CT EDUCATION AND COLLABORATION CENTER

CT 101: Introduction

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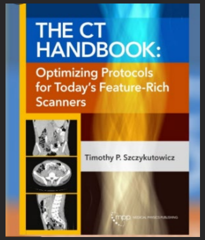
- Tim Stick's Disclosures
  - Funds or equipment to UW-Madison
    - Supplies CT protocols to GE Healthcare under a licensing agreement
    - Research support from GE Healthcare
    - Receives research support from Canon Medical Systems USA
  - Personal
    - Medical Advisory Board of iMALOGIX LLC
    - Consult to ALARA Imaging LLC.
    - Licensing Patent US10957444B2 (repeat rates) to Qaelum.
    - Royalties from Medical Physics Publishing
    - Founder of RadUnity Corp.

No personal $ from GE/Canon



Learning Objectives

- Learn how CT has evolved from the 1970s to modern-day scanners.
- Understand the major components of a CT scanner and how they work together.
- Appreciate how advances in technology have directly enabled clinical impact.

What is Computed Tomography?

On the Determination of Functions From Their Integral Values Along Certain Manifolds

JOHANN RADON

Translated by P. C. Parks from the original German text

Published in German 1917

WHEN one integrates a function of two variables x, y—a *point function* $f(P)$ in the plane—subject to suitable regularity conditions along an arbitrary straight line g then one obtains in the integral values $F(g)$, a *line function*. In Part A of the present paper the problem which is solved is the inversion of this linear functional transformation, that is the following questions are answered: can every line function satisfying suitable regularity conditions be regarded as constructed in this way? If so, is f uniquely known from F and how can f be calculated?

In Part B a solution of the dual problem of calculating a line function $F(g)$ from its point mean values $f(P)$ is solved in a certain sense.

Finally in Part C certain generalizations are discussed, prompted by consideration of non-Euclidean manifolds as well as higher dimensional spaces.

The treatment of these problems, themselves of inter-

$$\lim_{r \to \infty} \overline{f}_P(r) = 0.$$

Then the following theorems hold good.

Theorem I: The straight line integral value of f along the line g having the equation $x \cos \phi + y \sin \phi = p$ is given by

$$F(p, \phi) = F(-p, \phi + \pi)$$

$$= \int_{-\infty}^{\infty} f(p \cos \phi - s \sin \phi, p \sin \phi + s \cos \phi)\, ds \qquad \text{(I)}$$

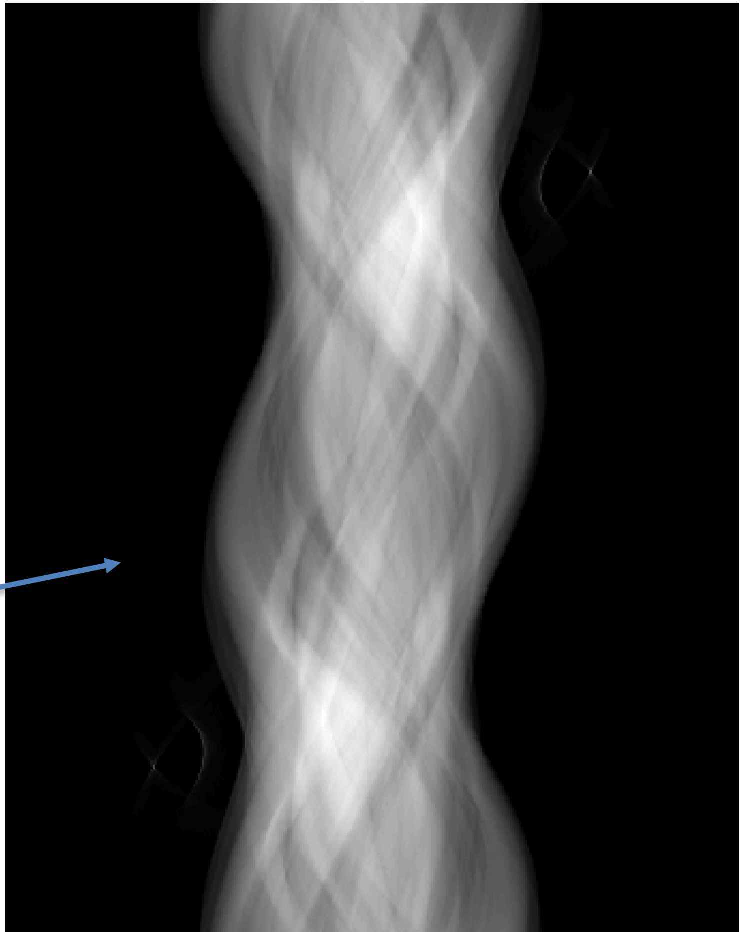
and exists almost everywhere: this means that on every circle the set of tangency points of all tangents for which F does not exist has a linear measure of zero. □

Theorem II: Constructing the mean value of $F(p, \phi)$ for the tangents of the circle with centre $P = [x, y]$ and radius q as

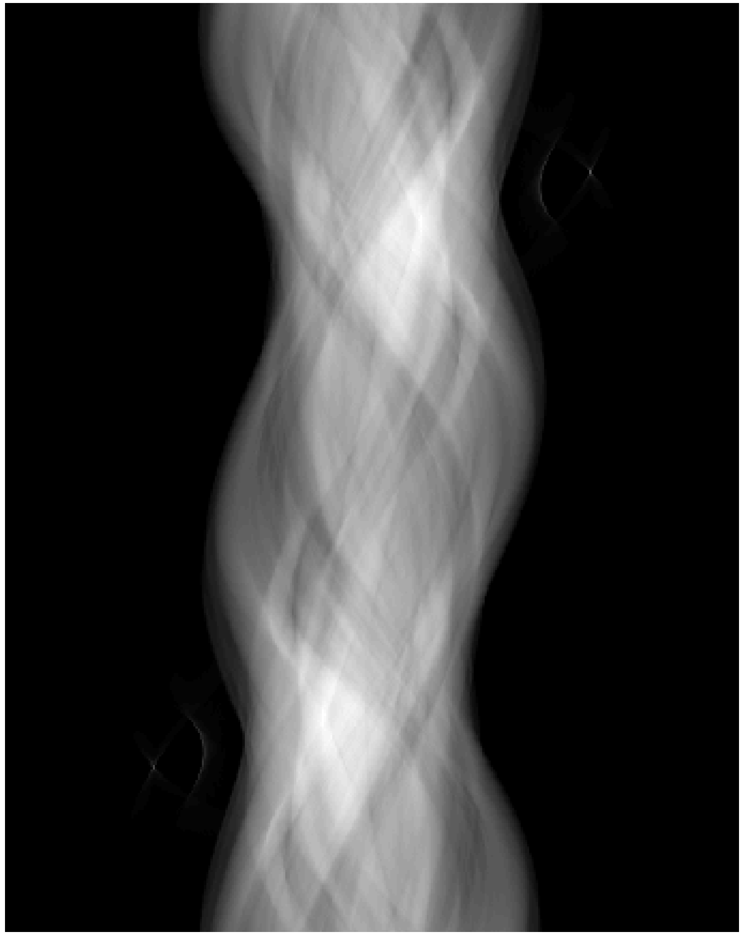
$$f(P) = -\frac{1}{\pi}\int_0^{\infty} \frac{d\overline{F_P}(q)}{q}.$$

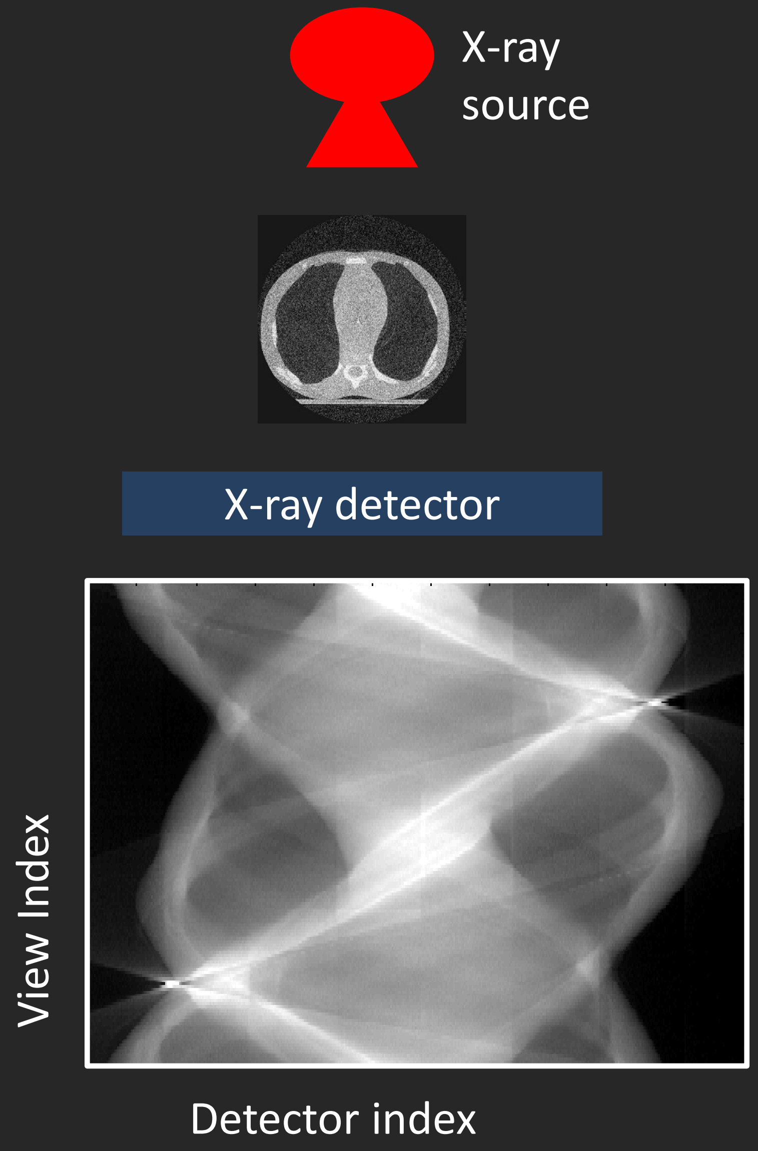
$$F(p, \phi) = F(-p, \phi + \pi)$$

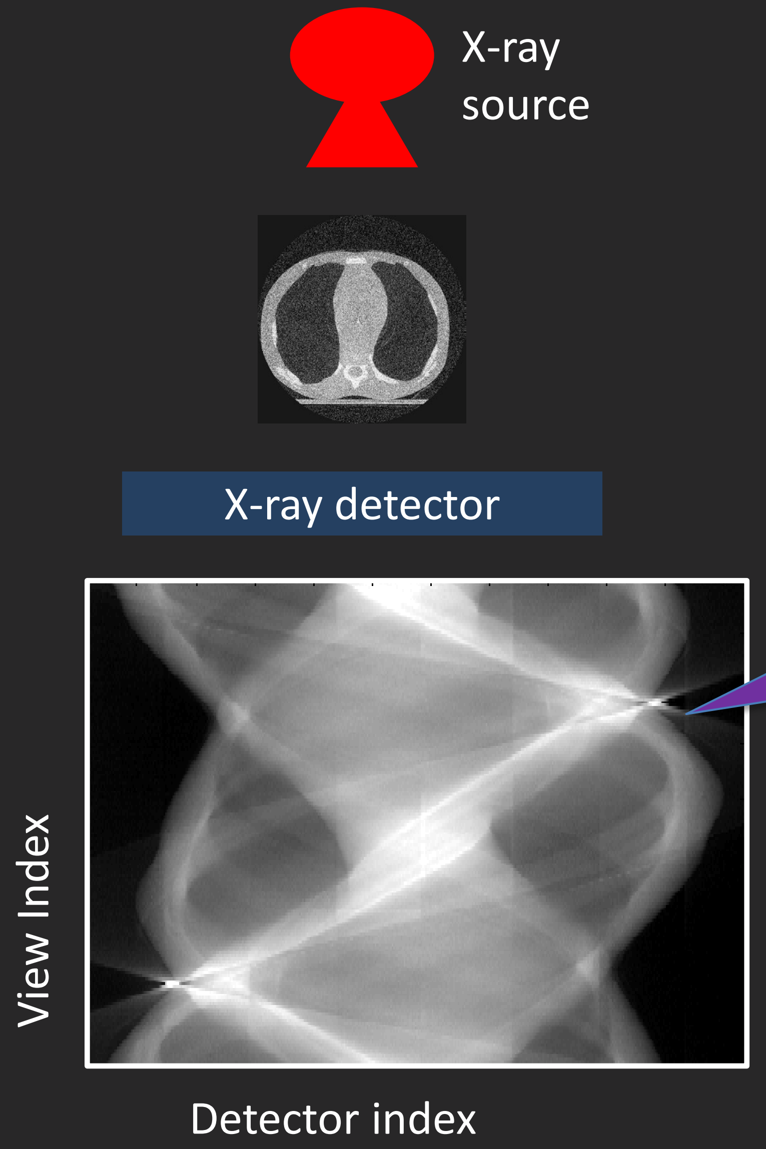
$$= \int_{-\infty}^{\infty} f(p \cos \phi - s \sin \phi, p \sin \phi + s \cos \phi)\, ds$$



How do we get projection data?




X-ray
source
X-ray detector
View Index
Detector index



This is a sinogram, not a sonogram

Latin *sinus* “curve, fold, hollow, bay”

Greek *gramma* “something written or recorded

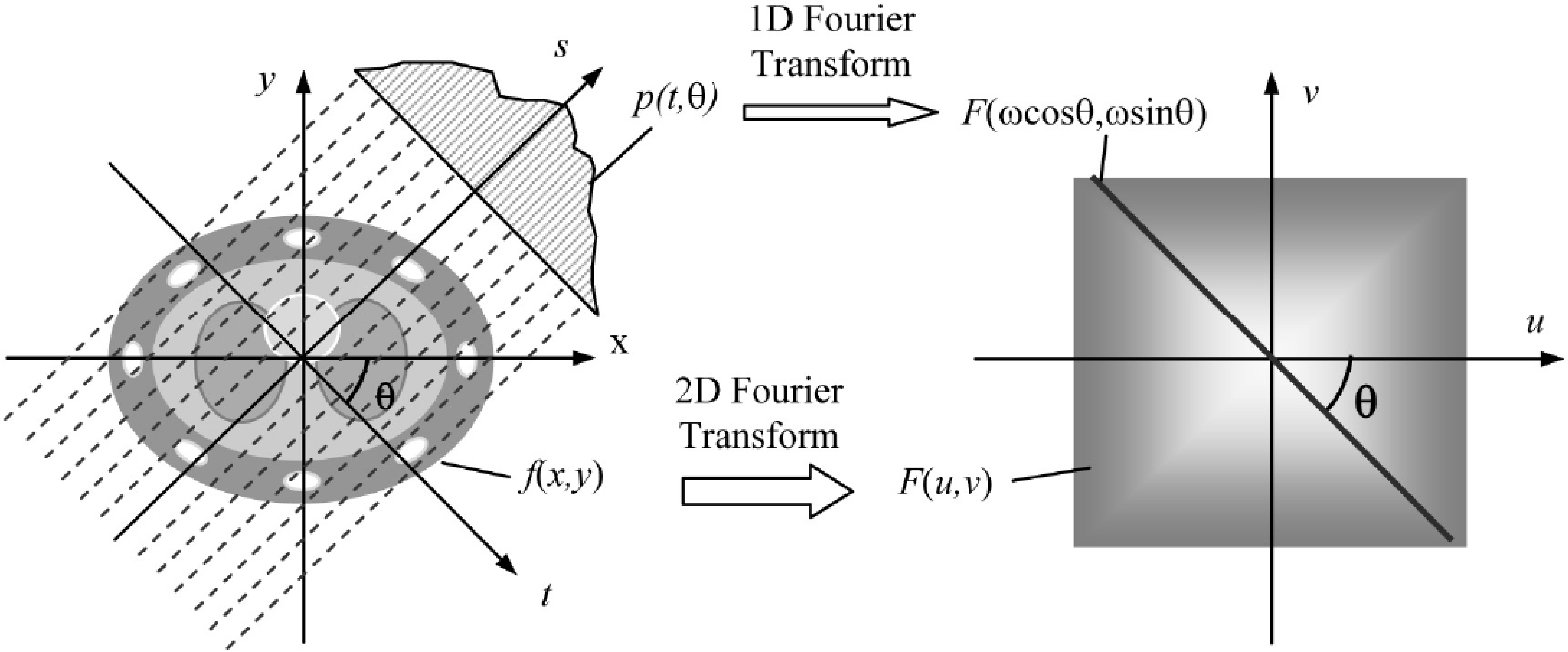


Figure 3.9 Illustration of the Fourier slice theorem.

Hsieh, Jiang. *Computed tomography: principles, design, artifacts, and recent advances*. Vol. 114. SPIE press, 2003.

Flavors of Computed Tomography

“The CT Handbook: Optimizing Protocols for Today’s feature-rich scanners” By Tim Szczykutowicz. Medical Physics Publishing 2020

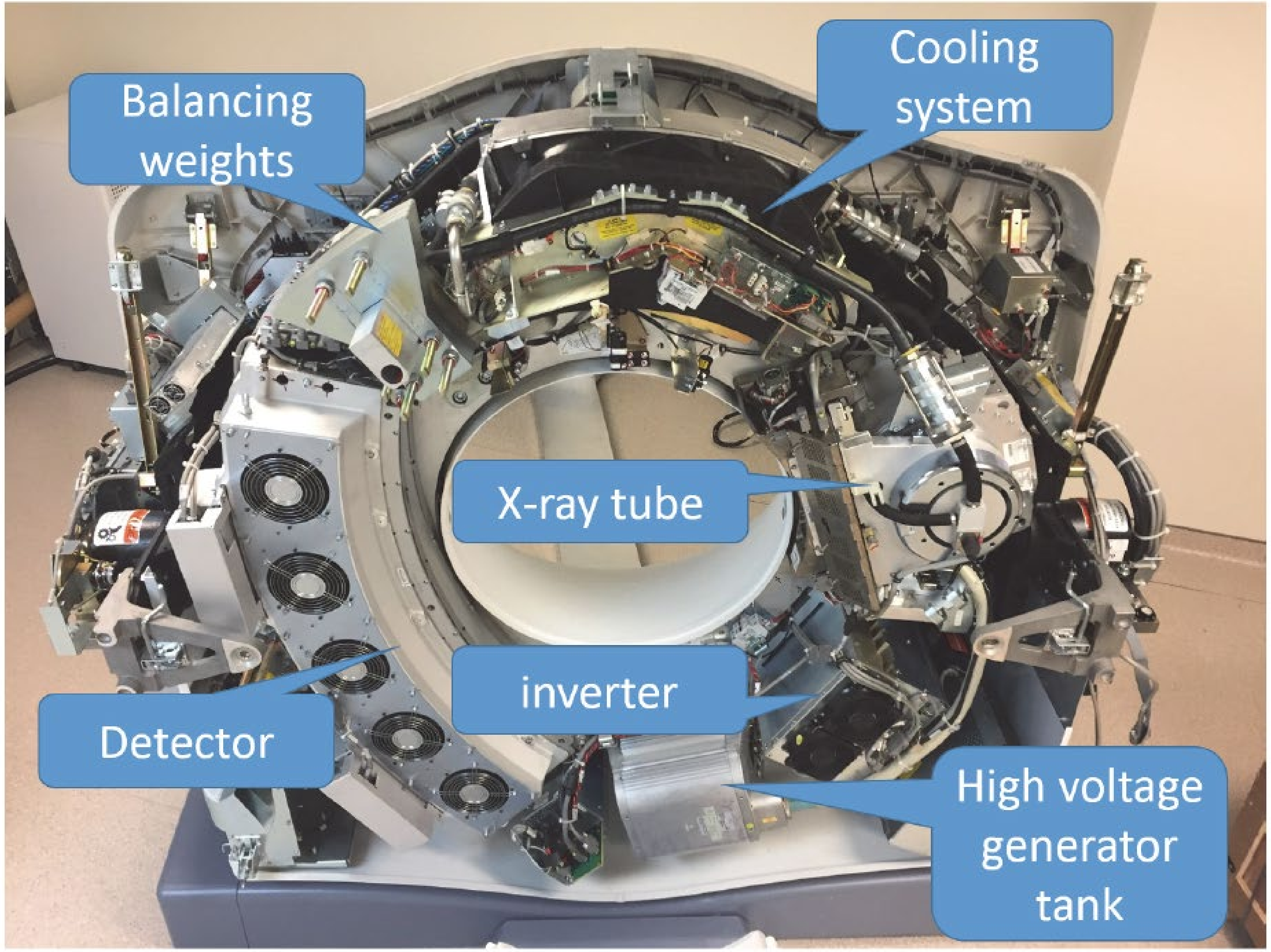
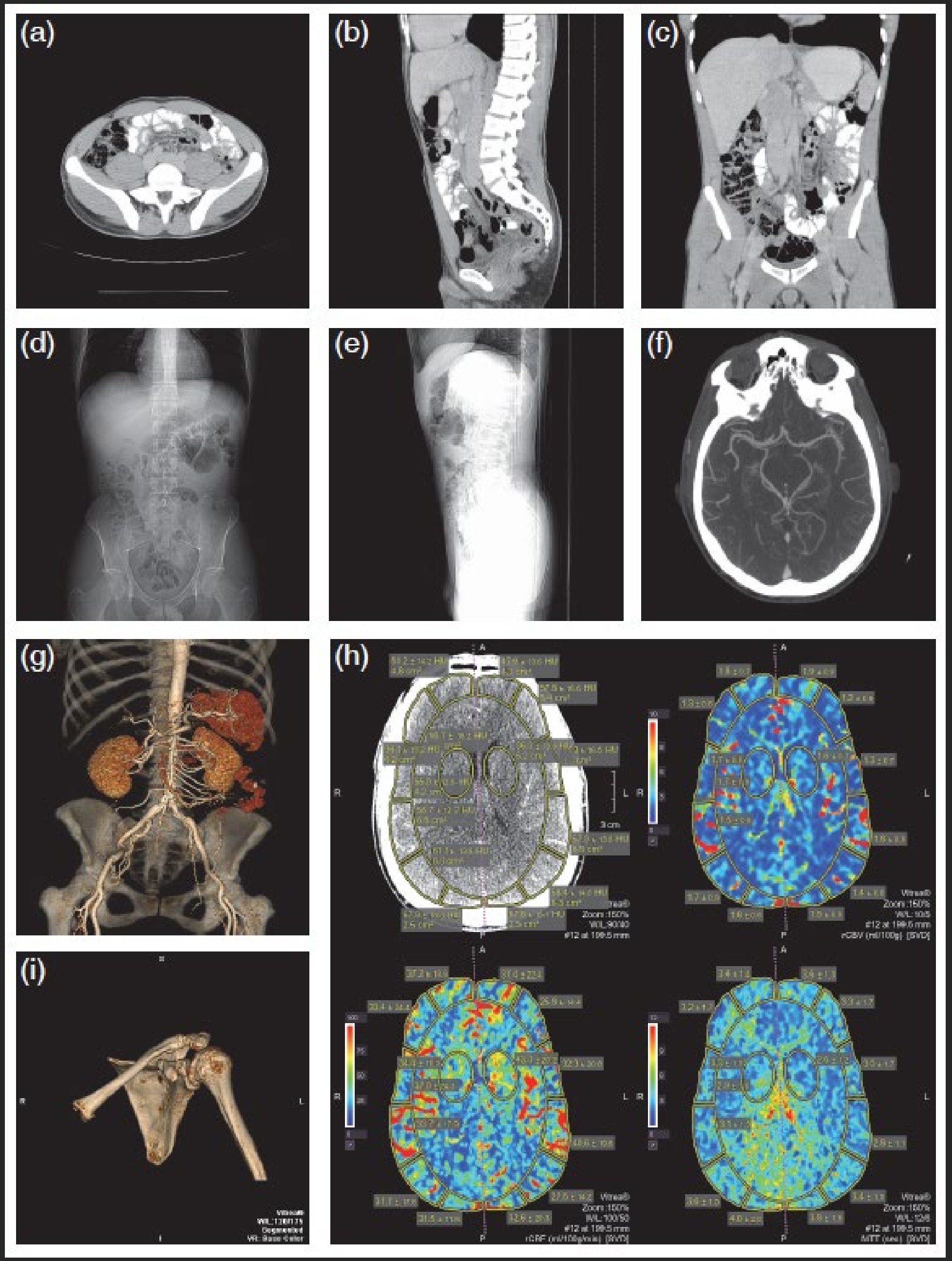


Figure 1.14 A modern MDCT scanner without its cover is shown. Different from many c-arm-based CBCT units, the high-voltage generator and cooling system resides on the gantry.

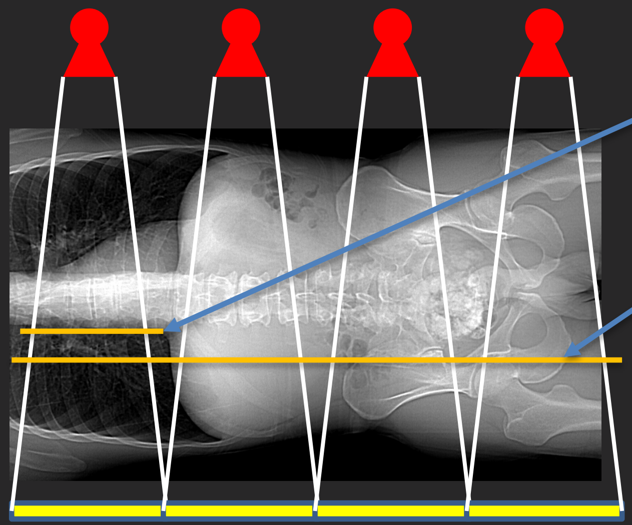
"The CT Handbook: Optimizing Protocols for Today's feature-rich scanners" By Tim Szczykutowicz. Medical Physics Publishing 2020


Bore sizes ~70-80 cm
Speed of this table ~20-700 mm/s
Table a.k.a. couch
Width of detector is ~2-16 cm



“The CT Handbook: Optimizing Protocols for Today’s feature-rich scanners” By Tim Szczykutowicz. Medical Physics Publishing 2020

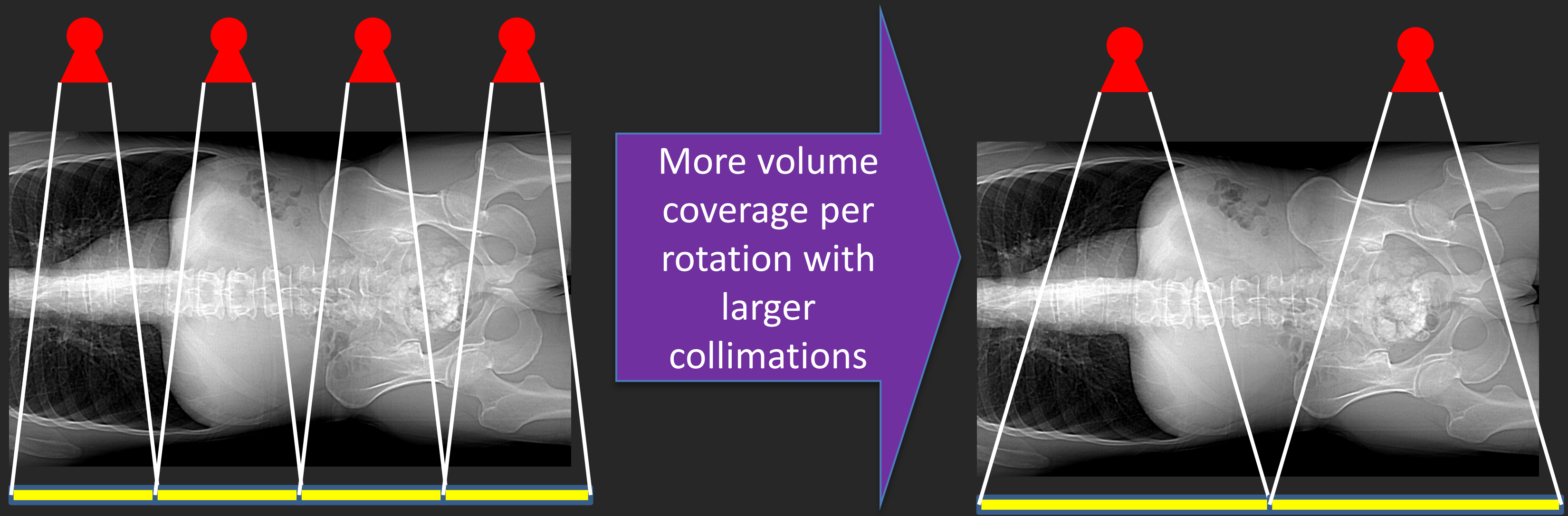
- Axial/sequential scan coverage
  - The scan coverage is going to be equal to the beam collimation for each rotation's worth of data. If multiple slabs are acquired, you just add up the collimation*number of slabs to get the total coverage. Note, the axial collimation may change from couch position to couch position.
    - The Ubiquitous 64/128 slice scanners of the past have a maximum collimation of ~4 cm, but not all vendors let you actually use that large of a collimation in axial mode.



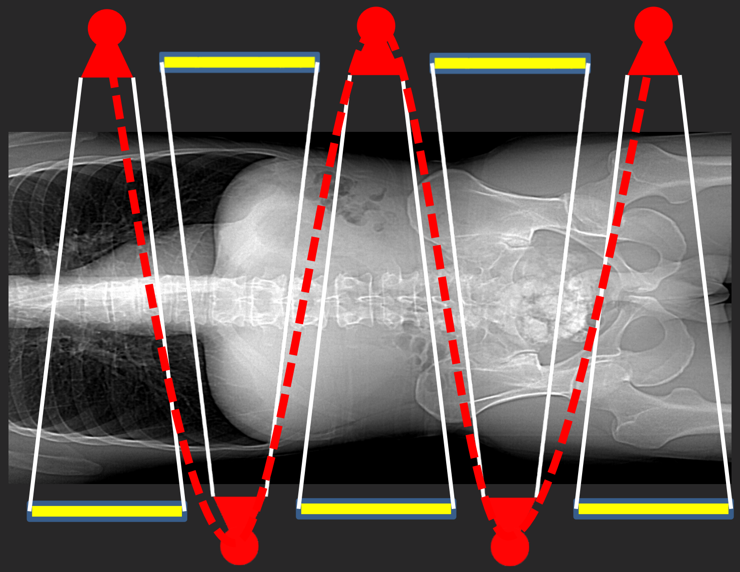
Single rotation's worth of data covers a beam collimation's worth of the patient

The entire scan may cover much more than the beam collimation as many axial scans are added together

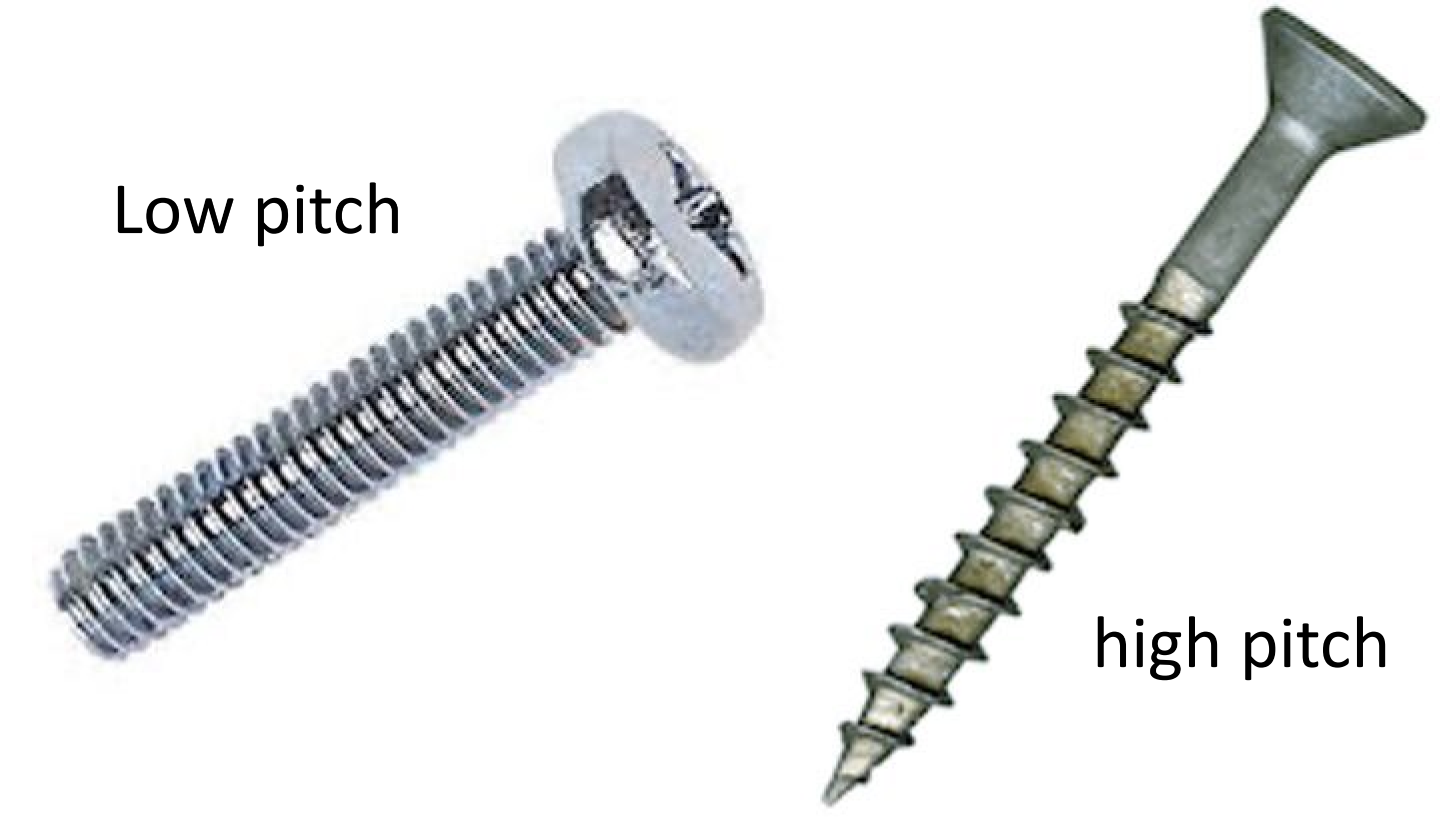
- Axial/sequential Scan coverage continued
  - As the beam collimation increases, more tissue is irradiated per couch position and fewer axial slabs are needed to scan a volume larger than the beam collimation
  - In axial scanning, the volumetric coverage per rotation is equal to the beam collimation. So if you have a 16 cm collimation, you get 16 cm of volumetric coverage per rotation.



- Helical/spiral scan coverage
  - This is more complicated than with axial scanning.
    - Pitch = (distance moved in 1 tube rotation)/(width of beam collimation)
    - Per rotation, we irradiate a volume equal to the pitch*collimation + collimation
    - Per rotation, **we only move** a distance equal to the pitch*collimation



Single rotation's worth of data covers pitch * beam collimation's worth of the patient. So wider collimations and higher pitches give faster scanning.

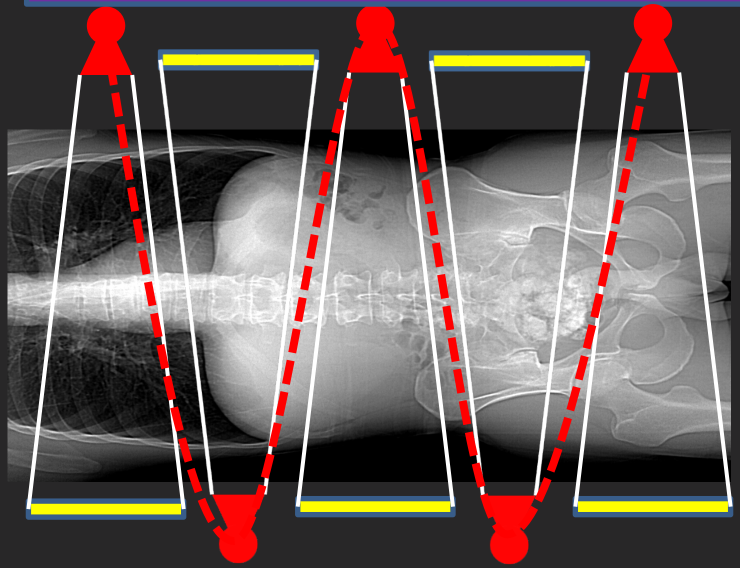


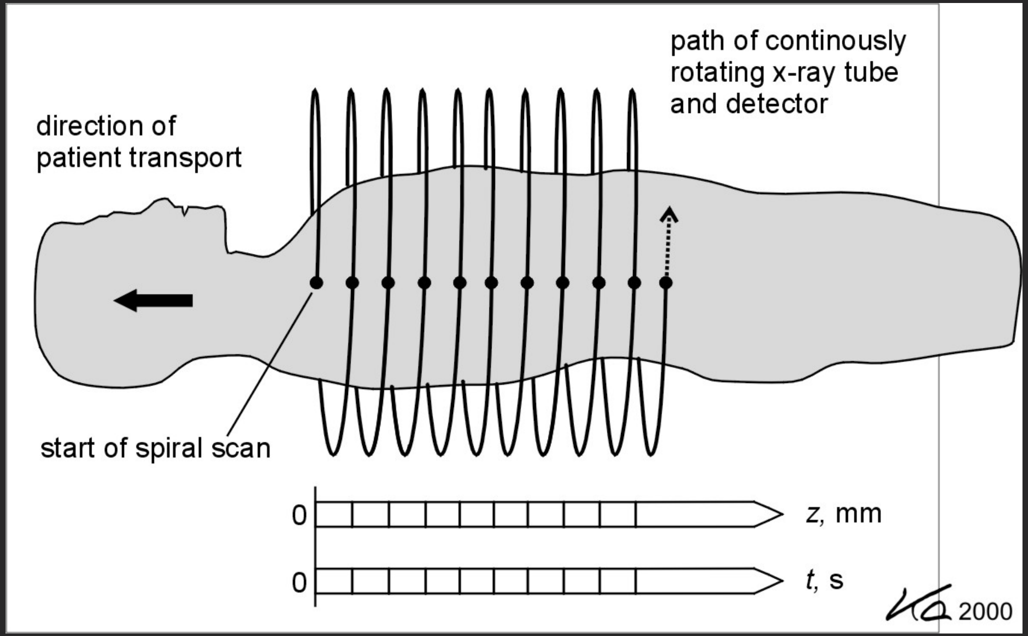
1 turn, moves a little

Slow and precise → brain and MSK imaging

1 turn, moves a lot

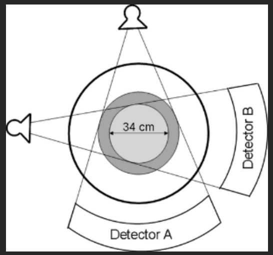
Quick and sloppy (artifacts) → pediatric scanning and chest scanning e.g. Pitch = 2:1, in 1 rotation tube moves 2x collimation width





Kalender, Willi A. *Computed tomography: fundamentals, system technology, image quality, applications*. John Wiley & Sons, 2011.

Pitch varies: ~0.1-3.2 in diagnostic CT



Siemens Healthineers only (dual source scanners needed for this range)
Very fast peds and prospectively gated cardiac at 3.1:1 pitch

Retrospectively gated cardiac, and respiratory gated CT

Brain, MSK

Bread and butter for torso (chest, CTA CAP, abd/pelvis) scanning all vendors

~[-0.1:1 0.3:1] [0.5:1 1:1] ~[1:1 1.5:1] ~[1.75:1 3.2:1]

pitch

- Scan speed in axial scanning

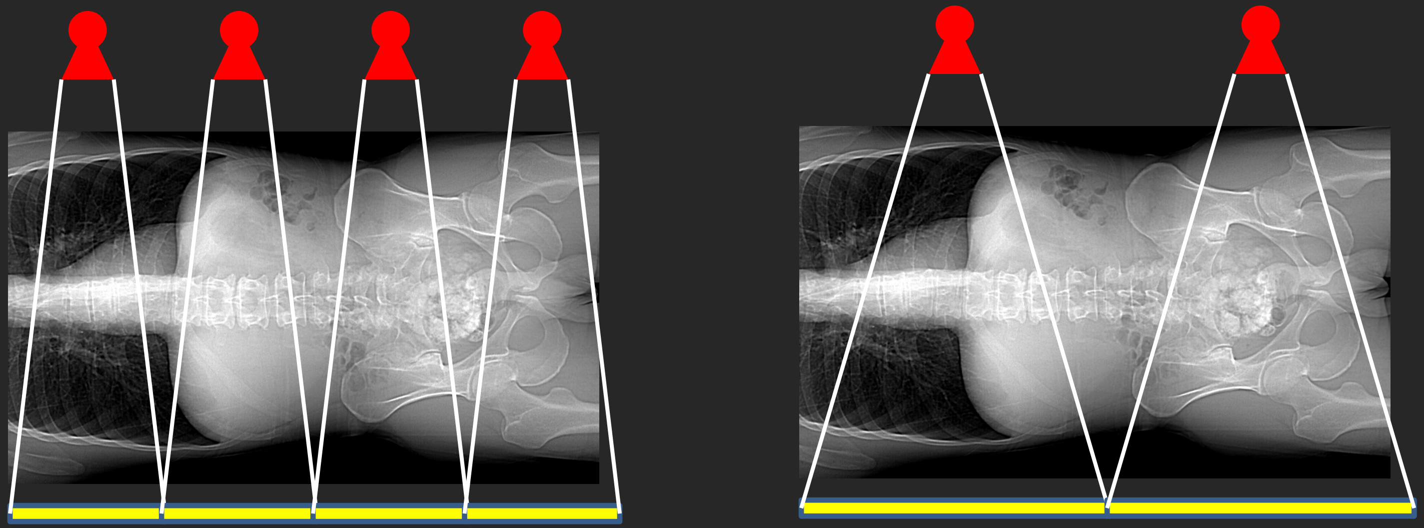
Time per slab location

Time spent moving between slab locations

Total scan time = rotation time * number of slabs + time to move between slabs* (number of slabs -1)

Scan time per image = rotation time * weighting factor

~1/2 for a short scan reconstruction and 1 for a reconstruction using all the projection data



Note, in reality, the couch positions overlap at iso-center, not at the detector plane

- Scan speed in helical scanning

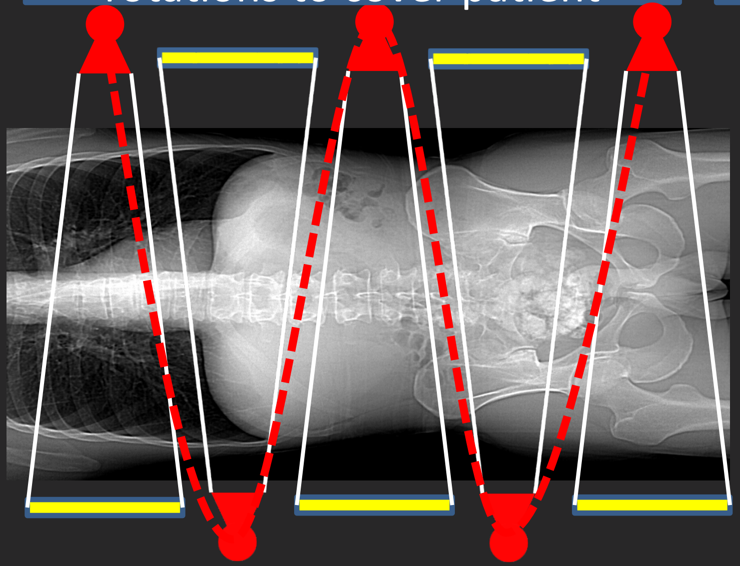
$$\text{Total scan time} = \frac{\text{rotation time } x \text{ scan length}}{\text{pitch } x \text{ beam collimation}}$$

Scan time per image = rotation time * weighting factor

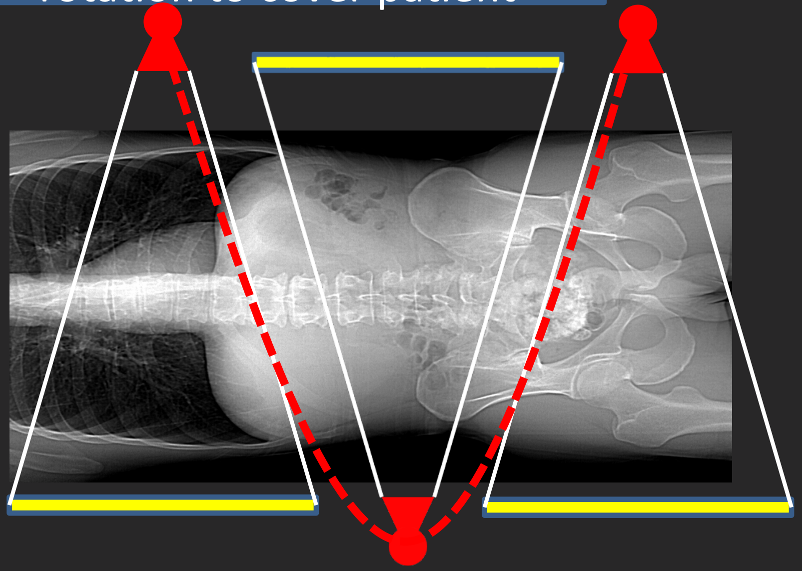
~1/2 for a short scan reconstruction, increases as more out of plane data is used. Usually >1 for routine non cardiac or high pitch scanning.

For the same pitch, if we increase collimation, we reduce scan time

Pitch = 2:1 it takes 2 tube rotations to cover patient

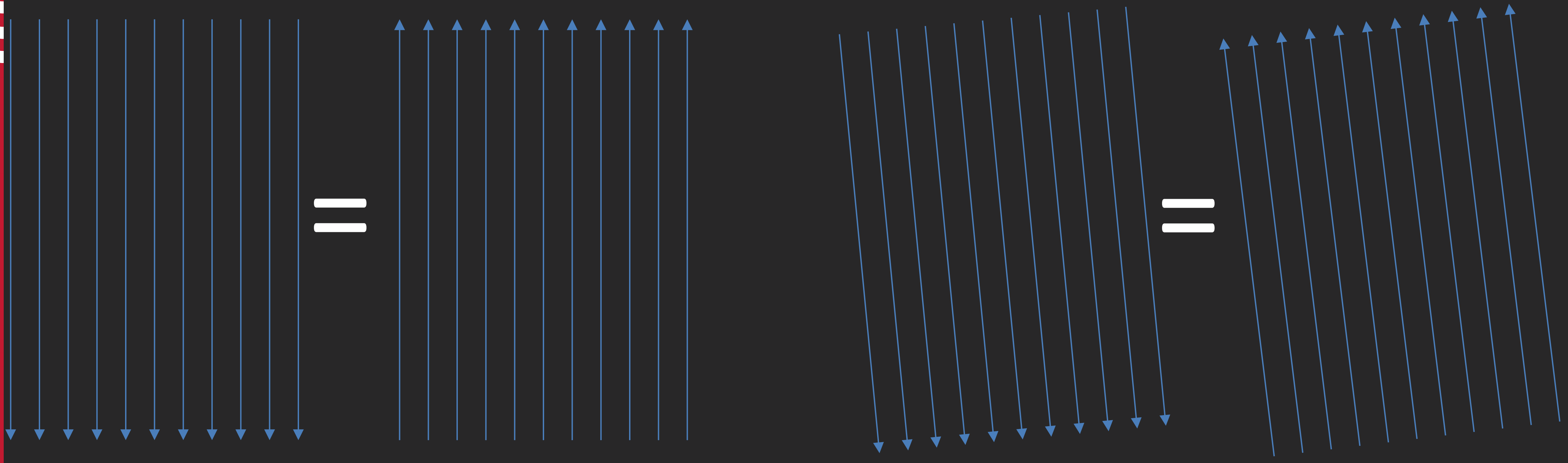


Pitch = 2:1 it takes 1 tube rotation to cover patient



Note, in reality, the couch positions overlap at iso-center, not at the detector plane

- What is the “weighting factor” I kept referring to?
  - The data we collect in CT is redundant. The data we take at 0 degrees is the same as 180 degrees, the data we take a 1 degree is the same as 181 degrees… and so on



- So to get data for 360 degrees, we only need to move the x-ray tube 180 degrees

Data angle	Where the tube is located to get this data
0	At 0 degrees
60	At 60 degrees
120	At 120 degrees
180	At 180 degrees
240	This data is the same as the data from 60 degrees
300	This data is the same as the data from 120 degrees
360	This data is the same as the data from 0 degrees

- So to get data for 360 degrees, we only need to move the x-ray tube 180 degrees

We need data for all these angles (and the angles in between) to get an image

Data angle	Where the tube is located to get this data
0	At 0 degrees
60	At 60 degrees
120	At 120 degrees
180	At 180 degrees
240	This data is the same as the data from 60 degrees
300	This data is the same as the data from 120 degrees
360	This data is the same as the data from 0 degrees

All the needed data is collected using tube positions from 0→180

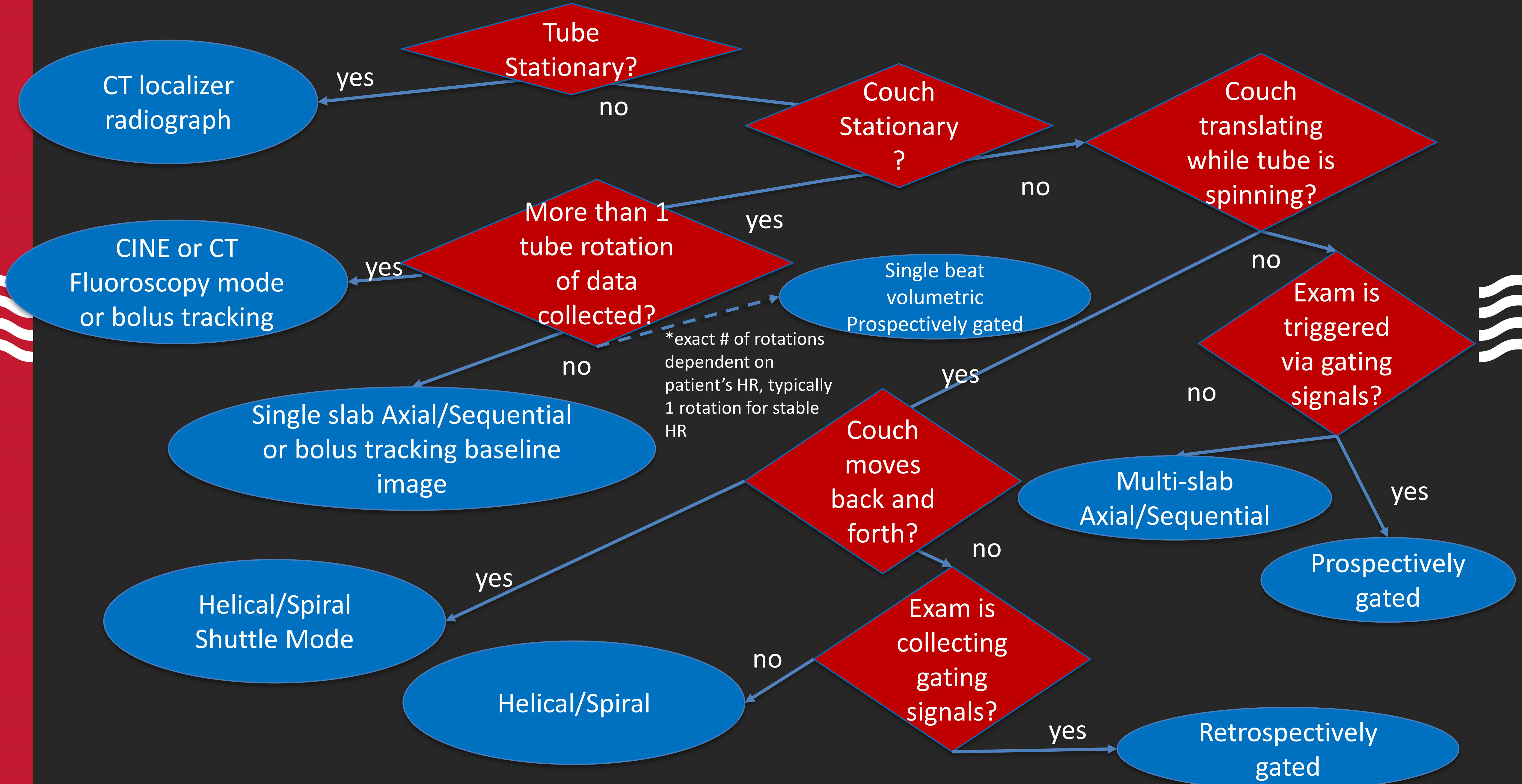
This explanation holds perfect for parallel rays, but we have a fan beam. So it turns out our weighting factor is a little bit greater than 0.5, it would be exactly 0.5 for parallel rays as shown here.

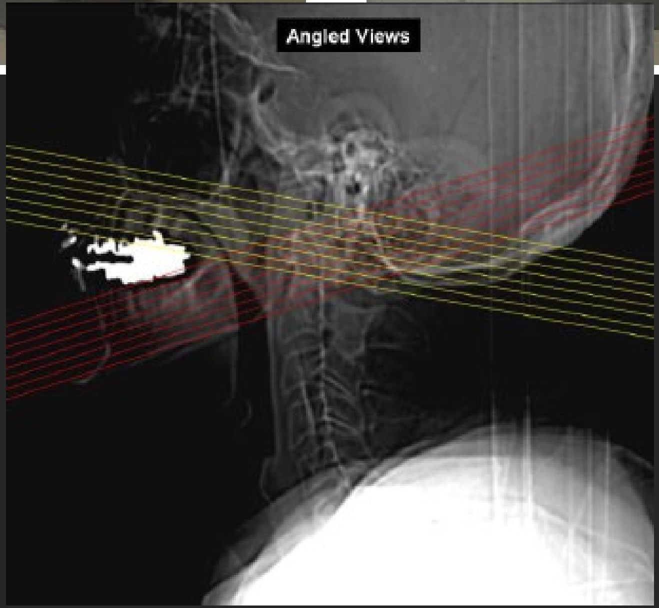
We have a lot of modes in CT when you consider we have a tube, optional filtration, a gantry, and a detector that all have different modes of operations. Lots of possible combinations we actually use clinically.

- Scan modes “if you can imagine it, the scanner can probably do it…”
  - Do a single rotation with patient in the same spot (axial/sequential)
  - Do multiple rotations with patient in the same spot (CINE/Perfusion)
  - Continuously scan with patient slowly moving through scanner (helical/spiral)
  - Move the patient back and forth over ~8-12 cm continuously (Shuttle perfusion)
  - Do a single rotation “on demand” via a foot pedal with a physician standing next to the scanner (CT fluoroscopy)

CT scan modes

Scan Modes Overview




Angled Views

History of Medical (diagnostic) Computed Tomography

Focus on Speed

EARLY 1970S

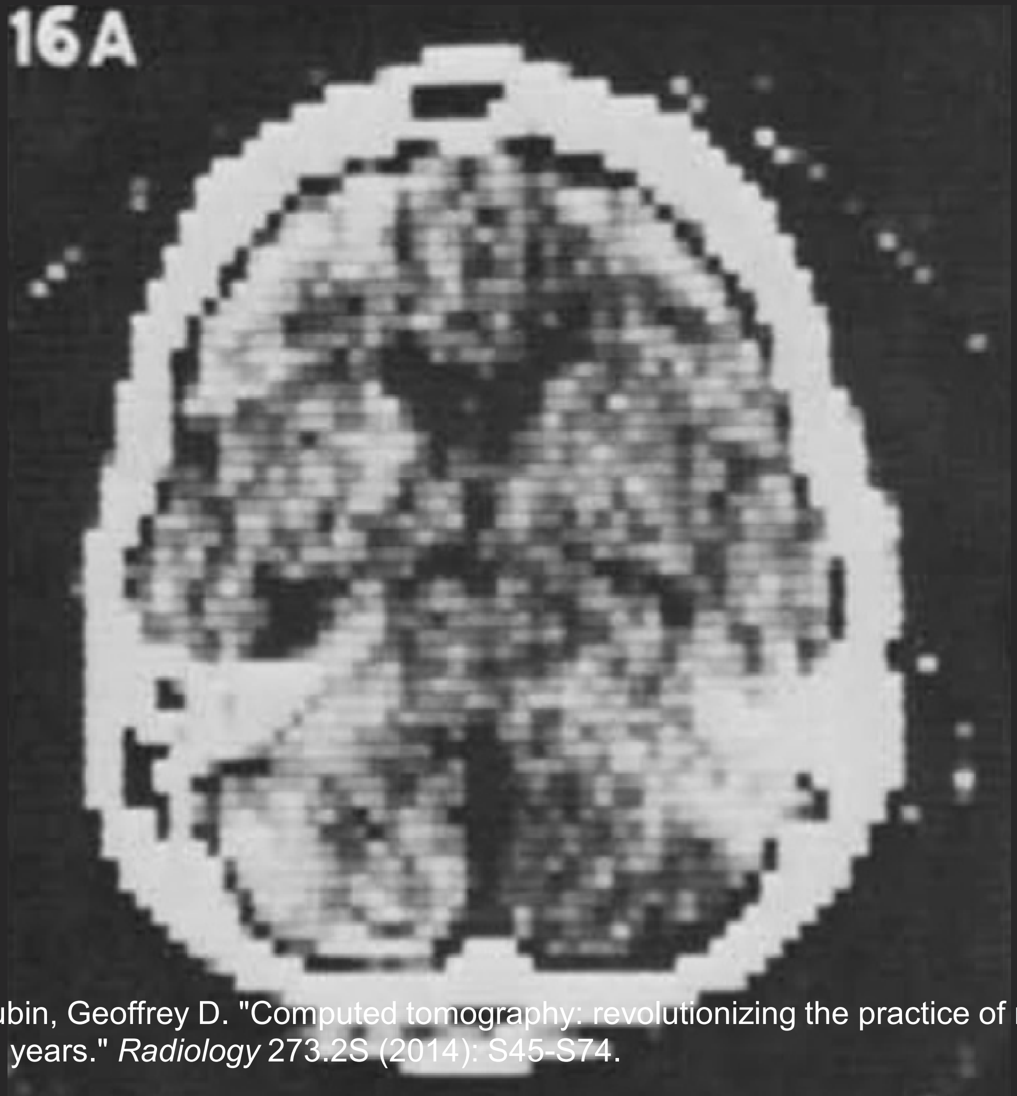
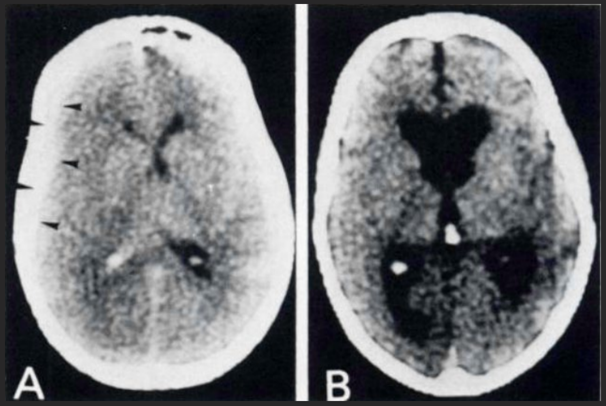


Image from 1974. 'shows a wedge-shaped zone of decreased attenuation in the right cerebellar hemisphere of a 60-year old man with sudden vertigo and inability to stand or walk 8 days prior to the examination"

80 pixels across image
4.5 minute acquisition time (single slice)

160x160 matrix

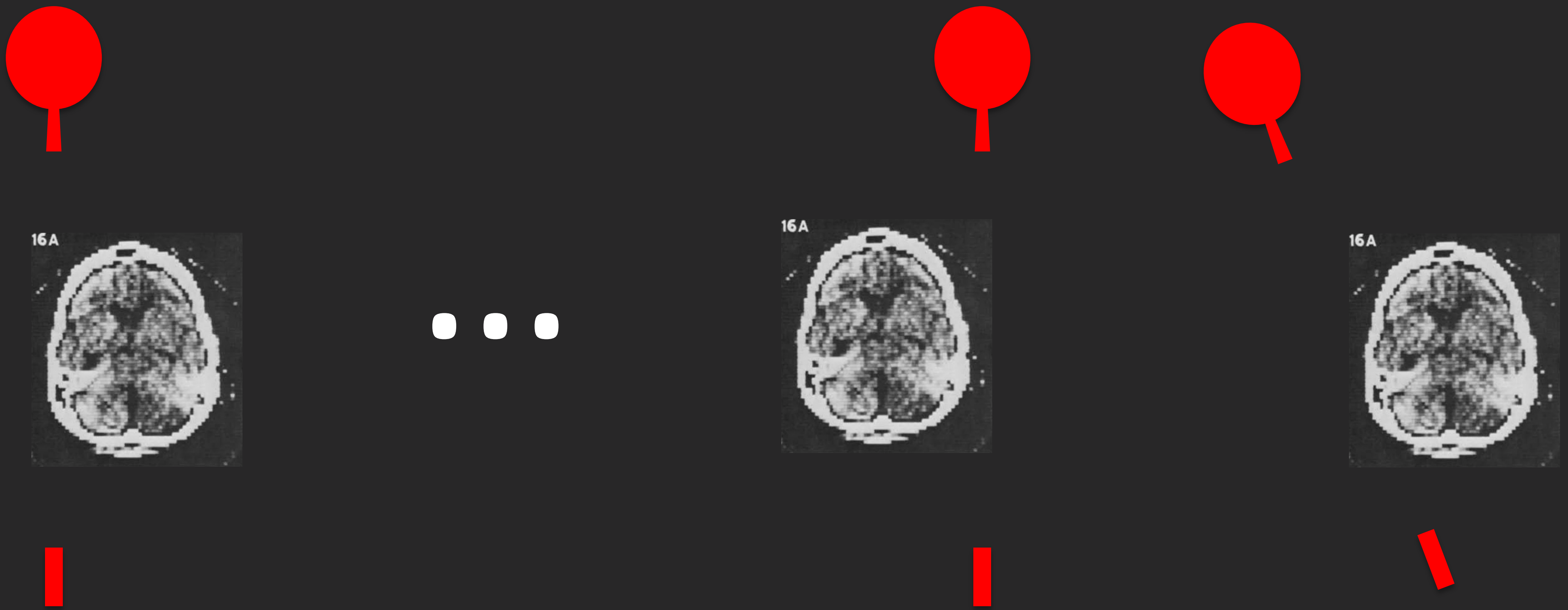


LATER 70S

Rubin, Geoffrey D. "Computed tomography: revolutionizing the practice of medicine for 40 years." *Radiology* 273.2S (2014): S45-S74.

Zimmerman, R. A., Bilaniuk, L. T., Gennarelli, T., Bruce, D., Dolinskas, C., & Uzzell, B. (1978). Cranial computed tomography in diagnosis and management of acute head trauma. *American Journal of Roentgenology*, *131*(1), 27-34.

First clinical CT scanner (EMI circa 1971) had 160 detector positions, 1 degree angle increments, 3x13 mm detector elements, 180 degree rotation, FOV 23.5 cm

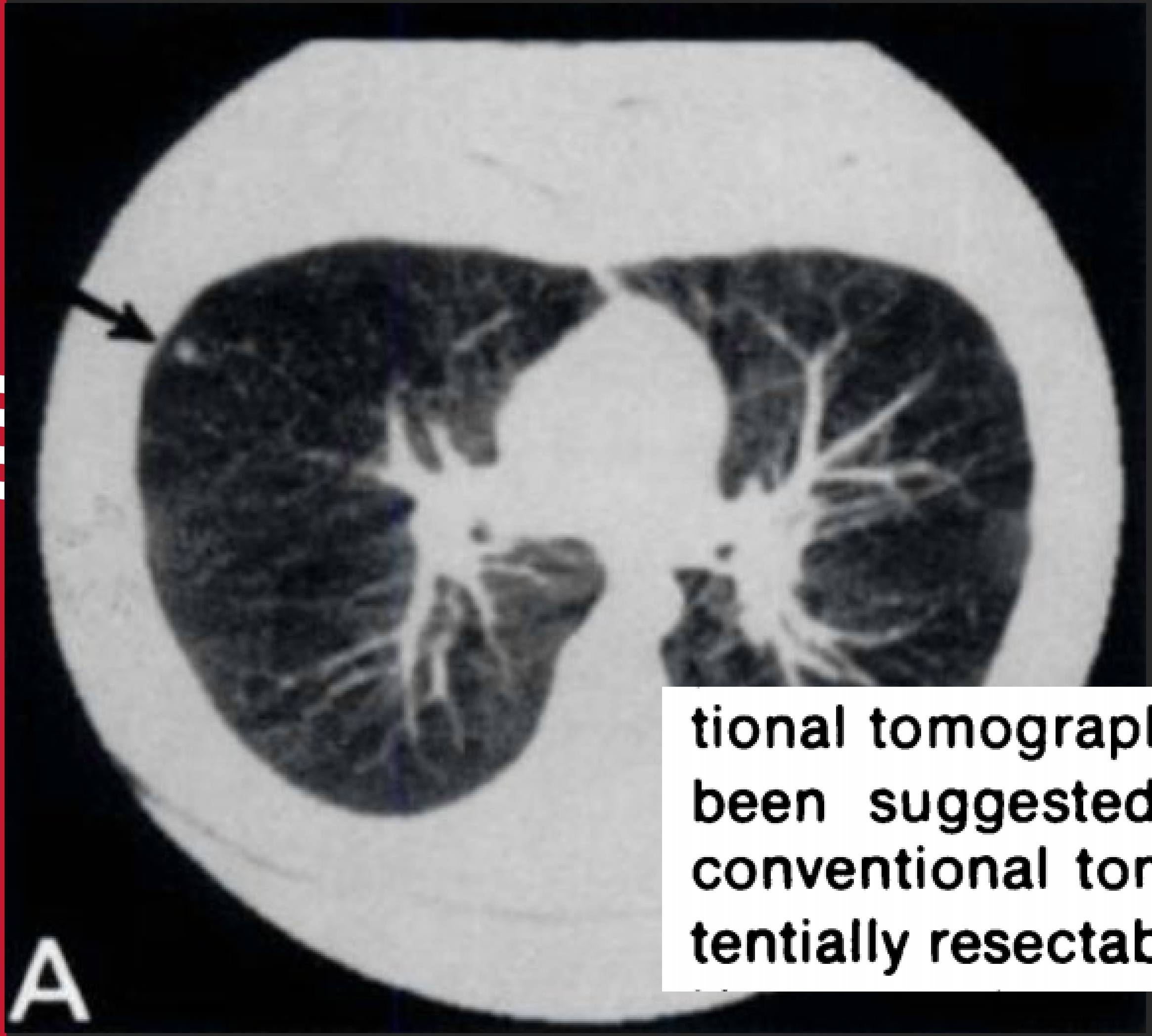


View angle 1, detector position 1-2

View angle 1, detector position (1-N)-N

View angle 2, detector position 1-2

END OF THE 70S



EMI 5000 model scanner

320x320 pixels

18 second scan time

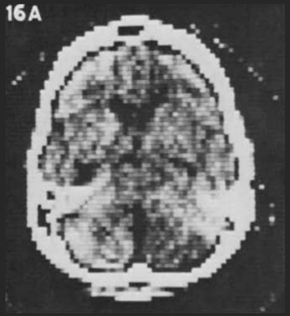
Typically 16-18 ‘cuts” per patient every 1 cm were acquired

tional tomography [11, 12]. From this experience, it has been suggested that whole lung CT should replace conventional tomography in evaluating patients for potentially resectable parenchymal metastatic disease [13].

Schaner, E. G., Chang, A. E., Doppman, J. L., Conkle, D. M., Flye, M. W., & Rosenberg, S. A. (1978). Comparison of computed and conventional whole lung tomography in detecting pulmonary nodules: a prospective radiologic-pathologic study. *American Journal of Roentgenology*, *131*(1), 51-54.

BY THE END OF THE 70S, DATA ACQUISITION WAS RADICALLY DIFFERENT

1st generation scanner

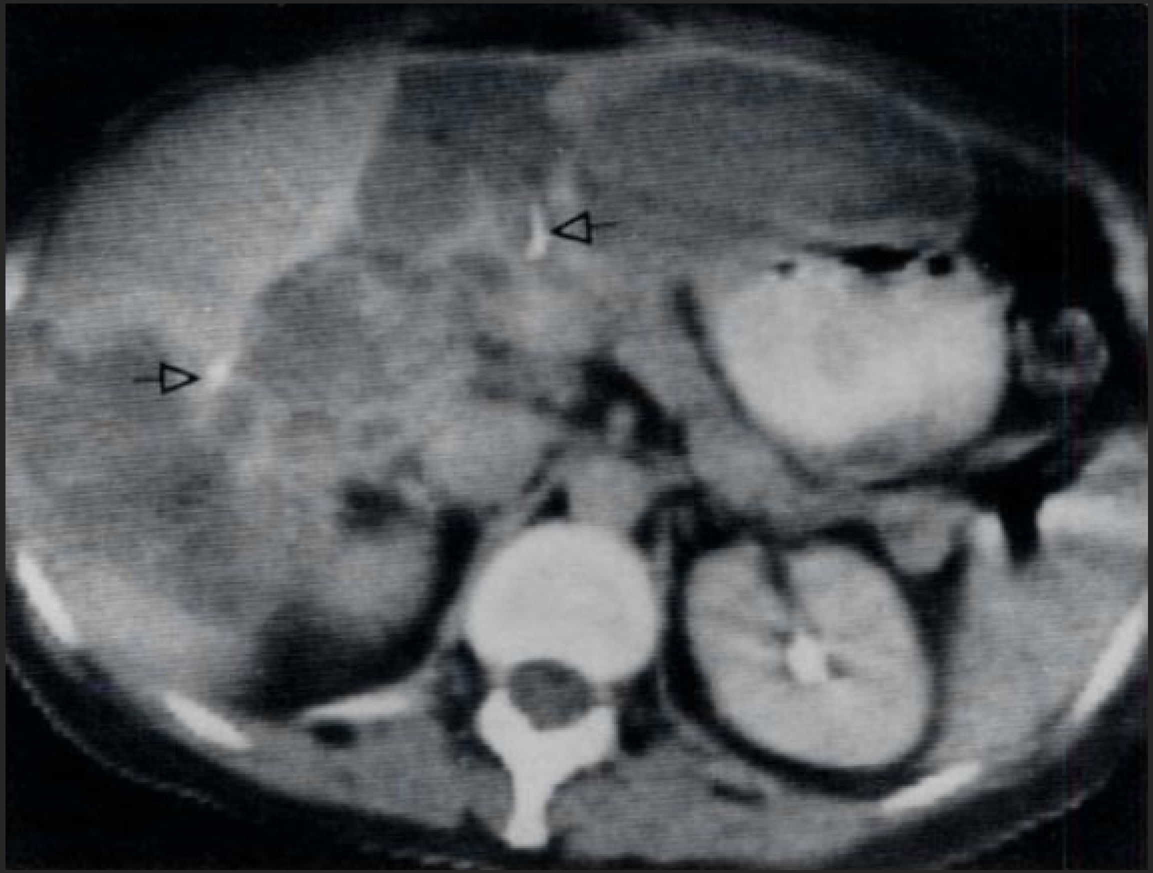


3rd generation scanner

1980S

Cohen, R. A., Kaufman, R. A., Myers, P. A., & Towbin, R. B. (1986). Cranial computed tomography in the abused child with head injury. *American journal of roentgenology*, *146*(1), 97-102.

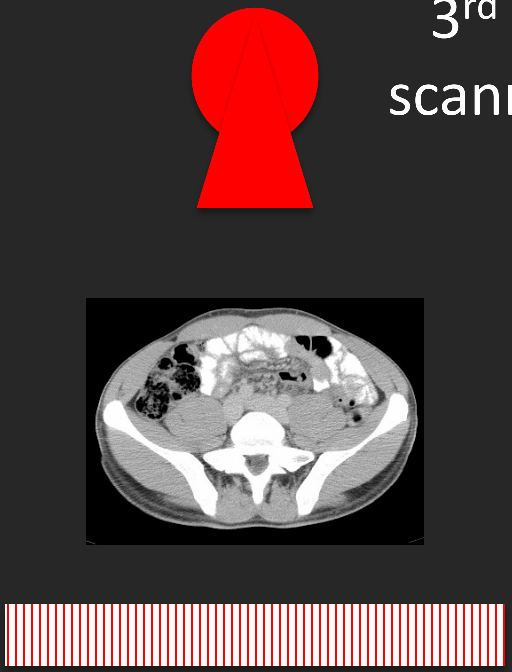
4.8 seconds per slab!



Kunstlinger, Francis, et al. "Computed tomography of hepatocellular carcinoma." *American Journal of Roentgenology* 134.3 (1980): 431-437.

3rd generation scanner (~4 slice)

Fan angle direction



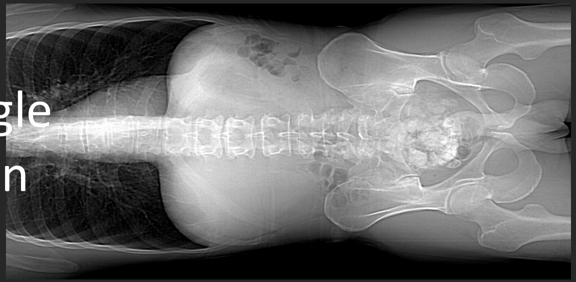
3rd generation scanner (~64 slice)

Fan angle direction

3rd generation scanner (~4 slice)

Fan angle direction

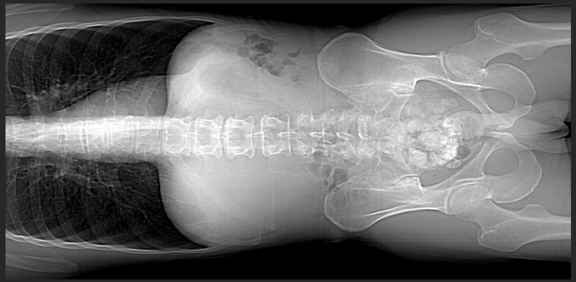
Cone angle direction



3rd generation scanner (~64 slice)

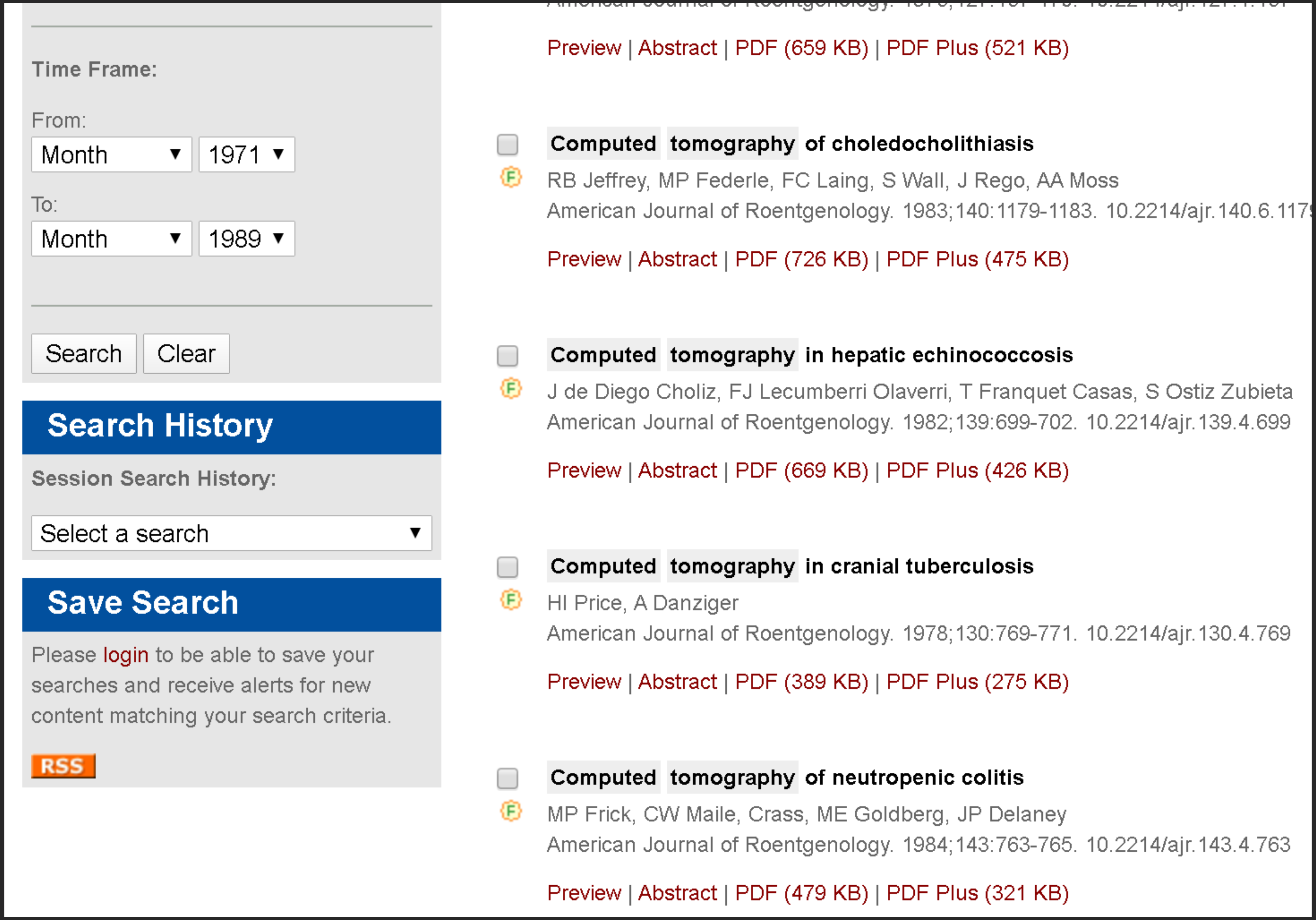
Fan angle direction

Cone angle direction



$$\text{Total scan time} = \frac{\text{rotation time } x \text{ scan length}}{\text{pitch } x \text{ beam collimation}}$$

70S AND 80S, WE LEARNED A LOT



Time Frame:

From: Month 1971

To: Month 1989

Search | Clear

Search History

Session Search History:

Select a search

Save Search

Please login to be able to save your searches and receive alerts for new content matching your search criteria.

RSS

Preview | Abstract | PDF (659 KB) | PDF Plus (521 KB)

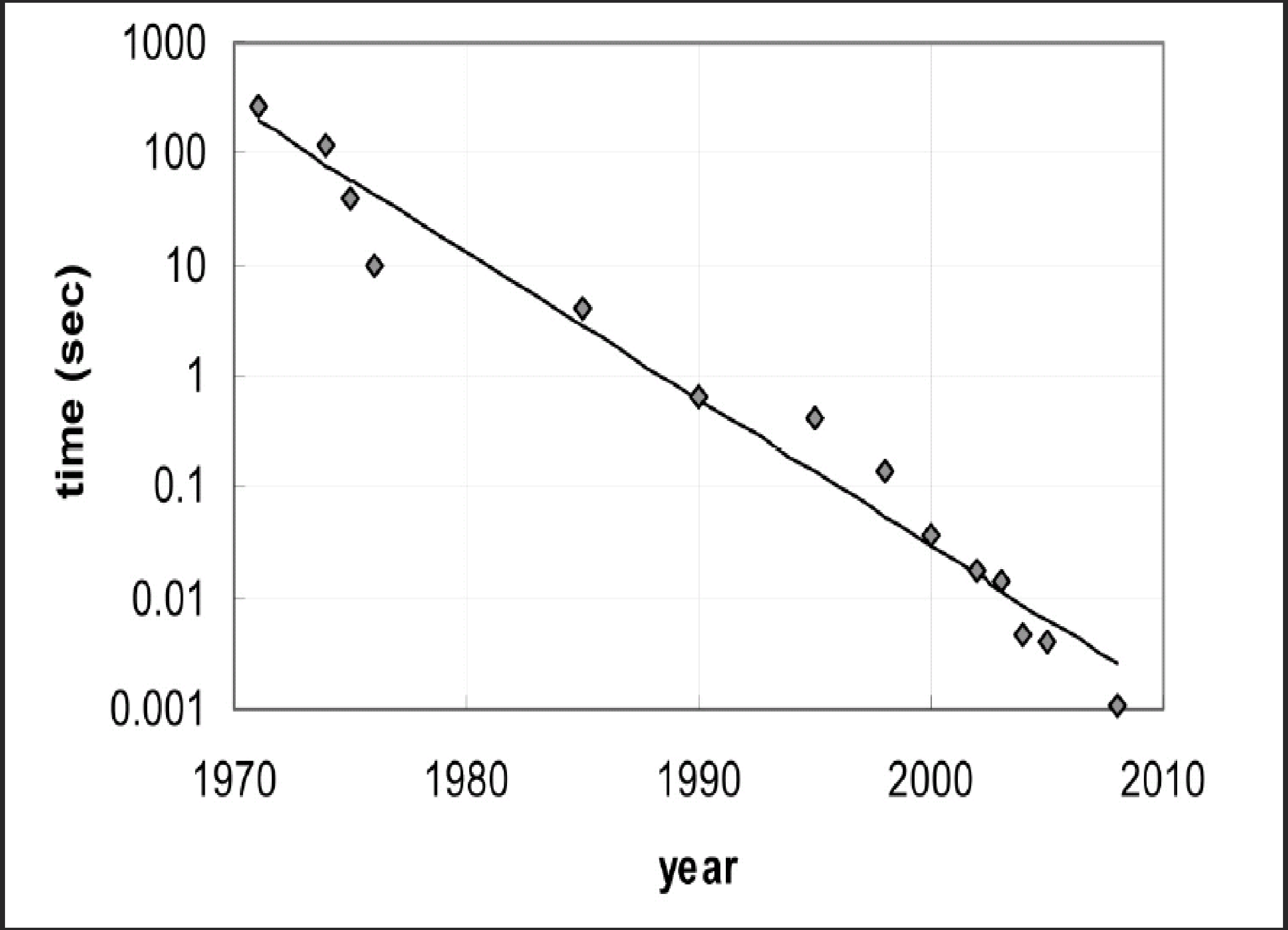
Computed tomography of choledocholithiasis
RB Jeffrey, MP Federle, FC Laing, S Wall, J Rego, AA Moss
American Journal of Roentgenology. 1983;140:1179-1183. 10.2214/ajr.140.6.117
Preview | Abstract | PDF (726 KB) | PDF Plus (475 KB)

Computed tomography in hepatic echinococcosis
J de Diego Choliz, FJ Lecumberri Olaverri, T Franquet Casas, S Ostiz Zubieta
American Journal of Roentgenology. 1982;139:699-702. 10.2214/ajr.139.4.699
Preview | Abstract | PDF (669 KB) | PDF Plus (426 KB)

Computed tomography in cranial tuberculosis
HI Price, A Danziger
American Journal of Roentgenology. 1978;130:769-771. 10.2214/ajr.130.4.769
Preview | Abstract | PDF (389 KB) | PDF Plus (275 KB)

Computed tomography of neutropenic colitis
MP Frick, CW Maile, Crass, ME Goldberg, JP Delaney
American Journal of Roentgenology. 1984;143:763-765. 10.2214/ajr.143.4.763
Preview | Abstract | PDF (479 KB) | PDF Plus (321 KB)

Scan time per slice

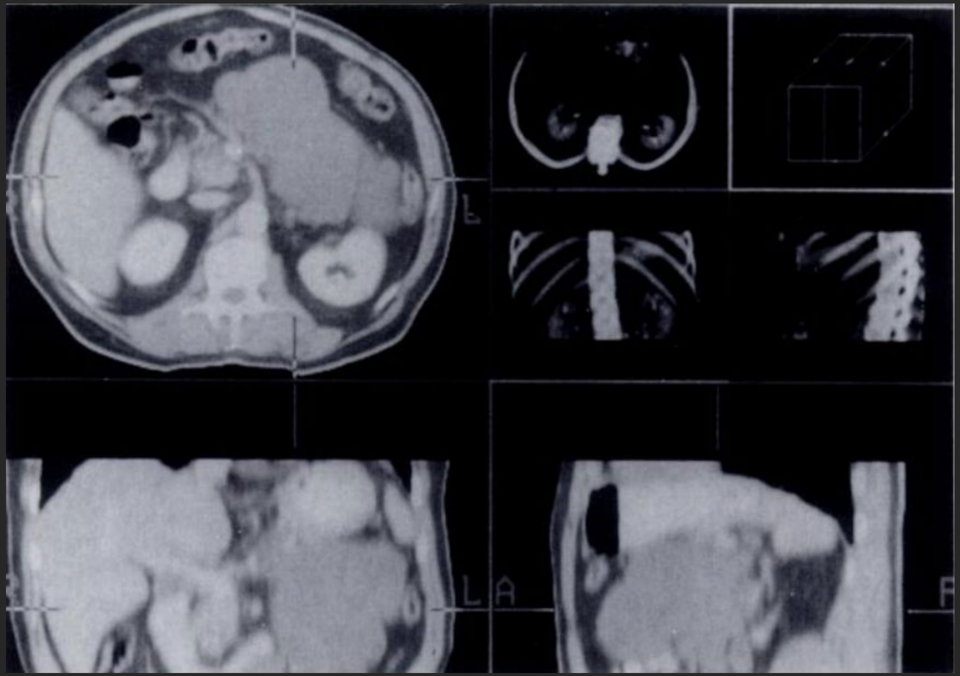


Hsieh, Jiang. *Computed tomography: principles, design, artifacts, and recent advances*. Vol. 114. SPIE press, 2003.

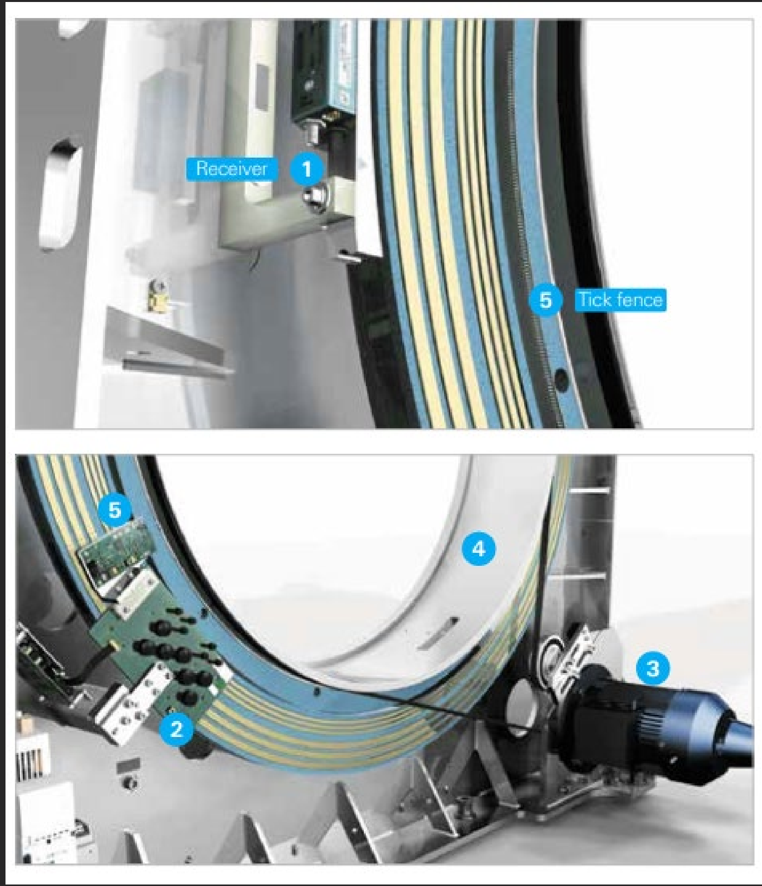
We can get 320 slices in ~0.25 seconds, that is 0.0008 s per image!

- By 1990 we had a “gantry that could spin without stopping to “rewind”

Images from first CT scanner with spiral/helical mode (Siemens Somatom-Plus)



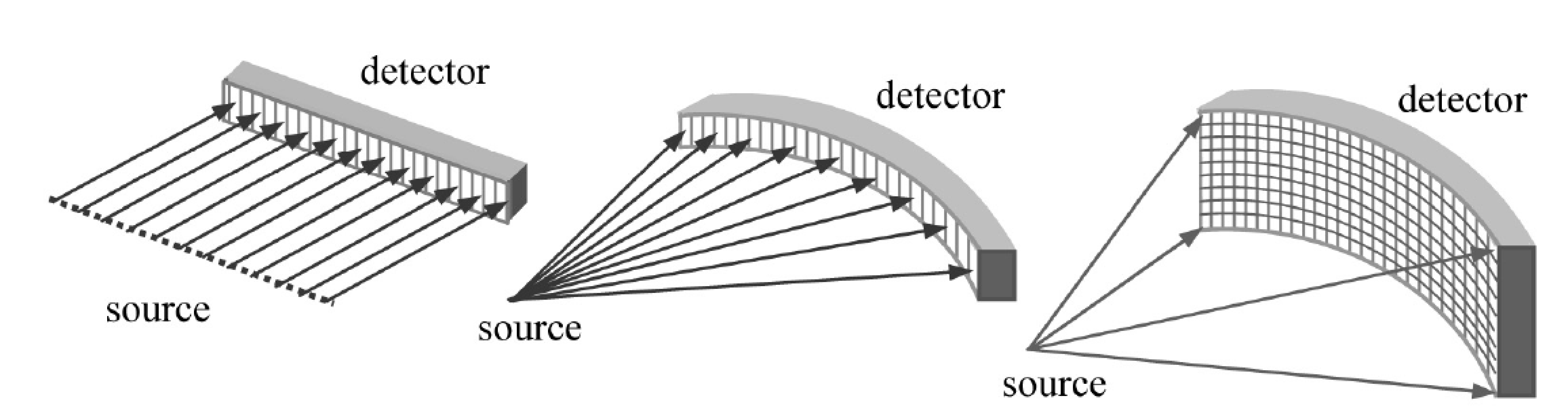
Fishman, Elliot K., et al. "Spiral CT of the pancreas with multiplanar display." *AJR. American journal of roentgenology* 159.6 (1992): 1209-1215.



http://rsna2013.rsna.org/files/1678/SCHLEIFRING_CTApplications.pdf

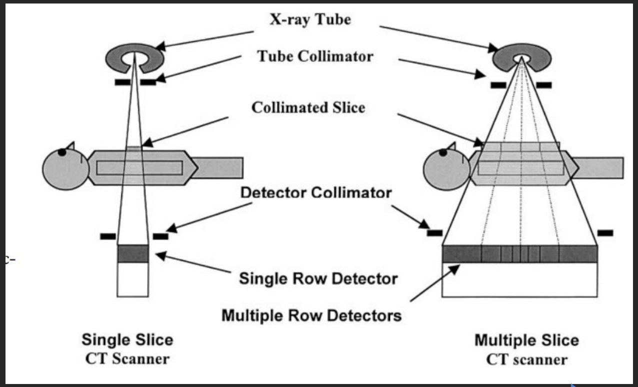
- In 1998 we had 4 slice CT scanners

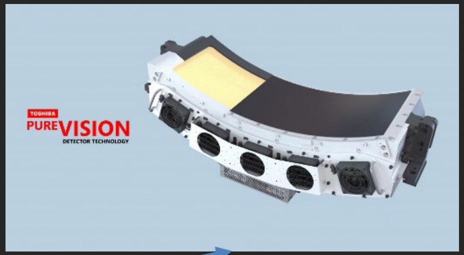
Single slice | Single slice | 9 slices

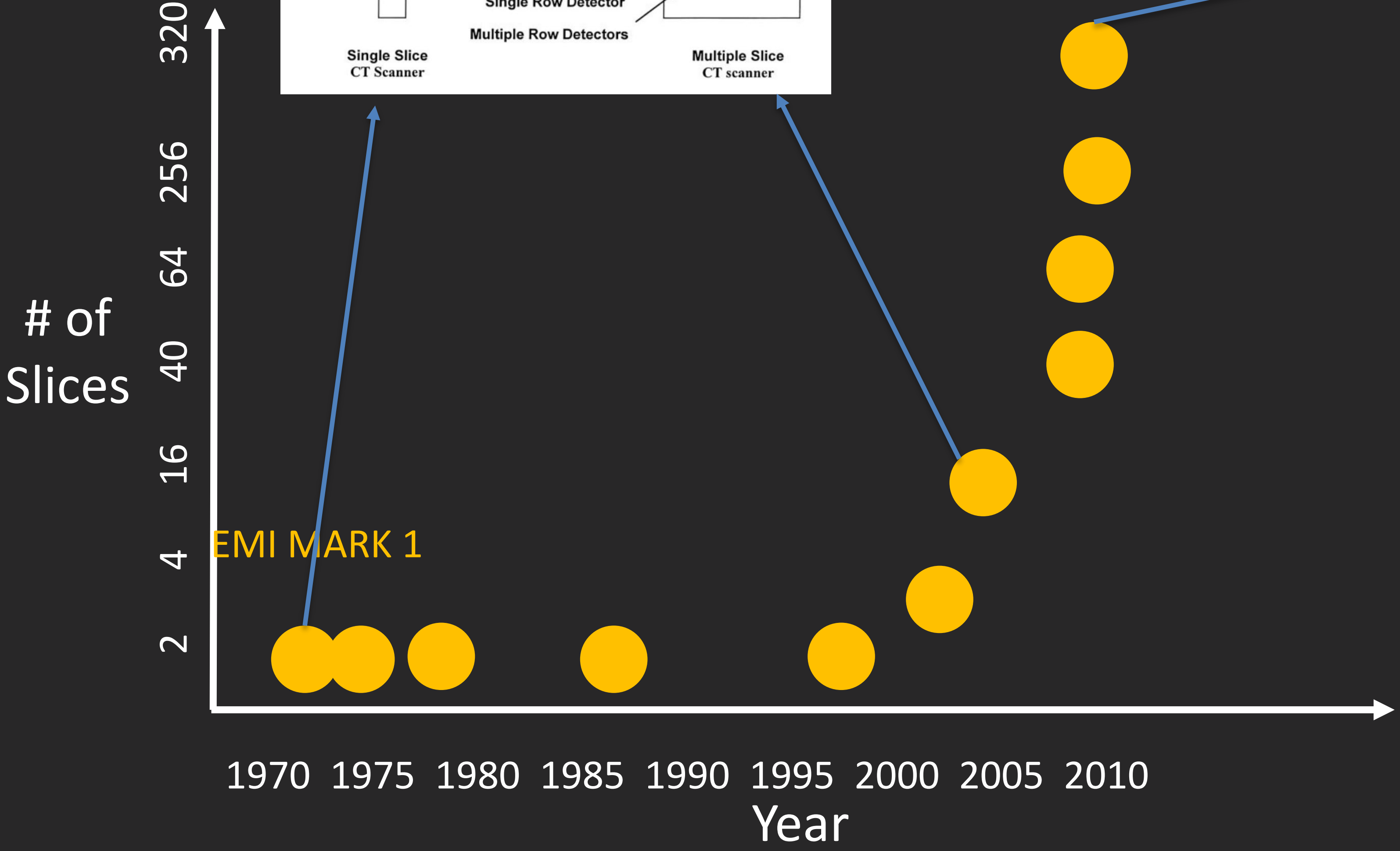


Hsieh, Jiang. *Computed tomography: principles, design, artifacts, and recent advances*. Vol. 114. SPIE press, 2003.

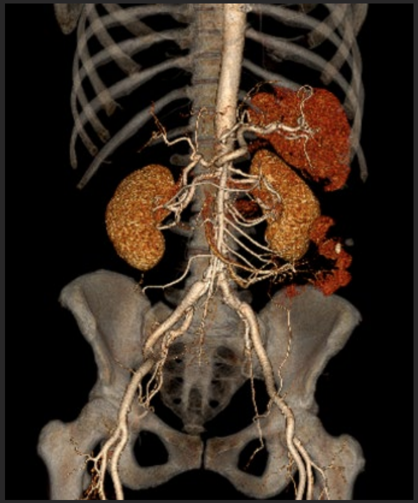
Mahesh, M. (2002). The AAPM/RSNA physics tutorial for residents: search for isotropic resolution in CT from conventional through multiple-row detector. *Radiographics*, *22*(4), 949-962.

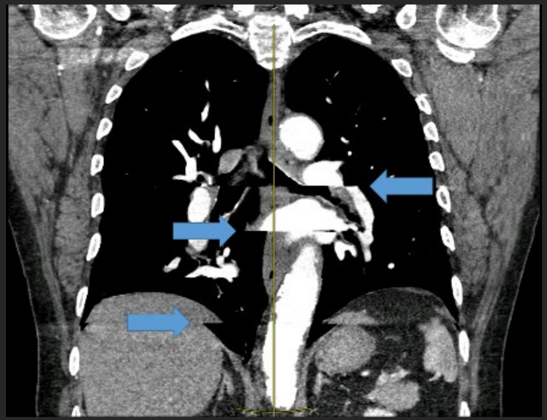




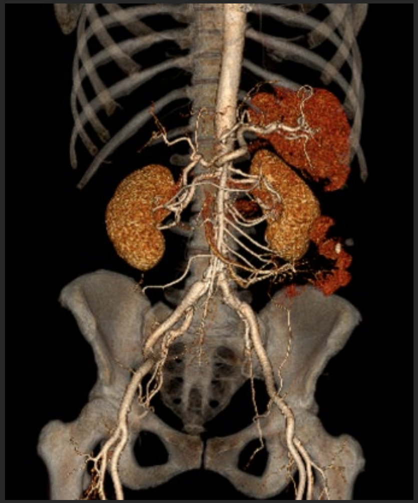


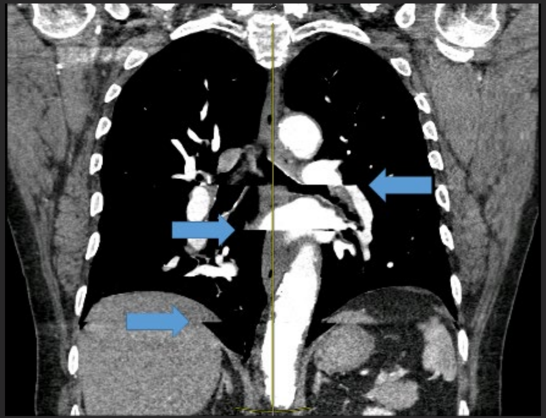
- Faster scanning helps
  - Capture an entire organ with the same contrast dynamics (i.e. perfusion images without shuttle, cardiac imaging without gating, chest or abdomen CTA's of an organ group)
  - The imaging of pediatrics who may not be capable of staying still for long periods
  - Reduce cardiac motion artifacts
  - Reduce respiratory motion artifacts
  - Reduce swallowing/peristalsis motion artifacts
- Scan times for patient throughput consideration are not really an issue in CT
  - In your typical 20 minute slot, the scanner is usually only acquiring data for ~10 seconds…

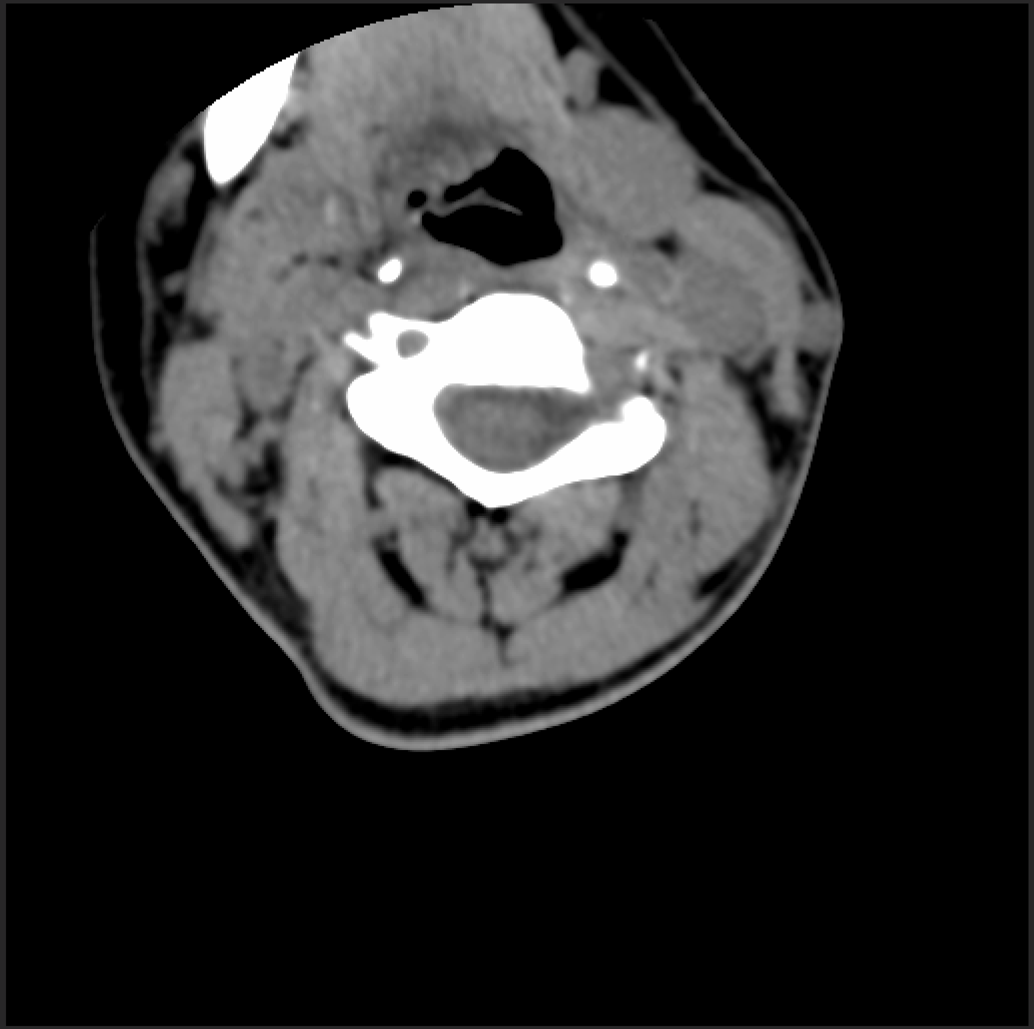


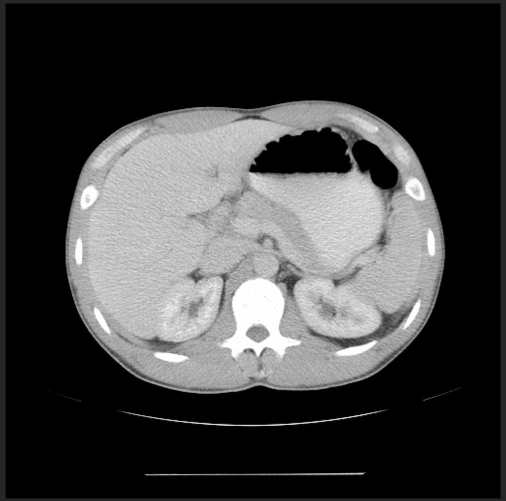


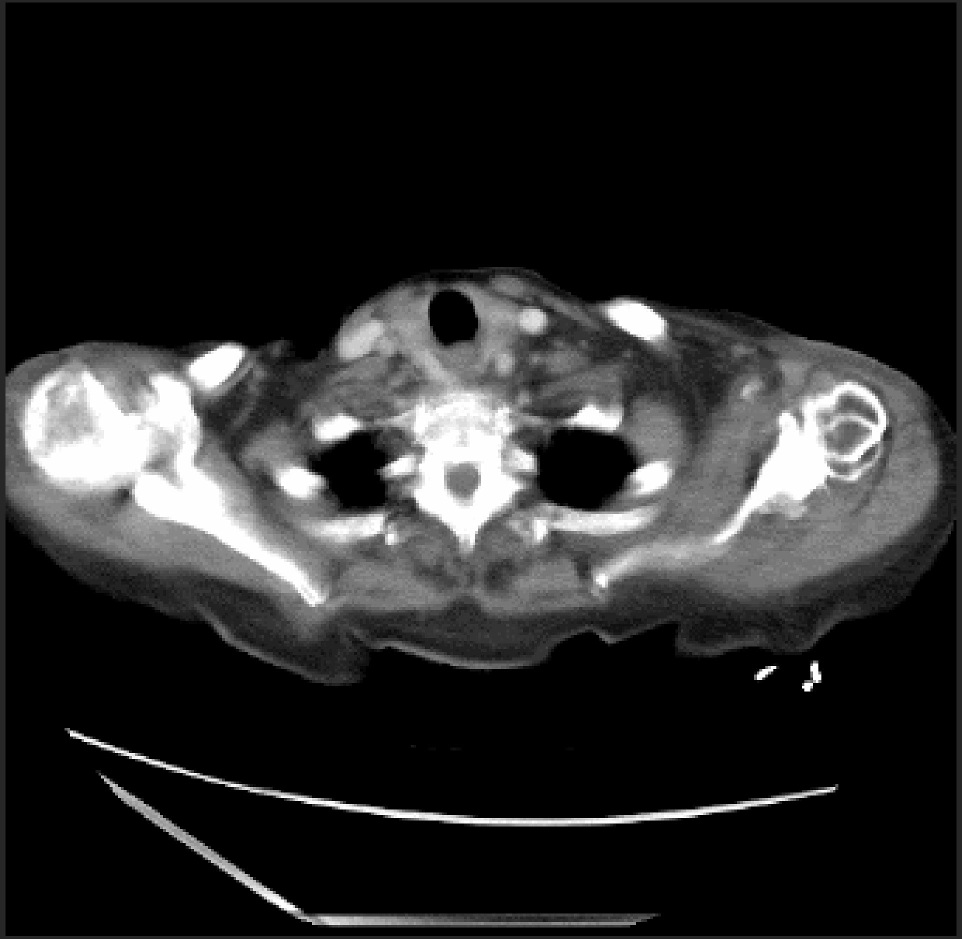
- Faster scanning helps
  - Things in our bodies that move
  - Patients that cannot help from moving

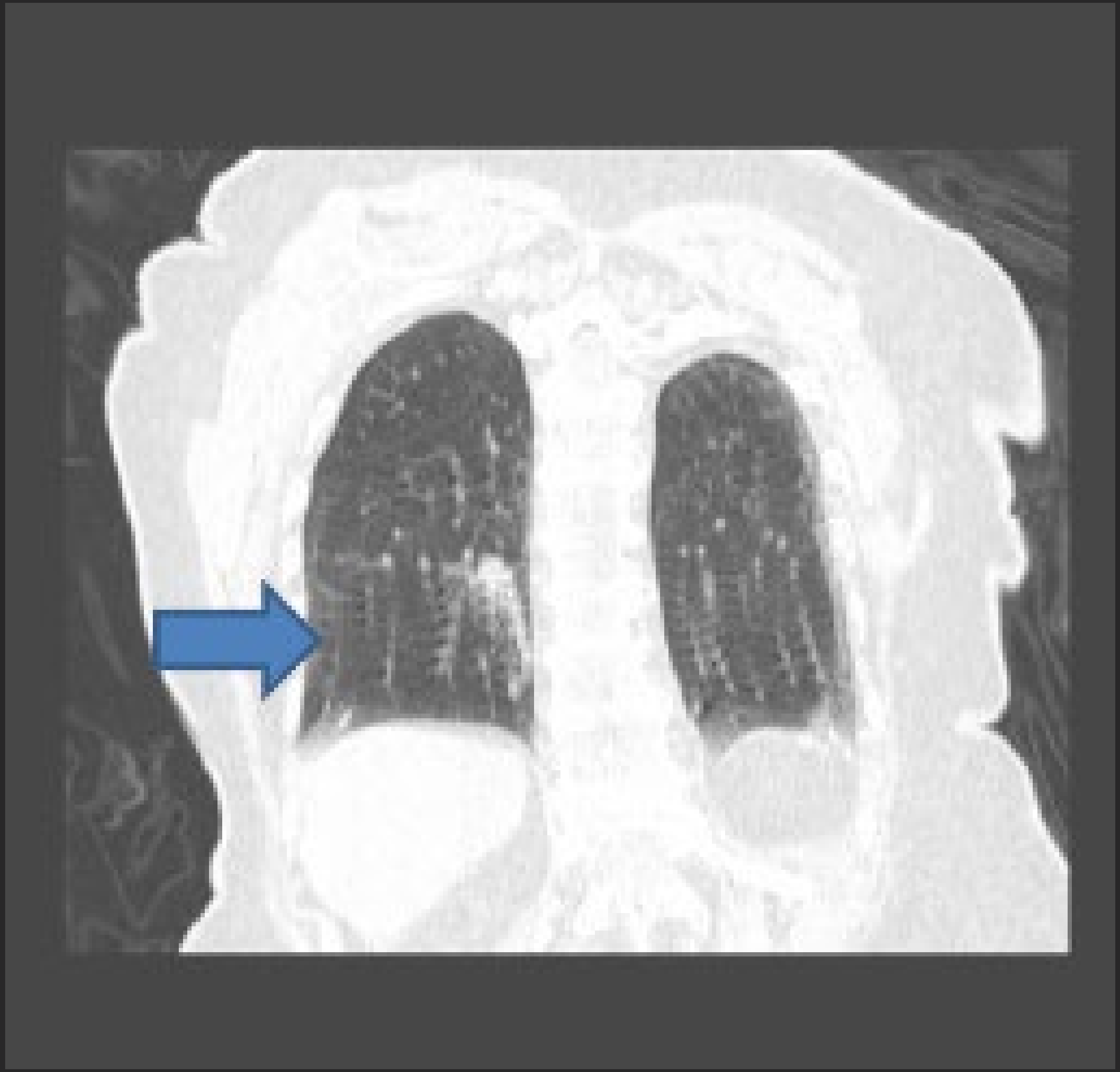
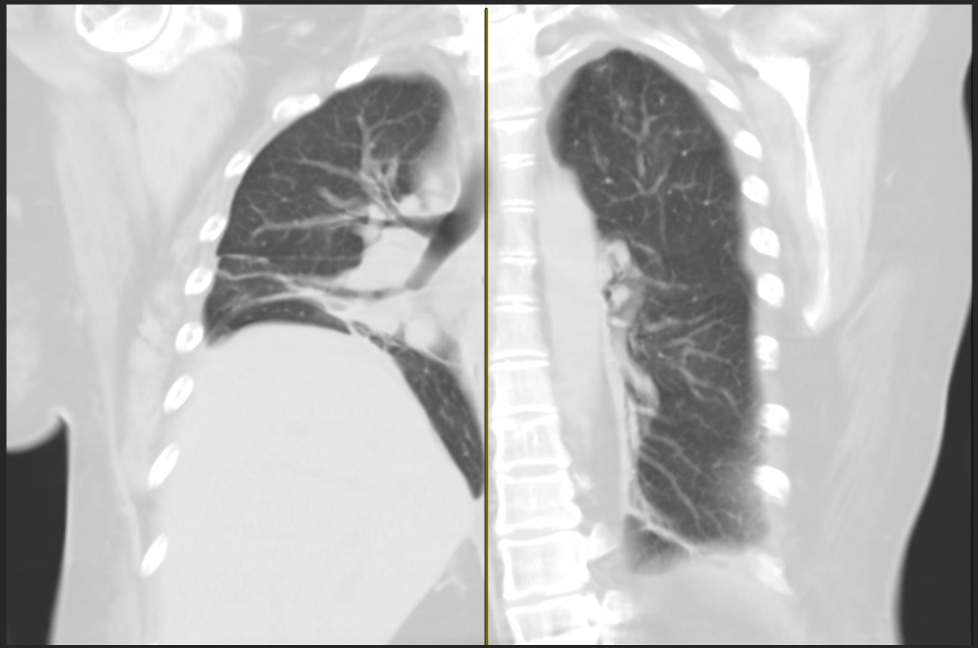


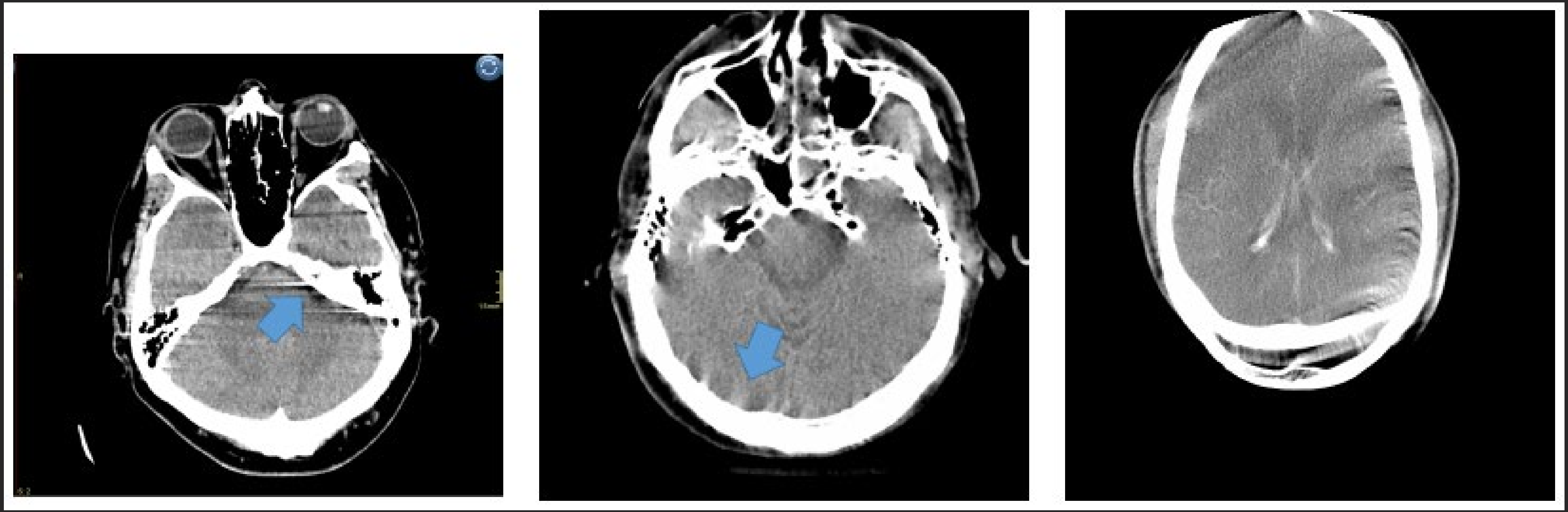










2 cm (i.e. 16 slice) CT scanner

1.4 sec
breath hold

Scan speed: 46 mm/s

Scan range: 288 mm

Total Scan time: 6.26 s

This scan was repeated

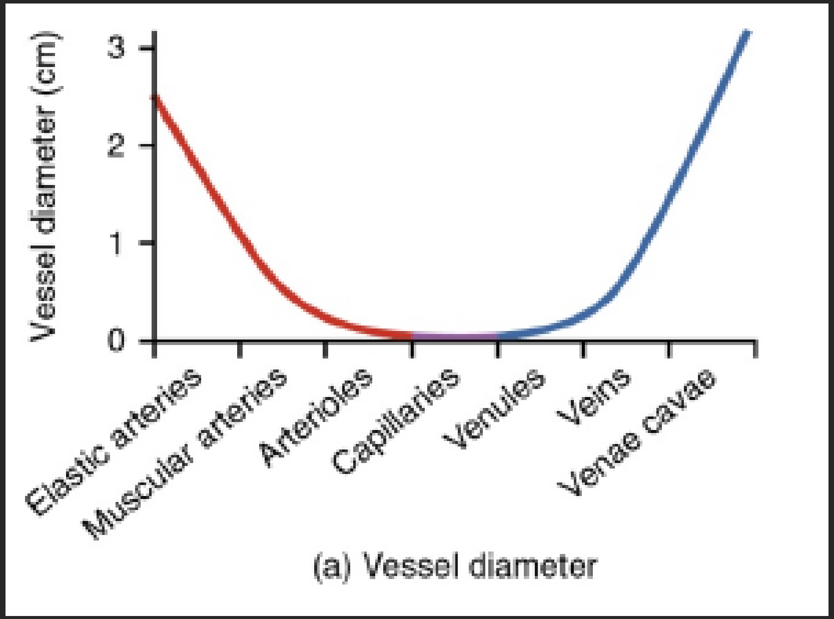
Premium (i.e., wide axial) CT scanner

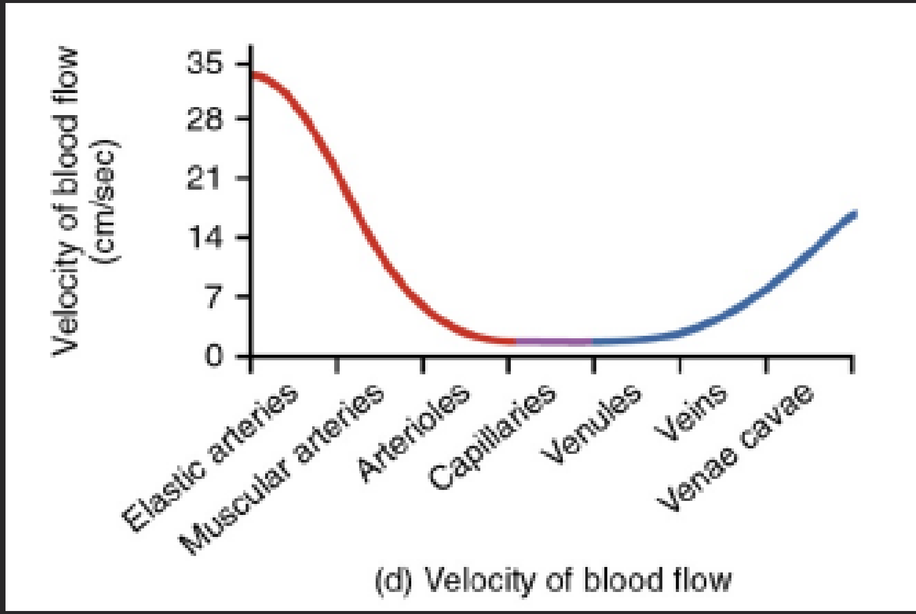
1.0 sec
breath hold

Scan speed: 283 mm/s

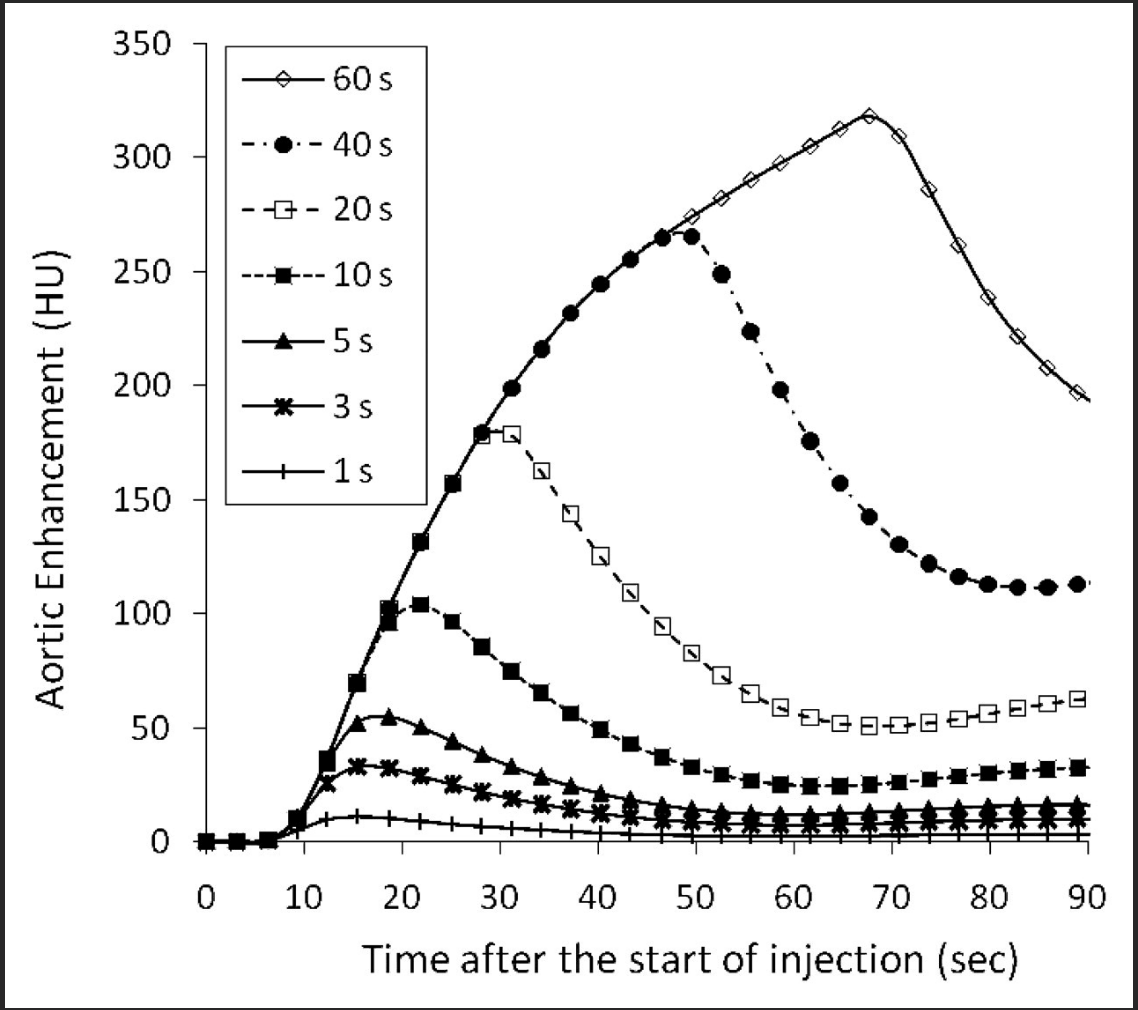
Scan range: 288 mm

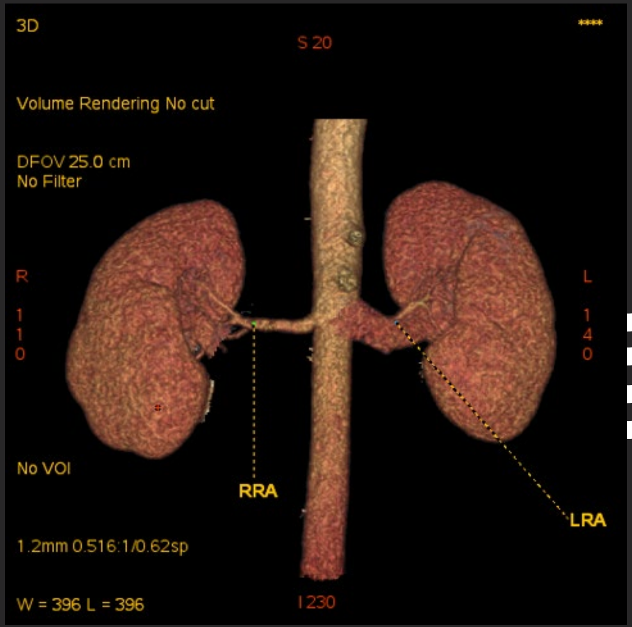
Total scan time: 1.02 s


Vessel diameter (cm)
3
2
1
0
Elastic arteries
Muscular arteries
Arterioles
Capillaries
Venules
Veins
Venae cavae
(a) Vessel diameter


Velocity of blood flow (cm/sec)
35
28
21
14
7
0
Elastic arteries
Muscular arteries
Arterioles
Capillaries
Venules
Veins
Venae cavae
(d) Velocity of blood flow

30 seconds

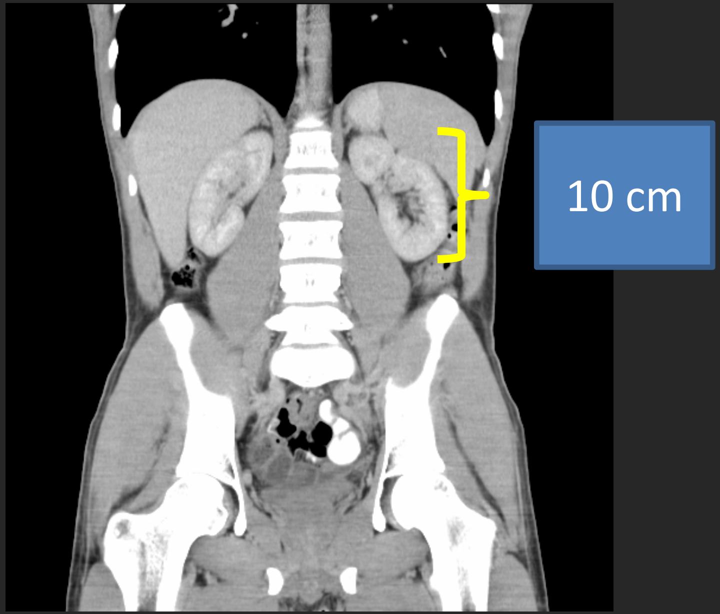




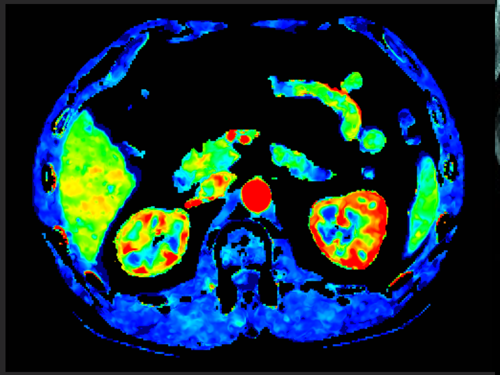
Plot: Bae, Kyongtae T. "Intravenous contrast medium administration and scan timing at CT: considerations and approaches." *Radiology* 256.1 (2010): 32-61.

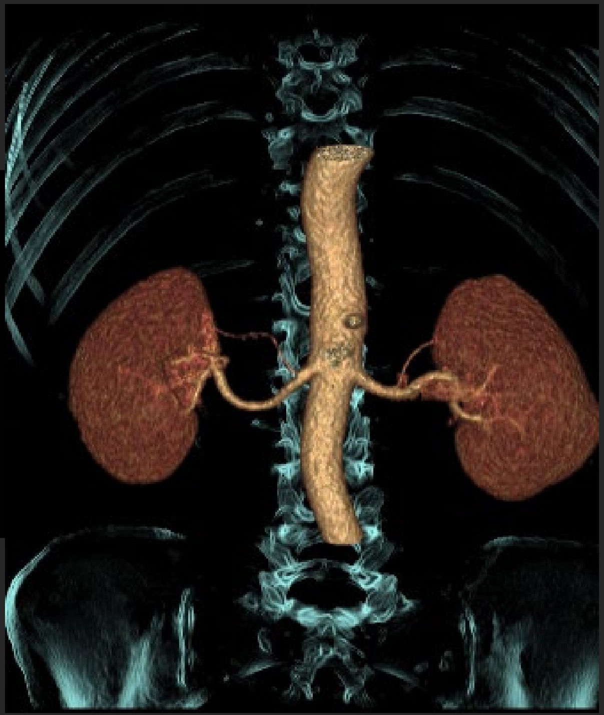
Scan Coverage: Kidney perfusion applications for wide axial coverage

Wide axial coverage perfusion
scan of the kidneys

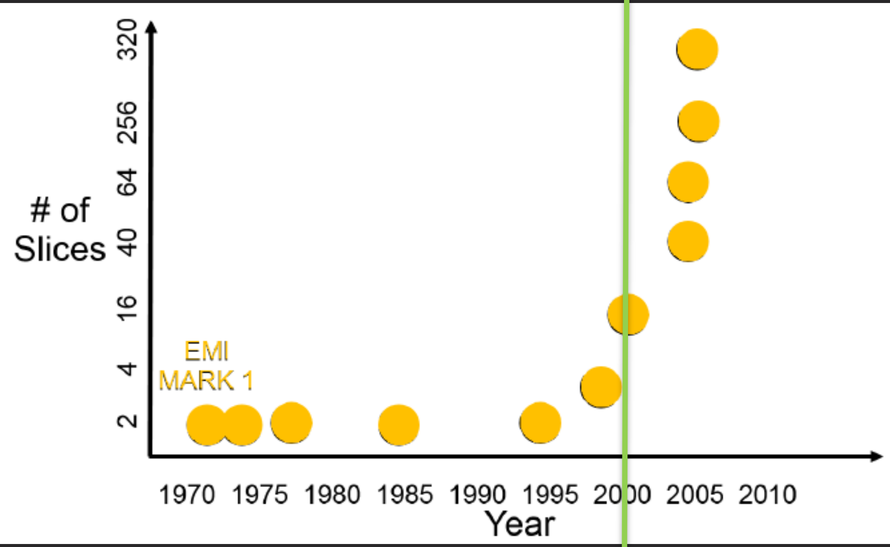


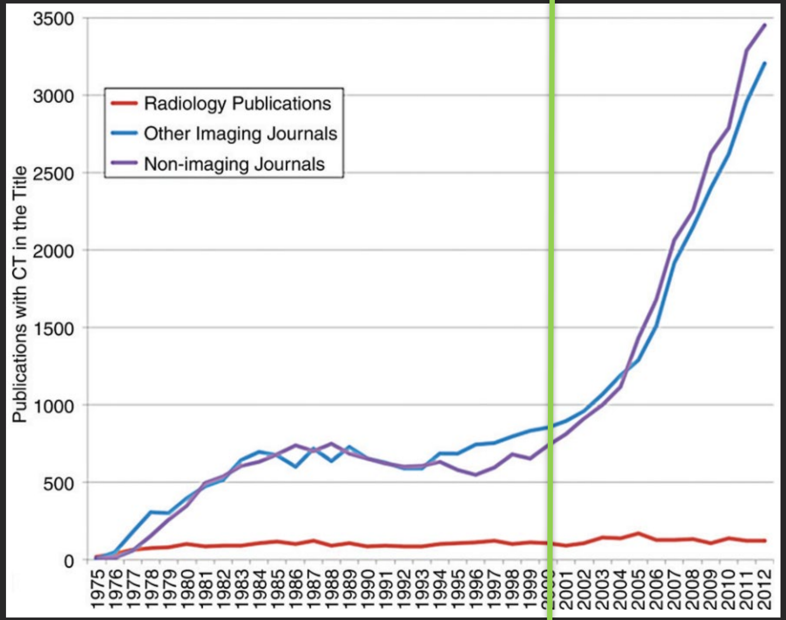
The ubiquitous 64/128 slice scanners of today with ~4 cm of coverage cannot image the entire kidneys in at a single couch position





CTA/perfusion images courtesy GE Healthcare

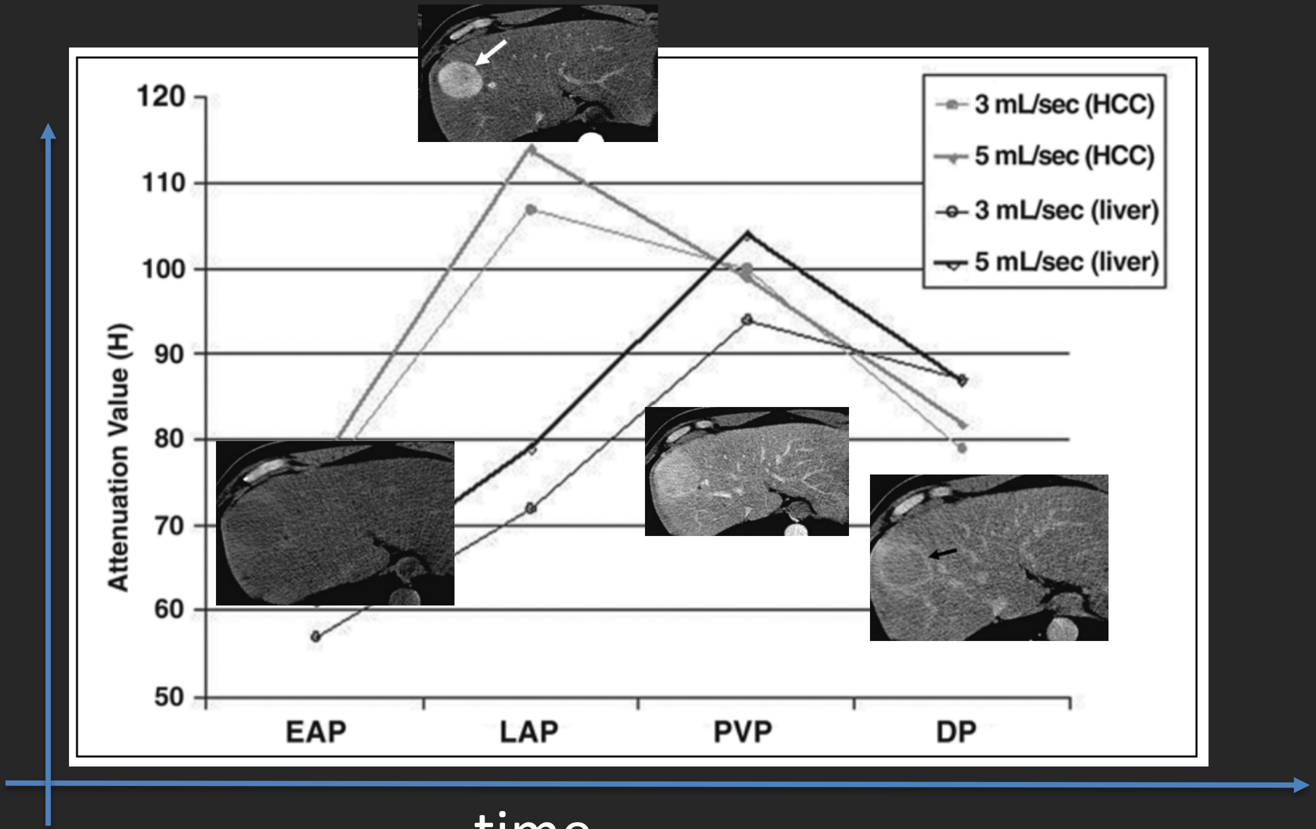




Bottom plot: Rubin, Geoffrey D. "Computed tomography: revolutionizing the practice of medicine for 40 years." *Radiology* 273.2S (2014): S45-S74.

Scan speed: The need and benefits of fast scanning

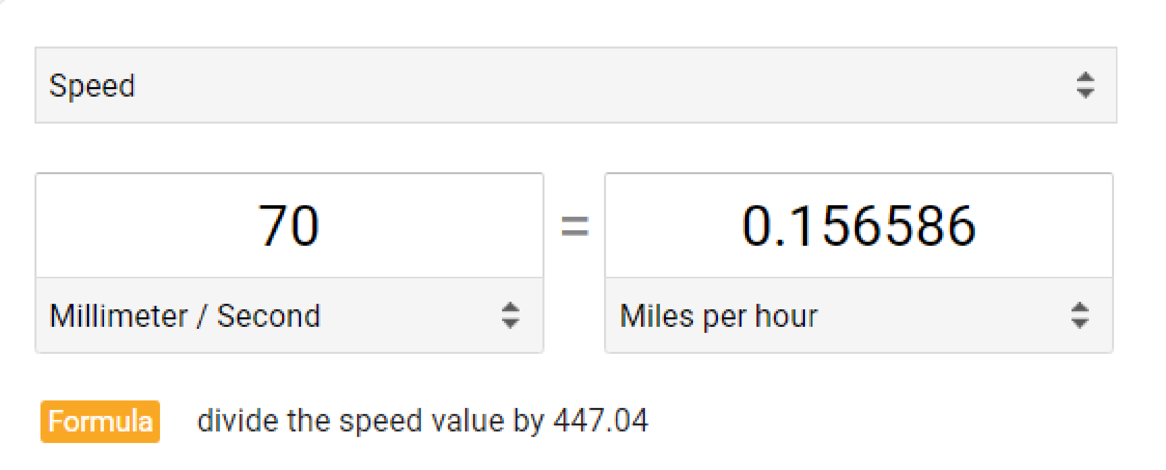
CT number



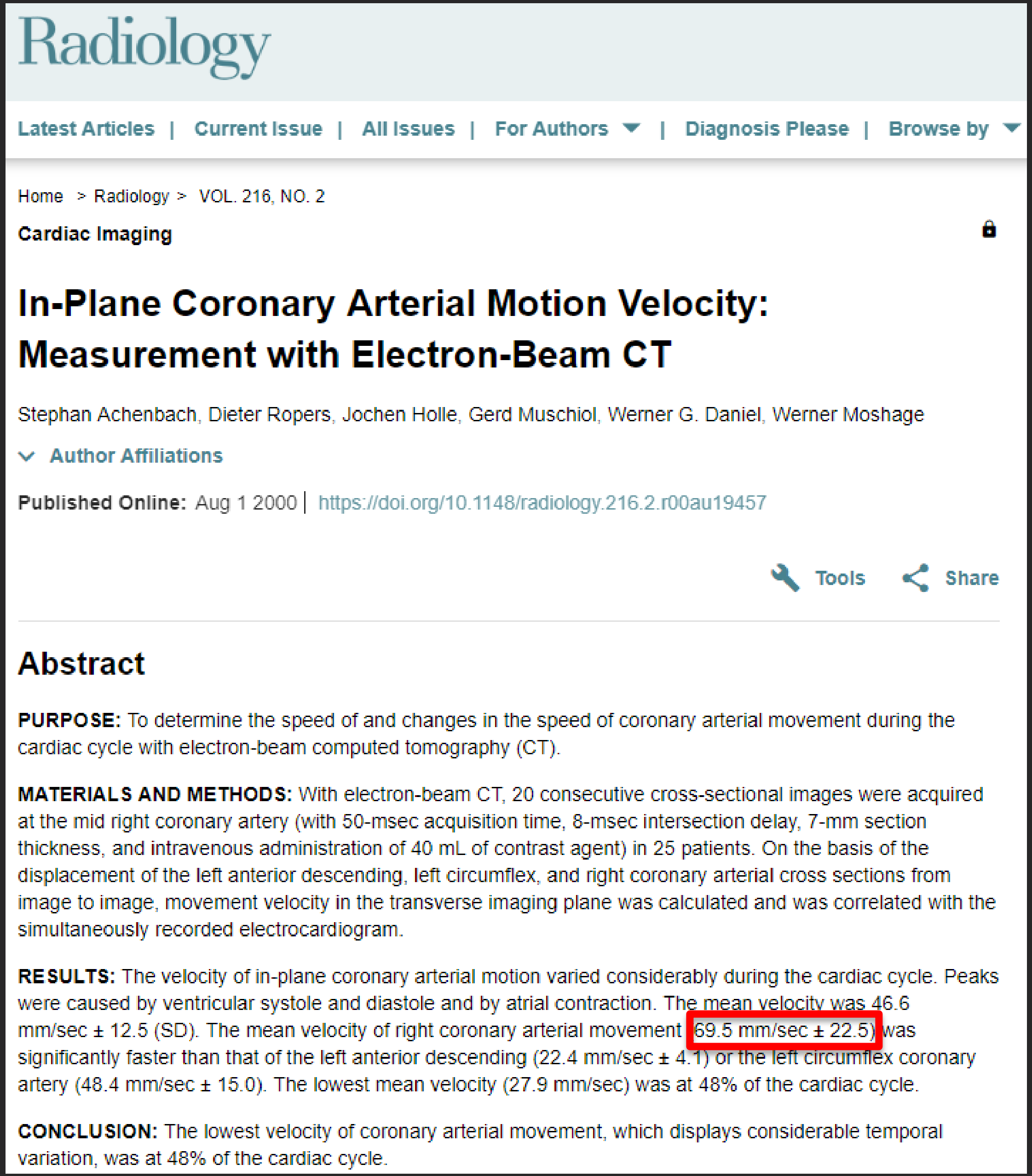
time

HCC staging, you need precise imaging of contrast enhancement at various phases to make a diagnosis

Hennedige, Tiffany, and Sudhakar Kundapur Venkatesh. "Imaging of hepatocellular carcinoma: diagnosis, staging and treatment monitoring." *Cancer Imaging* 12.3 (2012): 530.
Schima, Wolfgang, et al. "Quadruple-phase MDCT of the liver in patients with suspected hepatocellular carcinoma: effect of contrast material flow rate." *American Journal of Roentgenology* 186.6 (2006): 1571-1579.



This may not seem fast, but consider we commonly use a RFOV of 25 cm and 512 voxels, that's a voxel size of 0.48 mm. In 1 second @ 70 mm/s…we will see blurring



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Cardiac Imaging

In-Plane Coronary Arterial Motion Velocity: Measurement with Electron-Beam CT

Stephan Achenbach, Dieter Ropers, Jochen Holle, Gerd Muschiol, Werner G. Daniel, Werner Moshage

Author Affiliations

Published Online: Aug 1 2000 | https://doi.org/10.1148/radiology.216.2.r00au19457

Tools Share

Abstract

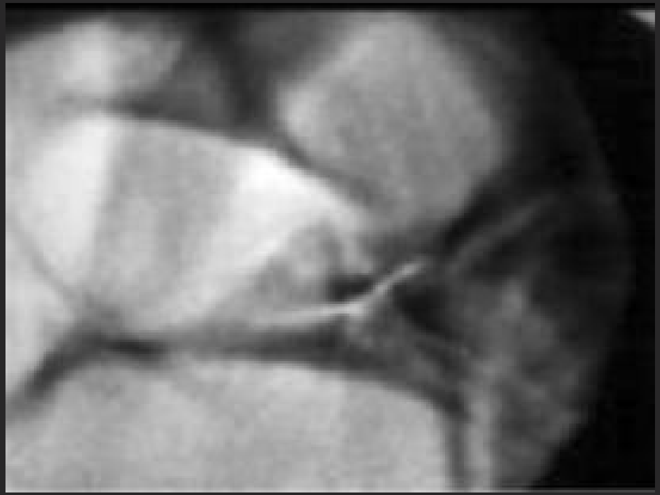
PURPOSE: To determine the speed of and changes in the speed of coronary arterial movement during the cardiac cycle with electron-beam computed tomography (CT).

MATERIALS AND METHODS: With electron-beam CT, 20 consecutive cross-sectional images were acquired at the mid right coronary artery (with 50-msec acquisition time, 8-msec intersection delay, 7-mm section thickness, and intravenous administration of 40 mL of contrast agent) in 25 patients. On the basis of the displacement of the left anterior descending, left circumflex, and right coronary arterial cross sections from image to image, movement velocity in the transverse imaging plane was calculated and was correlated with the simultaneously recorded electrocardiogram.

RESULTS: The velocity of in-plane coronary arterial motion varied considerably during the cardiac cycle. Peaks were caused by ventricular systole and diastole and by atrial contraction. The mean velocity was 46.6 mm/sec ± 12.5 (SD). The mean velocity of right coronary arterial movement (69.5 mm/sec ± 22.5) was significantly faster than that of the left anterior descending (22.4 mm/sec ± 4.1) or the left circumflex coronary artery (48.4 mm/sec ± 15.0). The lowest mean velocity (27.9 mm/sec) was at 48% of the cardiac cycle.

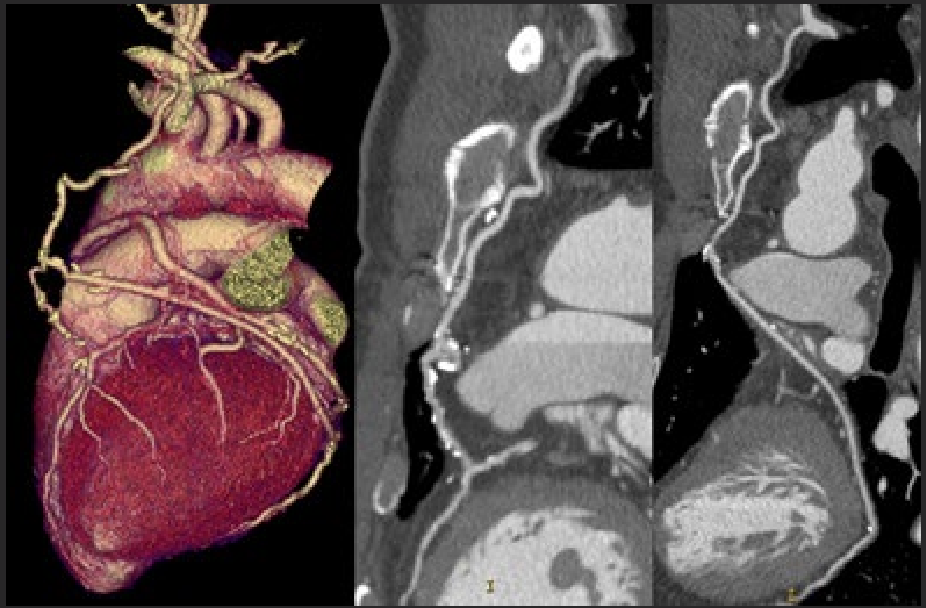
CONCLUSION: The lowest velocity of coronary arterial movement, which displays considerable temporal variation, was at 48% of the cardiac cycle.

1990



4.5 second gantry rotation, 10 mm slice

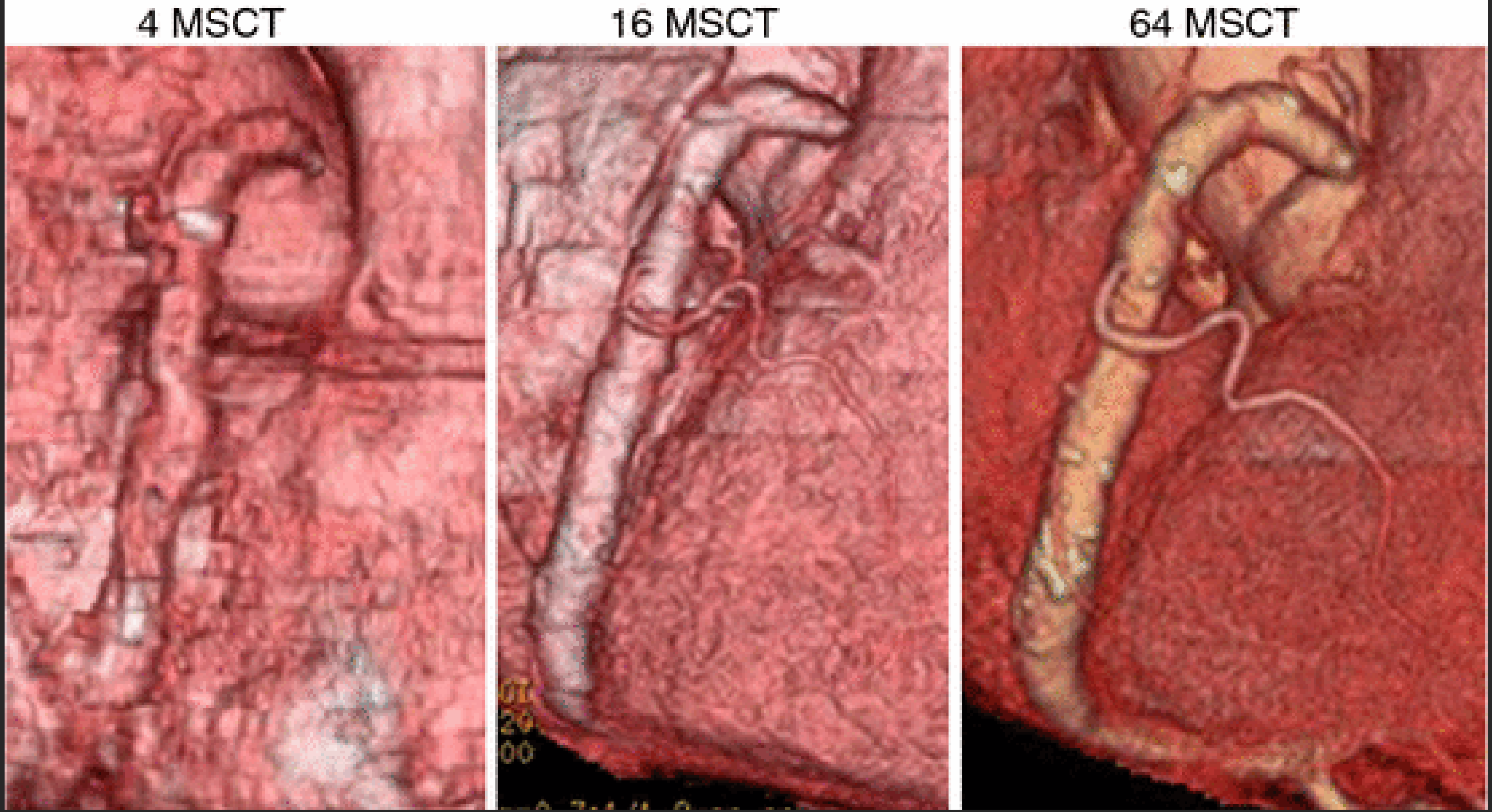
2004



0.33 second gantry rotation, 0.5 mm slice

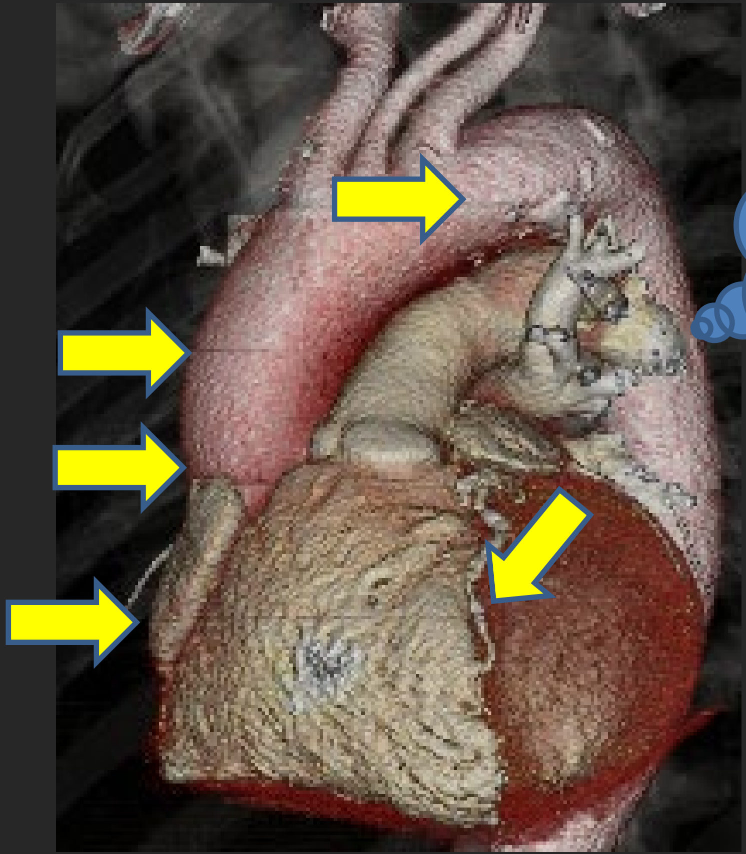
Left image: Hurlock, Gregory S., Hiroshi Higashino, and Teruhito Mochizuki. "History of cardiac computed tomography: single to 320-detector row multislice computed tomography." *The international journal of cardiovascular imaging* 25.1 (2009): 31-42.
Right: https://www.auntminnie.com/index.aspx?sec=sup&sub=xra&pag=dis&ItemID=74628

1998 2002 2004



Hurlock, Gregory S., Hiroshi Higashino, and Teruhito Mochizuki. "History of cardiac computed tomography: single to 320-detector row multislice computed tomography." *The international journal of cardiovascular imaging* 25.1 (2009): 31-42.

2004



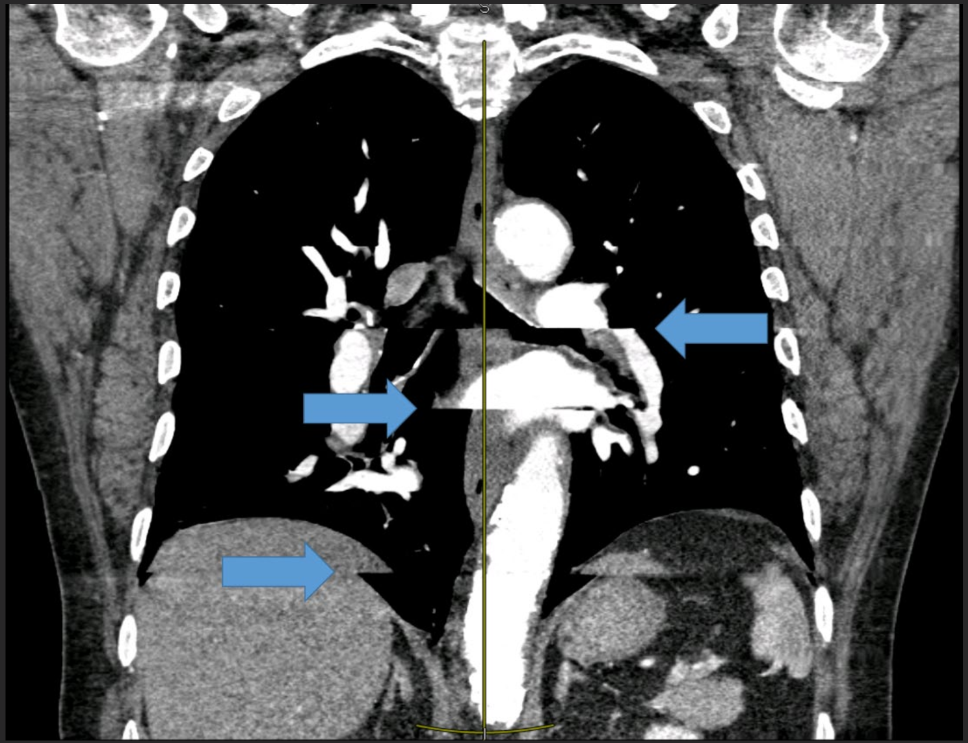
The artifacts appear every 4 cm…

Prospective gating, 4 cm beam collimation

2014

16 cm coverage scanner, 1 heart beat gated image, 0.27 second rotation

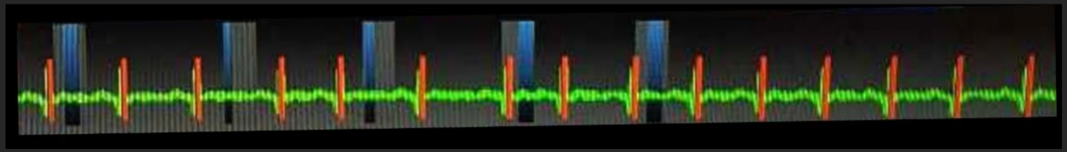
Benz, Dominik C., et al. "Minimized Radiation and Contrast Agent Exposure for Coronary Computed Tomography Angiography: First Clinical Experience on a Latest Generation 256-slice Scanner." *Academic radiology* 23.8 (2016): 1008-1014.

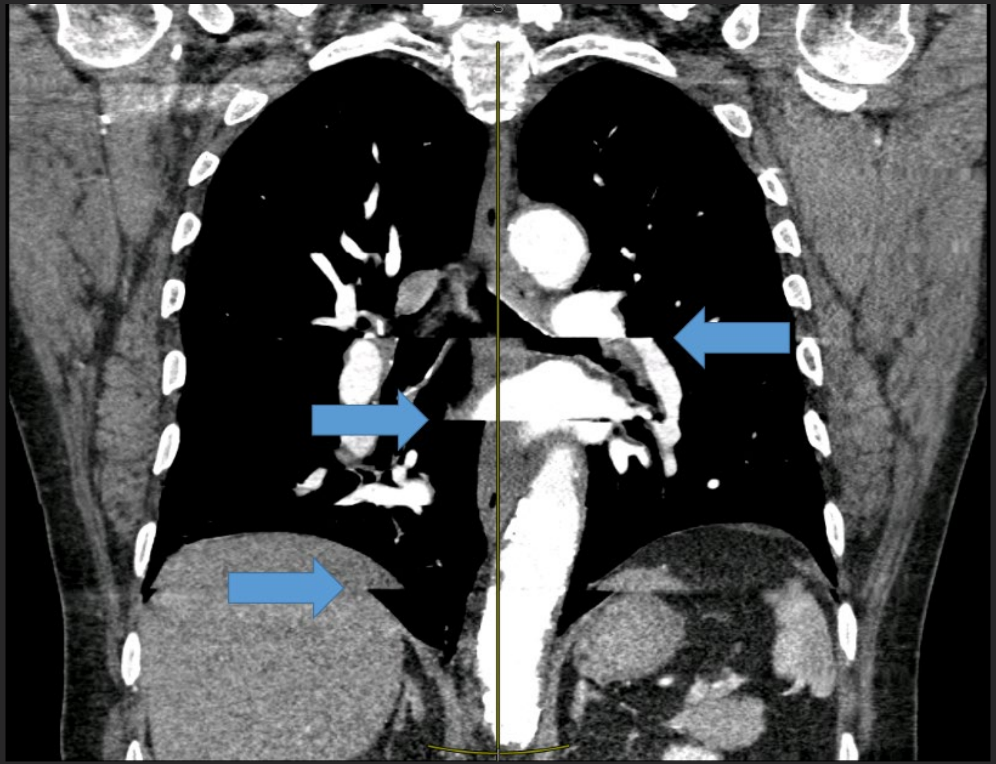


average heart rate of 70 bpm

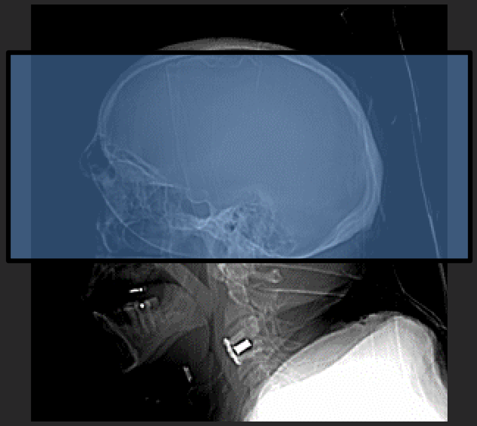
varied from a minimum of 51 to a maximum of 79 during the exam

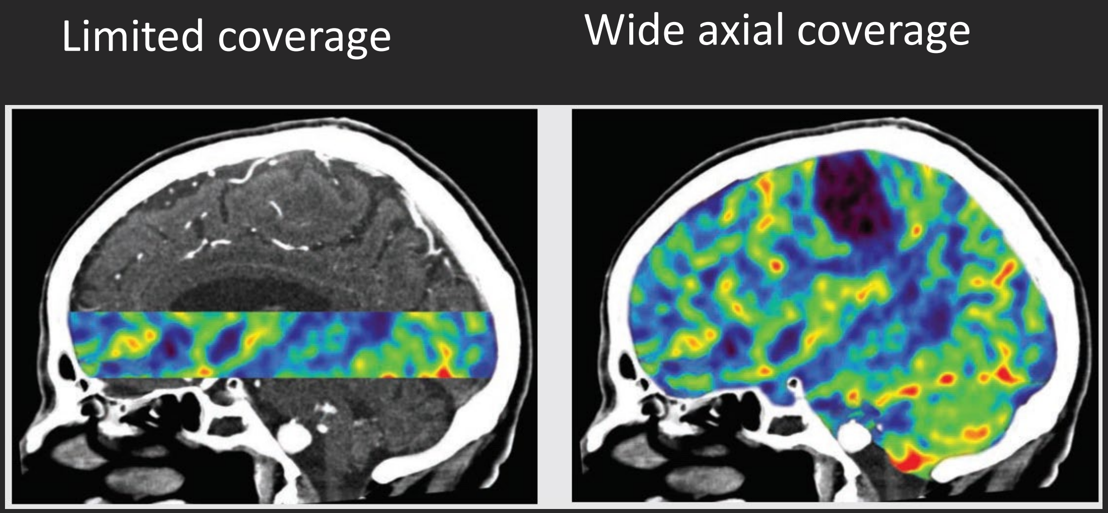
3 irregular heart beats during the prospective cardiac acquisition



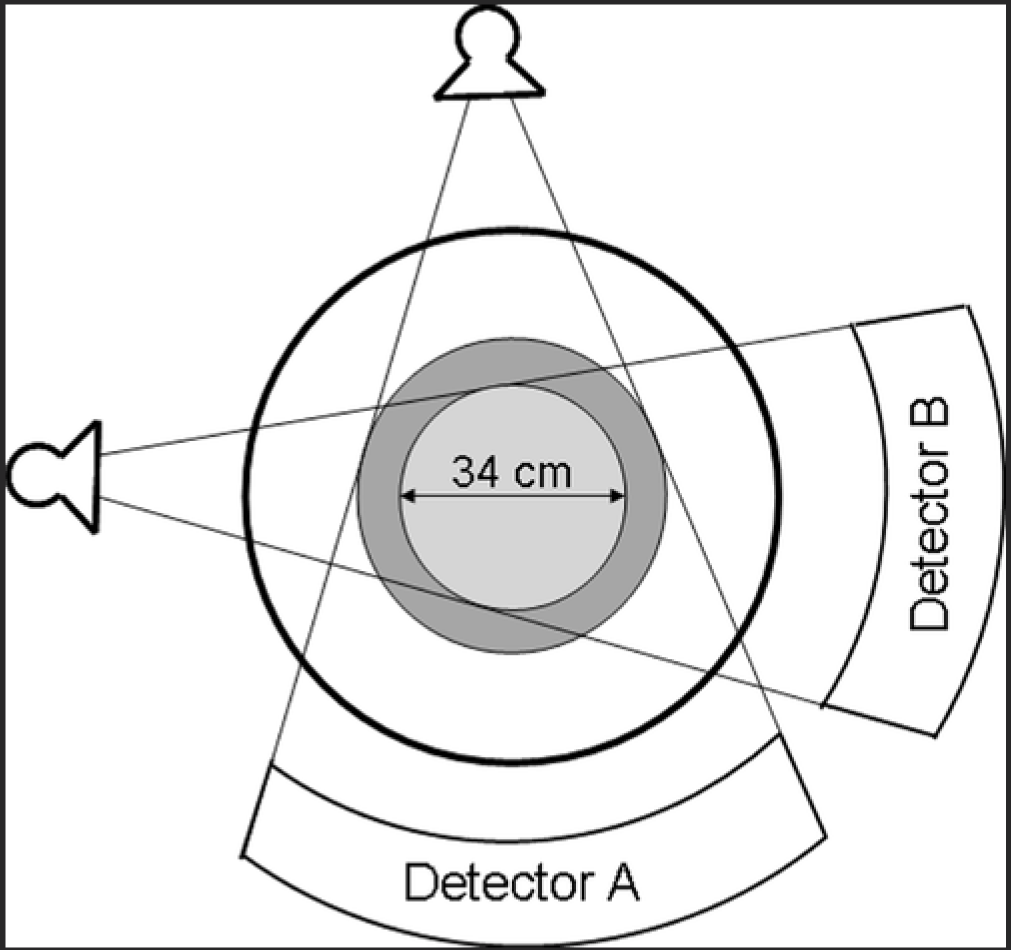


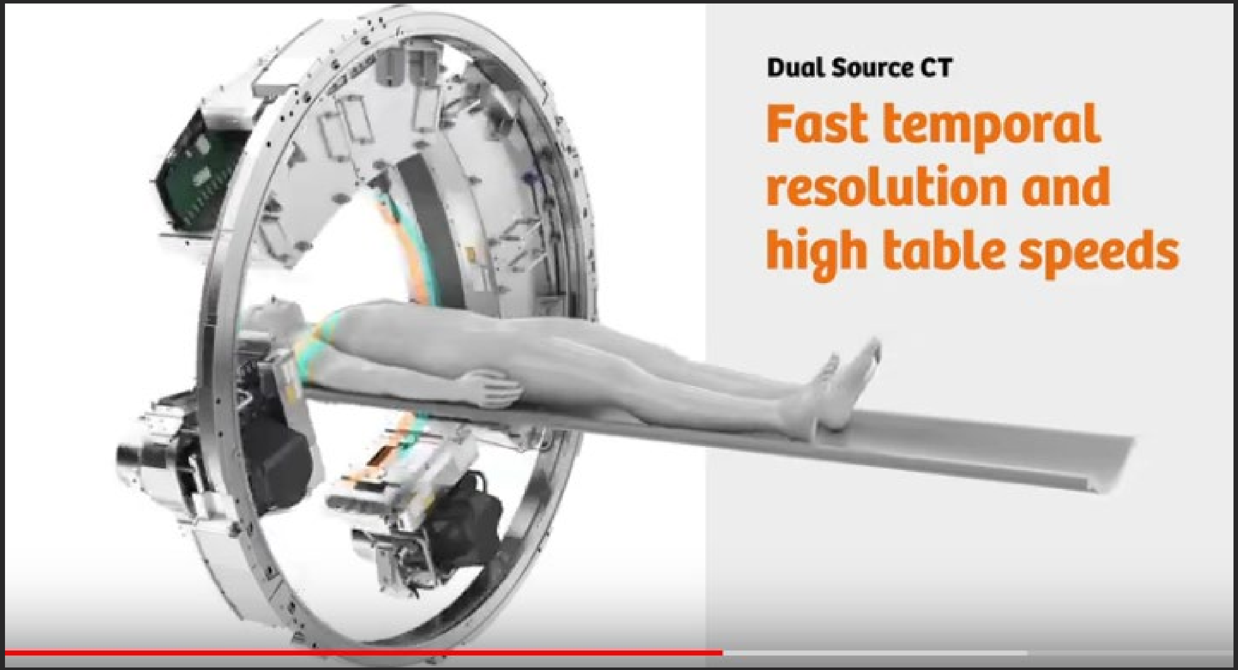
Choi, S.I., George, R.T., Schuleri, K.H. et al. Int J Cardiovasc Imaging (2009) 25(Suppl 1): 23. doi:10.1007/s10554-009-9443-4



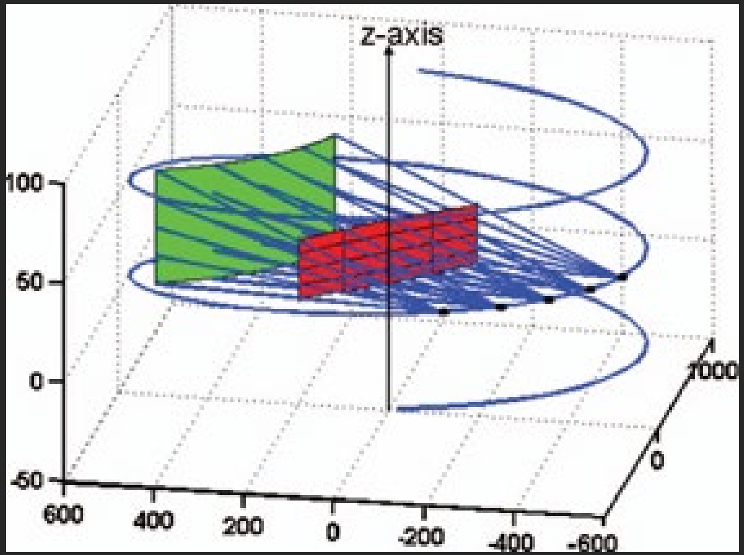


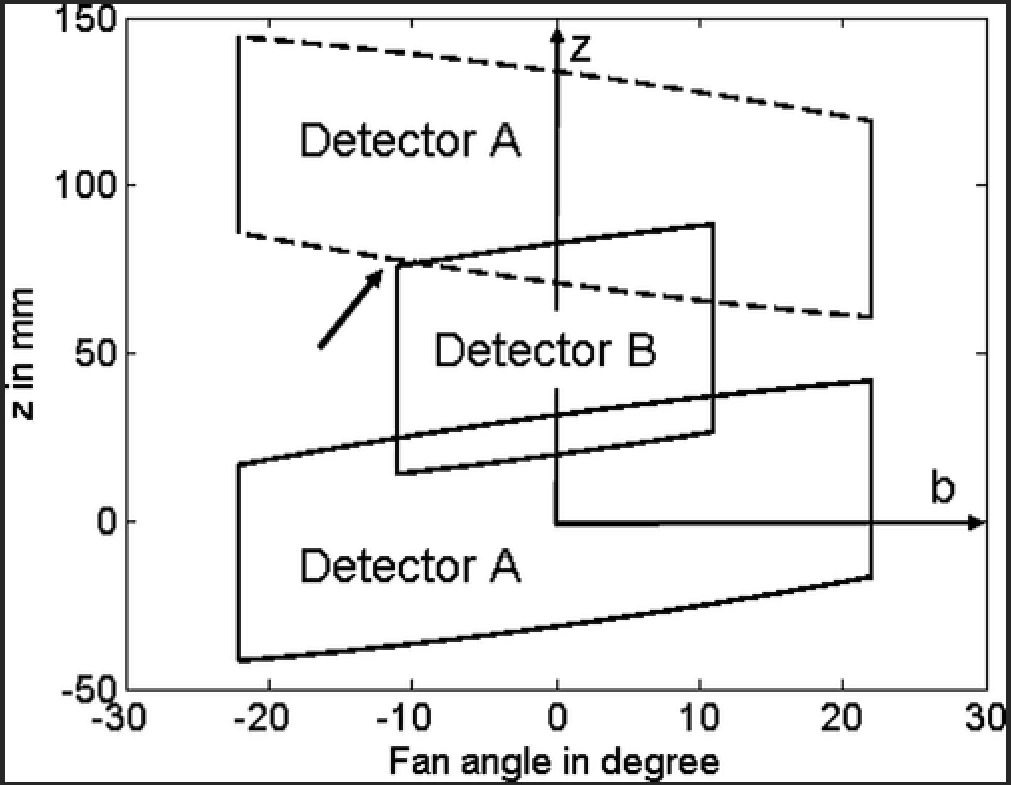
Right Images: Image from "Neuro and acute stroke imaging with dynamic volume CT" by Richard Mather Toshiba Medical Systems whitepaper 2008



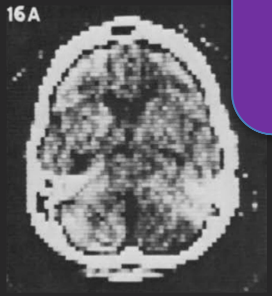


Flohr, T. G., Leng, S., Yu, L., Allmendinger, T., Bruder, H., Petersilka, M., ... & McCollough, C. H. (2009). Dual-source spiral CT with pitch up to 3.2 and 75 ms temporal resolution: image reconstruction and assessment of image quality. *Medical physics*, *36*(12), 5641-5653.





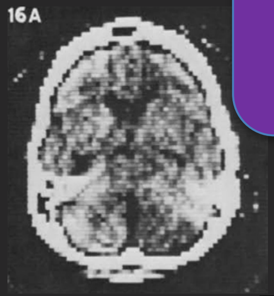
Flohr, T. G., Leng, S., Yu, L., Allmendinger, T., Bruder, H., Petersilka, M., ... & McCollough, C. H. (2009). Dual-source spiral CT with pitch up to 3.2 and 75 ms temporal resolution: image reconstruction and assessment of image quality. *Medical physics*, *36*(12), 5641-5653.



Rubin, Geoffrey D. "Computed tomography: revolutionizing the practice of medicine for 40 years." Radiology 273.2S (2014): S45-S74.

Actually imaging the entire body- head to feet

70s



Actually imaging the entire body- head to feet

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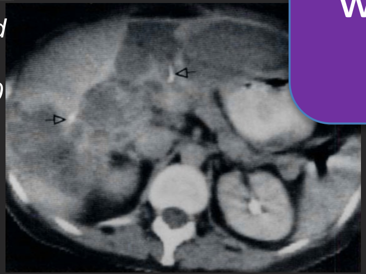


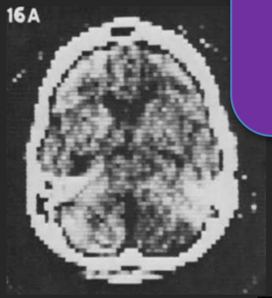
So my patient has X, what does it look like on CT?

70-80s

Kunstlinger, Francis, et al. "Computed tomography of hepatocellular carcinoma." American Journal of Roentgenology 134.3 (1980): 431-437.

Actually imaging the entire body- head to feet

70s



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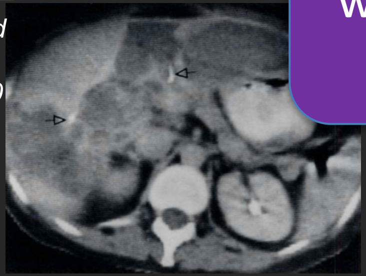
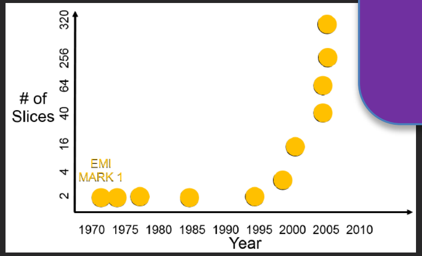


Kunstlinger, Francis, et al. "Computed tomography of hepatocellular carcinoma." American Journal of Roentgenology 134.3 (1980): 431-437.

Imaging blood vessels

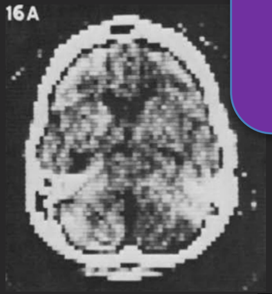
00s



“The CT Handbook: Optimizing Protocols for Today’s feature-rich scanners” By Tim Szczykutowicz. Medical Physics Publishing 2020

Actually imaging the entire body- head to feet

70s



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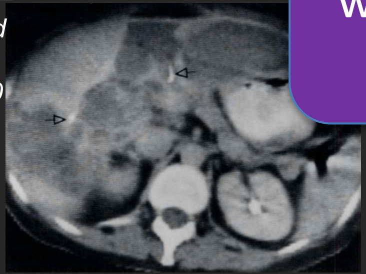

Imaging blood vessels

00s

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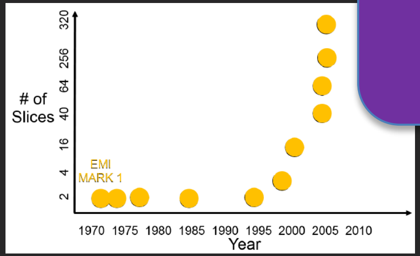
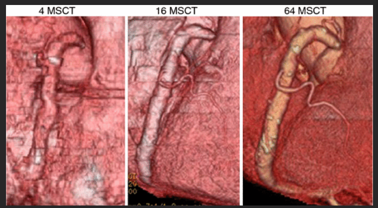


Imaging the heart

00s

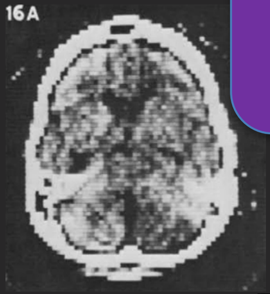
"The CT Handbook: Optimizing Protocols for Today's feature-rich scanners" By Tim Szczykutowicz. Medical Physics Publishing 2020



Hurlock, Gregory S., Hiroshi Higashino, and Teruhito Mochizuki. "History of cardiac computed tomography: single to 320-detector row multislice computed tomography." The international journal of cardiovascular imaging 25.1 (2009): 31-42.

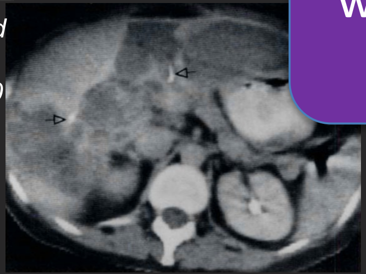
Actually imaging the entire body- head to feet

70s



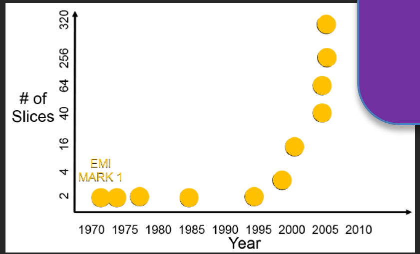
So my patient has X, what does it look like on CT?

70-80s



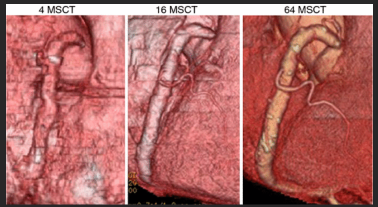
Imaging blood vessels

00s



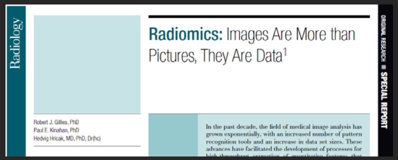
Imaging the heart

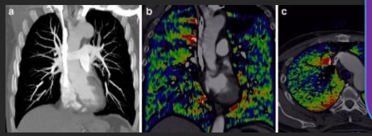
00s



More than just CT number?

teens





Rubin, Geoffrey D. "Computed tomography: revolutionizing the practice of medicine for 40 years." Radiology 273.2S (2014): S45-S74.

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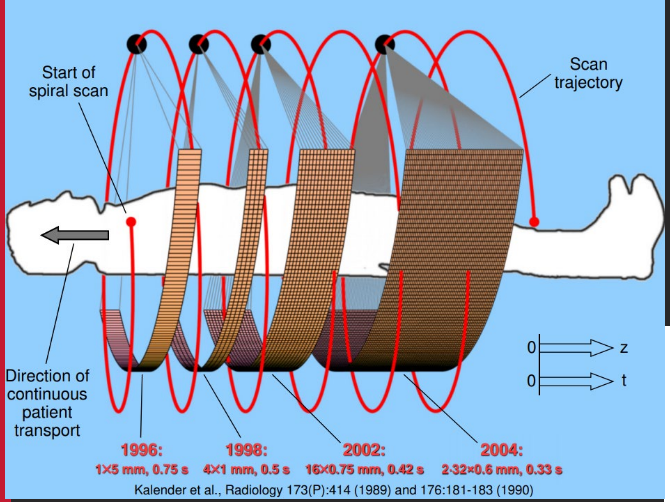
Johnson, Thorsten RC, Bernhard Krauss, Martin Sedlmair, Michael Grasruck, Herbert Bruder, Dominik Morhard, Christian Fink et al. "Material differentiation by dual energy CT: initial experience." *European radiology* 17, no. 6 (2007): 1510-1517.

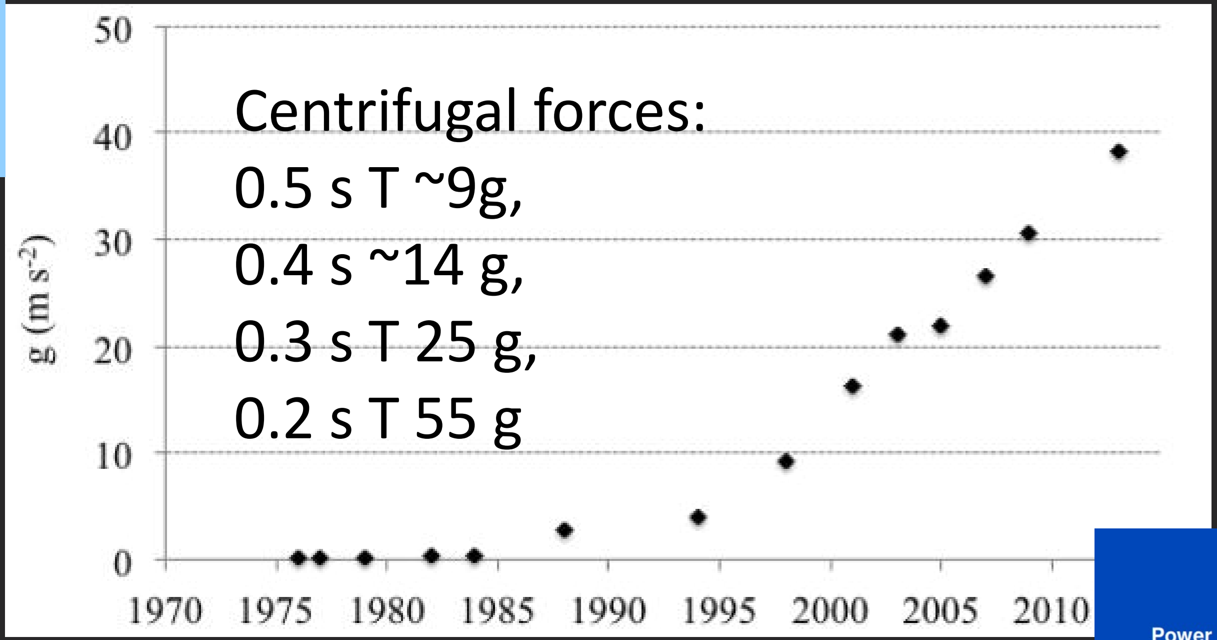
CTECC
CT EDUCATION AND COLLABORATION CENTER

Thanks!

Feel free to contact me at
tszczykutowicz@uwhealth.org

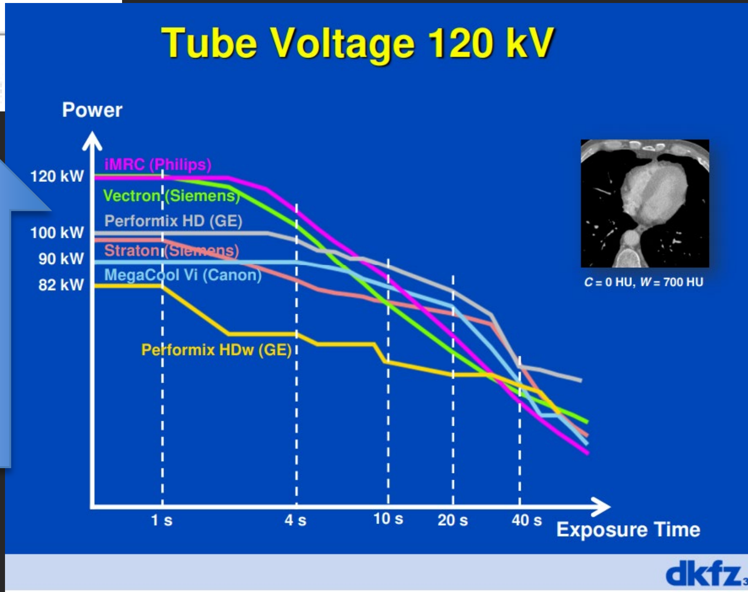


Bigger, faster, more powerful



Centrifugal forces:
0.5 s T ~9g,
0.4 s ~14 g,
0.3 s T 25 g,
0.2 s T 55 g

90s-teens



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