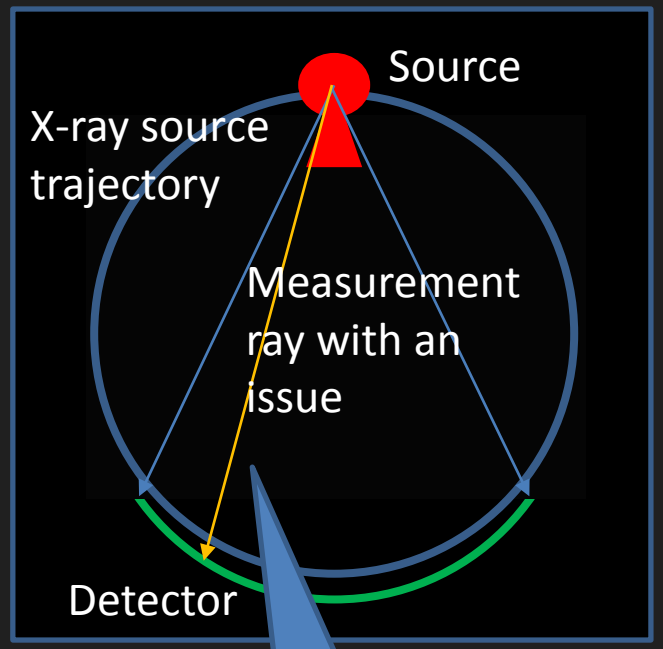




Gain issues may make artifacts in low noise head scans, offset issues may make artifacts in high noise body scans

Detectors will have problems with their gain, offsets, and linearity. Things like temperature changes, age, radiation damage will effect these detector characteristics.

Iso-centric Artifacts: “gunk” or debris on tube or detector side of system



Dirt anywhere along this ray can cause this

Artifacts Caused by Collimator Grease

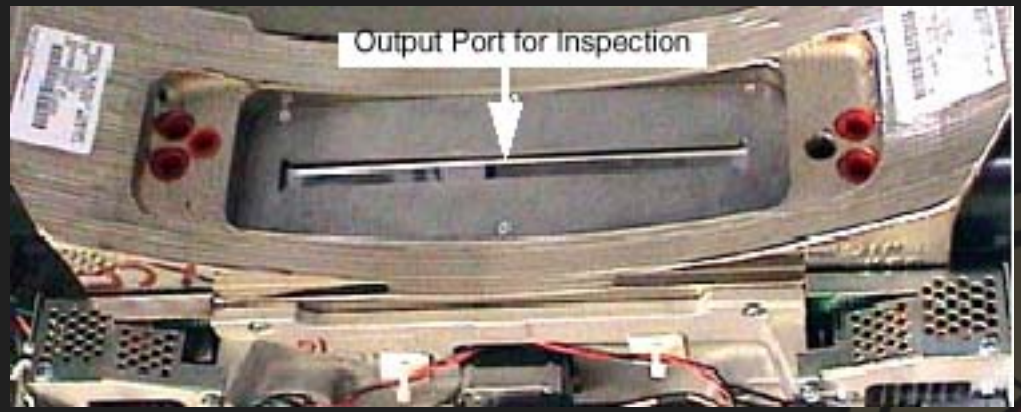
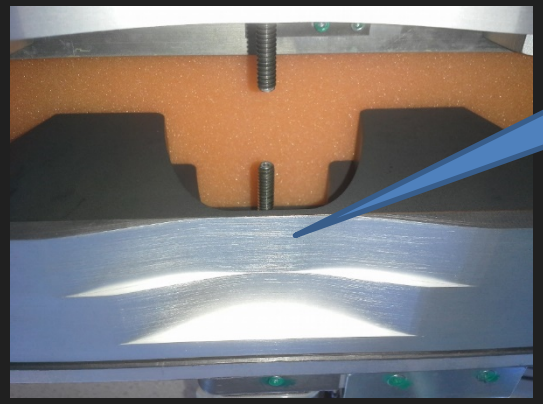


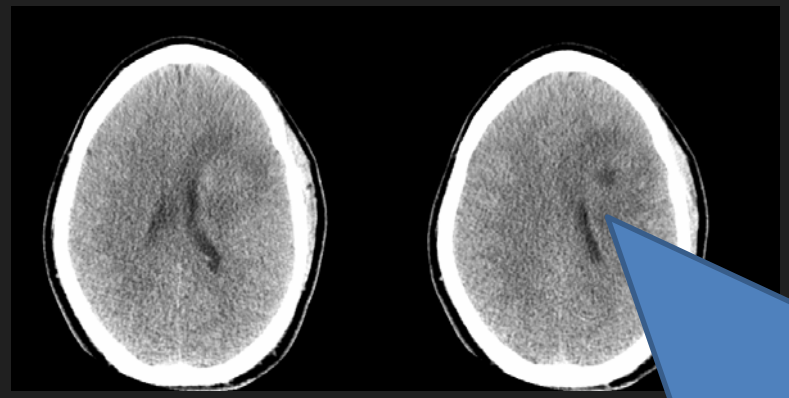
Image Artifacts have been generated and reported on some CT systems due to the contamination of the bowtie and the primary copper filter. This contamination is from the lubricating grease used on the filter positioning drive screw assembly.
GE service manual for Optima CT660 scanner

Iso-centric Artifacts: “gunk” or debris on tube or detector side of system

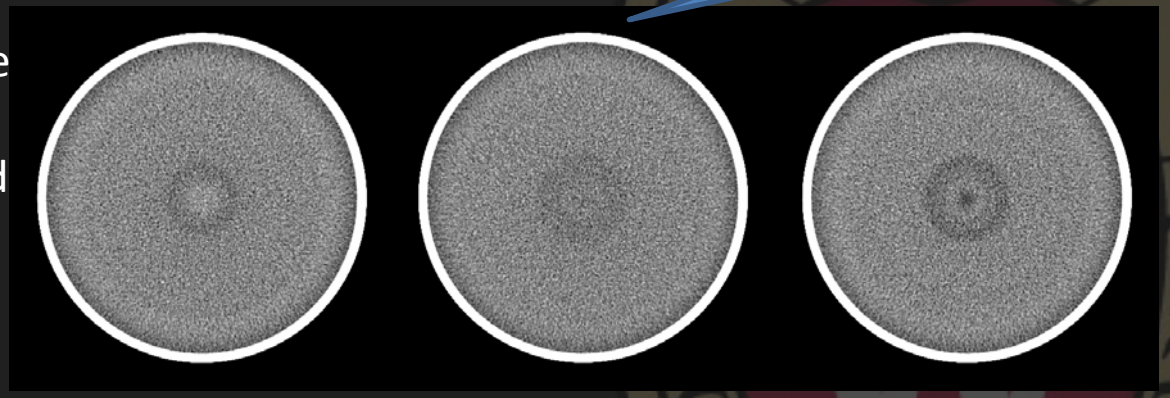


Grease was on here

The artifact looks different on different image slices



A single spec of grease from the collimator drive assembly caused this artifact. The grease fell onto the bowtie filter.

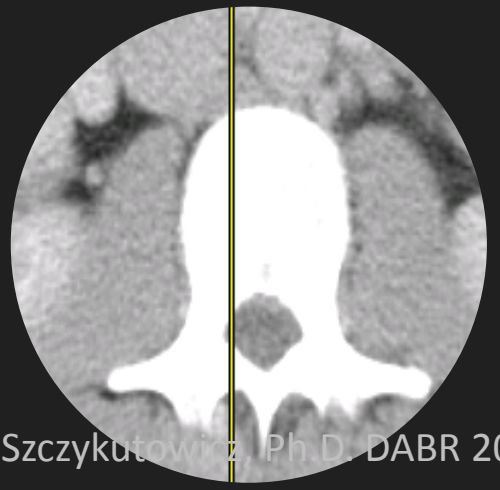


Notice, on the clinic images the artifact did not appear at the center…difficult for the docs to know the patient wasn’t positioned at iso-center even though the artifact was

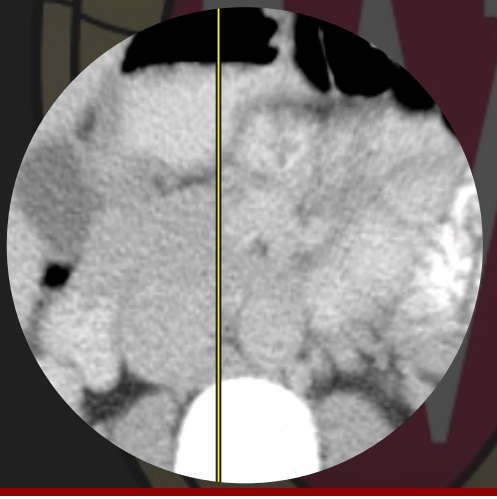
Iso-centric Artifacts: iso-center not always at image center

- Some exams and patient positions necessitate a shifting of the image reconstruction center. This is common practice for techs. It does, however, make the “center of the image on PACS” not line up with the scanner iso-center.

Recon not at isocenter (but it is where the neuro radiologists wants it to read the spine)

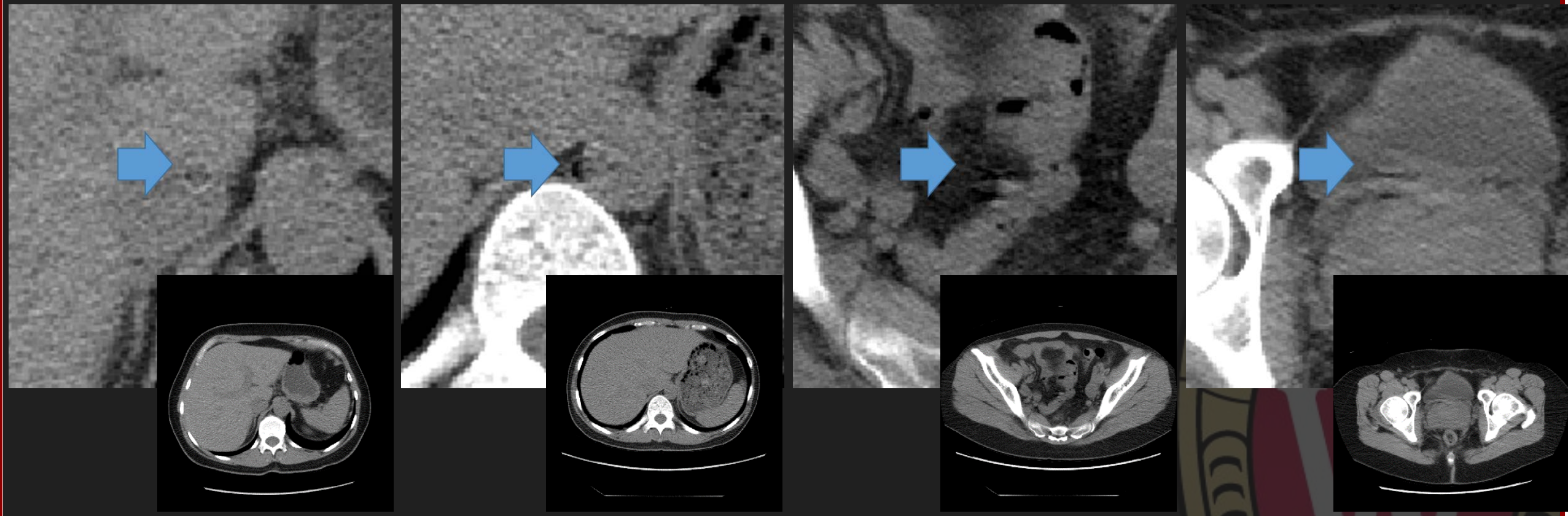


Recon at isocenter



Iso-centric Artifacts: Partial Ring

When a ring is not a ring



The ring is partial in this case due to adaptive filtering of the CT scanner combined with the low signal through the long lateral direction of the patient. Notice how it looks like a full ring when the patient is circular and like 2 horizontal lines (partial ring) when the patient is elliptical.

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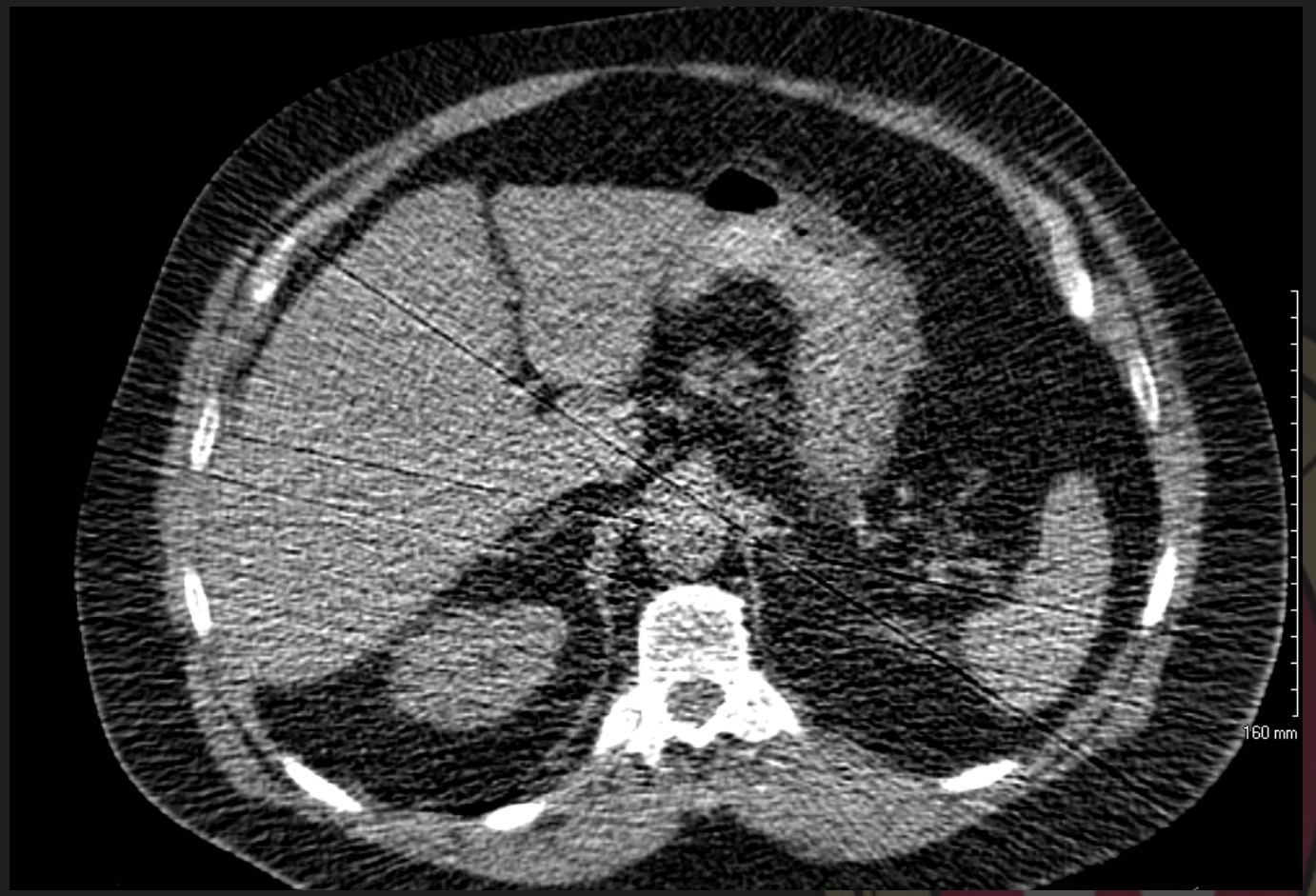
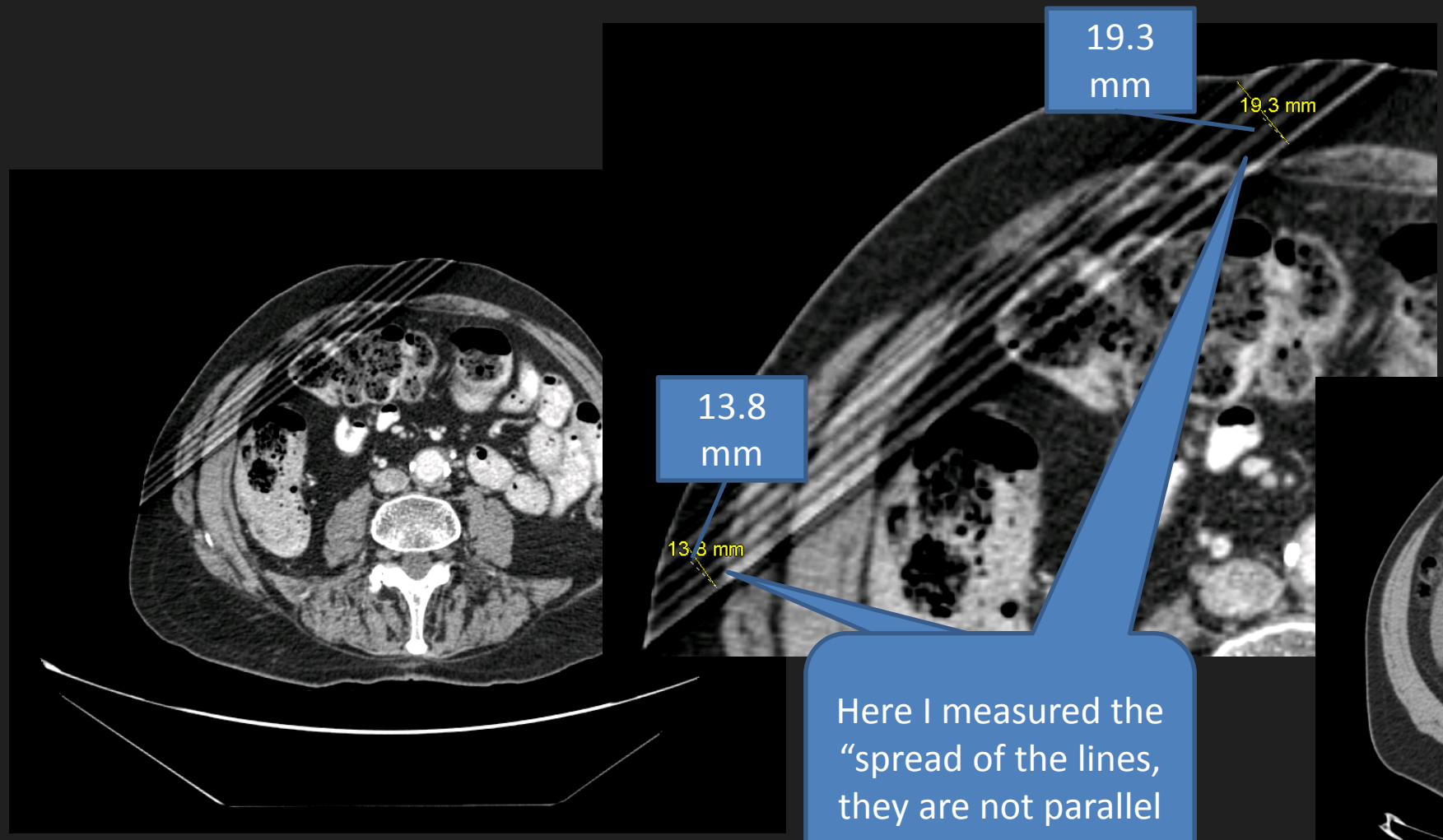
Iso-centric Artifacts: Streak/Line artifact

Artifact our technologists were seeing on bolus tracking phase (contrast dynamics monitoring series of a CT scan).

These are usually done using a very low technique and the vendors may not be applying their full suite of data prep here. The result for us was artifacts.



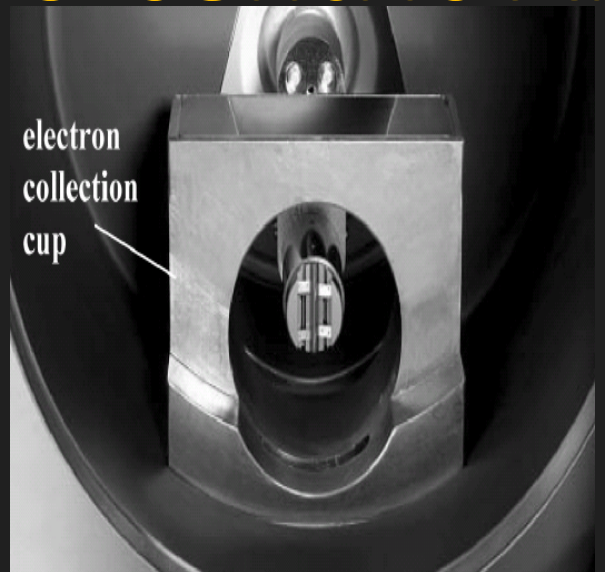
Iso-centric Artifacts: Streaks – bad detector module



Here I measured the "spread of the lines, they are not parallel

Same scanner as shown on the left, but 2 days later…the issue is getting worse.

Iso-centric Artifacts: Tube arcing (spitting)



The tube can detect when it arcs and adjust the voltage tube current to stop the arc. It will also not use the projection data from the arc event. Therefore, if you read CT you probably have read through a tube arcing scan and never knew it!

However, if the tube arcs enough, you will eventually see artifacts as the scanner cannot compensate for everything.

Hsieh, Jiang. "Computed tomography: principles, design, artifacts, and recent advances." Bellingham, WA: SPIE, 2009.

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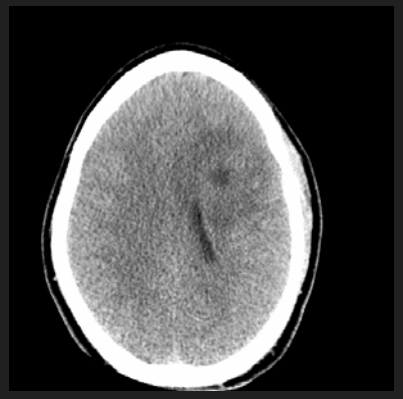
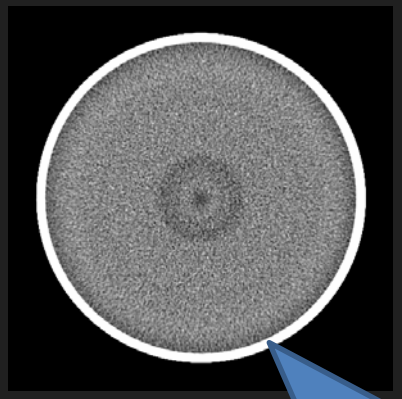
Iso-centric Artifacts: how to find isocenter

Now we will go over a few ways to know if the feature you see is likely an artifact at isocenter or pathology off center…

This artifact is at isocenter



ISOCENTER IS NOT ALWAYS THE CENTER F THE IMAGE!



We don't always have a nice phantom image to make it obvious

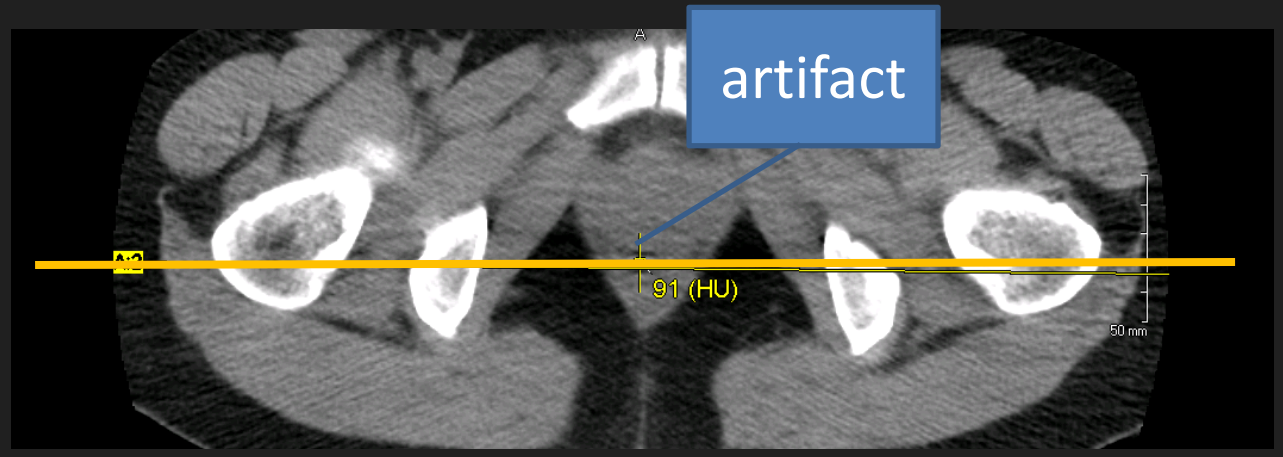
Iso-centric Artifacts: how to find isocenter

How do I know if the artifact is at isocenter?

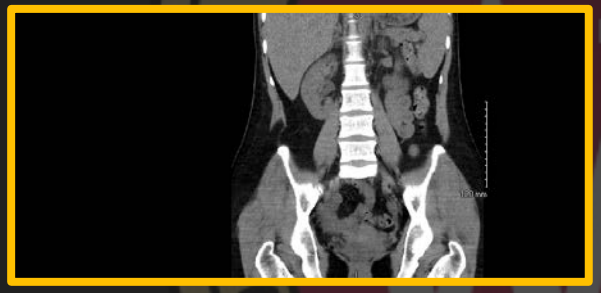
1. Pull up a lateral CT localizer radiograph
2. Pull up a coronal reformat
3. Scroll through coronal reformat until you are at the plane where the artifact lies
4. Does this line up with isocenter?

Step 1, locate iso-center on lateral CT localizer radiograph

For our PACS, iso-center is simply the center of the image



Step 2, Navigate to the artifact on a coronal reformat



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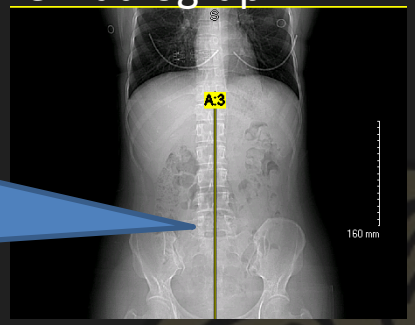
Iso-centric Artifacts: how to find isocenter

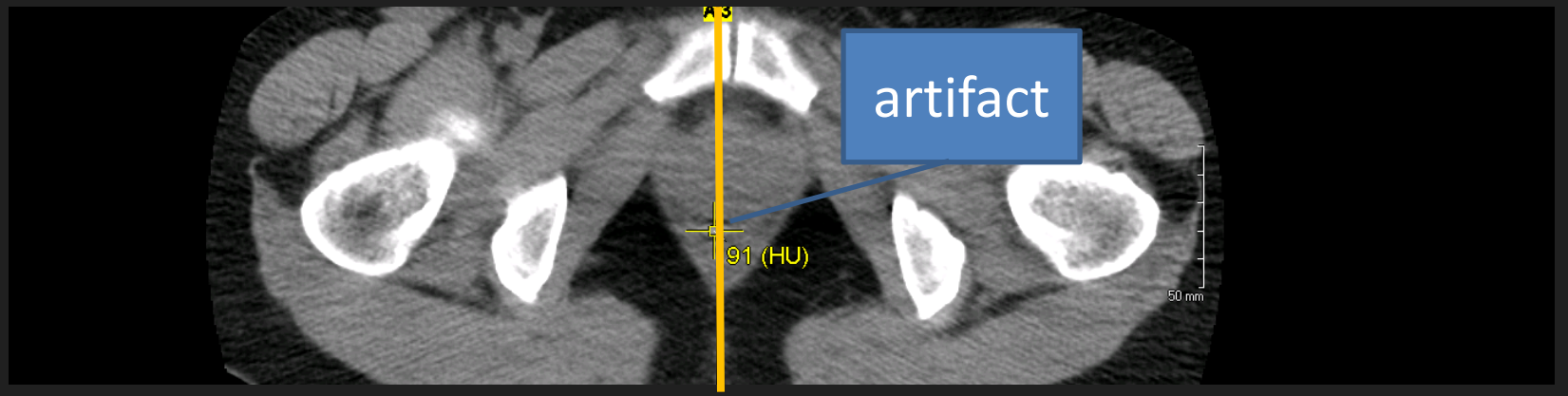
How do I know if the artifact is at isocenter?

1. Pull up an AP CT localizer radiograph
2. Pull up a sagittal reformat
3. Scroll through sagittal reformat until you are at the plane where the artifact lies
4. Does this line up with isocenter?

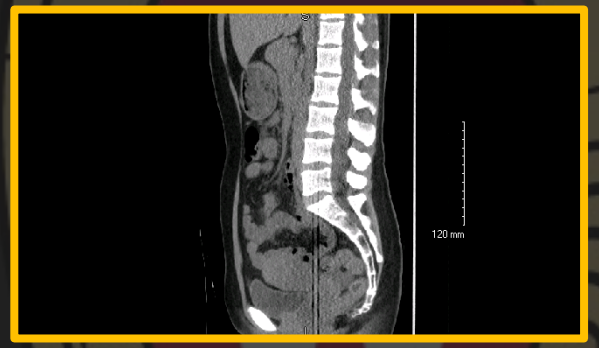
Step 1, locate iso-center on AP CT localizer radiograph

For our PACS, iso-center is simply the center of the image





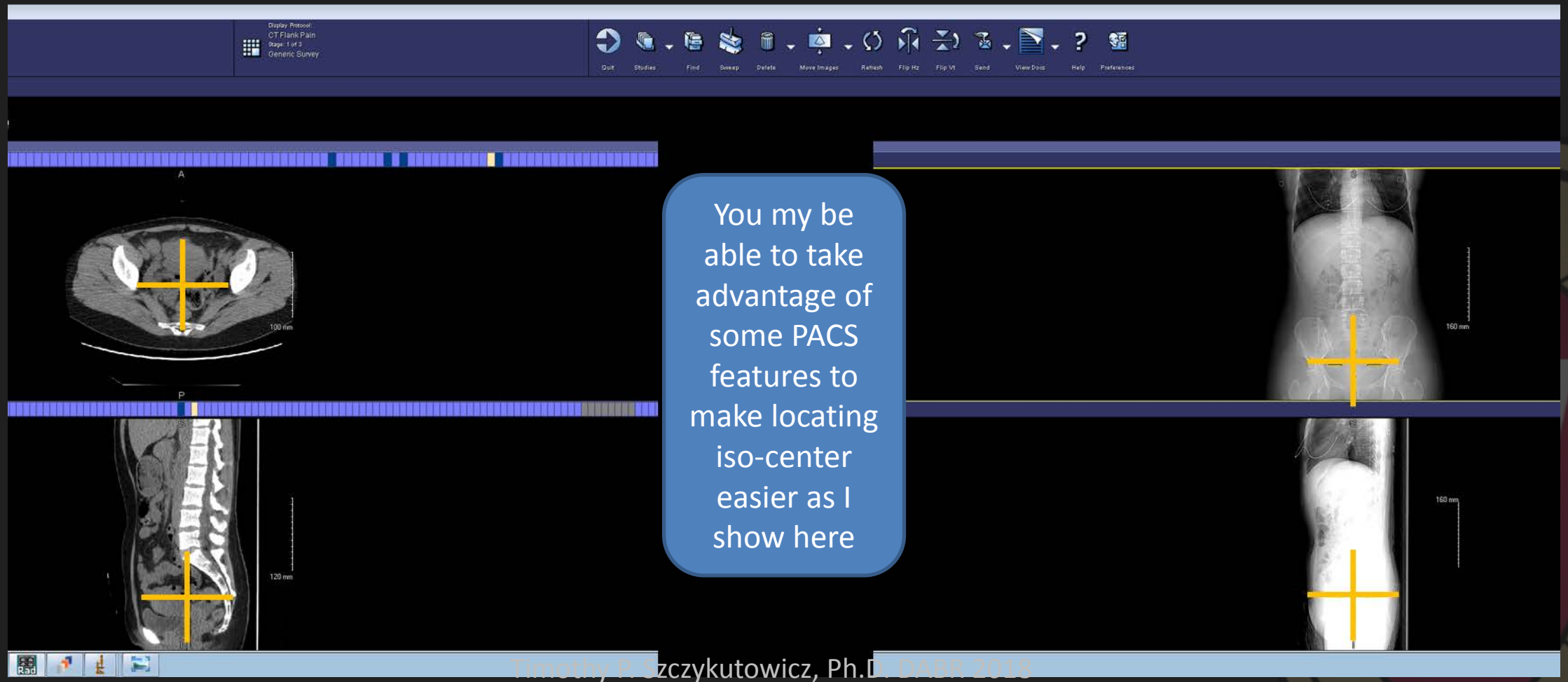
Step 2, Navigate to the artifact on a sagittal reformat



If the artefact lines up with isocenter in these the Coronal and Sagittal CT localizer radiographs, then your artifact Is at isocenter!

Iso-centric Artifacts: how to find isocenter

On our PACS, simply double clicking on the center of the CT localizer radiograph image produces a point localizer tool that shows you the same point in all images.



You my be able to take advantage of some PACS features to make locating iso-center easier as I show here

Outline

- Overview of CT Scanner Parts (what can break ☺)
- Iso-centric Artifacts
- Iso-centric Artifacts: how to find isocenter
- Non Iso-centric Artifacts
- General tips for troubleshooting Artifacts
- QA for Artifact Detection

Non Iso-centric Artifacts

2 camps for CT artifacts

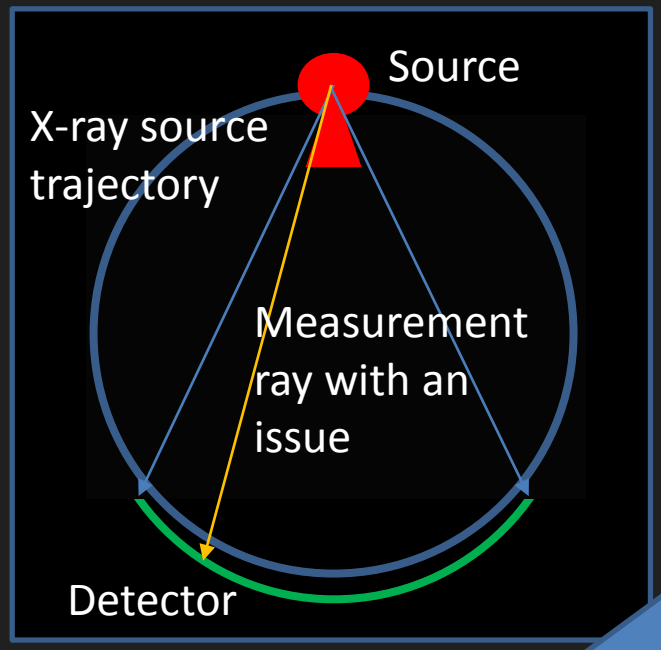
Artifacts that look like:
Rings
Arcs
Bands
Lines/bands emanating from source to detector array

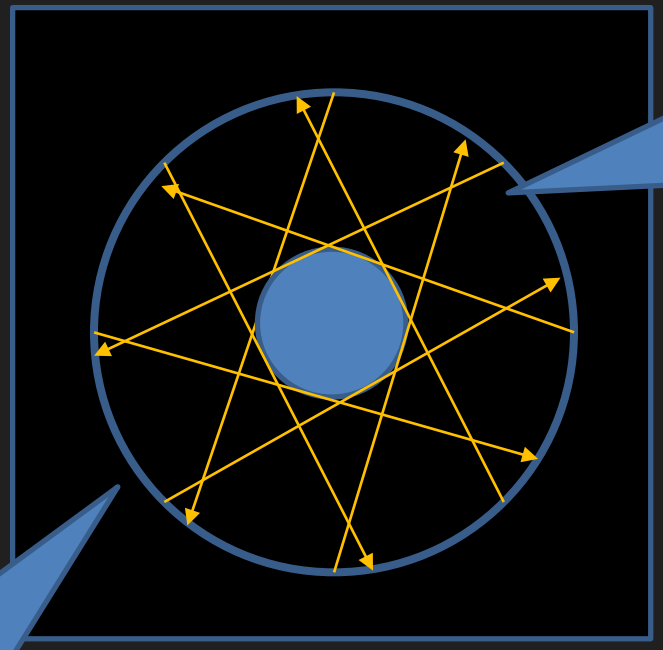
Iso-centeric

Artifacts that do not seem related to the circular system geometry of the CT scanner:
Beam hardening
Partial volume
Aliasing
Cone beam
Display/PACs issues
Recon computer trouble
Geometric calibration
truncation

Non Iso-centeric

Non Iso-centric Artifacts

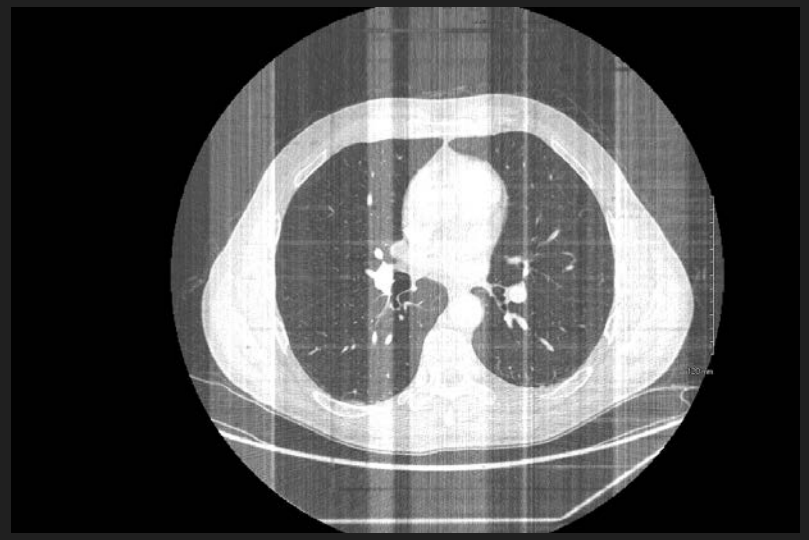




Because of the circular nature of CT geometry, we got nice circular looking artifacts or artifacts that spread from source to detector

Any artifact that doesn't follow this nice geometry we will classify as non-iso-centric

Non Iso-centric Artifacts: “The Tartan”



Odd, the artifact only showed up on a few slices from a single recon. Other recons using the same detector data showed no issues. Field engineer ended up replacing some of the reconstruction computer hardware. “glitch in the matrix” type artifact.

These recons used the same data as the artifact image, but were artifact free.

Tartan (Scottish Gaelic: breacan [ˈbrʲɛxkən]) is a pattern consisting of criss-crossed horizontal and vertical bands in multiple colours. - wikipedia

Unfortunately, my google search for a “Szczykutowicz tartan” came up empty…

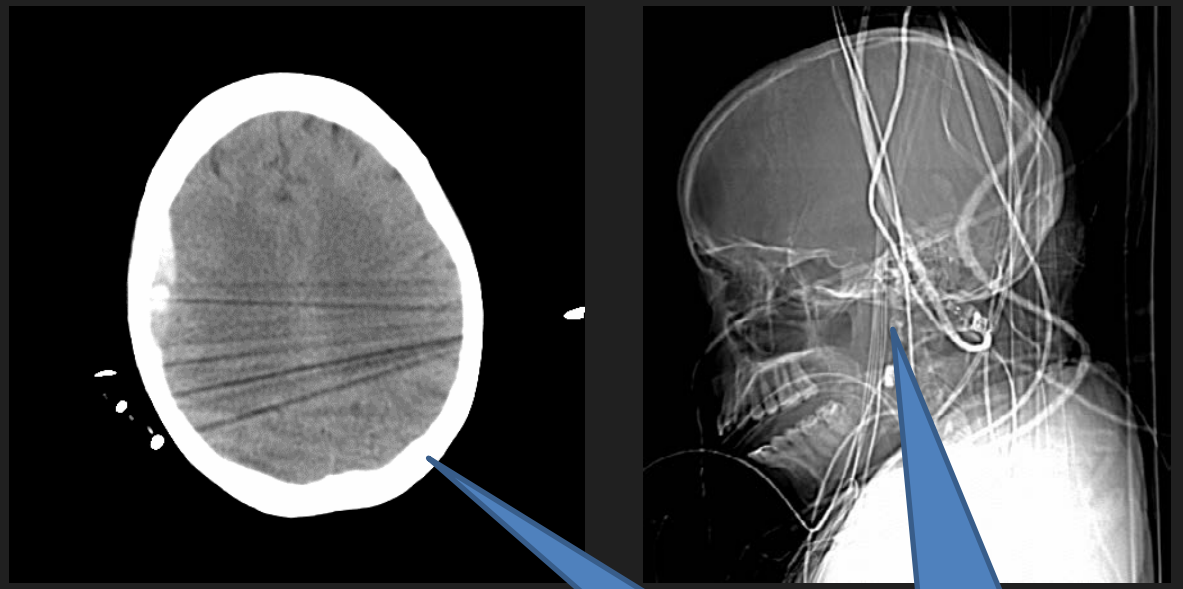
Non Iso-centric Artifacts: Beam Hardening Streak

Probably something was outside the scan field of view, like a wire

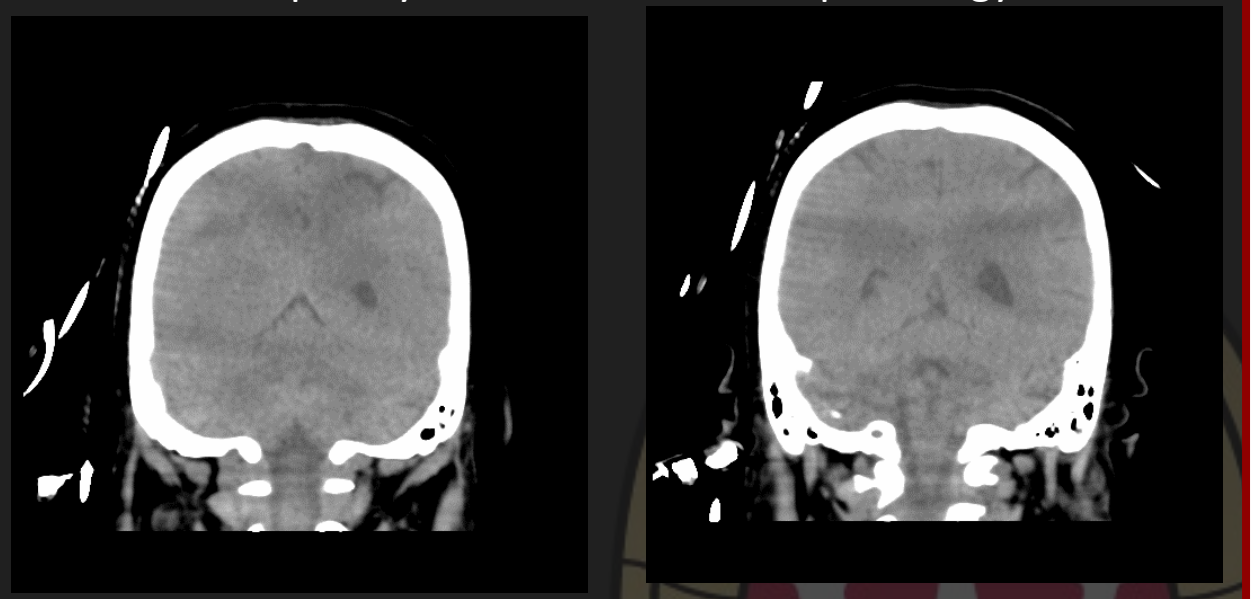
Non Iso-centric Artifacts: Beam Hardening Streak

Same patient, same scan data, different planes

High frequency artifact obviously not pathology



Low frequency artifact that mimics pathology



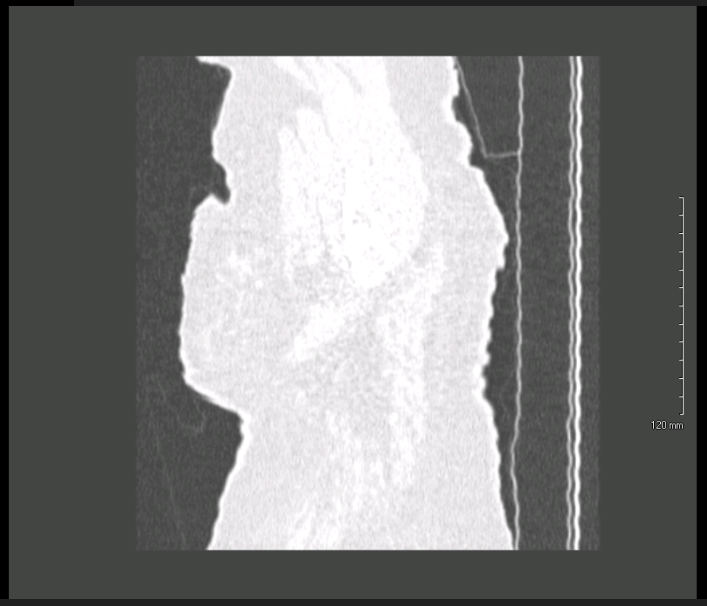
This case of streak is definitely due to wires outside the patient head

Interesting thing here is to notice how the same artifact manifests itself in these different planes. High frequency streak in axial plane, low frequency pathology like artifact in coronal planes.

Non Iso-centric Artifacts: “Bumpy table”

Axial images look fine when viewed one at a time

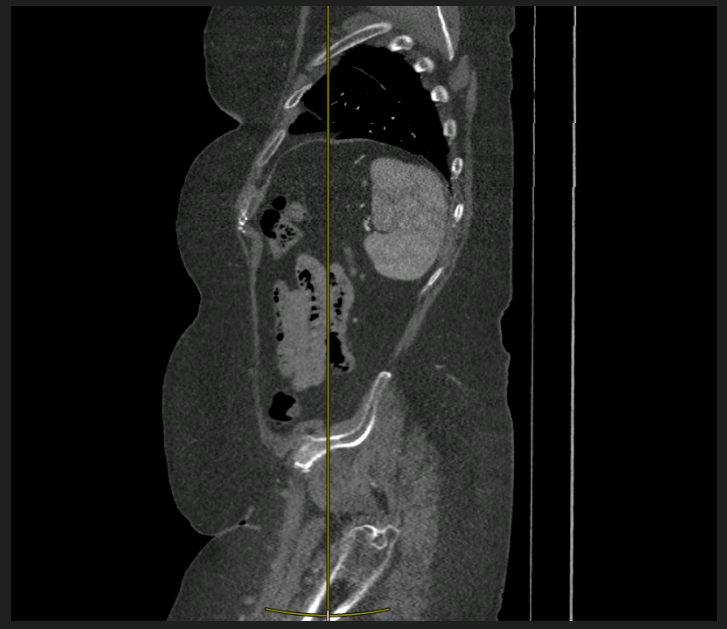
Coronal and sagittal images display a “bumpy” pattern at the skin edge



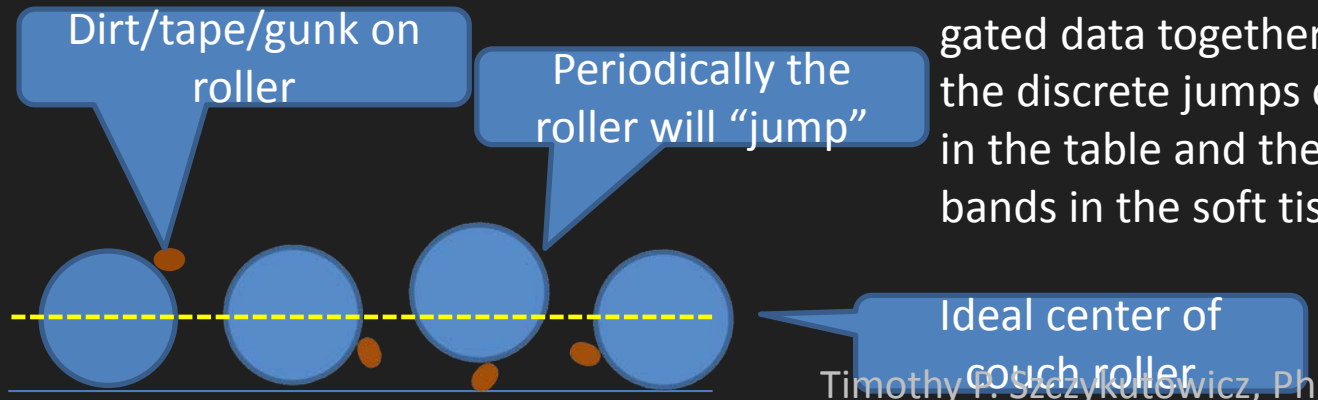
Scanner was not calibrated properly by service. Isocenter location was incorrect according to field engineer.

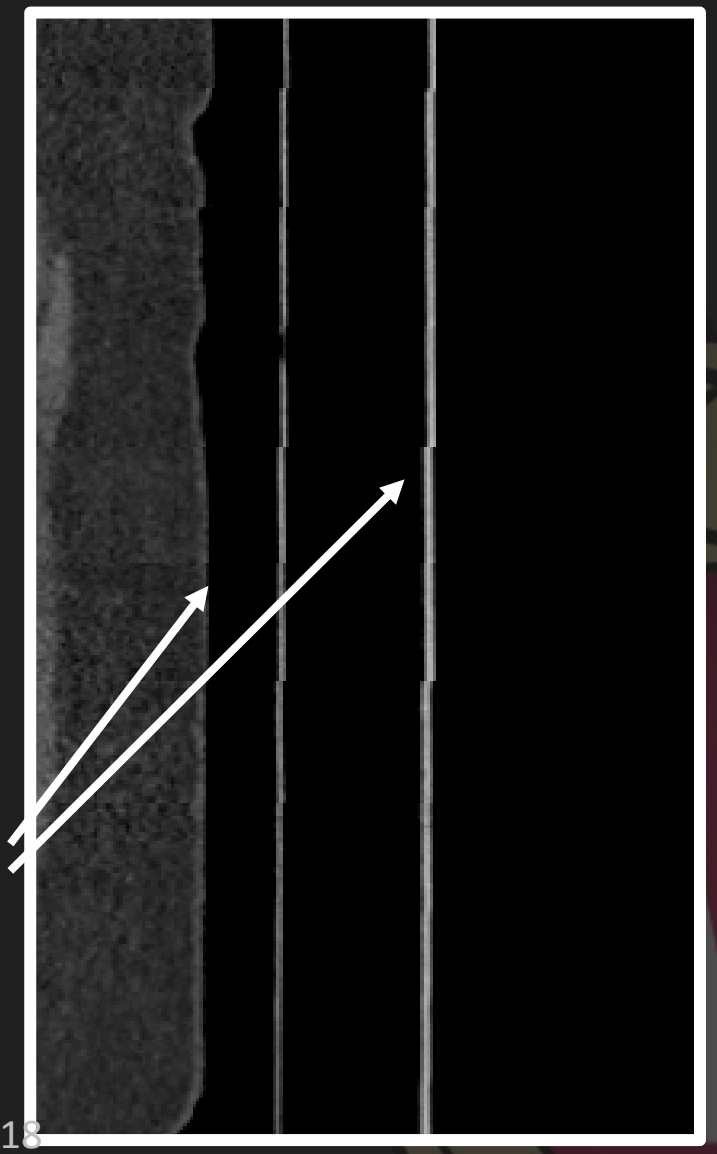
Non Iso-centric Artifacts: “Bumpy table flavor 2”

Service said “there was a syringe wedged into the couch track”
There also was a wad of tape on the roller for the couch and the couch drive belt was slack…

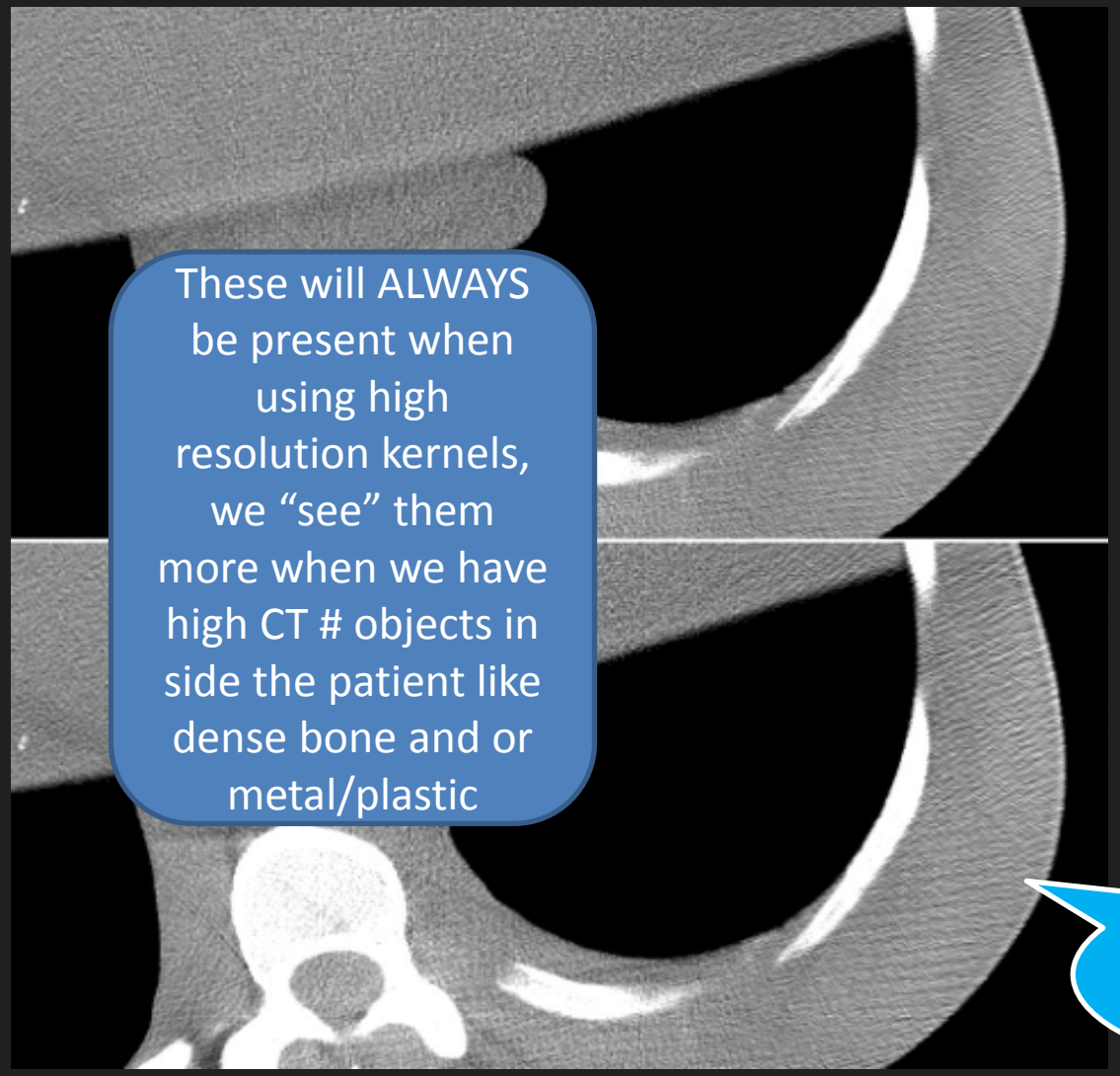


TAVI scan which combines gated data together, hence the discrete jumps observed in the table and the dark bands in the soft tissue

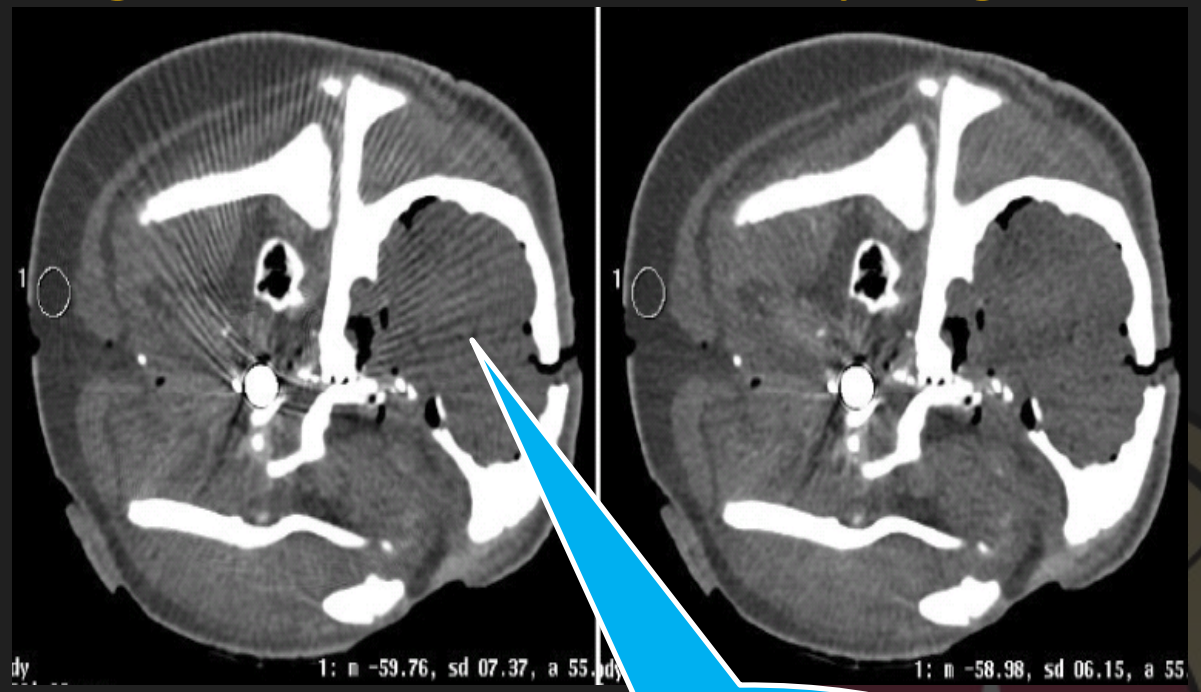




Non Iso-centric Artifacts: Aliasing artifacts (undersampling)



These will ALWAYS be present when using high resolution kernels, we “see” them more when we have high CT # objects in side the patient like dense bone and or metal/plastic



Aliasing artifacts

Aliasing artifacts

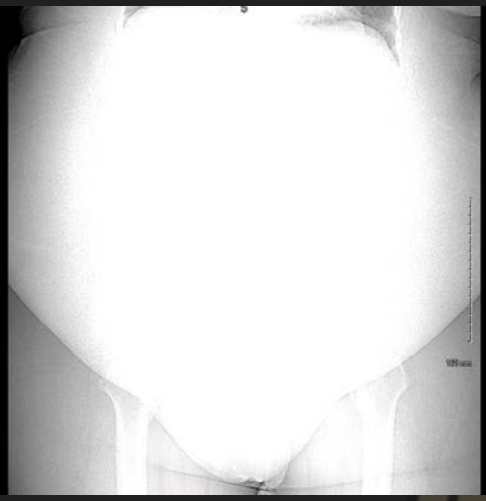
Here the “good” looking images were made with more view angles, this increased the sampling and reduced the artifact level

Hsieh, Jiang. "Computed tomography: principles, design, artifacts, and recent advances." Bellingham, WA: SPIE, 2009.

Non Iso-centric Artifacts: truncation

Bariatric patient

Truncation artifacts at edge of field of view



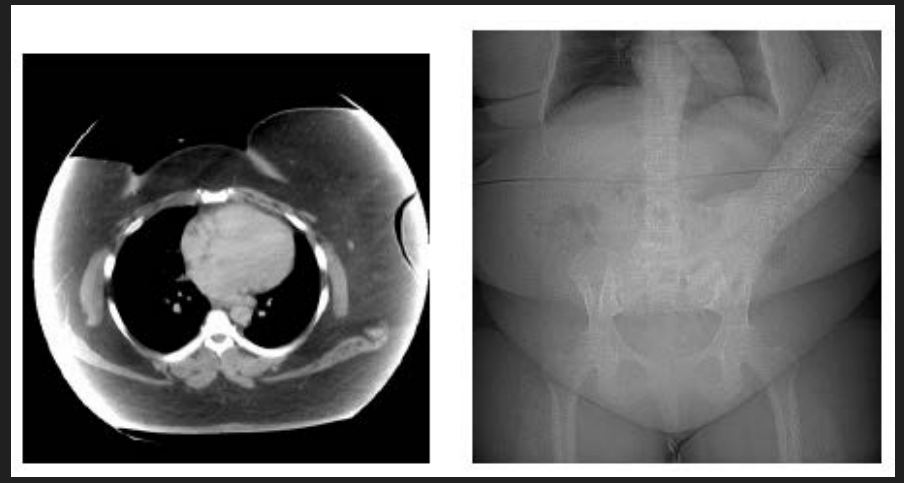
53 cm

Bariatric patient's localizer radiograph

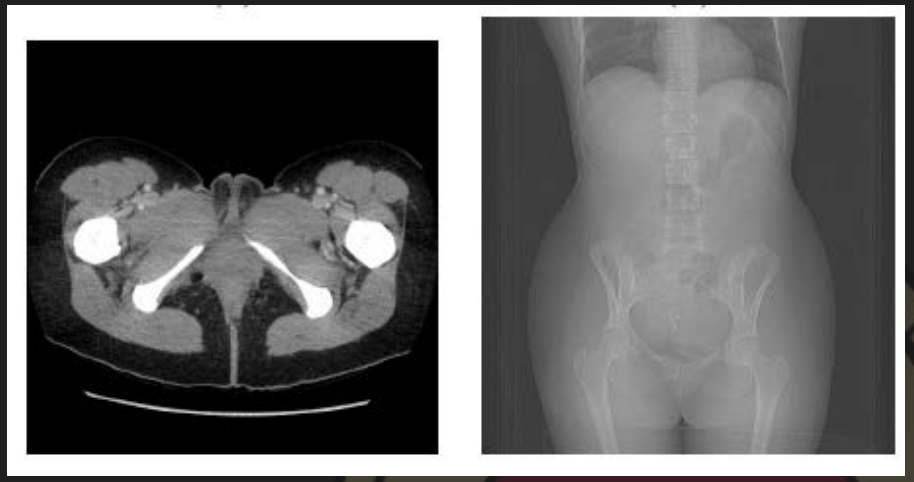
Some scanners come with extra large bore sizes for interventions, radiotherapy, and bariatric scanning. Those scanners then also usually come with optional reconstruction/display field of view algorithms to mitigate these types of artifacts

Non Iso-centric Artifacts: truncation

Truncation of data on both sides of patient, we get artifact on both sides

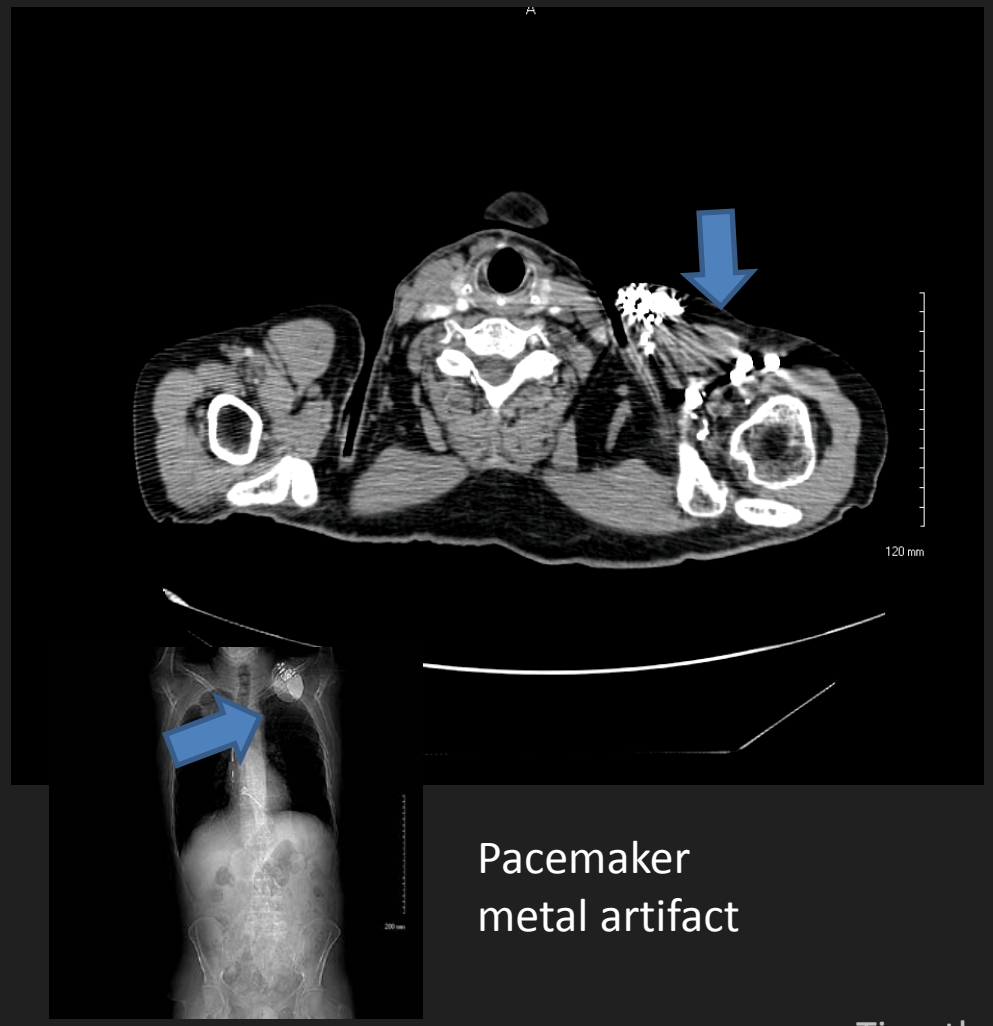


No data truncation, but the tech chose to use a reconstruction field of view smaller than the patient→ we wont see any artifact in this case



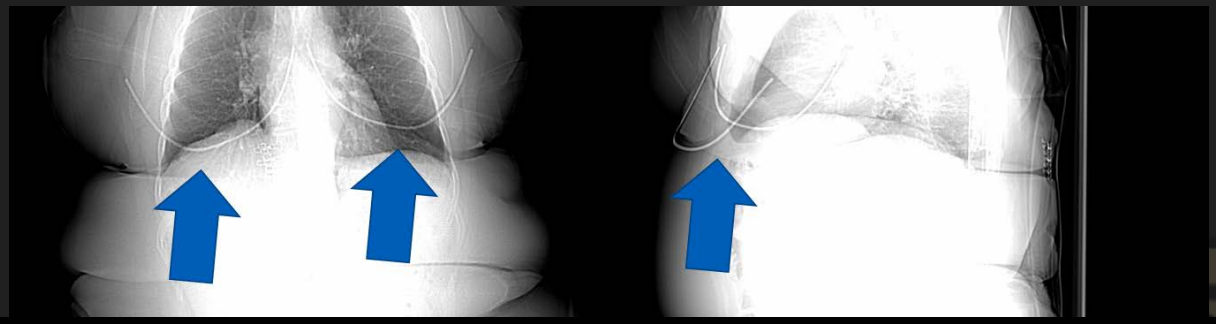
Truncation of data on one side of patient, we get artifact on one side

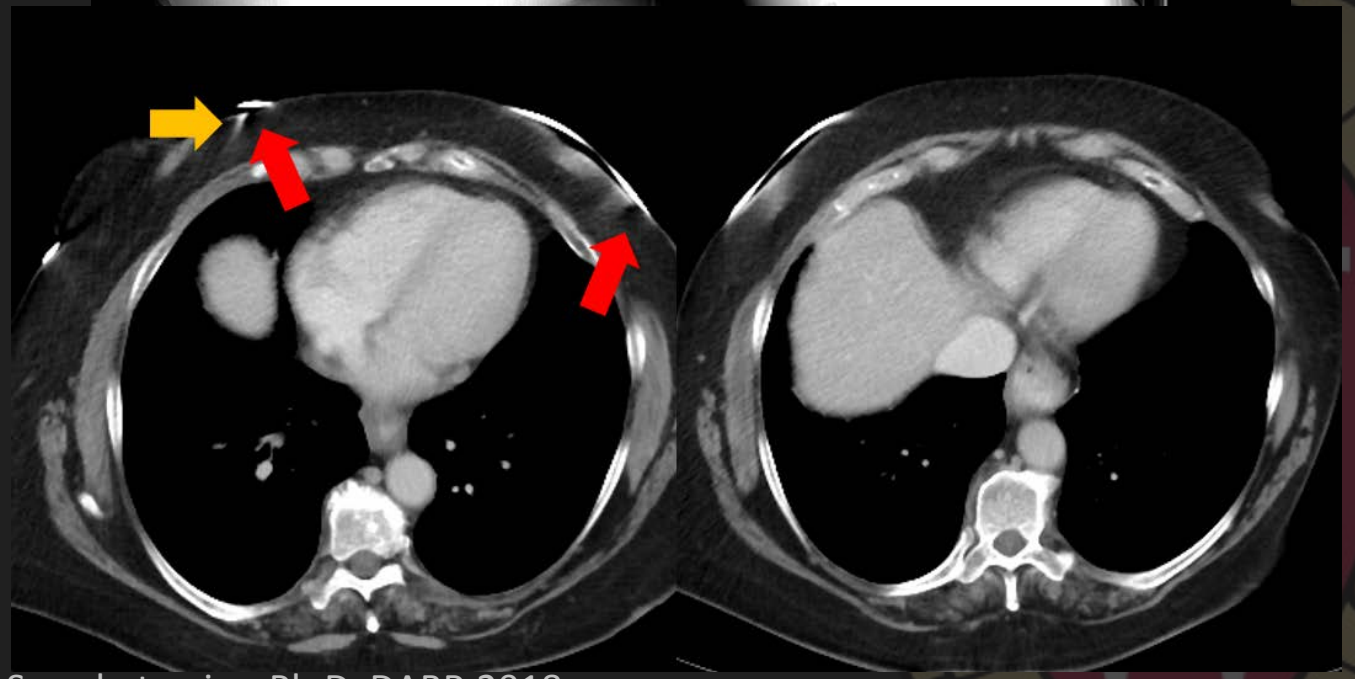
Non Iso-centric Artifacts: Metal



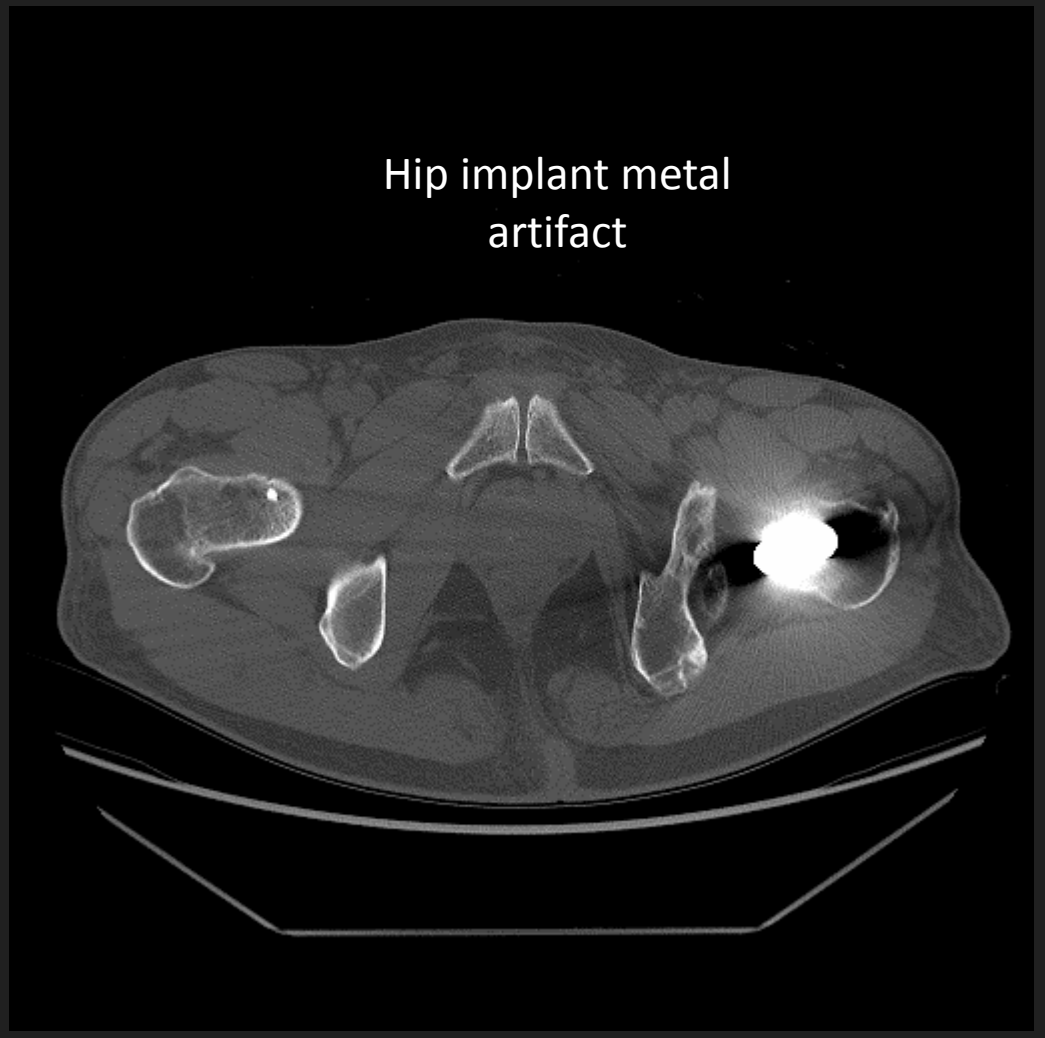
Pacemaker
metal artifact

underwire metal artifact

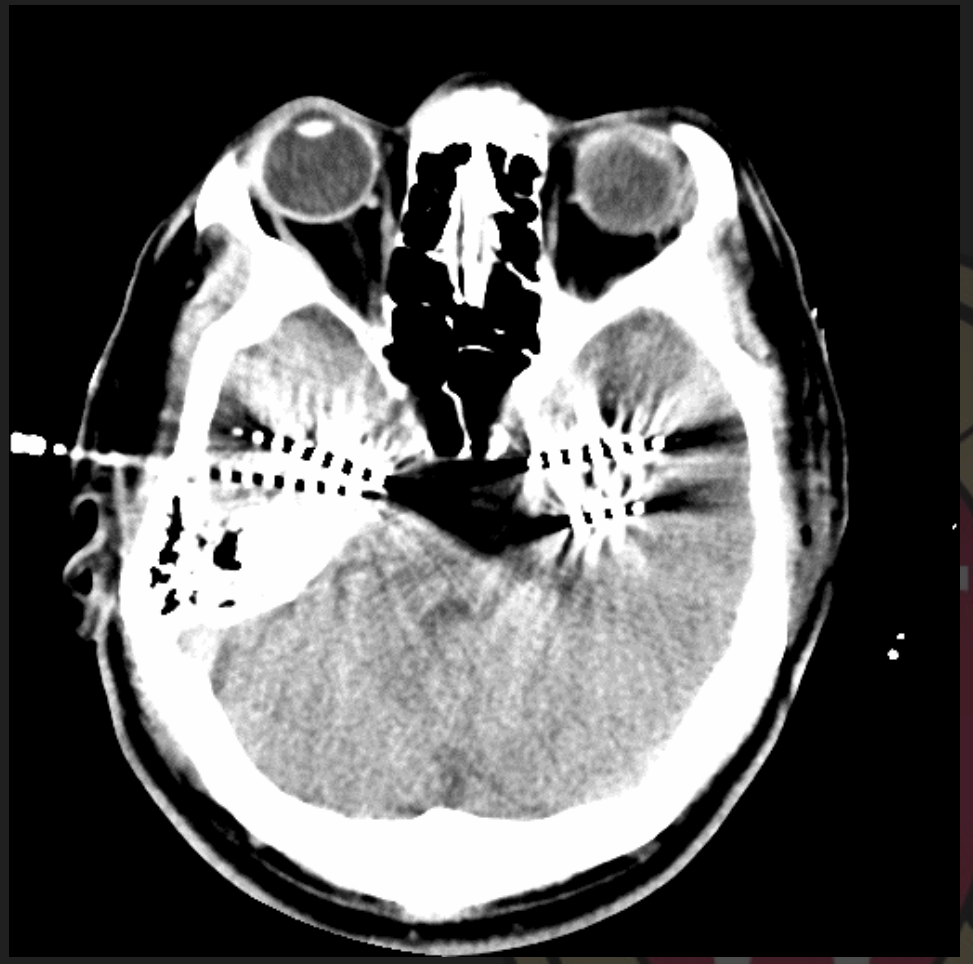




Non Iso-centric Artifacts: Metal

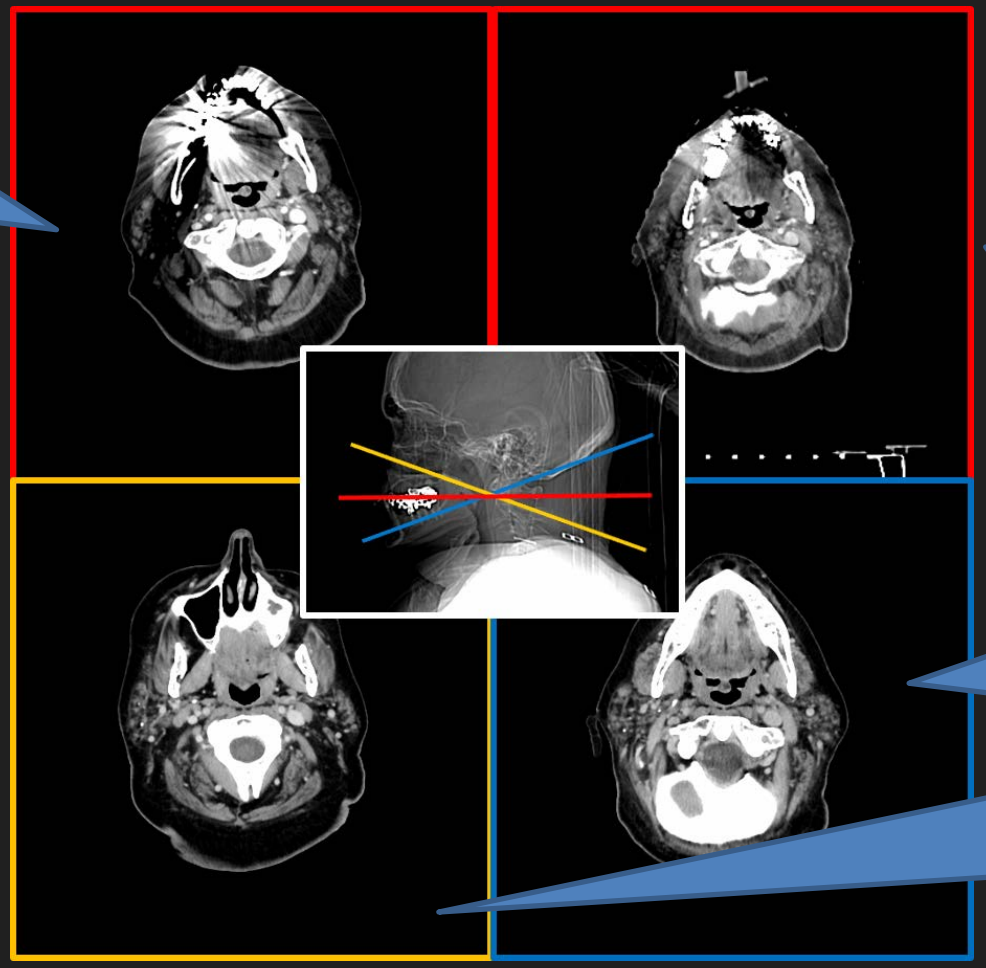


Electrodes metal
artifact



Non Iso-centric Artifacts: Metal

Dental amalgam artifact, scan acquired without gantry tilt or metal artifact reduction software



Dental amalgam artifact mitigated to a large degree, scan acquired without gantry tilt but with metal artifact reduction software

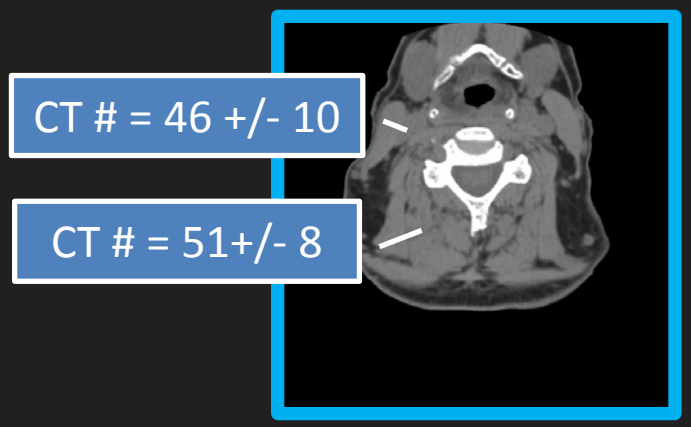
Scans acquired in titled gantry mode and without metal artifact reduction software

Timothy P. Szczykutowicz, Ph.D. DABR 2018

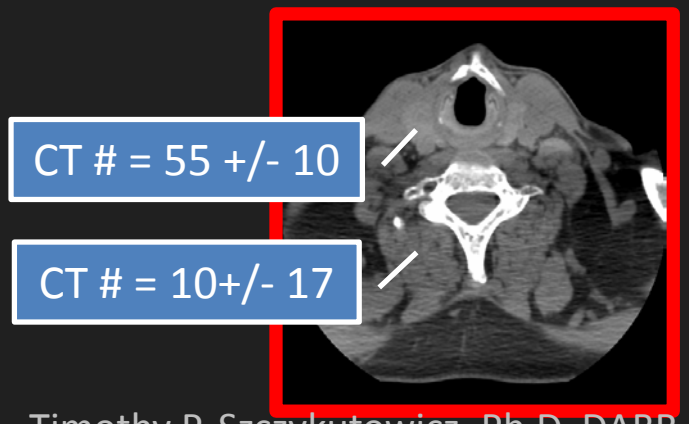
Non Iso-centric Artifacts: Beam hardening

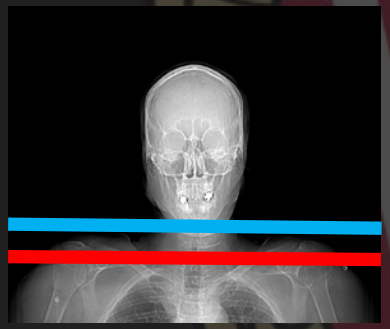
- We see beam hardening induced CT number changes in every head and neck case… (the shoulders harden the beam for the neck which reduces the CT number for that part of the image

2 ROI locations with equal beam hardening

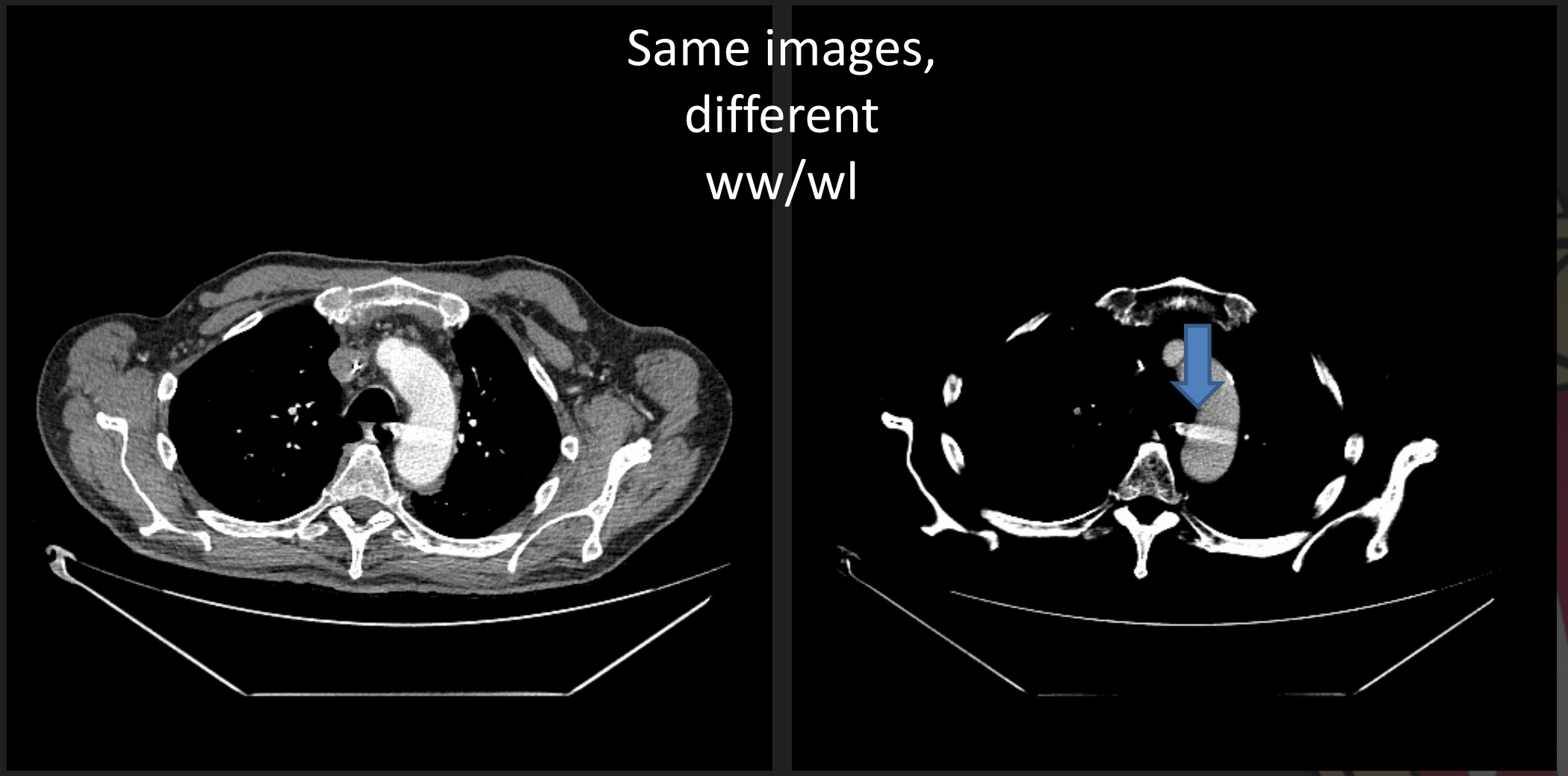


Posterior ROI has a lot of beam hardening from the shoulders



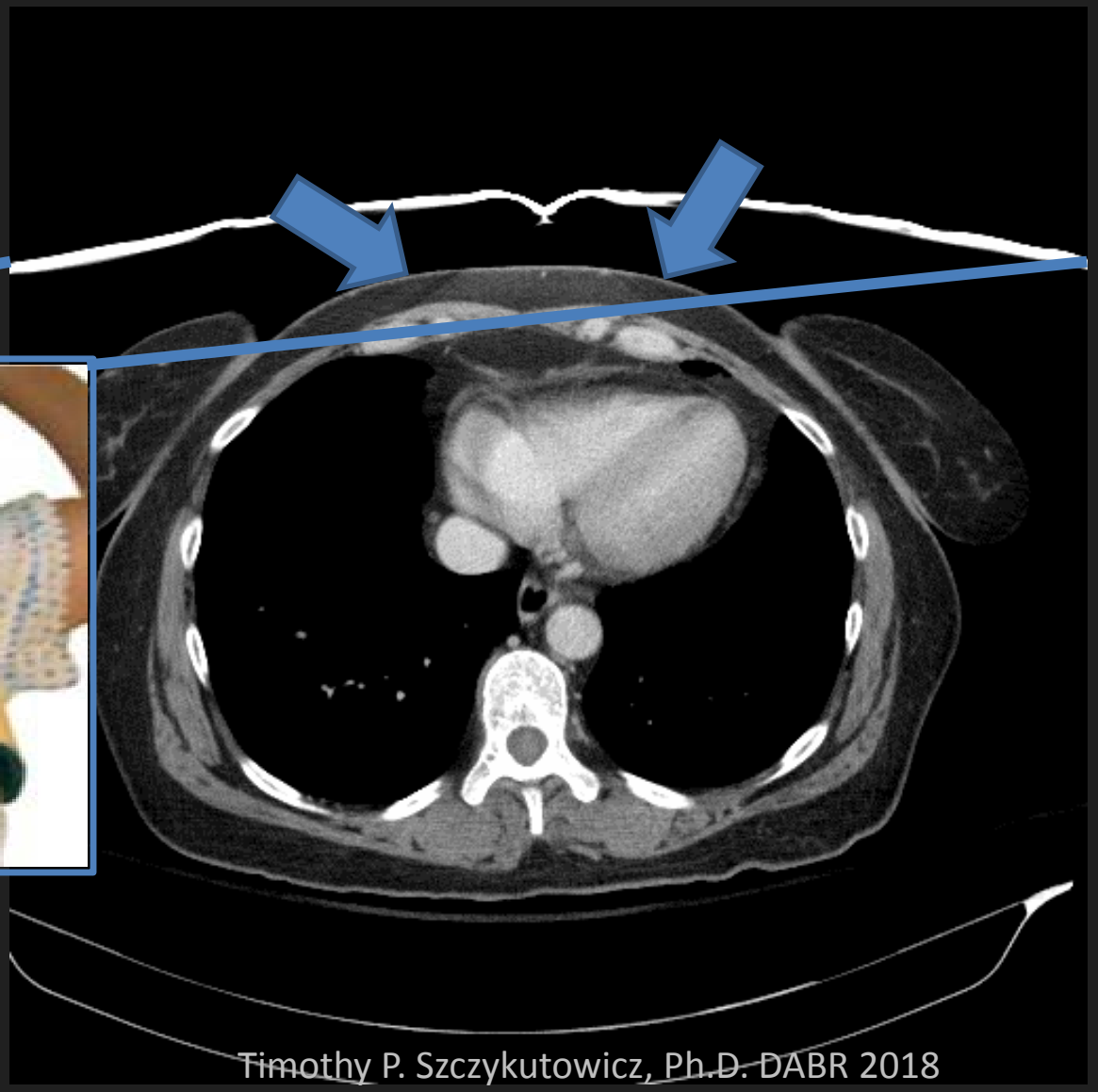


Non Iso-centric Artifacts: Beam hardening

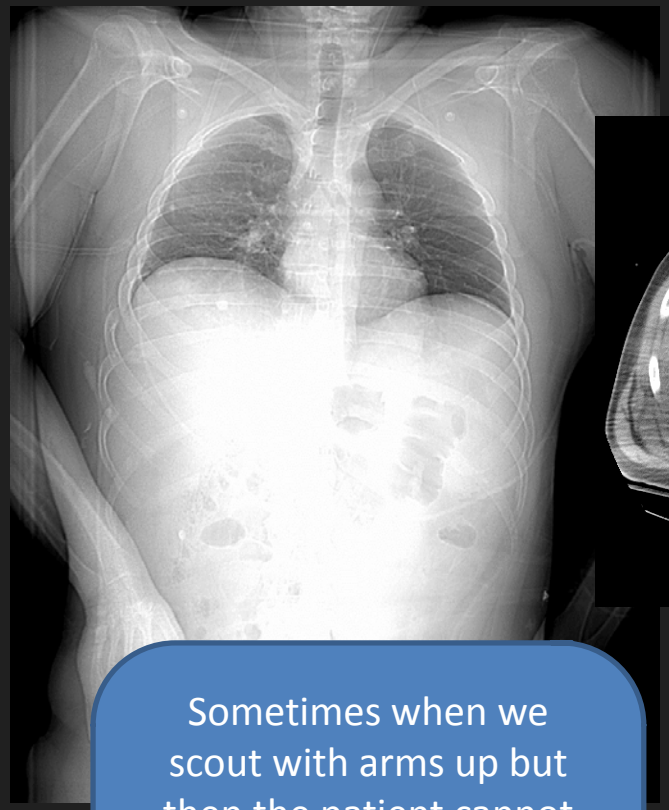


Non Iso-centric Artifacts: Beam hardening

Breast and thyroid shields will cause beam hardening artifacts

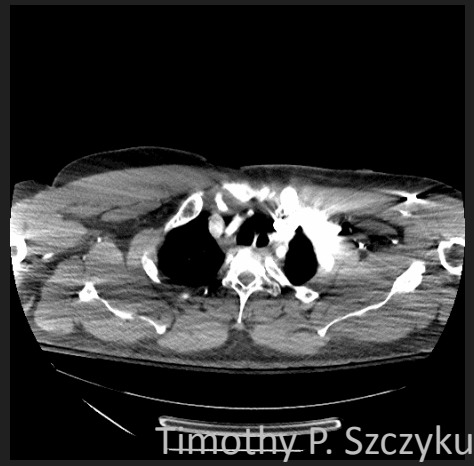


Non Iso-centric Artifacts: Photon Starvation

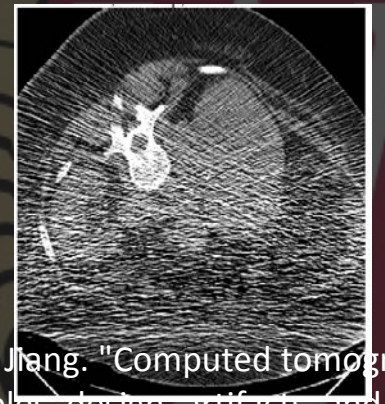


Arms down, increases attenuation and we see some beam hardening

Sometimes when we scout with arms up but then the patient cannot hold them any more they bring them down. Then we get an even worse scan since the AEC doesn't know about the arms

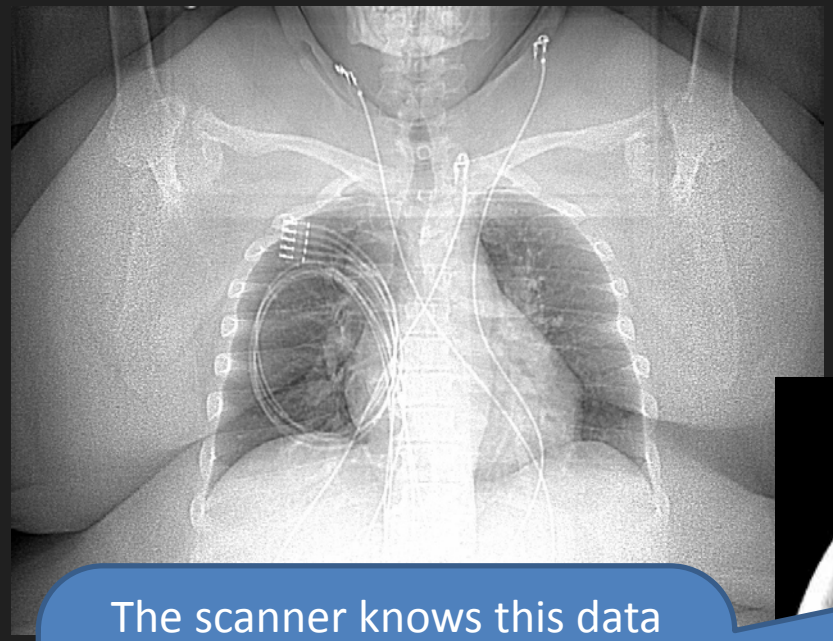


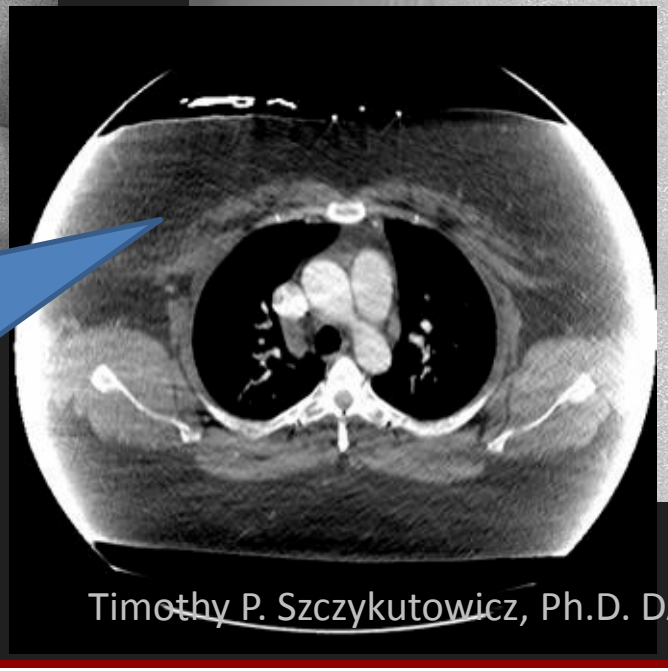
Pretty much always present in shoulder region



Hsieh, Jiang. "Computed tomography: principles, design, artifacts, and recent advances." Bellingham, WA: SPIE, 2009.

Non Iso-centric Artifacts: Photon Starvation

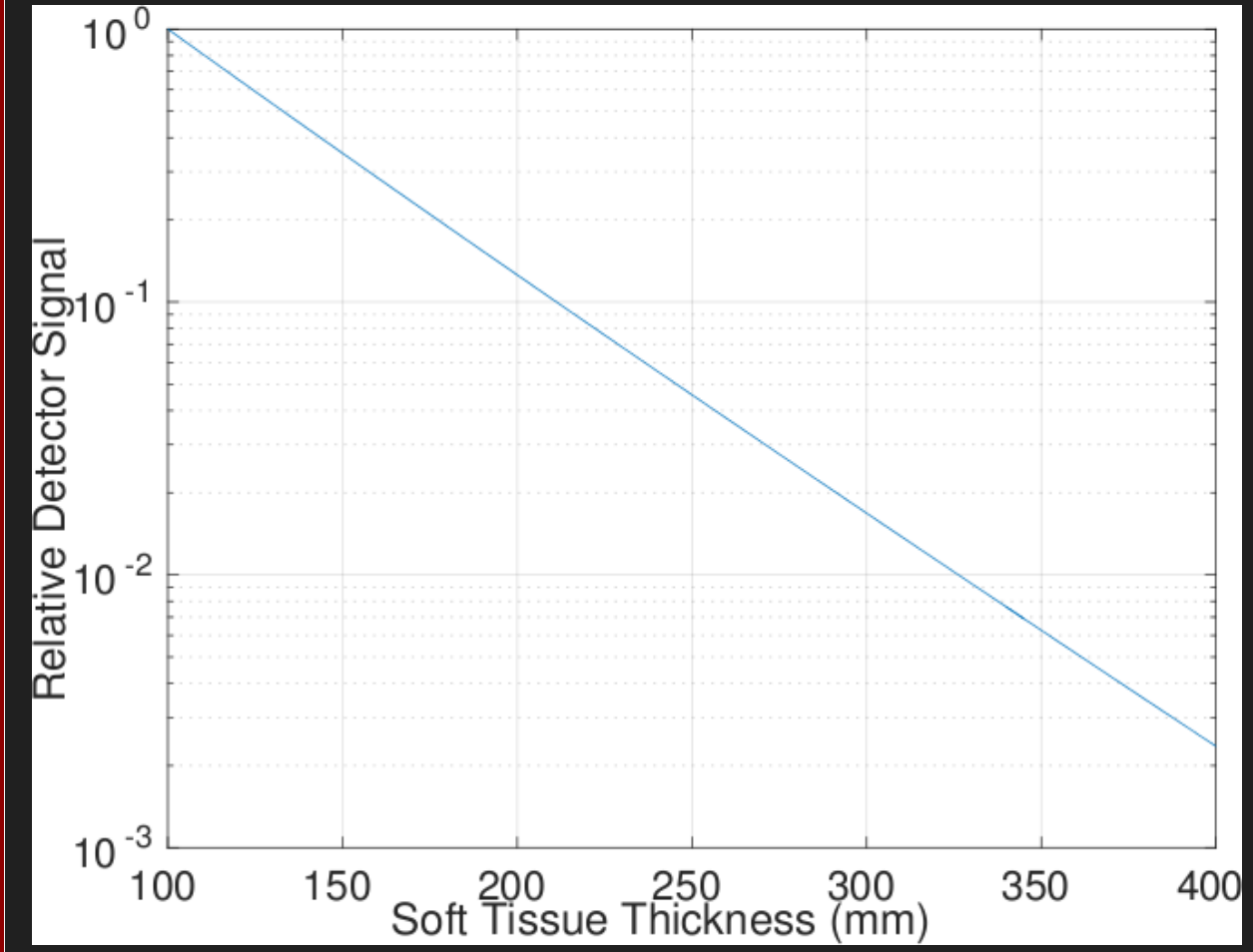




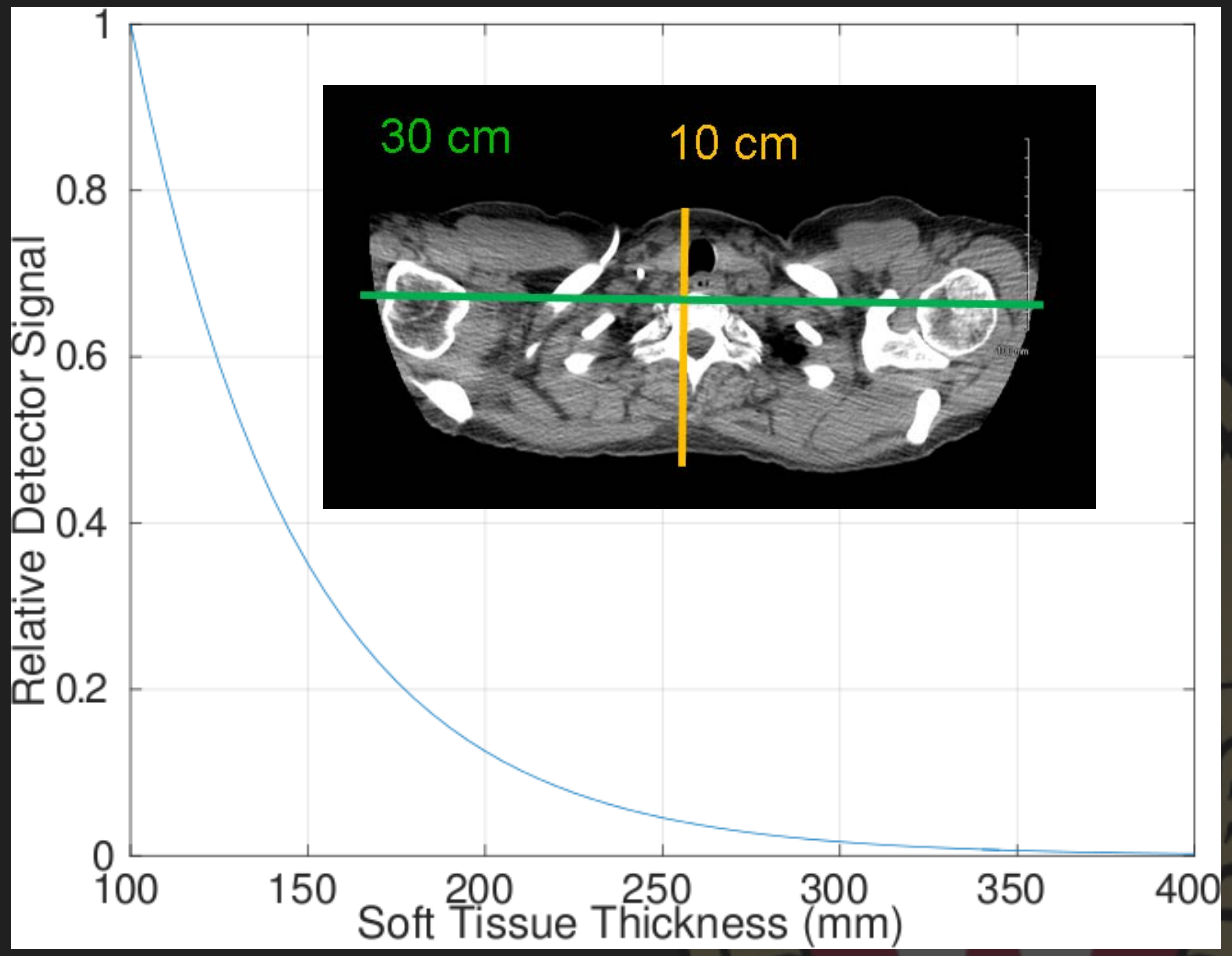
The scanner knows this data has very high noise so it applies a lot of smoothing before reconstruction so we end up with a “soft”/“blurry” looking image

When you see this speckled appearance on the localizer…you know the patient is big or your localizer technique is too low

Non Iso-centric Artifacts: Photon Starvation

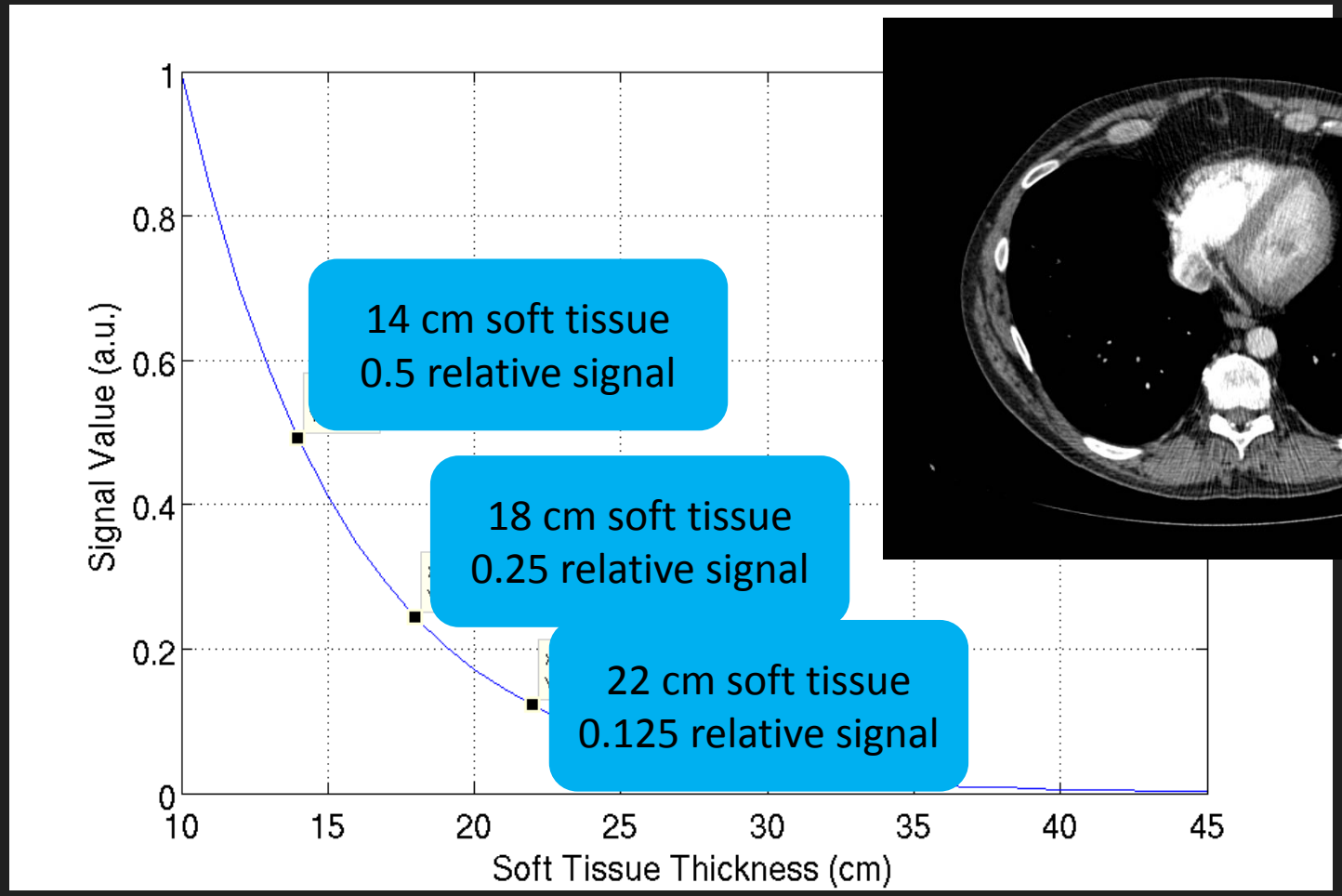


Signal versus size on log plot

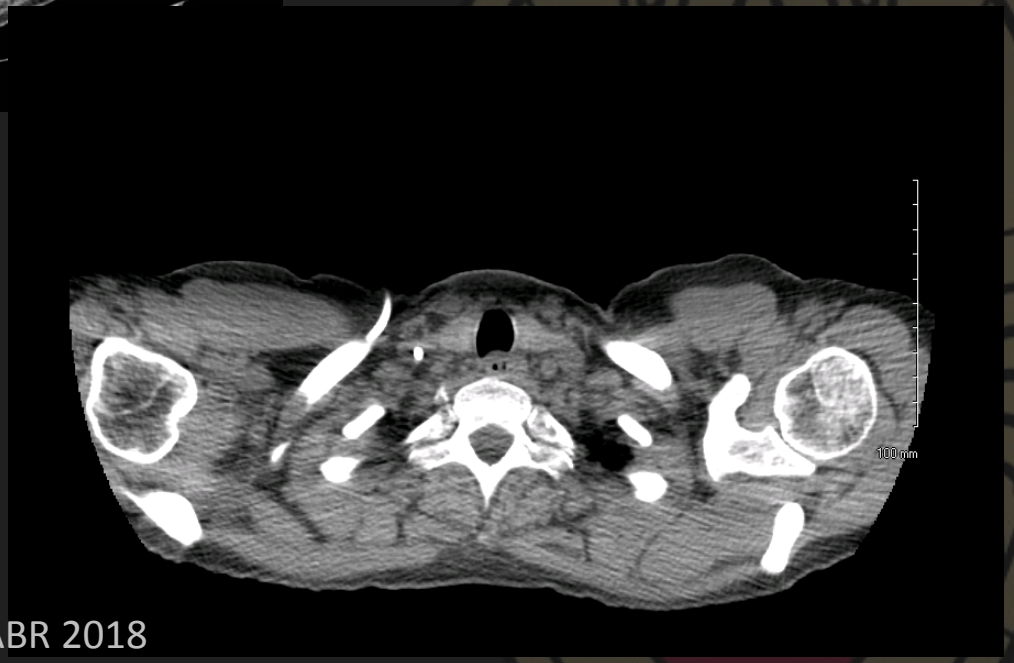


Signal versus size

Non Iso-centric Artifacts: Photon Starvation

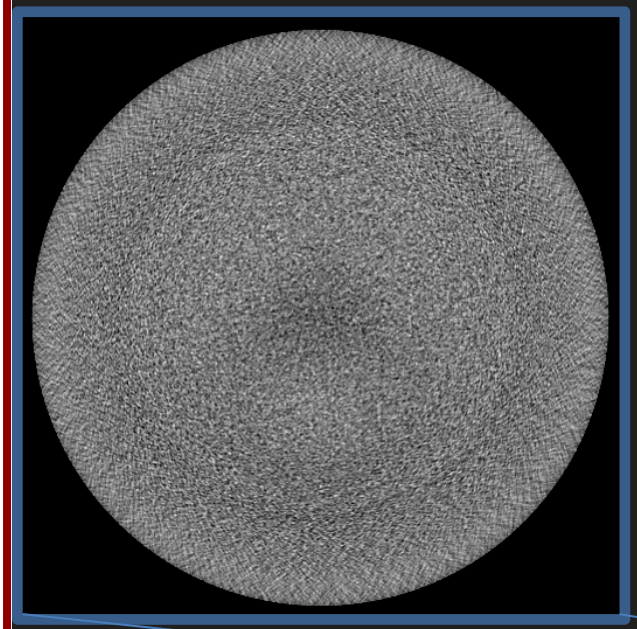


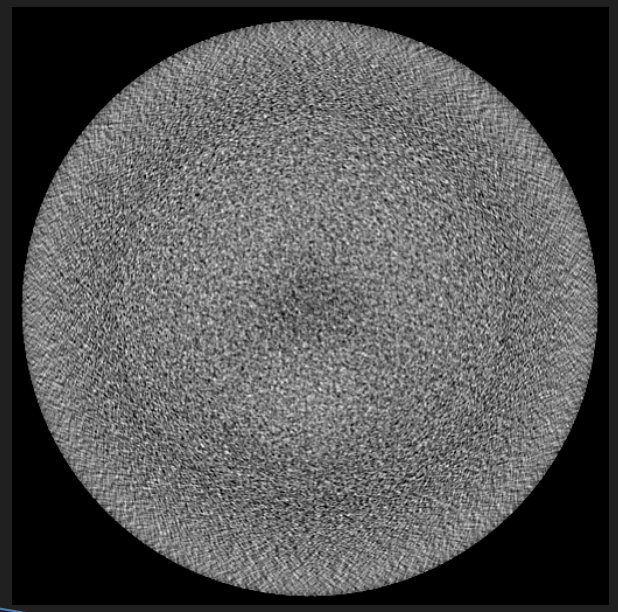
Rule of thumb in CT, every 4 cm of tissue halves the signal. That is a big deal both for dose adaption with patient size and scans over highly elliptical regions of a patient

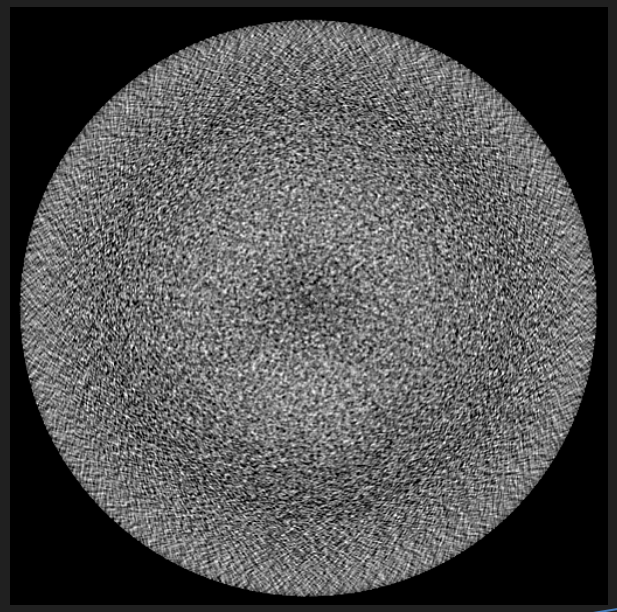


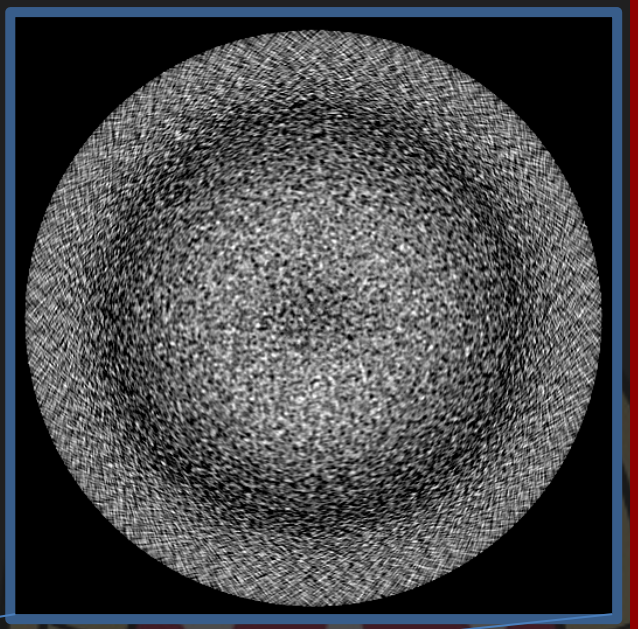
Non Iso-centric Artifacts: Photon Starvation

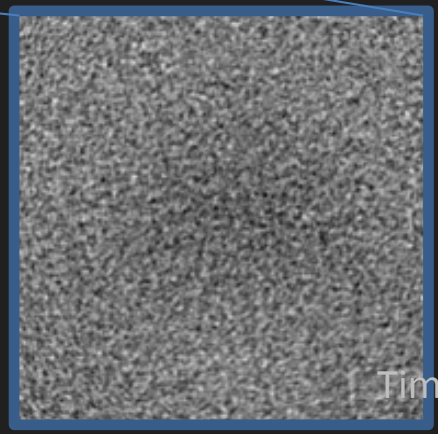
Dose decreases from left to right



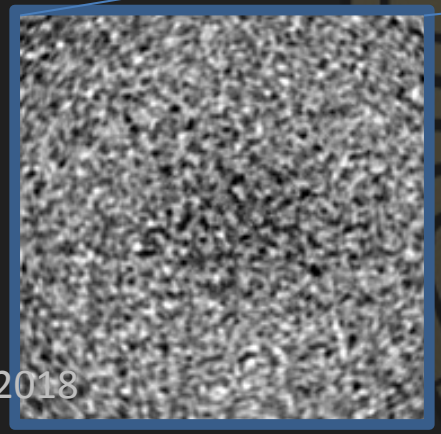


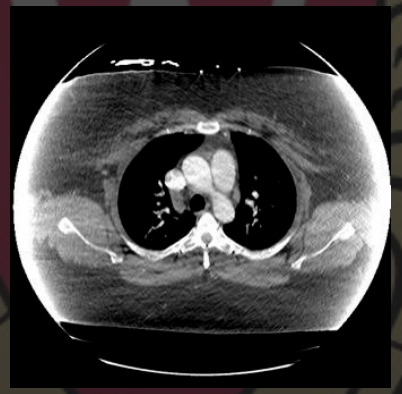




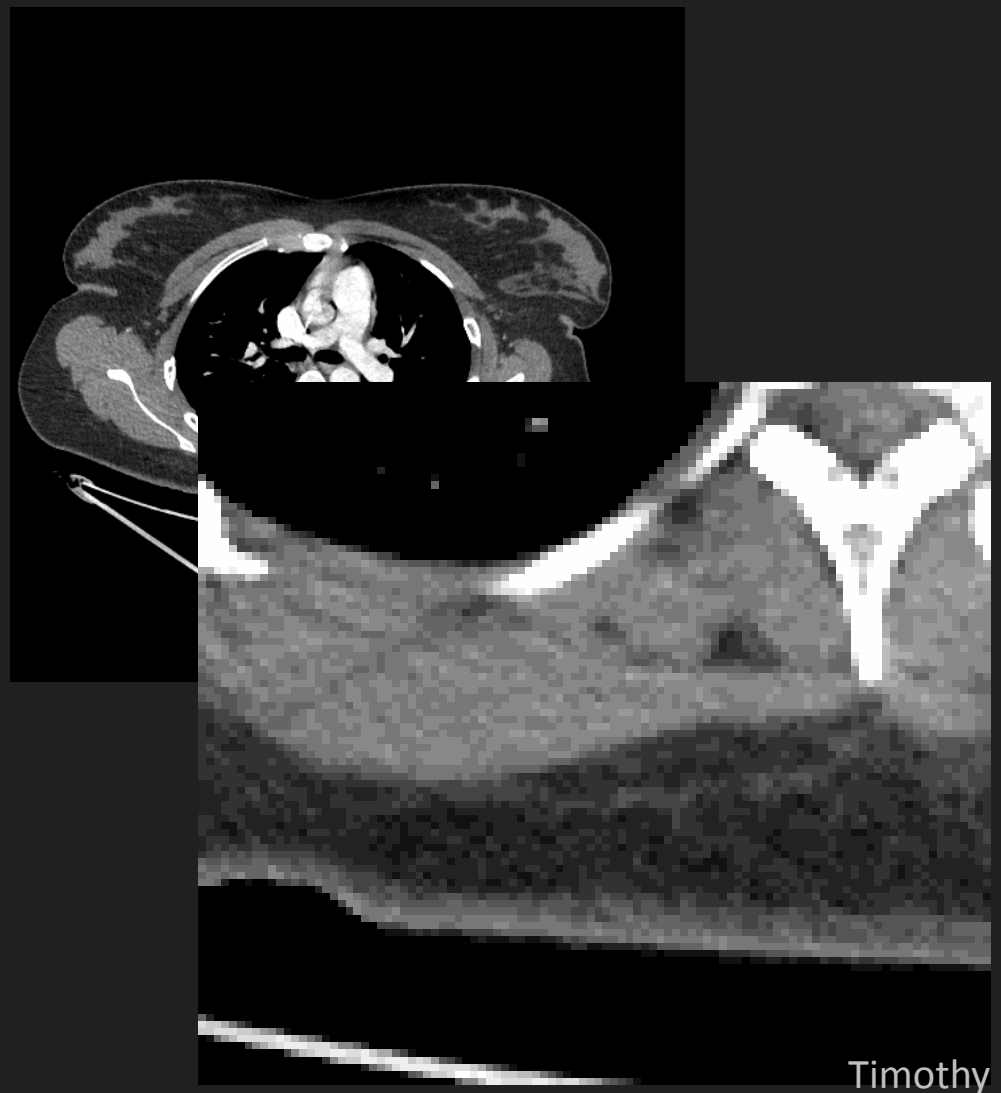


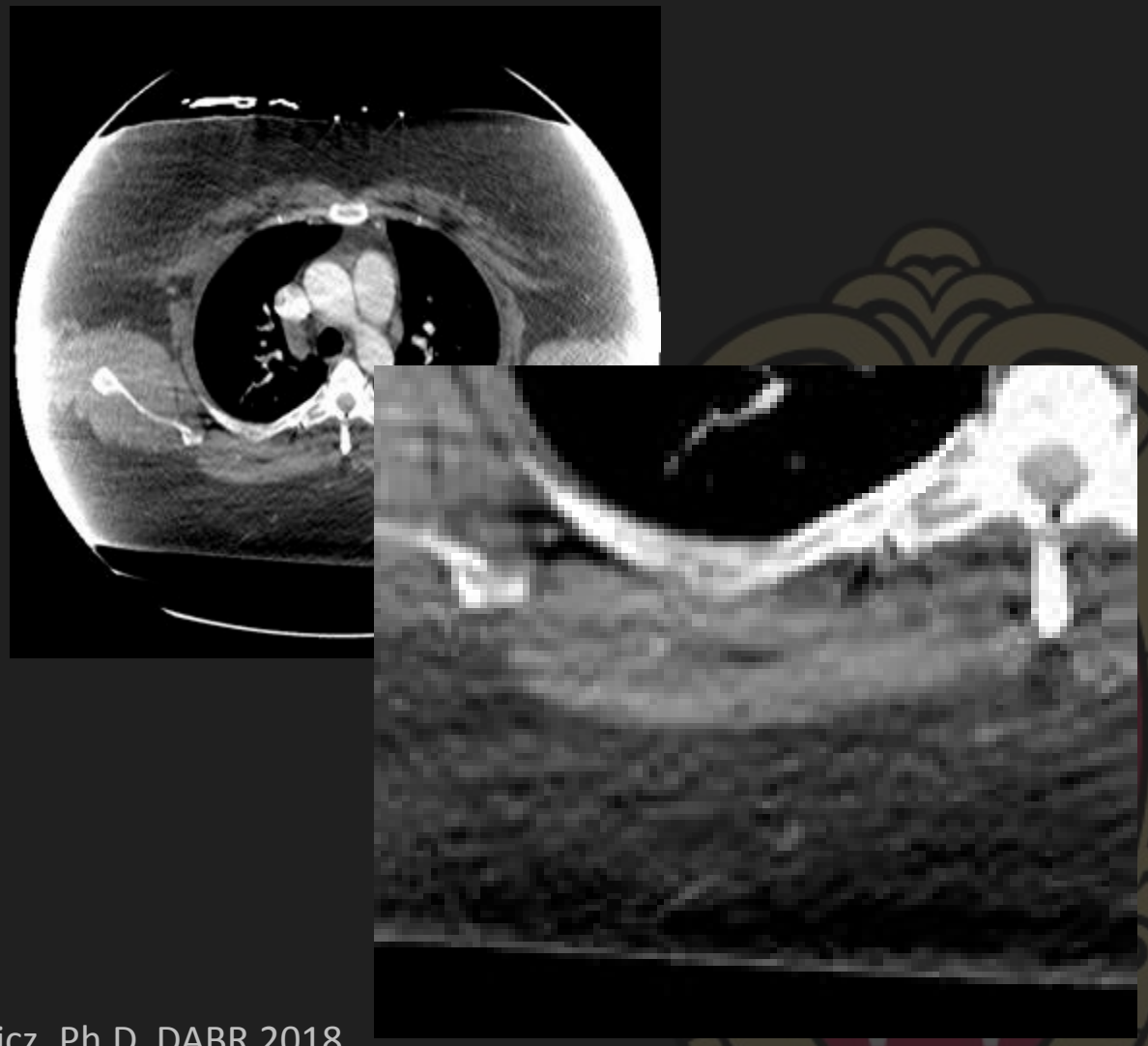
Noise texture becomes more “blotchy/low frequency” as detector signal goes down



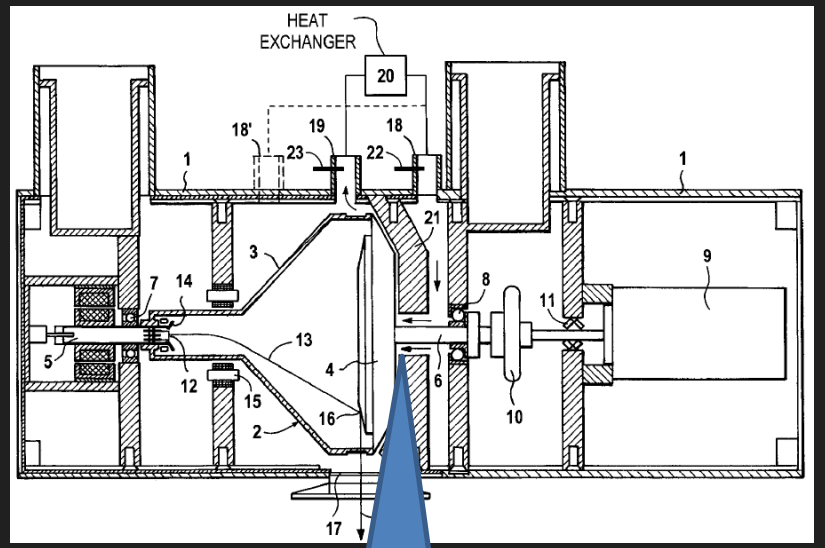


Non Iso-centric Artifacts: Photon Starvation



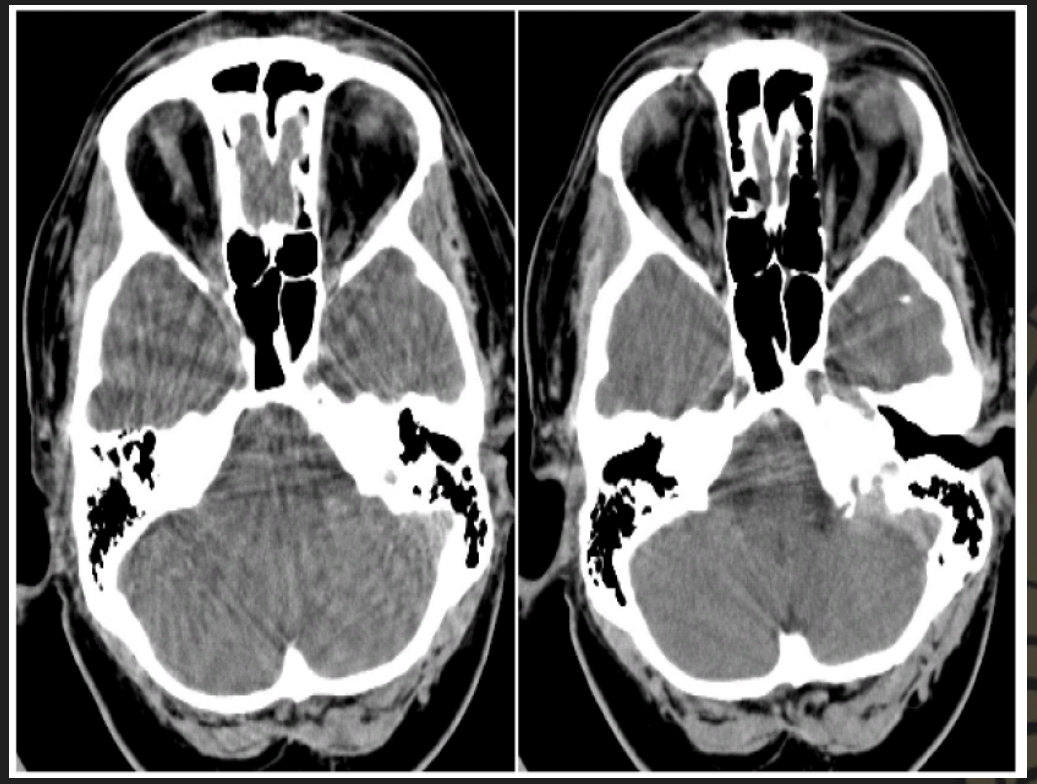


Non Iso-centric Artifacts: Tube wobble



Siemens Patent 6,084,942

Anode is spinning at thousands of times a second…

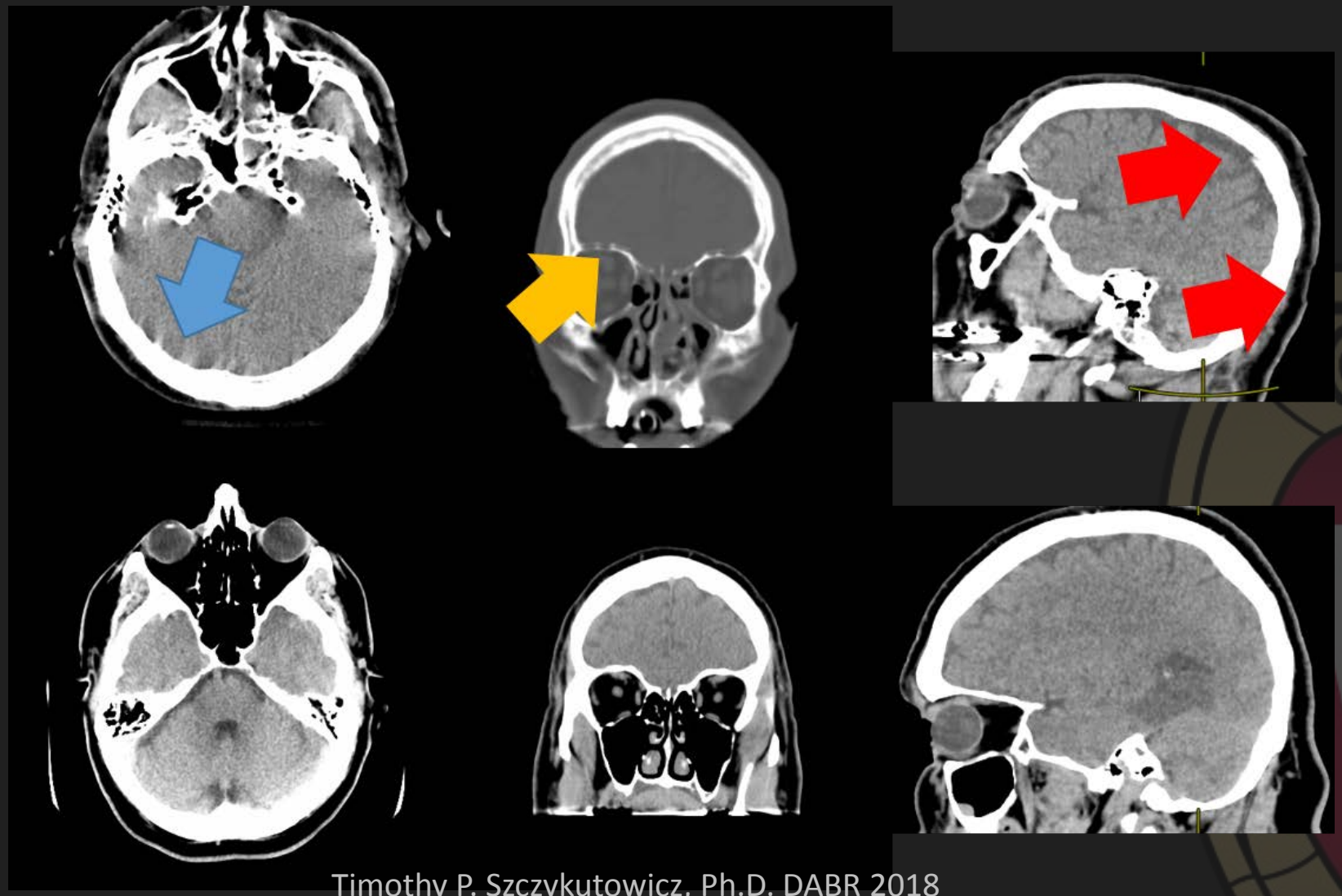


Hsieh, Jiang. "Computed tomography: principles, design, artifacts, and recent advances." Bellingham, WA: SPIE, 2009.

Non Iso-centric Artifacts: Motion

Patient with motion during head scan

Artifact free scan for reference



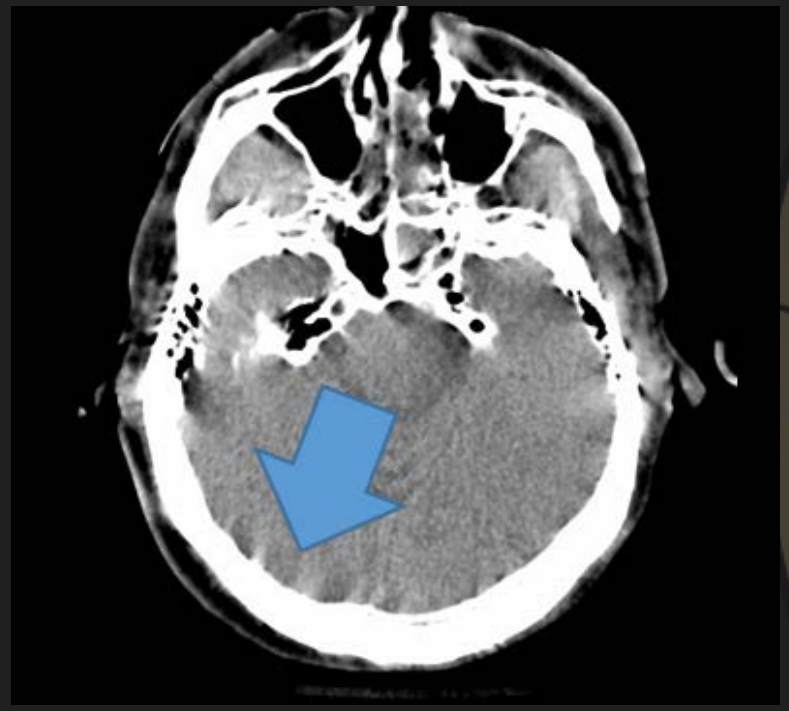
These motion artifact manifest very differently in these different planes

Non Iso-centric Artifacts: Motion

- Helical and axial motion artifacts will look different

axial

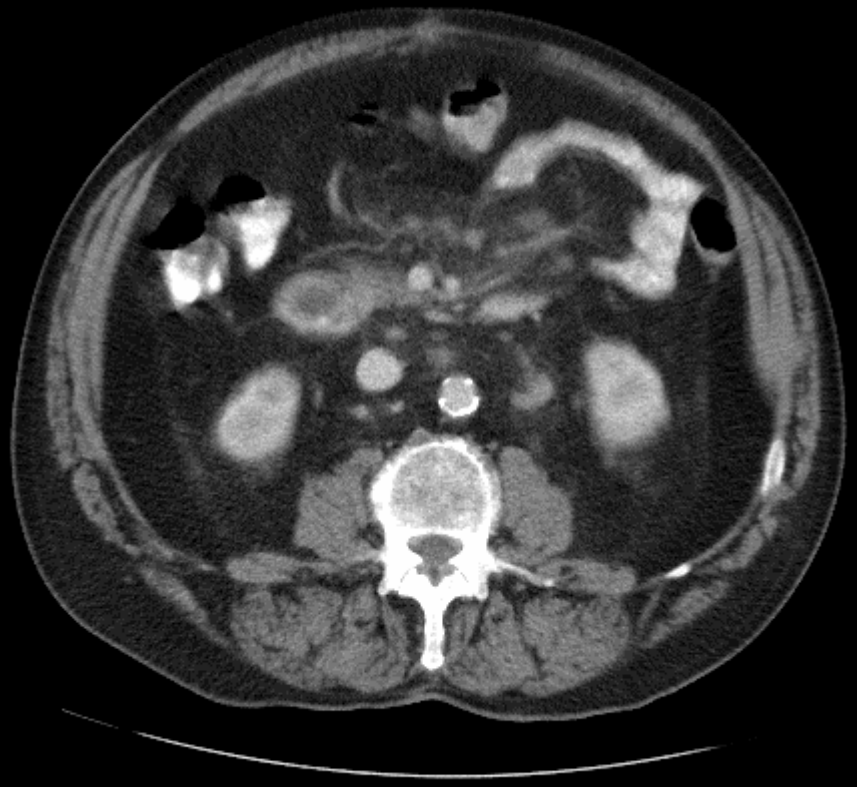
helical



Axial will be more streak like since the biggest difference in motion will be between where the tube started and ended the scan

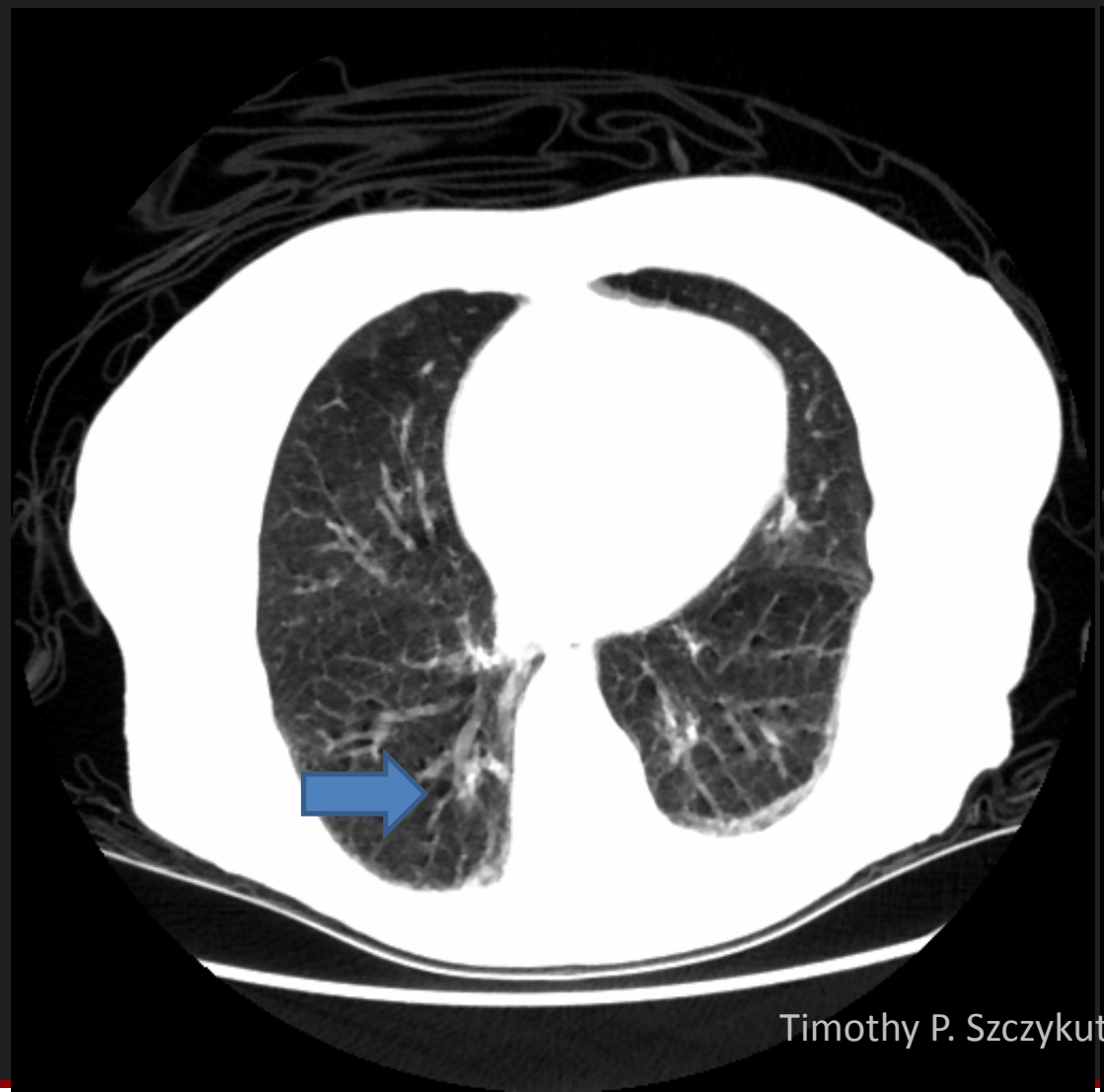
Non Iso-centric Artifacts: Motion

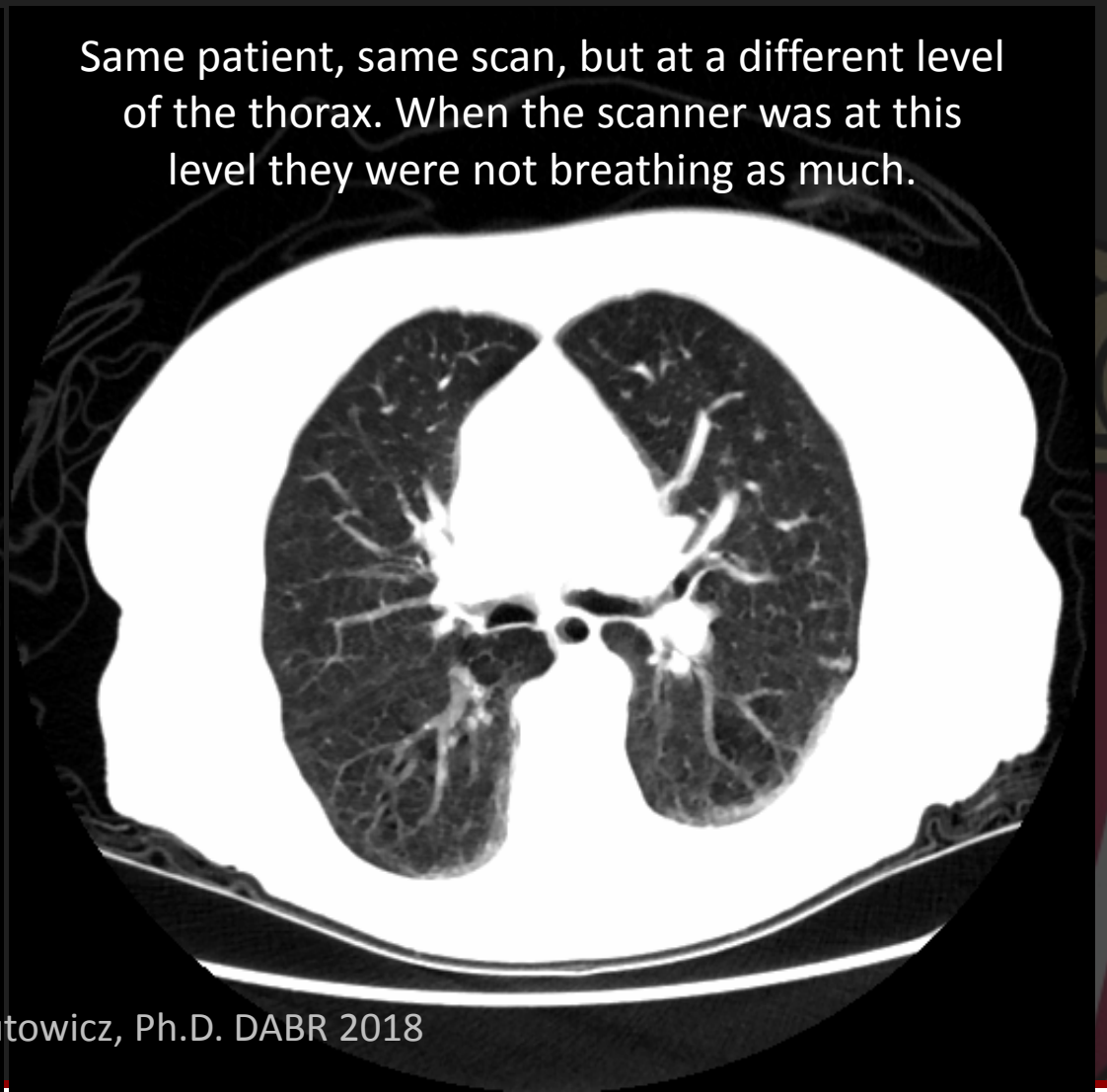
Abdomen scan with motion, look close, there is “double vision” going on



Same patient, different scan for reference

Non Iso-centric Artifacts: Motion

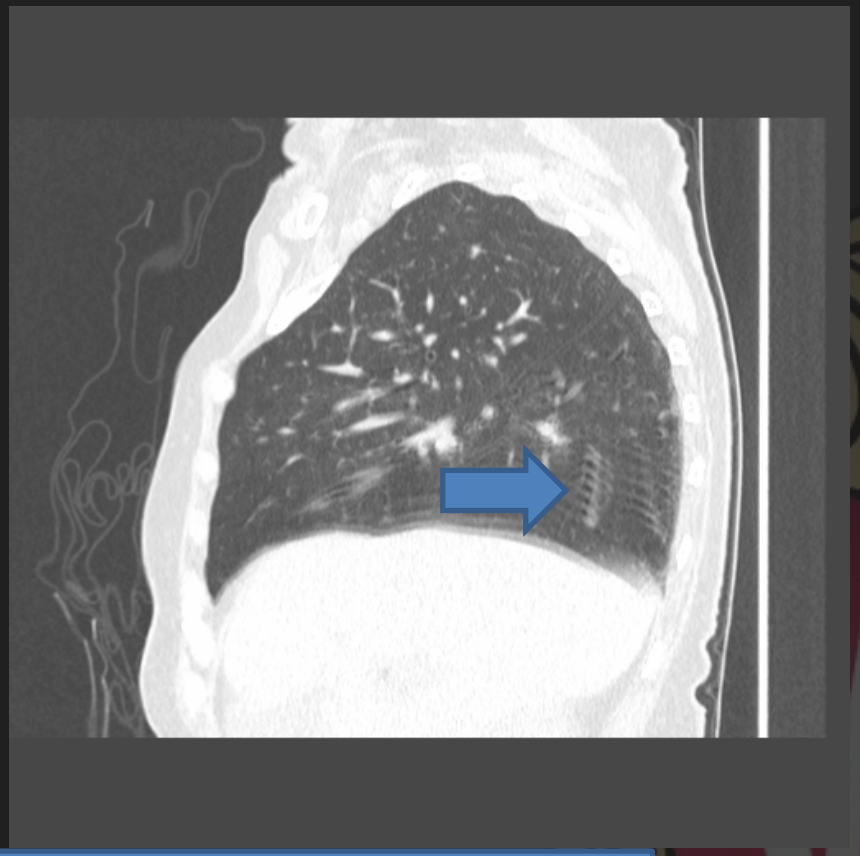




Same patient, same scan, but at a different level of the thorax. When the scanner was at this level they were not breathing as much.

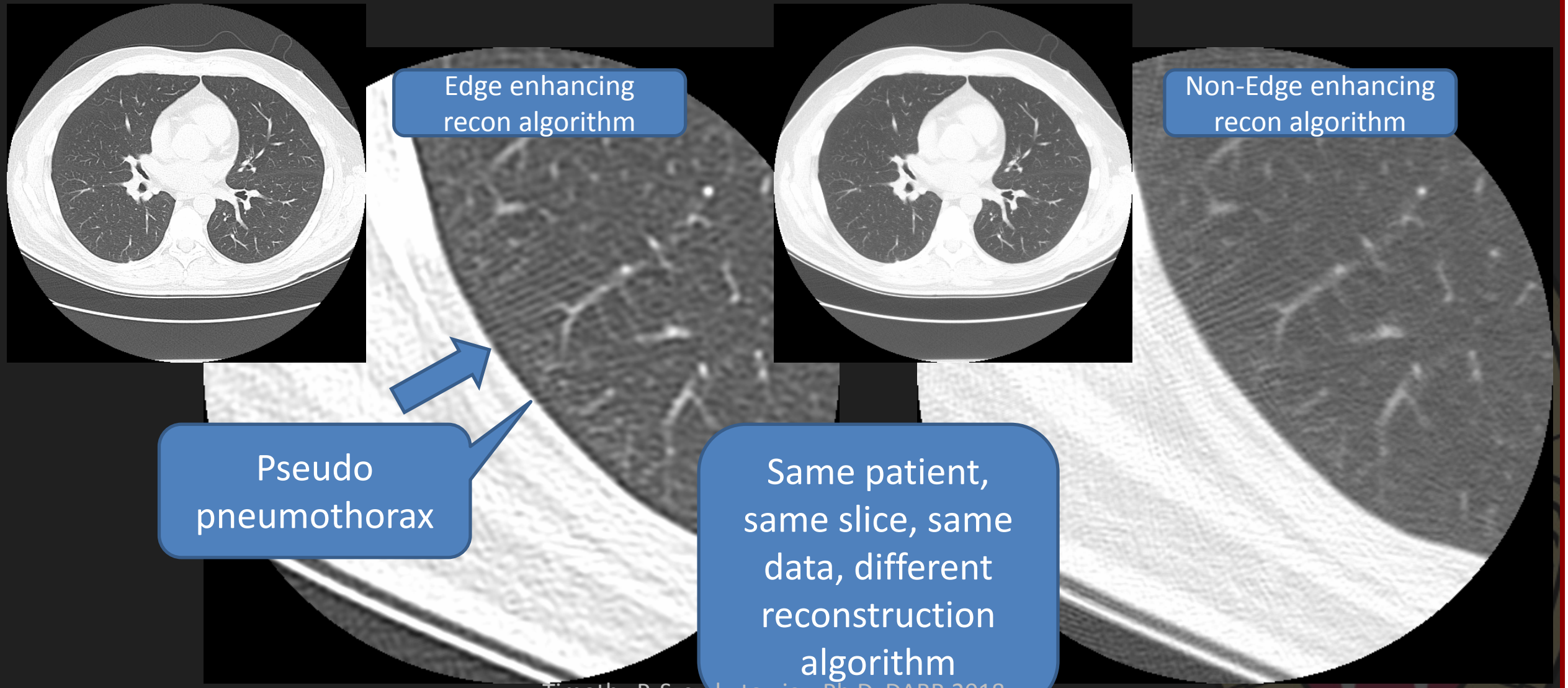
Non Iso-centric Artifacts: Motion

Same patient as last slide



Breathing artifacts on chest scans are best seen using the soft tissue kernel and a coronal or sagittal reformat plane with a lung window width and level

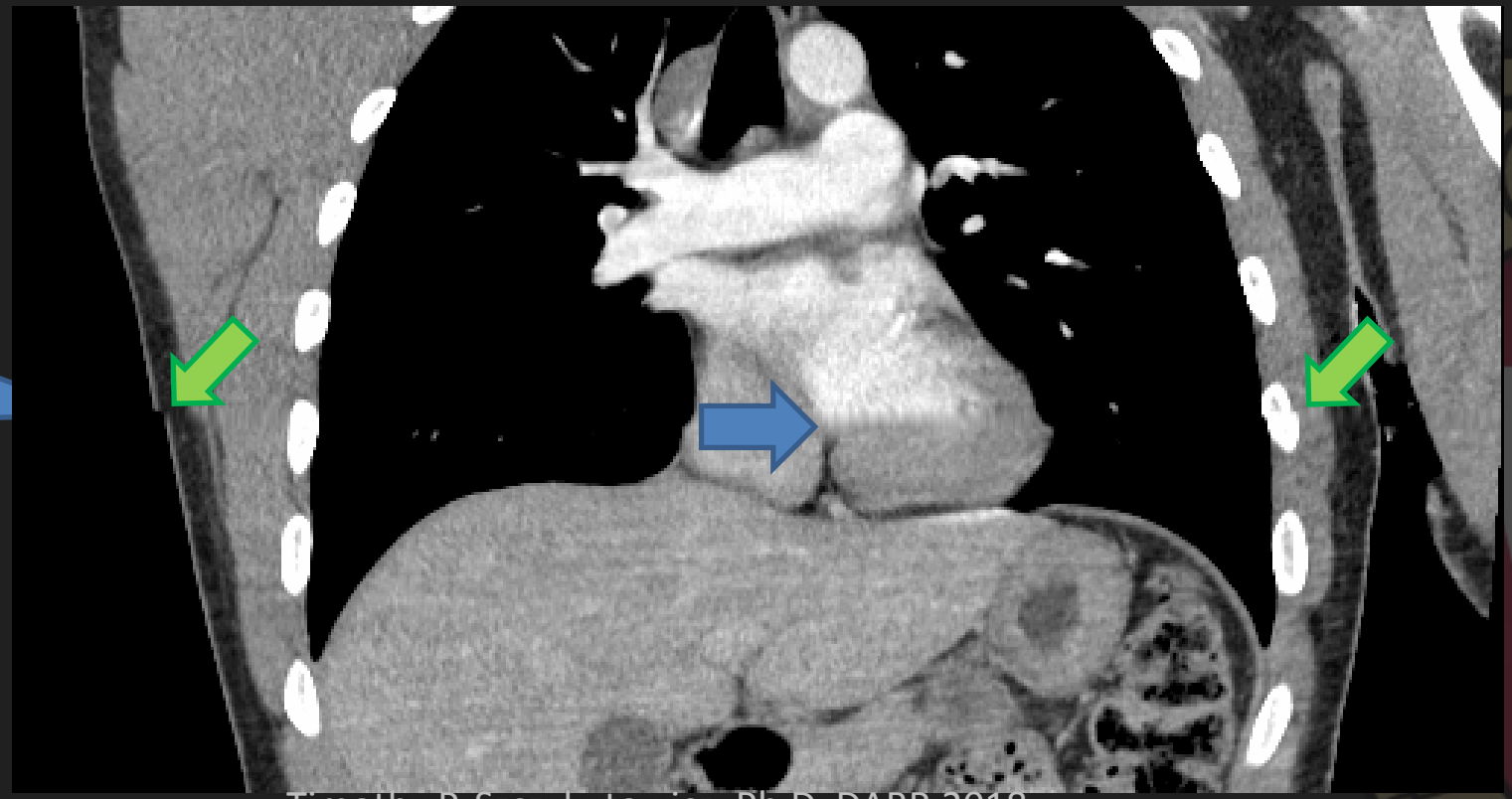
Non Iso-centric Artifacts: pseudo pathology



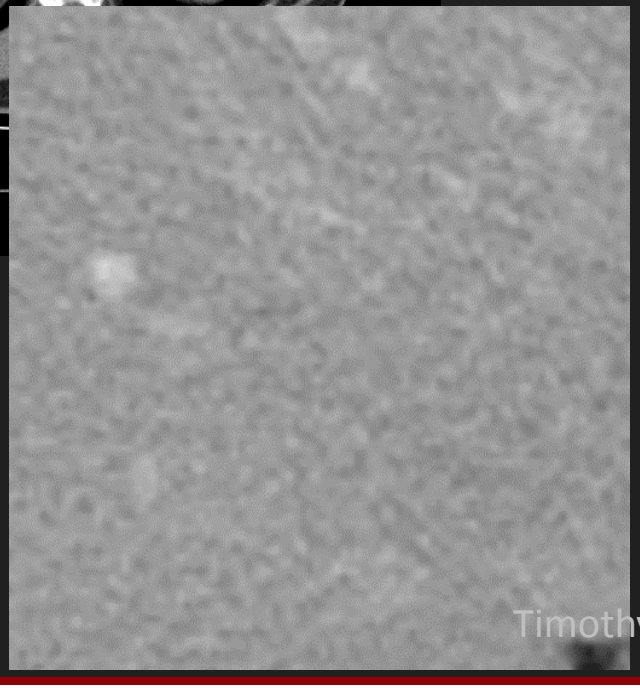
Non Iso-centric Artifacts: pseudo pathology

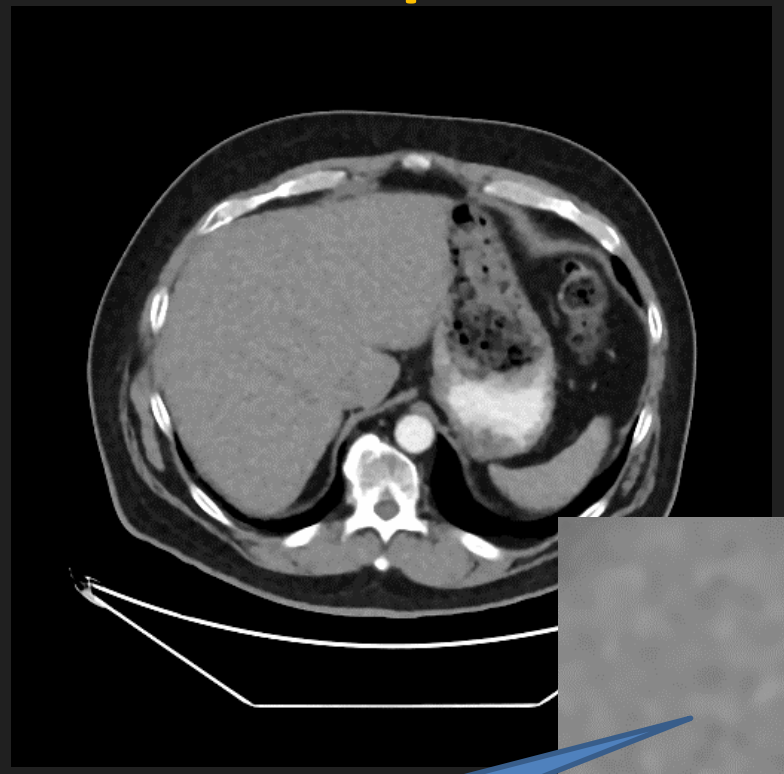
- Example of a “slab to slab” boundary artifact at the rib. This was called a fracture by a radiologist… (this was an outside UW study ☺)

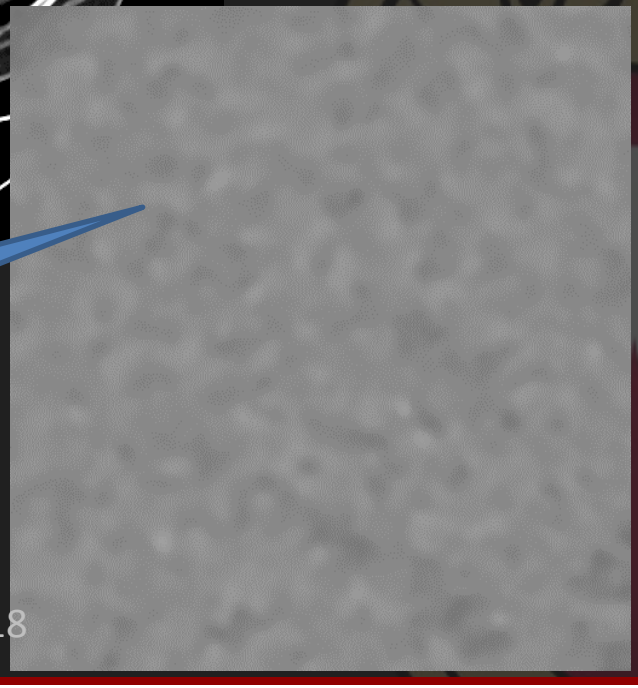
Easy to tell there is something wrong here, look at the skin line and the contrast in the heart



Non Iso-centric Artifacts: pseudo pathology



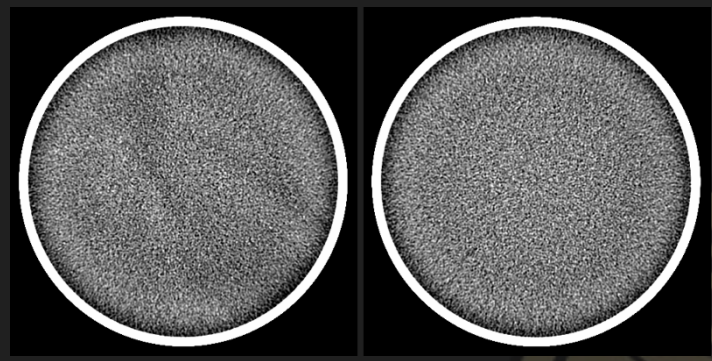




Pseudo lesions due to excessive de-noising

Non Iso-centric Artifacts: pseudo pathology - Air bubble in tube

These two scans were taken minutes apart, only 1 of them showed the artifact

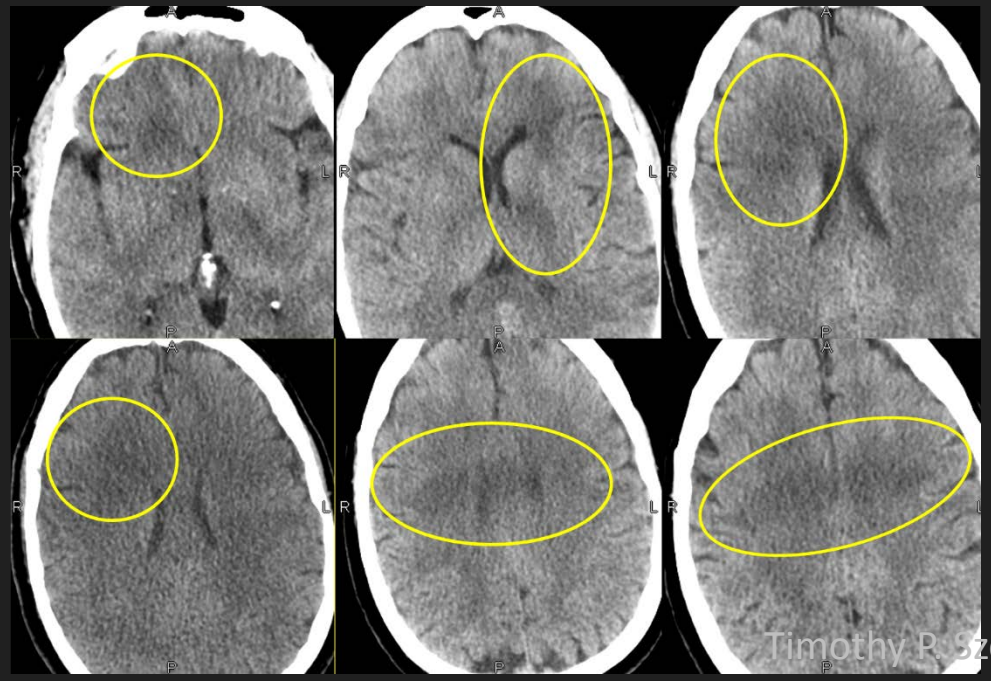


The worst artifact we have in MDCT in my opinion

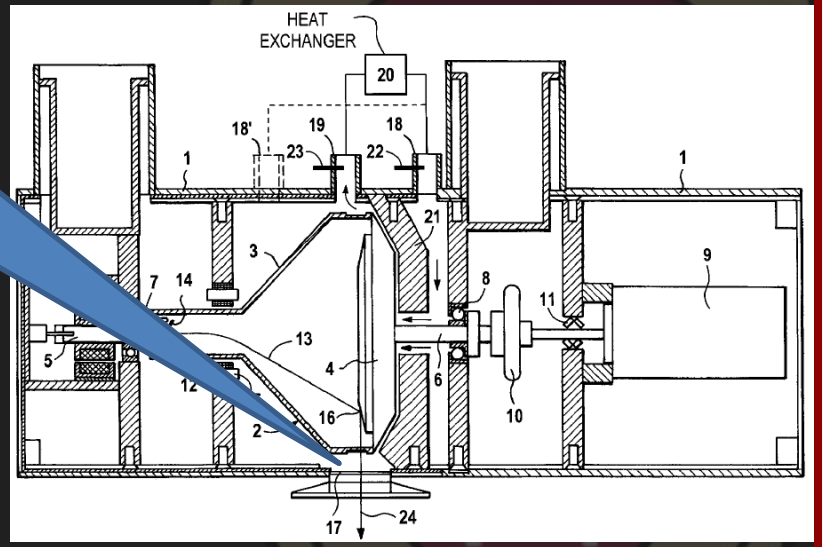
→ mimics pathology

→ not reproducible in patient

→ not reproducible in QA scans or in vendor scans



Bubbles get in the space between the tube (which is surrounded by oil) and the x-ray window



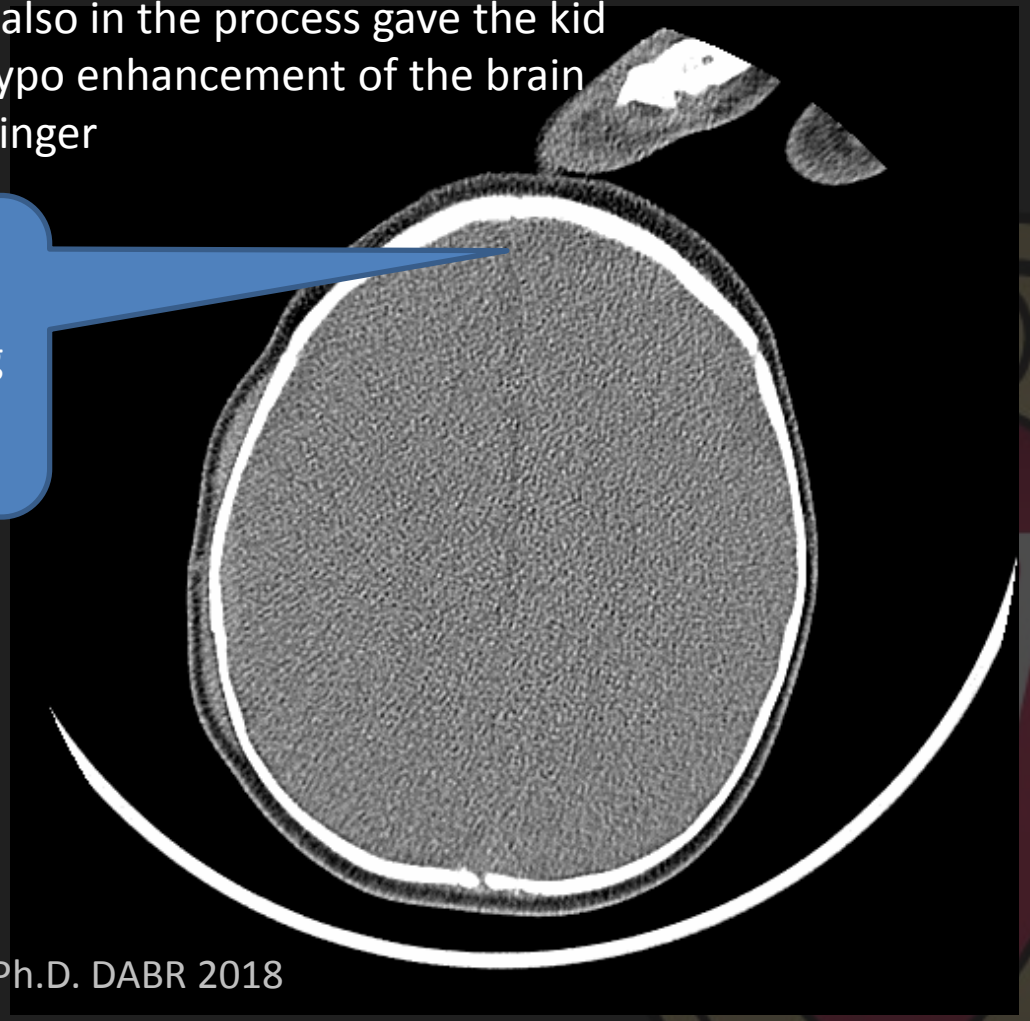
Siemens Patent 6,084,942

Non Iso-centric Artifacts: pseudo pathology

The first scan looked like this (suffered from motion artifact)

So they had someone hold the kids head down…but also in the process gave the kid a pseudo hypo enhancement of the brain under the finger

This is a beam hardening based artifact

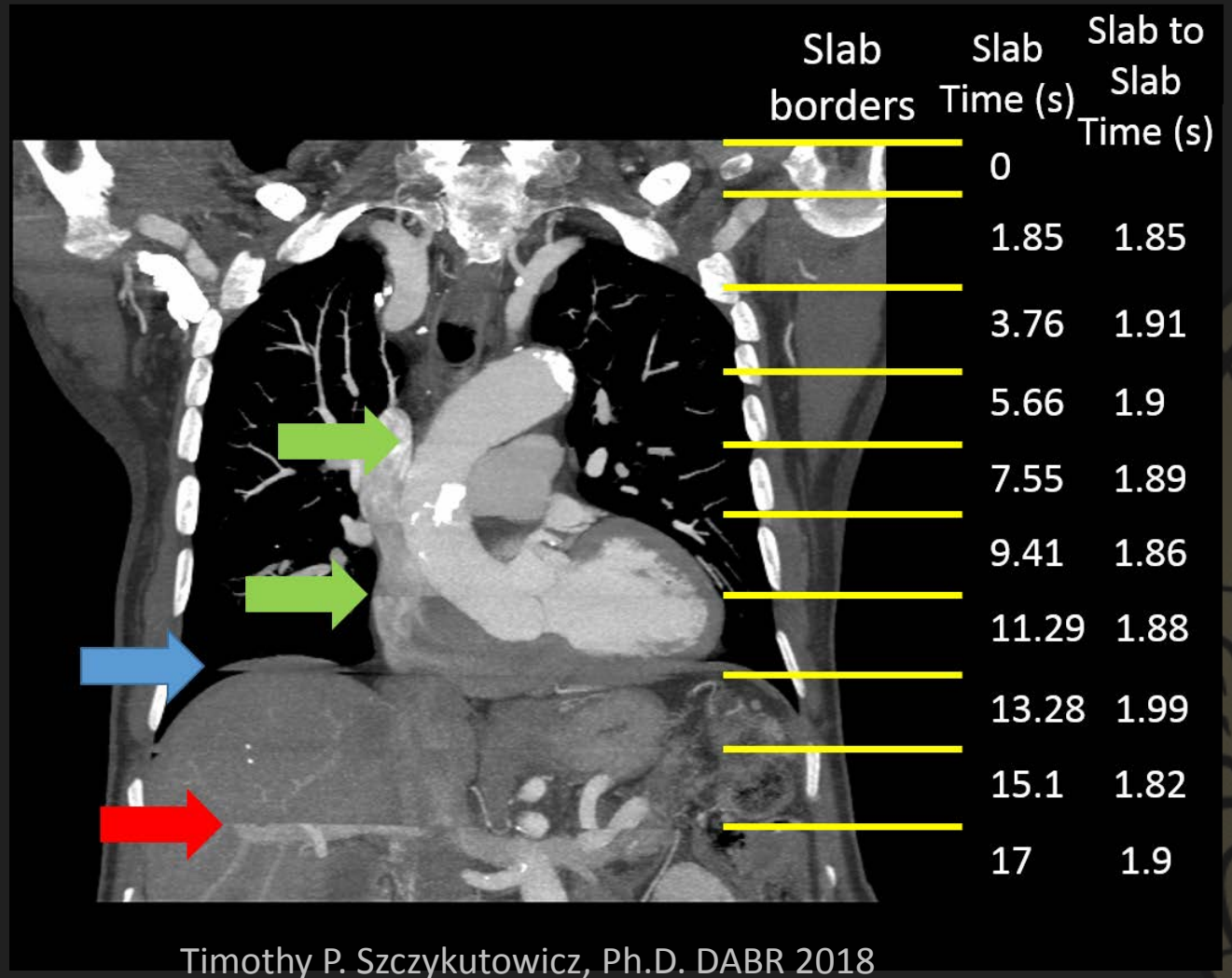


Non Iso-centric Artifacts: peristalsis

Hsieh, Jiang. "Computed tomography: principles, design, artifacts, and recent advances." Bellingham, WA: SPIE, 2009.

Non Iso-centric Artifacts: Patient motion during cardiac CT

This patient was imaged in prospective gating mode where the scanner did axial scan every 4 cm



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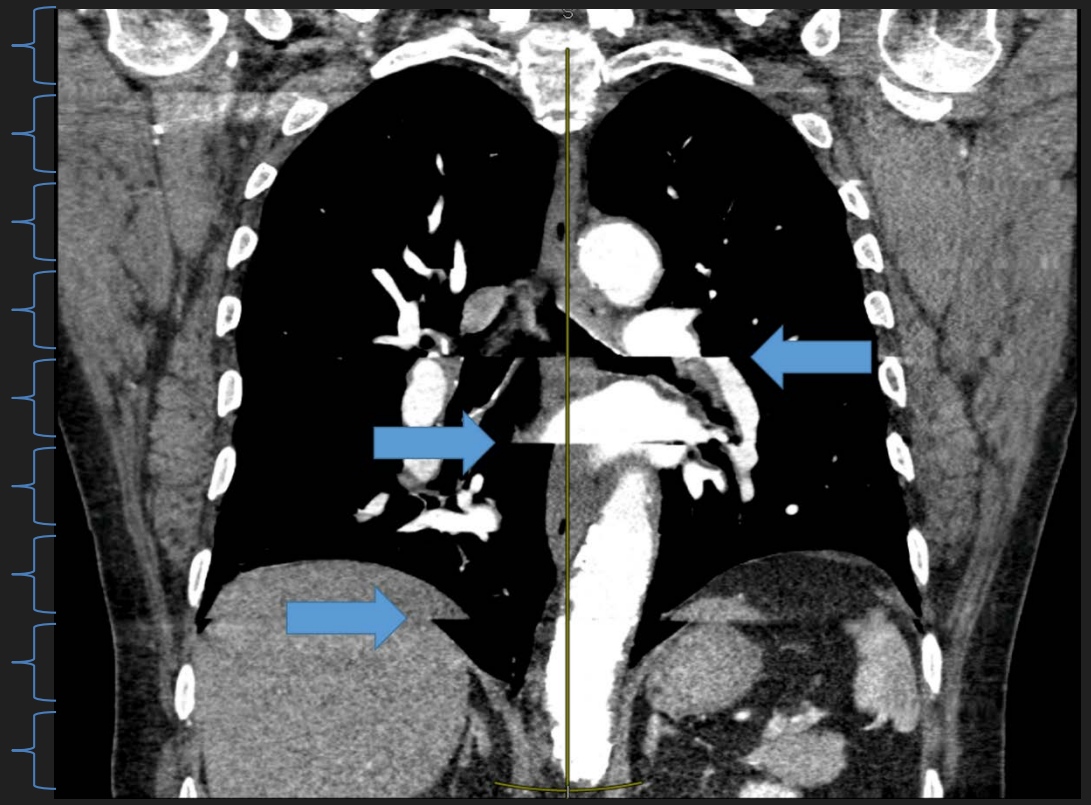
Green arrows show typical slab to slab artifacts.

Blue arrows show respiratory motion artifact at diaphragm.

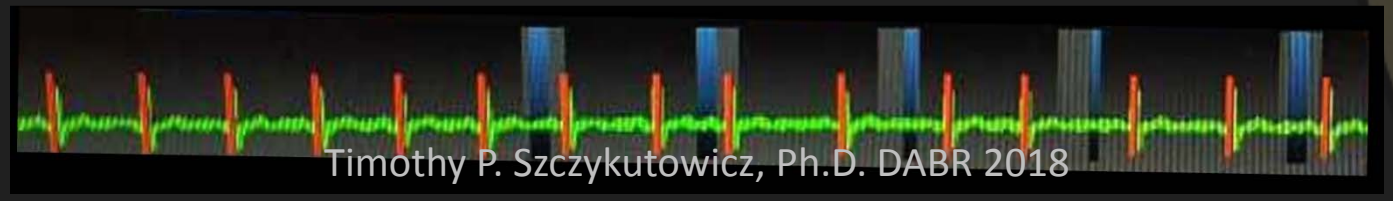
Red arrows show contrast dynamic artifact in liver vessel.

Non Iso-centric Artifacts: Patient motion during cardiac CT

This patient was imaged in prospective gating mode where the scanner did axial scan every 4 cm



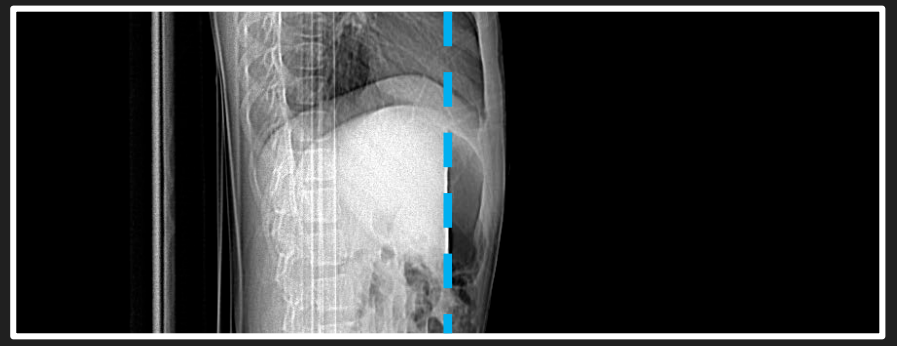
Patients HR was 70 average, but had a minimum of 51, a maximum of 79 and 3 irregular beats during the scan

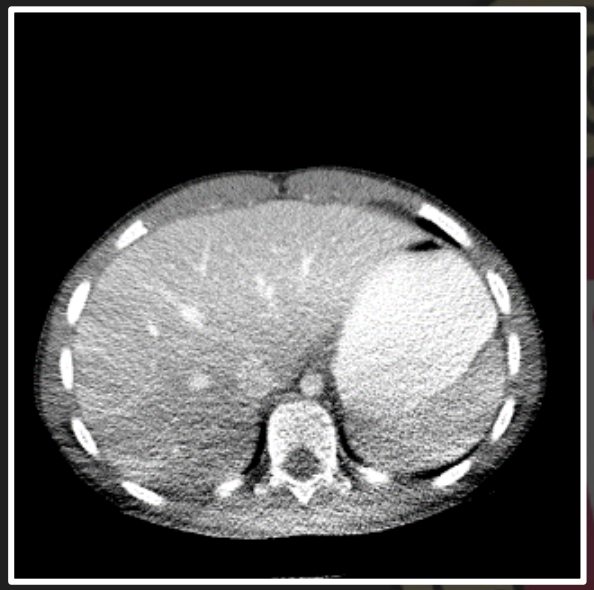


Non Iso-centric Artifacts: Poor Positioning

Resulting image has huge CT # non-uniformity in liver and a more than 2x change in image noise along the AP direction

Patient positioned too low in gantry

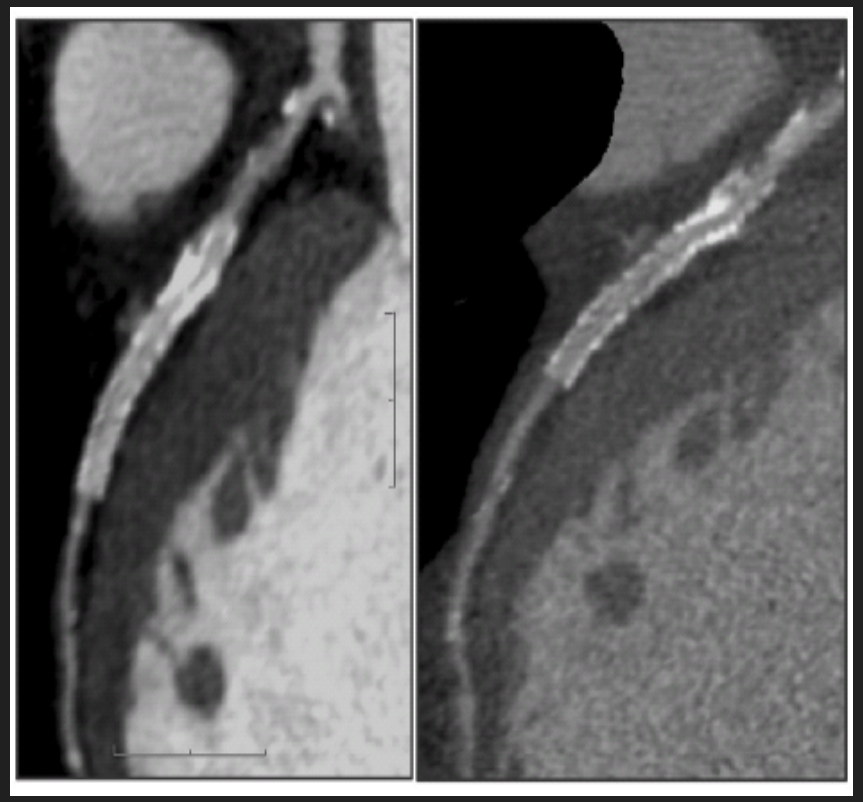




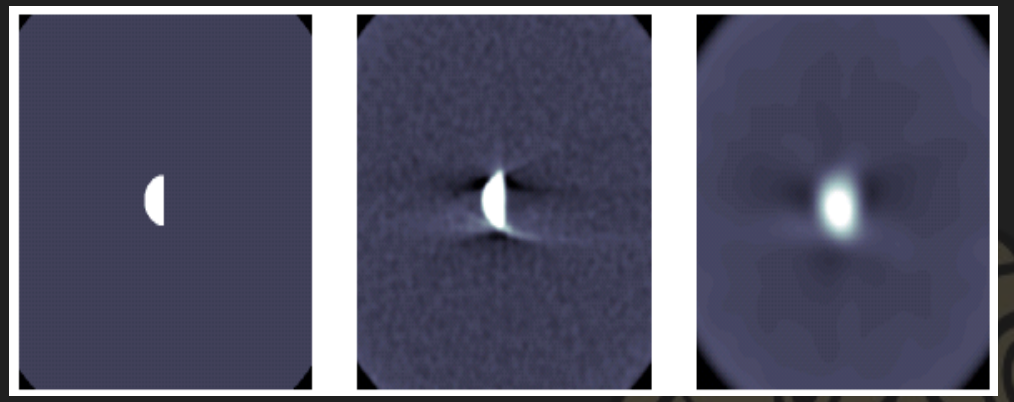
Szczykutowicz, Timothy P., Andrew DuPlissis, and Perry J. Pickhardt. "Variation in CT Number and Image Noise Uniformity According to Patient Positioning in MDCT." *American Journal of Roentgenology* 208.5 (2017): 1064-1072.

Non Iso-centric Artifacts: Calcium blooming

Low resolution→ calcium gets blurred→ calcium looks bigger than it "really is"



Hsieh, Jiang. "Computed tomography: principles, design, artifacts, and recent advances." Bellingham, WA: SPIE, 2009.



Ideal calcium shape

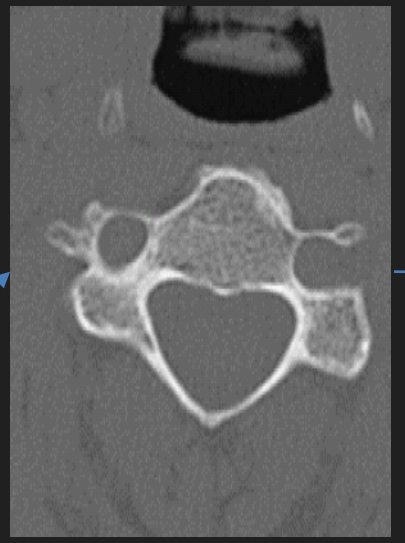
Acquired with ¼ nominal detector size (0.19 mm)

Acquired with nominal detector size (0.77 mm)

Non Iso-centric Artifacts: Pixilation

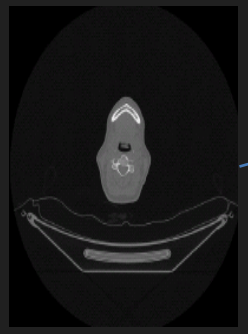
You scan and reconstruct an image with an 18 cm RFOV

Doc zooms in to inspect vertebrae

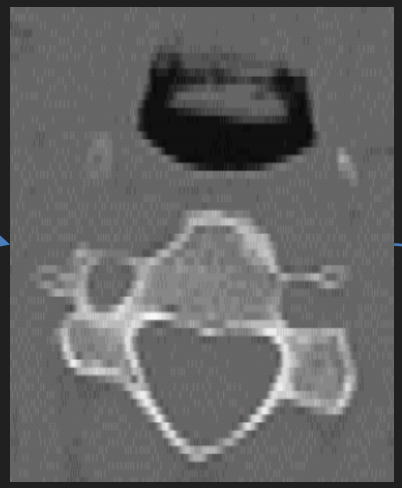


In this case, we are dealing with 18 cm / 512 = 0.35 mm pixels that support the resolution our rad desires

You scan and reconstruct an image with an 50 cm RFOV

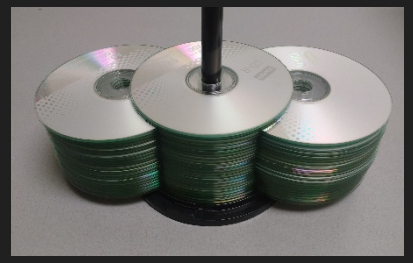


Doc zooms in to inspect vertebrae

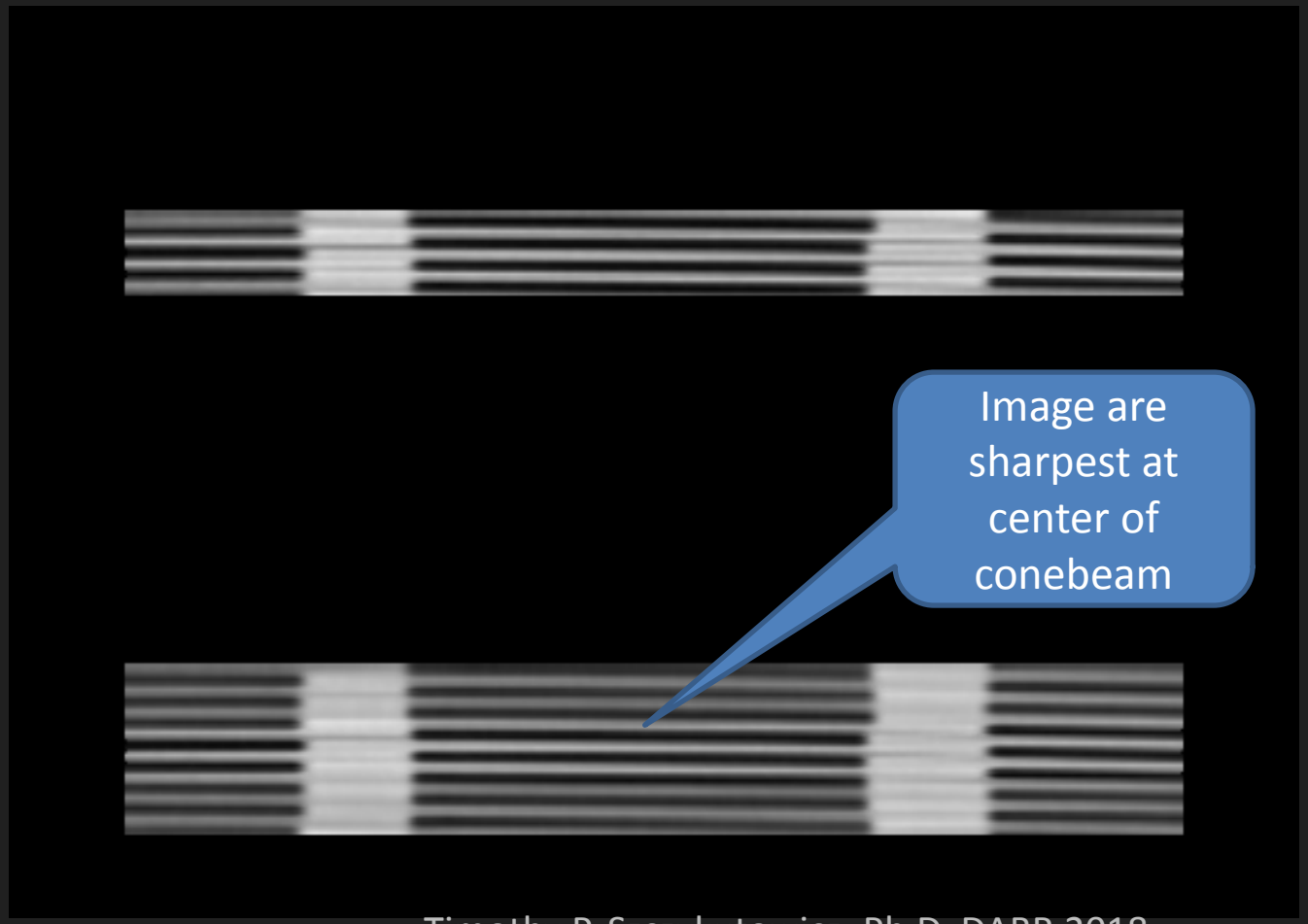


In this case, we are dealing with 50 cm / 512 = 0.98 mm pixels that do not support the resolution our rad desires

Non Iso-centric Artifacts: Cone beam artifacts



"CD Phantom"

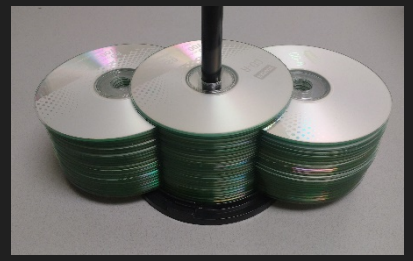


1 cm beam

2 cm beam

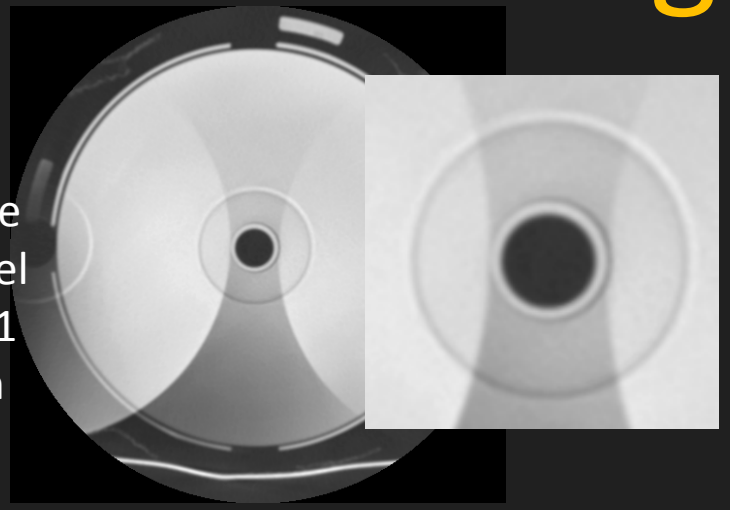
Not good for long bone/spine/EAC imaging…

Non Iso-centric Artifacts: Low versus high pitch

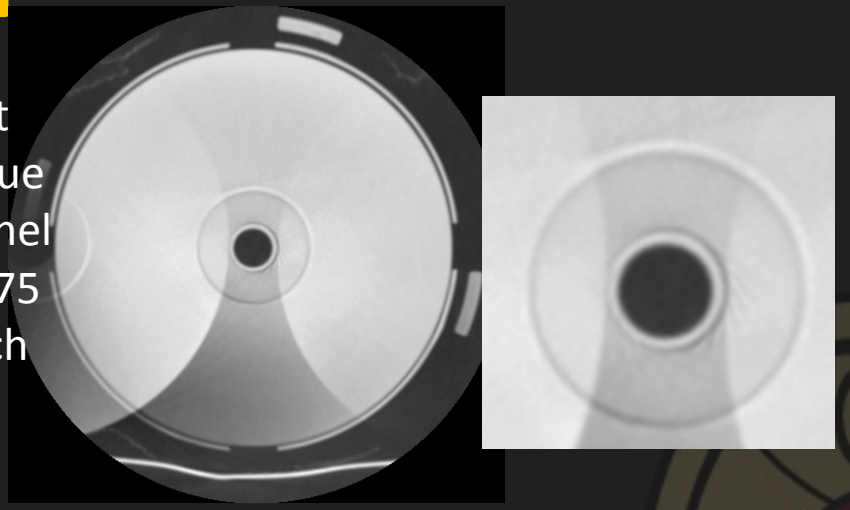


"CD Phantom"

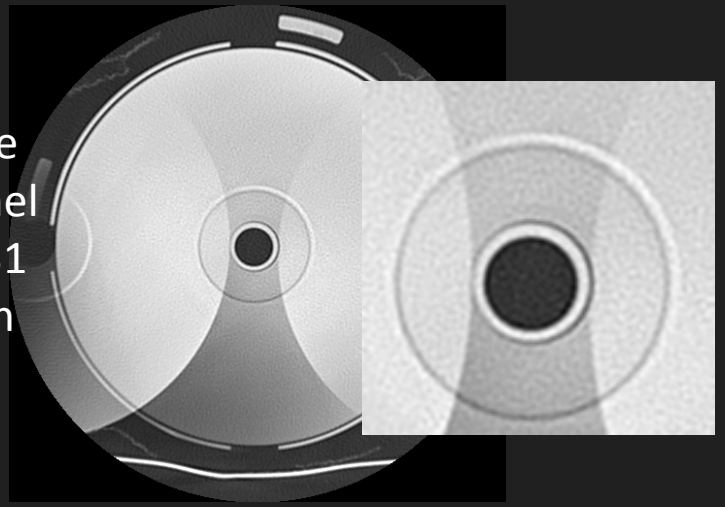
Soft tissue kernel 0.531 pitch



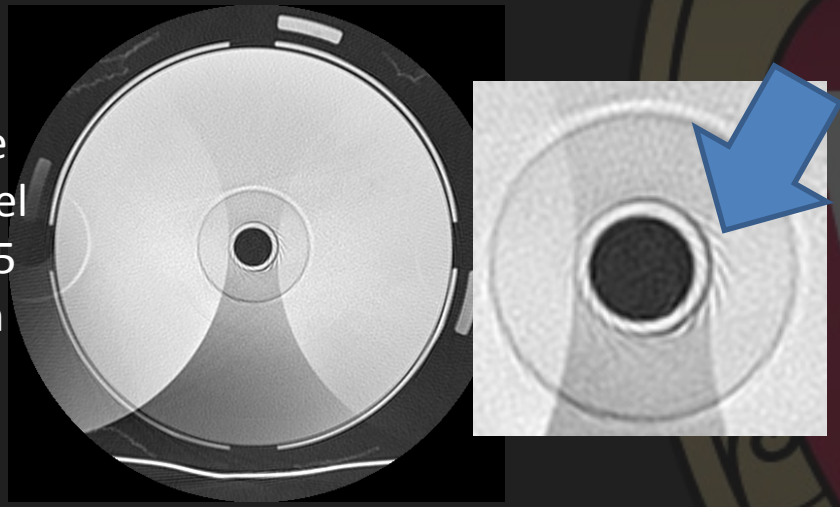
Soft tissue kernel 1.375 pitch



Bone kernel 0.531 pitch



Bone kernel 1.375 pitch



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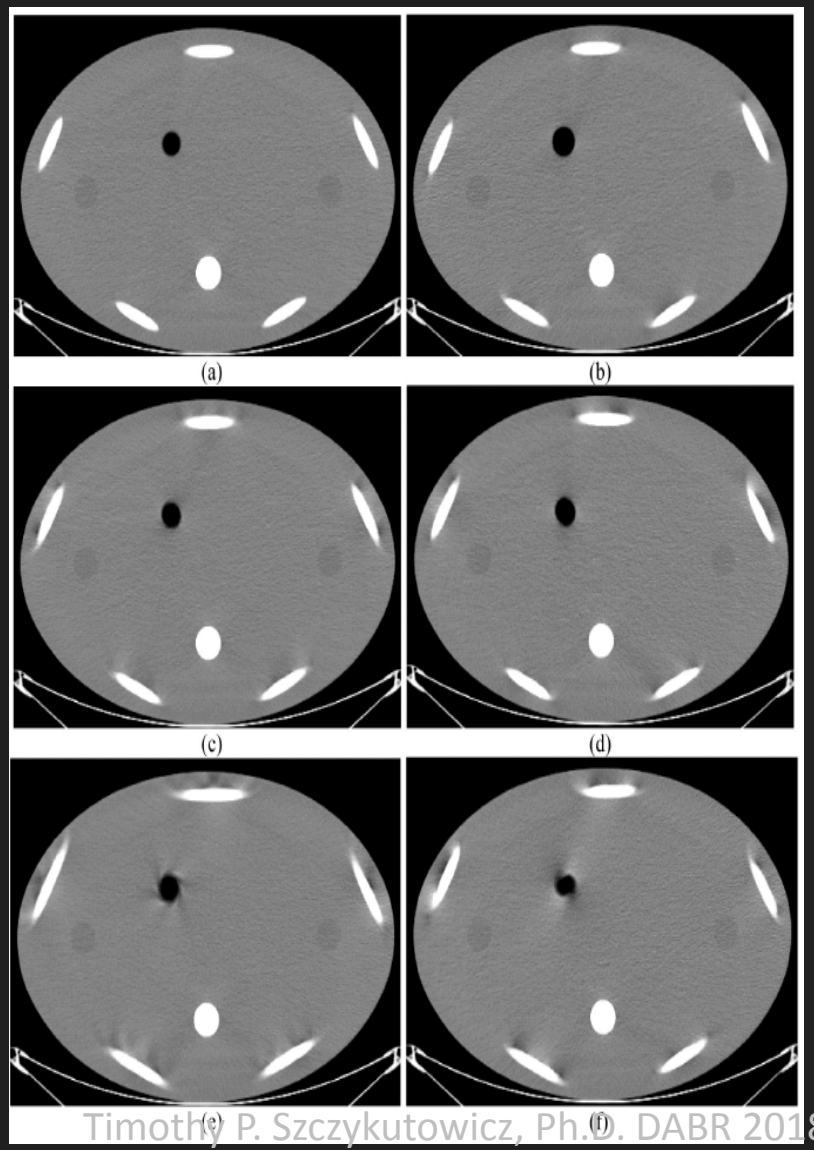
Non Iso-centric Artifacts: Windmill

Axial mode



Helical, pitch 1, single slice

Helical, pitch 0.75, 4 slice

Helical, pitch 1.5, single slice

Helical, pitch 1.5, 4 slice

Helical, pitch 2, single slice

Hard to show without a movie, but as you scroll through PACS the artifacts twirl around like a windmill

Hsieh, Jiang. "Computed tomography: principles, design, artifacts, and recent advances." Bellingham, WA: SPIE, 2009.

Outline

- Overview of CT Scanner Parts (what can break ☺)
- Iso-centric Artifacts
- Iso-centric Artifacts: how to find isocenter
- Non Iso-centric Artifacts
- General tips for troubleshooting Artifacts
- QA for Artifact Detection

General tips for troubleshooting Artifacts

- Some artifacts may only show up periodically as you scroll through a stack of images!
  - Think bad detector row (iso-centric example) or tape on roller (non iso-centric example)

To rule out artifact versus pathology scroll through the image set and see if the problem is present any where else

To rule out artifact versus pathology scroll through the daily QA images and see if the QA tech missed something

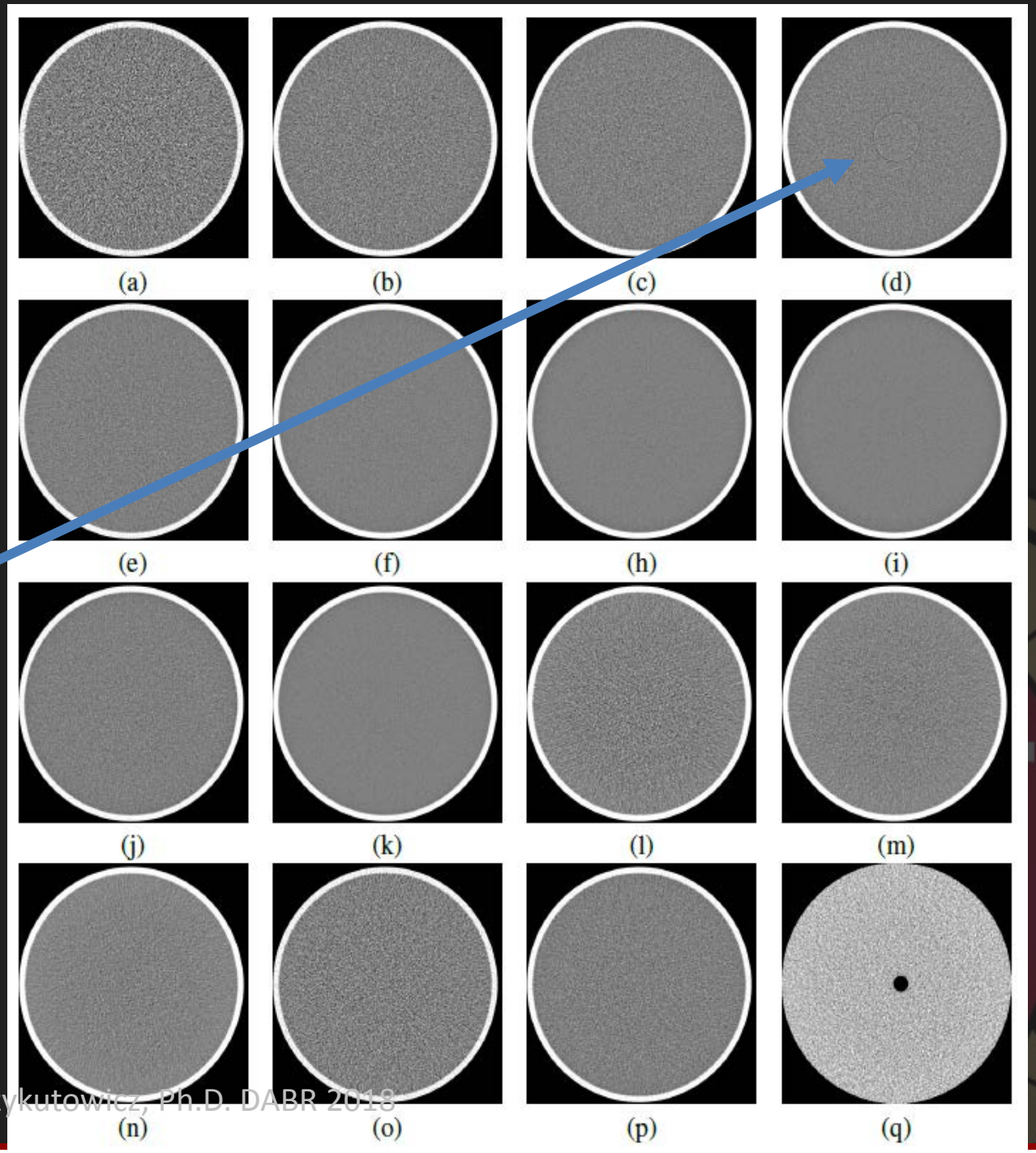
Our techs send our QA images to PACS every day to facilitate this

General tips for troubleshooting Artifacts

- Many times artifacts only show up in 1 set of acquisition parameters for 1 size of patient
  - This can make diagnosing a faulty scanner a very difficult task
  - The following two slides show 2 different examples of situations where we noticed an artifact and had time to do some phantom scanning.
  - Our phantom scanning shows how the artifact was only observable in 1 mode!

General tips for troubleshooting Artifacts

- All of these scans use different combinations of: scan mode (axial or helical), pitch, beam collimation, slice thickness, mAs, phantom size, bowtie
- An artifact is only seen on 1 of them!



General tips for troubleshooting Artifacts

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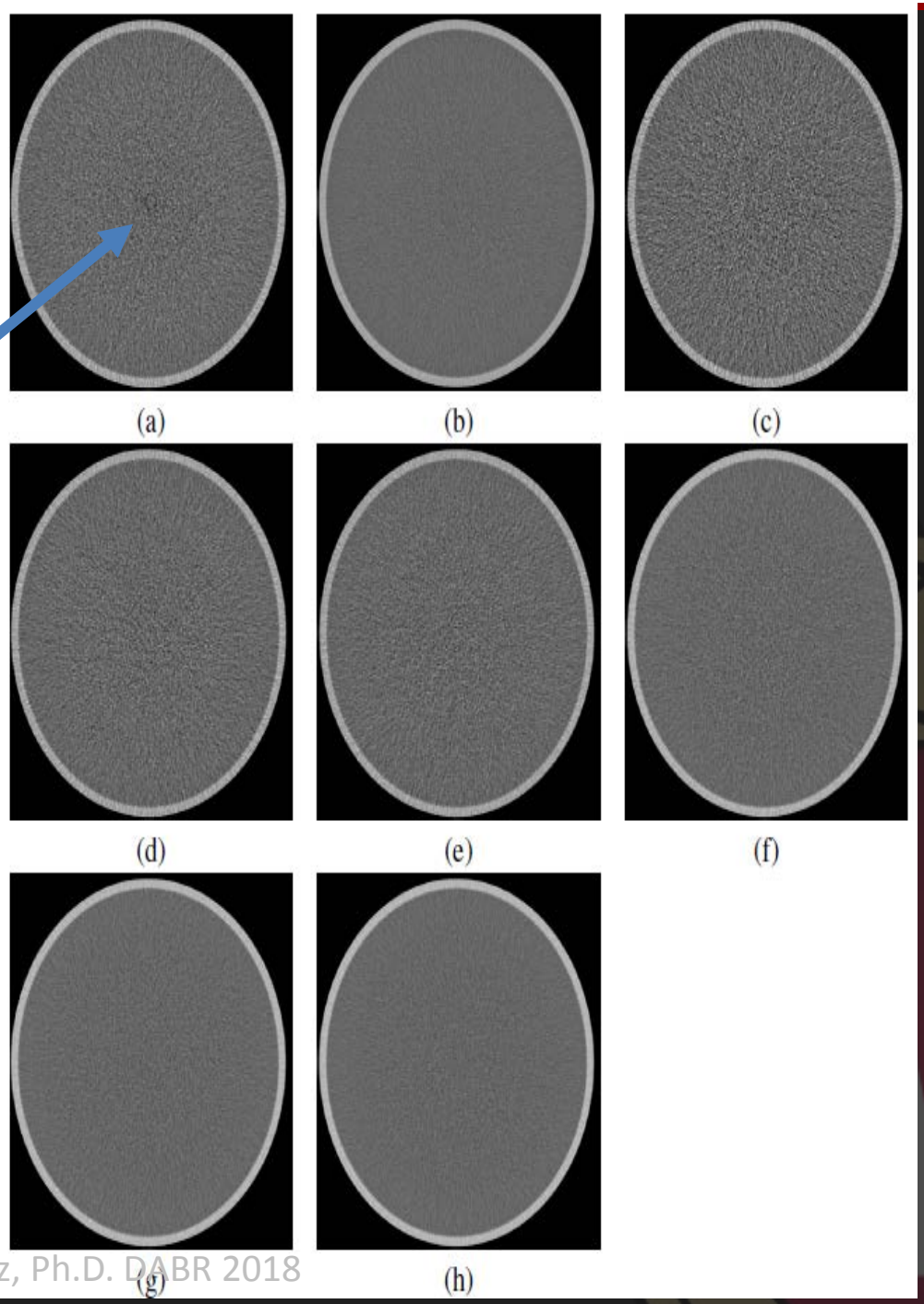


General tips for troubleshooting Artifacts

- The presence or absence of an artifact in a scan mode can tell us what is wrong with the scanner!
- The difference between these two scenarios is hours of scanner down time for repairs (case 1 requires taking apart the scanner and cleaning/replacing a filter module and then a full re-calibration, case 2 requires a re-calibration)
  - If an artifact is only present when 1 size bowtie filter is selected for **all** scan modes and kVs, then there is probably a dirt or a scratch on the filter surface
  - If an artifact is only present when 1 size bowtie is selected for 1 kV for **1 scan mode** then there is probably a problem with the calibration for the scanner in only that mode

General tips for troubleshooting Artifacts

- Realize that the vendor does a calibration scan to get calibration values for every possible combination of acquisition parameters
- This is why it takes the field engineer hours to do a “full calibration”
- Anything and everything needs to be calibrated…and they all usually will change with temperature and age…
  - Collimator locations, focal spot location, each detector’s offsets, each detectors gain, each kV station, each tube current, etc.

General tips for troubleshooting Artifacts

See an artifact on a patient or QA scan?

Re-scan the QA phantom or look at other patient scans, do you still see the artifact?

Keep all scan parameters fixed but change the scan mode from axial to helical or helical to axial

Do you see it for all kVs?

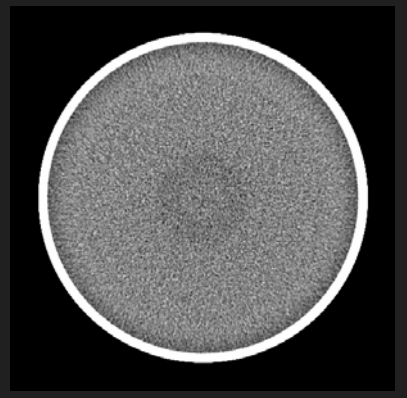
Do you see it for all bowtie filters?

Does it go away at high or low mAs?

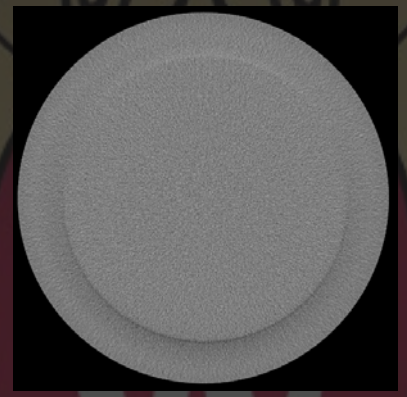
Do you see it for all detector configurations and or all image slices?

Constantly make a hypothesis on what is causing the artifact and run tests to confirm/deny that hypothesis, if you randomly scan the phantom you will just be wasting scanner time

Usually more mild artifacts only show up in a subset of these scan combinations

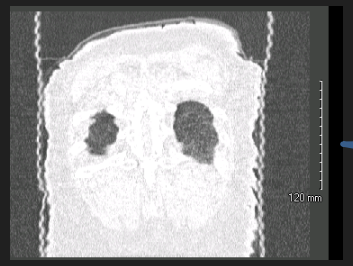


Usually only pretty bad detector artifacts show up for all of these combinations



General tips for troubleshooting Artifacts

- Always look for the artifact in both the patient AND table/couch
  - If you see it in both, it is likely an issue with the scanner
  - If you see it only in the patient, it likely was an issue with scanning just that patient

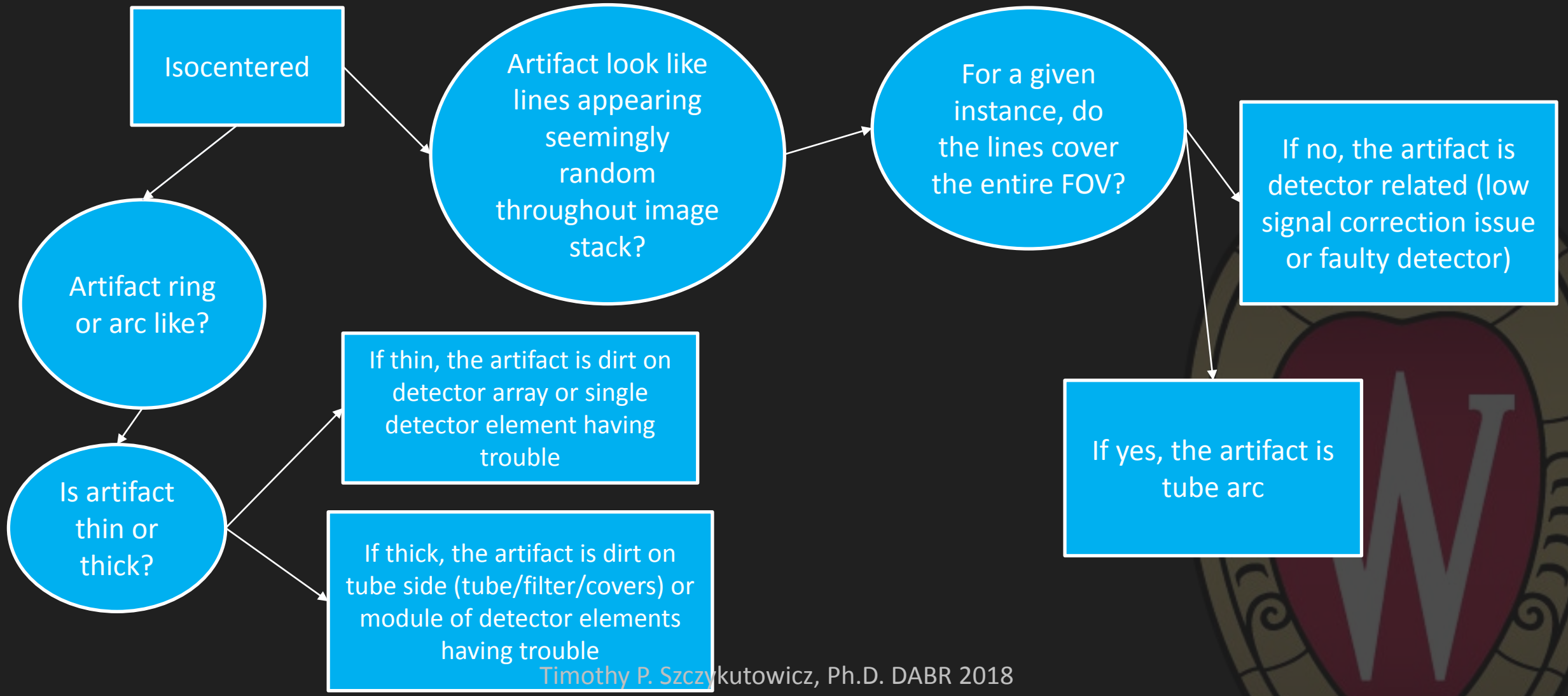


Remember the mis calibrated iso-center issue, we saw artifacts in both the couch and patient

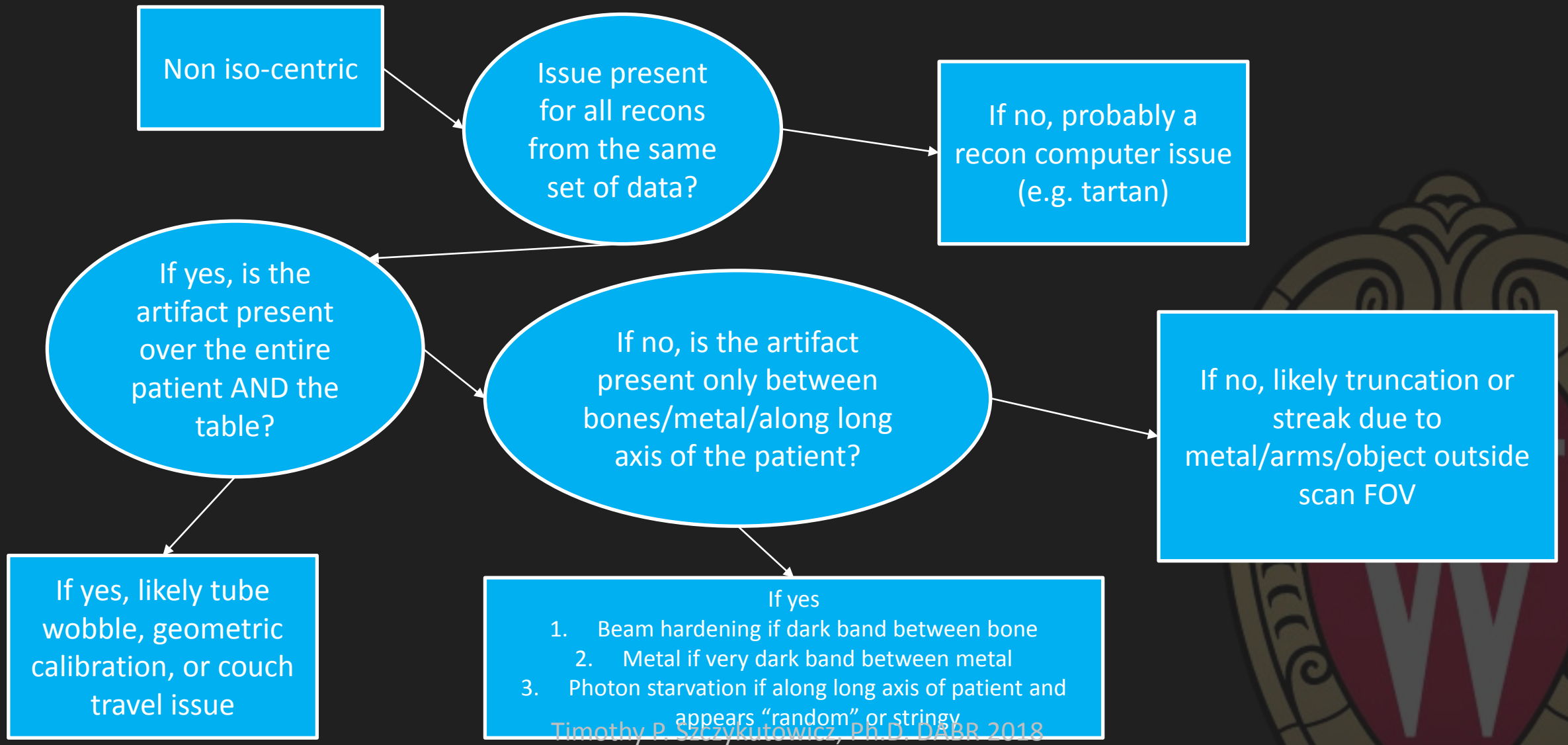
- Always view more than one reconstruction plane/slice thickness at different window widths and levels

Remember the example of the chest motion artifacts

General tips for troubleshooting Artifacts



General tips for troubleshooting Artifacts



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QA for Artifact Detection

- The American College of Radiology (ACR) mandates:
  - Daily quality assurance programs which check for artifacts
    - These programs will not catch all possible image artifacts!
  - From the ACR guidelines “Clinically severe artifacts must be addressed before the scanner is used. Subclinical artifacts may be carefully monitored, and service might be scheduled to avoid impacting the clinical exam schedule. Artifacts must be addressed within a maximum period of 30 days.”

We may tolerate a slight ring artifact for a radiation therapy simulator scan…but not for a brain scan. This is what the ACR means by “avoid impacting the clinical exam schedule”…certain scans can tolerate slight artifacts and get moved onto the faulty scanner until it is fixed.

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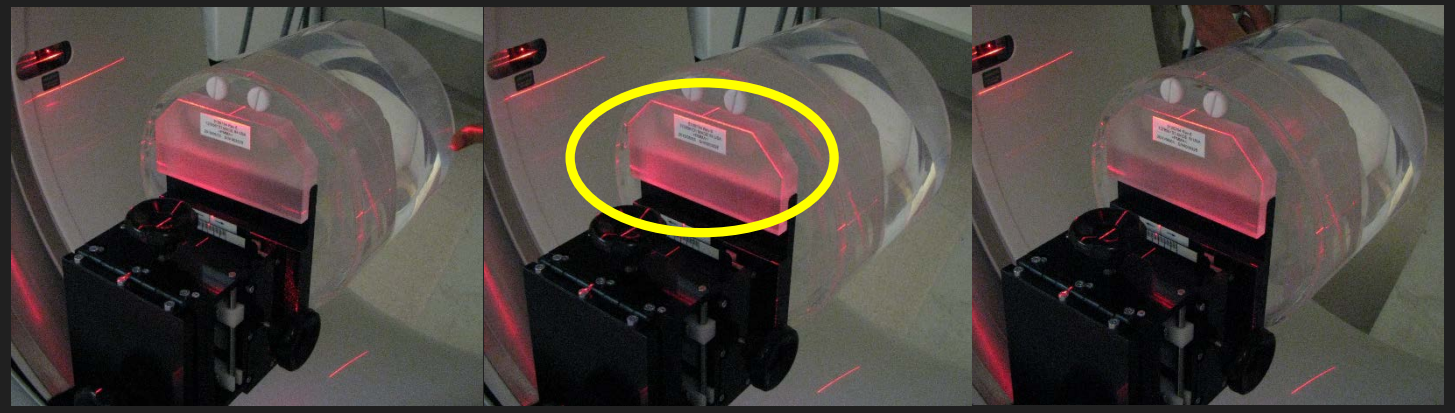
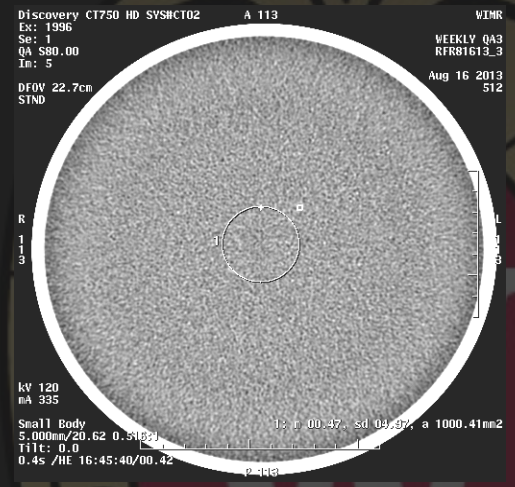
QA for Artifact Detection

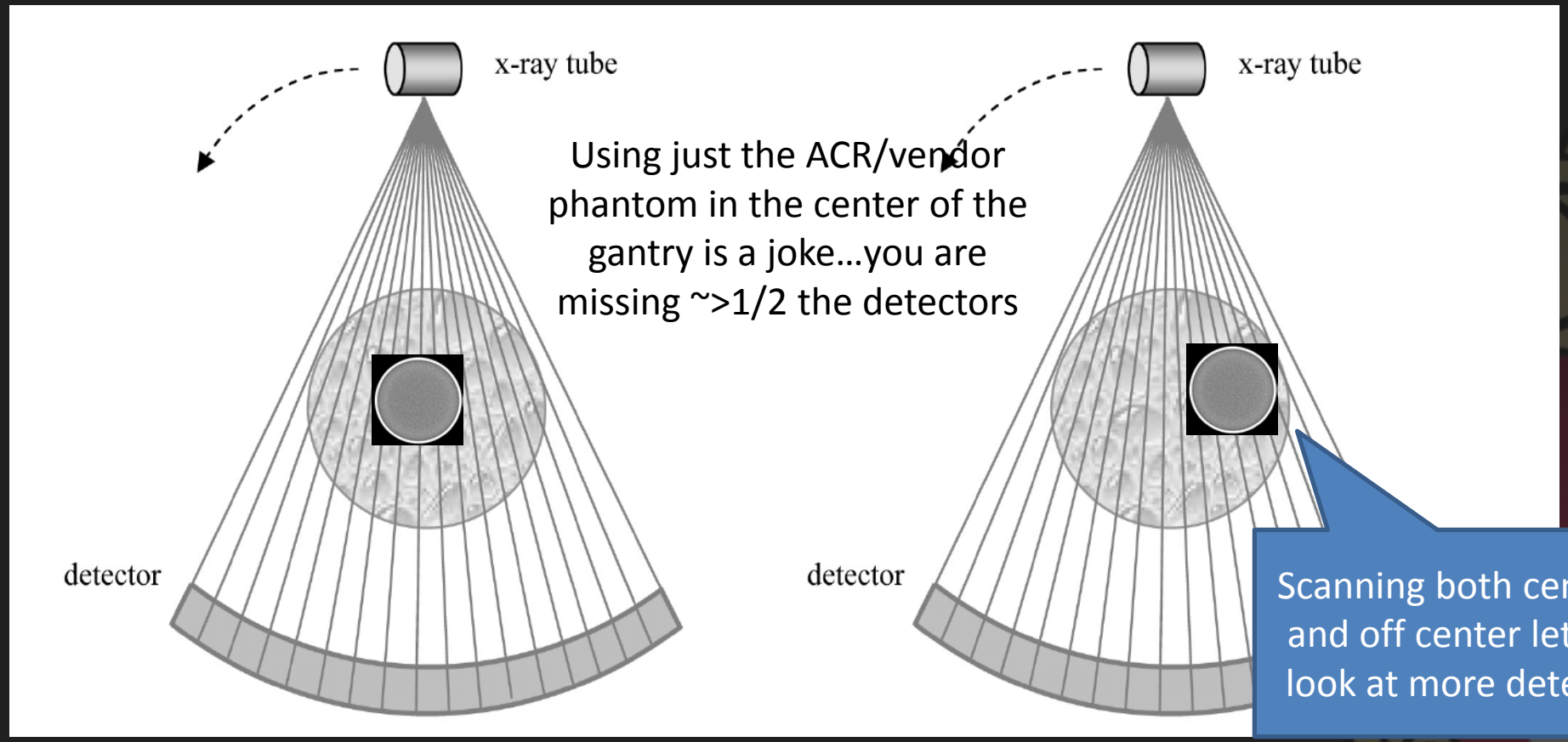
- Water phantom is positioned inside the scanner





- Mean CT #, noise, and the presence of artifacts is recorded from axial image slices

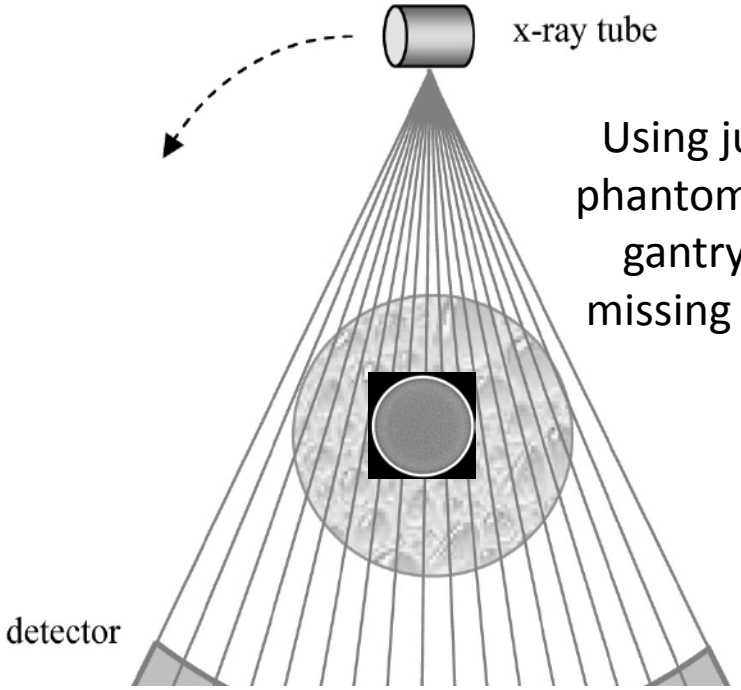
QA for Artifact Detection



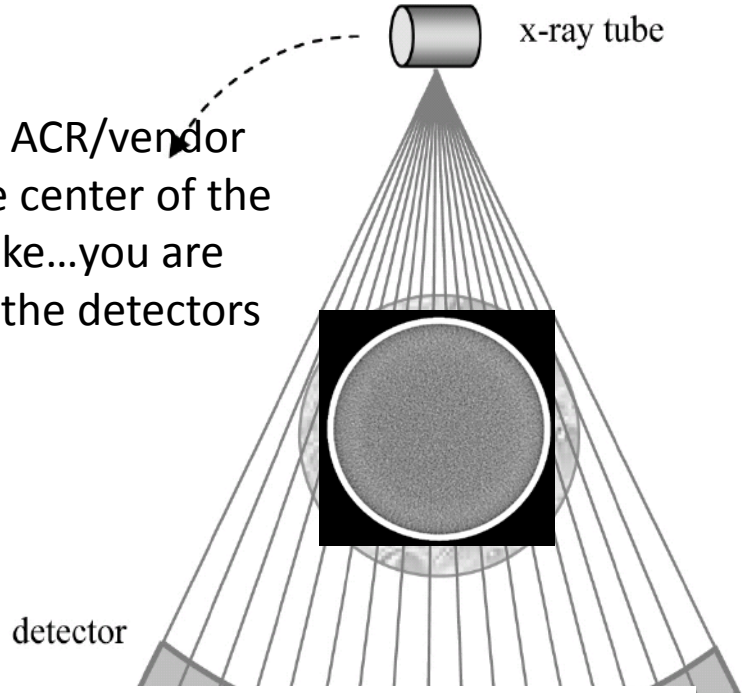
Using just the ACR/vendor phantom in the center of the gantry is a joke…you are missing ~>1/2 the detectors

Scanning both centered and off center lets you look at more detectors

QA for Artifact Detection



Using just the ACR/vendor phantom in the center of the gantry is a joke…you are missing ~>1/2 the detectors



I personally use a wide diameter 48 cm, or a 32 cm phantom off set in order to catch all detectors for artifact checking

QA for Artifact Detection

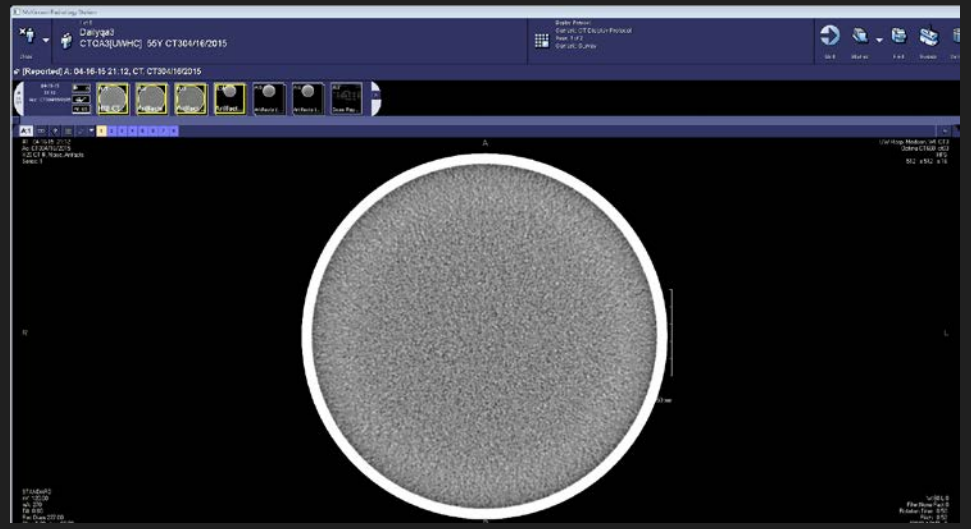
Phantom	Phantom Location	Scan Mode	kV	mA	Gantry period (s)	Slice thickness (mm)	Kernel	Artifacts?
GE QA Phantom	centered	Axial	80	260	1	5mm/0.625mm	standard	No
GE QA Phantom	centered	Axial	100	260	1	5mm/0.625mm	standard	No
GE QA Phantom	centered	Axial	120	260	1	5mm/0.625mm	standard	No
GE QA Phantom	centered	Axial	140	260	1	5mm/0.625mm	standard	No
GE QA Phantom	centered	0.516 pitch	120	260	1	5mm/0.625mm	standard	No
GE QA Phantom	centered	0.984 pitch	120	260	1	5mm/0.625mm	standard	No
GE QA Phantom	centered	1.375 pitch	120	260	1	5mm/0.625mm	standard	No
32 cm CTDI	centered	Axial	80	260	1	5mm/0.625mm	standard	No
32 cm CTDI	centered	Axial	100	260	1	5mm/0.625mm	standard	No
32 cm CTDI	centered	Axial	120	260	1	5mm/0.625mm	standard	No
32 cm CTDI	centered	Axial	140	260	1	5mm/0.625mm	standard	No
32 cm CTDI	centered	0.516 pitch	120	260	1	5mm/0.625mm	standard	No
32 cm CTDI	centered	0.984 pitch	120	260	1	5mm/0.625mm	standard	No
32 cm CTDI	centered	1.375 pitch	120	260	1	5mm/0.625mm	standard	No
32 cm CTDI	offcentered	Axial	80	260	1	5mm/0.625mm	standard	No
32 cm CTDI	offcentered	Axial	100	260	1	5mm/0.625mm	standard	No
32 cm CTDI	offcentered	Axial	120	260	1	5mm/0.625mm	standard	No
32 cm CTDI	offcentered	Axial	140	260	1	5mm/0.625mm	standard	No
32 cm CTDI	offcentered	0.516 pitch	120	260	1	5mm/0.625mm	standard	No
32 cm CTDI	offcentered	0.984 pitch	120	260	1	5mm/0.625mm	standard	No
32 cm CTDI	offcentered	1.375 pitch	120	260	1	5mm/0.625mm	standard	No

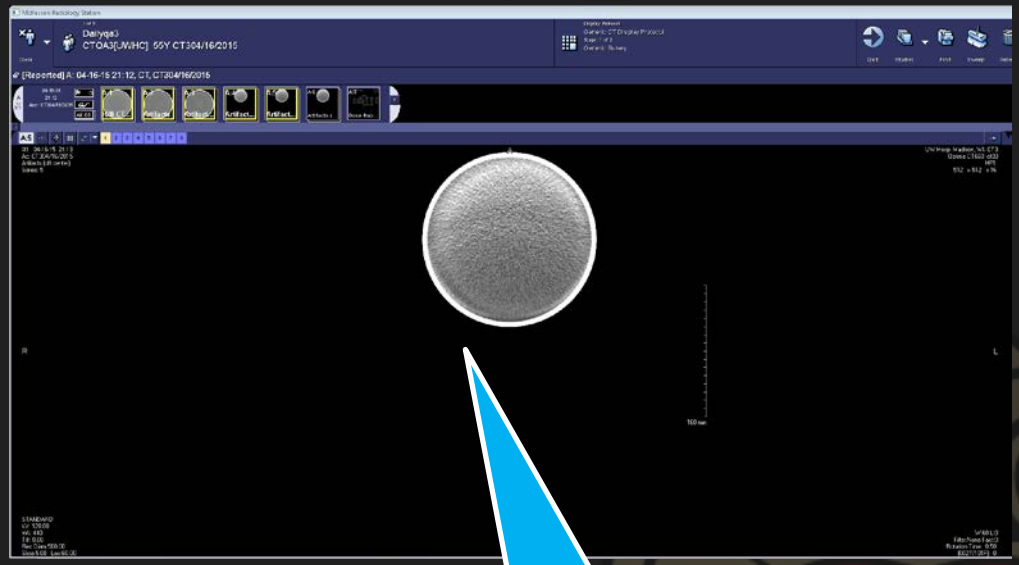
Checking for artifacts in 1 or 2 modes with one phantom doesn't match clinical reality…Here are examples of testing I have done which uses multiple phantoms in many different modes of the scanner

Table 1: Artifact testing

Phantom	Phantom Location	Scan Mode	kV	mA	Gantry period (s)	Slice thickness (mm)	Kernel	Artifacts?
BodyTomQA	centered	Axial	140	300	1	1.25	SoftTissue	No
BodyTomQA	centered	Axial	140	50	1	1.25	SoftTissue	No
BodyTomQA	centered	Axial	140	300	2	1.25	SoftTissue	No
BodyTomQA	centered	Axial	140	50	2	1.25	SoftTissue	No
BodyTomQA	centered	Axial	120	300	1	1.25	SoftTissue	No
BodyTomQA	centered	Axial	120	50	1	1.25	SoftTissue	No
BodyTomQA	centered	Axial	120	300	2	1.25	SoftTissue	No
BodyTomQA	centered	Axial	120	50	2	1.25	SoftTissue	No
BodyTomQA	centered	Axial	100	300	1	1.25	SoftTissue	No
BodyTomQA	centered	Axial	100	50	1	1.25	SoftTissue	No
BodyTomQA	centered	Axial	100	300	2	1.25	SoftTissue	No
BodyTomQA	centered	Axial	100	50	2	1.25	SoftTissue	No
		Axial	80	300	1	1.25	SoftTissue	No
		Axial	80	50	1	1.25	SoftTissue	No
		Axial	80	300	2	1.25	SoftTissue	No
		Axial	80	50	2	1.25	SoftTissue	No
		Axial	140	300	1	1.25	SoftTissue	Slight ripple
		Axial	140	50	1	1.25	SoftTissue	rings
		Axial	140	300	2	1.25	SoftTissue	Slight ripple
		Axial	140	50	2	1.25	SoftTissue	rings
		Axial	120	300	1	1.25	SoftTissue	rings
ter Poly								
48 cm Diameter Poly	centered	Axial	120	50	1	1.25	SoftTissue	rings
48 cm Diameter Poly	centered	Axial	120	300	2	1.25	SoftTissue	rings
48 cm Diameter Poly	centered	Axial	120	50	2	1.25	SoftTissue	rings
32 cm CTDI	off-	Axial	140	250	1	1.25	SoftTissue	No

QA for Artifact Detection





For daily QA, we have our techs do helical and axial scans with phantom at isocenter, then we repeat with the phantom off isocenter

We move phantom off isocenter so we can check the entire FOV

Timothy P. Szczykutowicz, Ph.D. DABR 2018

Outline

- Overview of CT Scanner Parts (what can break ☺)
- Iso-centric Artifacts
- Iso-centric Artifacts: how to find isocenter
- Non Iso-centric Artifacts
- General tips for troubleshooting Artifacts
- QA for Artifact Detection