



CT 101: Introduction



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- Tim Stick's Disclosures

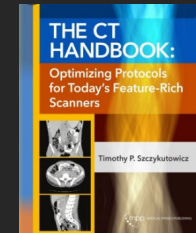
- Funds or equipment to UW-Madison

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

No
personal \$
from
GE/Canon

- Personal

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



Learning Objectives

- Learn how 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-

$$\lim_{r \rightarrow \infty} \bar{f}_P(r) = 0.$$

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

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

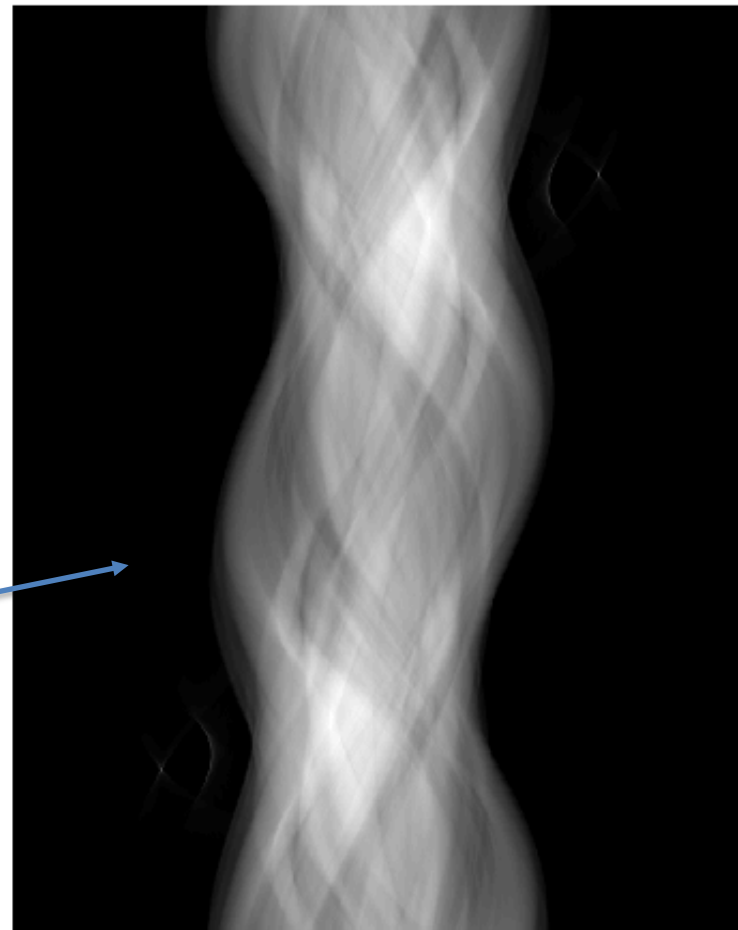
and exists almost everywhere: this means that on every circle the set of tangency points of all tangents for which F does not exist has a linear measure of zero. $\square$

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

$$f(P) = -\frac{1}{\pi} \int_0^\infty \frac{d\bar{F}_P(q)}{q}.$$

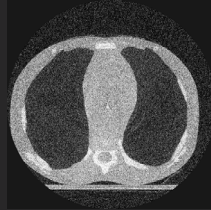


$$\begin{aligned} F(p, \phi) &= F(-p, \phi + \pi) \\ &= \int_{-\infty}^{\infty} f(p \cos \phi - s \sin \phi, p \sin \phi + s \cos \phi) ds \end{aligned}$$



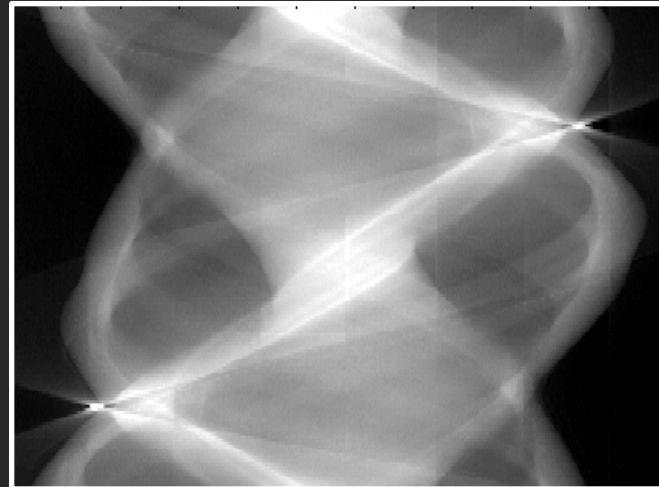
How do we get
projection data?





X-ray detector

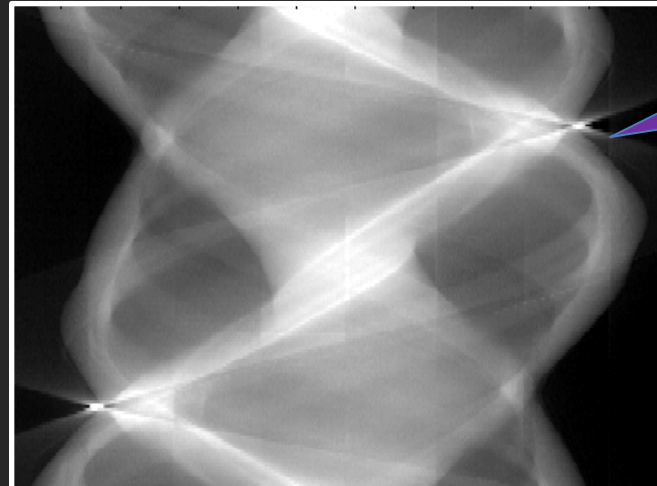
View Index



Detector index



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

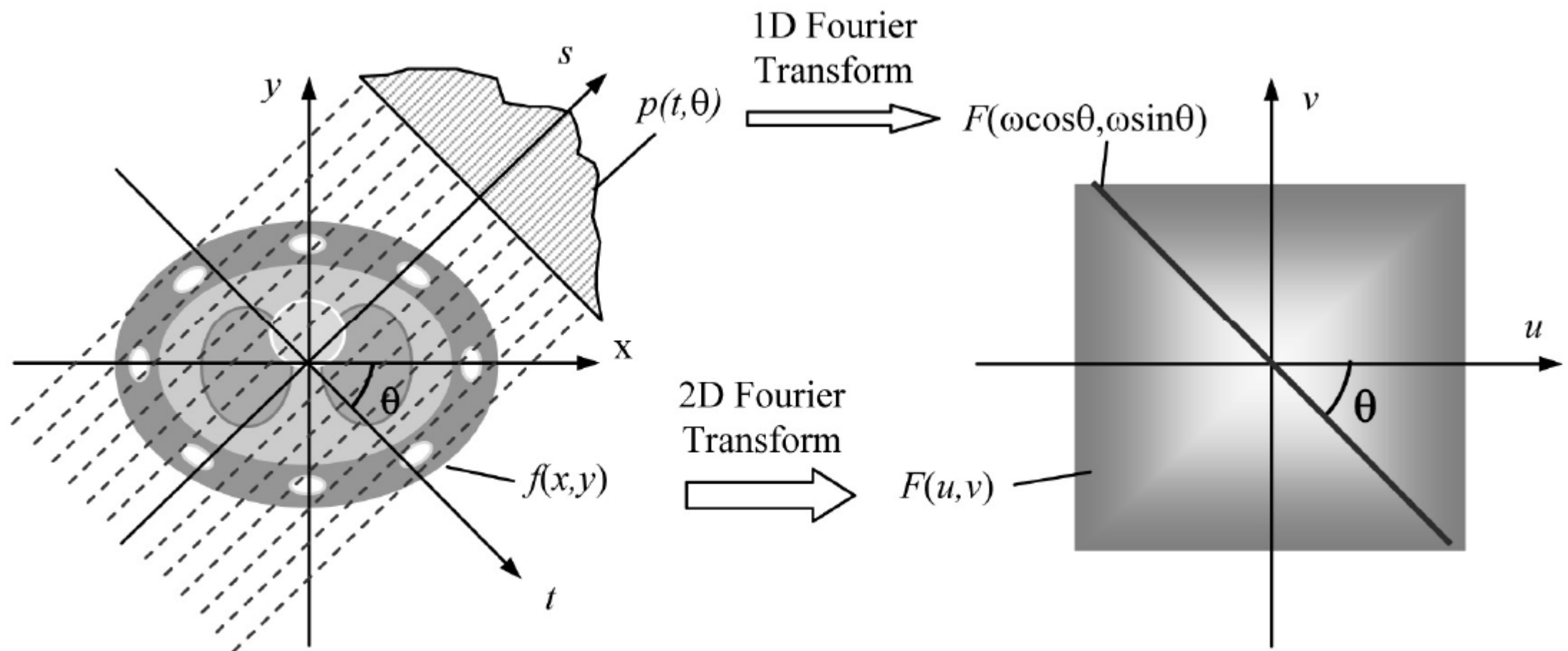


Figure 3.9 Illustration of the Fourier slice theorem.



Flavors of Computed Tomography



MDCT



**Neuro
CT**



Interventional CT



**Extremity CT
microCT**



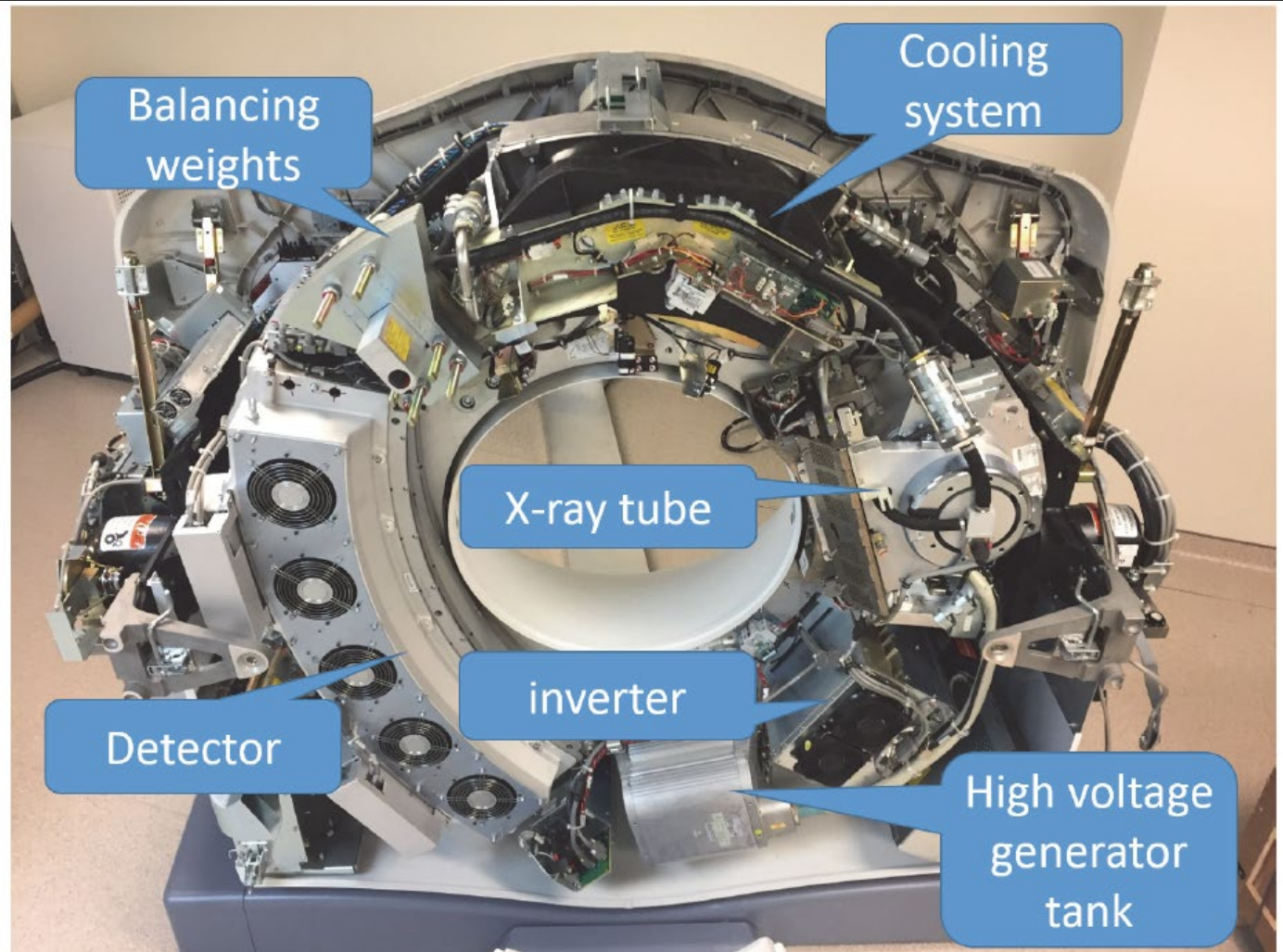
CBCT



Dental CT



**Mobile
CT**



“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.

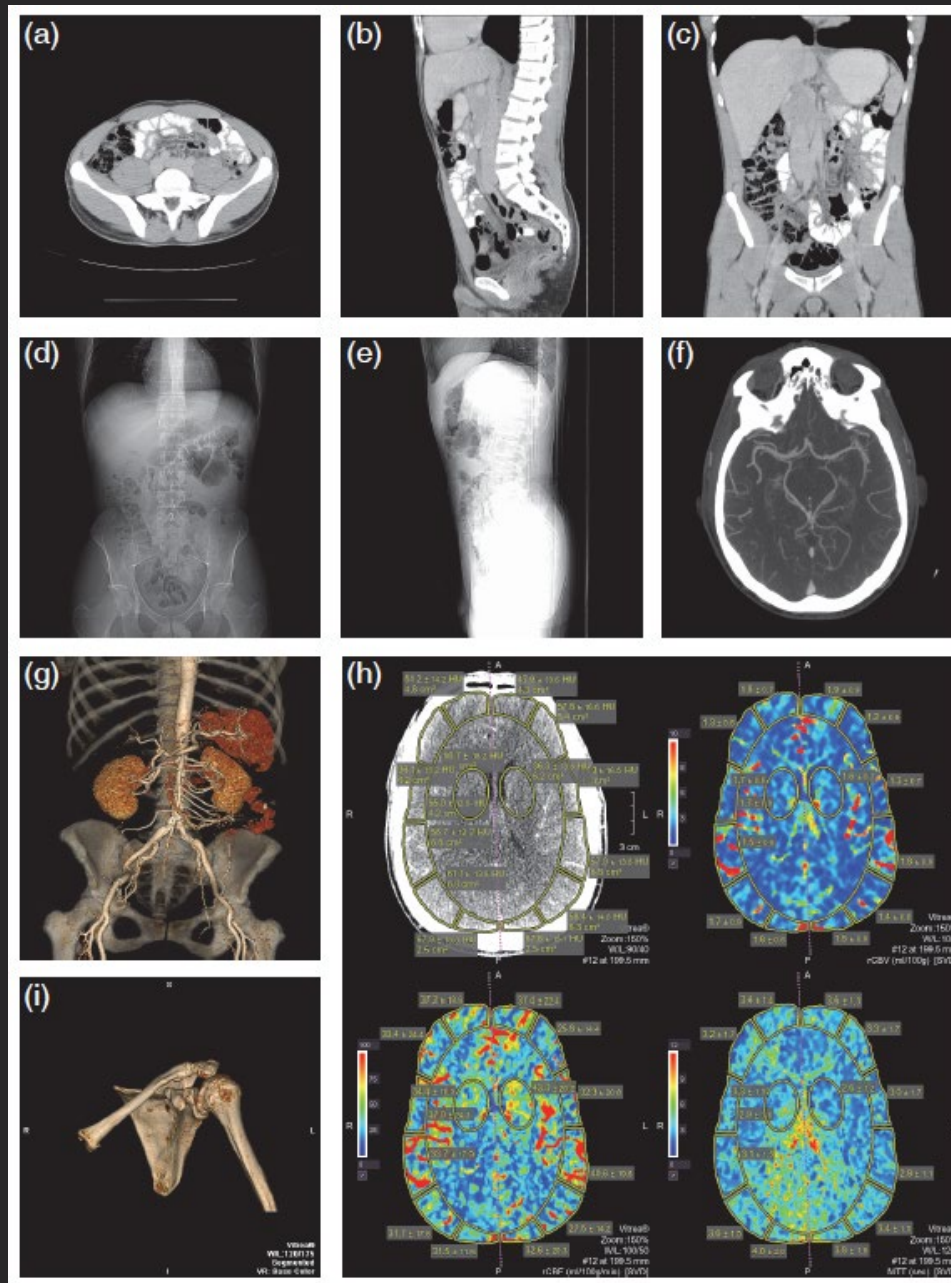
Bore sizes ~70-80 cm

Speed of
this table
~20-700
mm/s

Table a.k.a.
couch

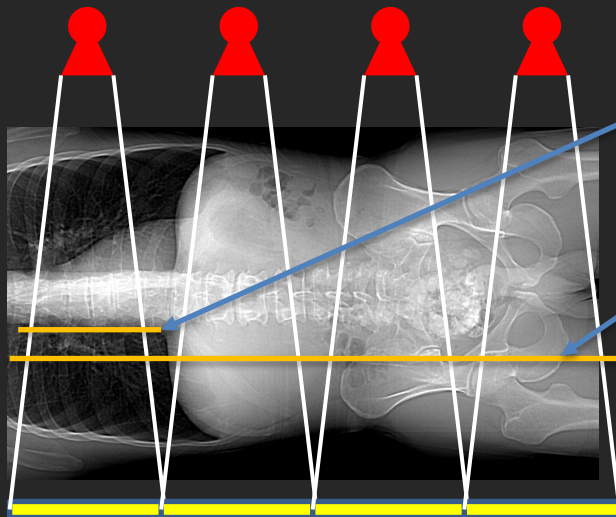


Width of
detector is
~2-16 cm



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

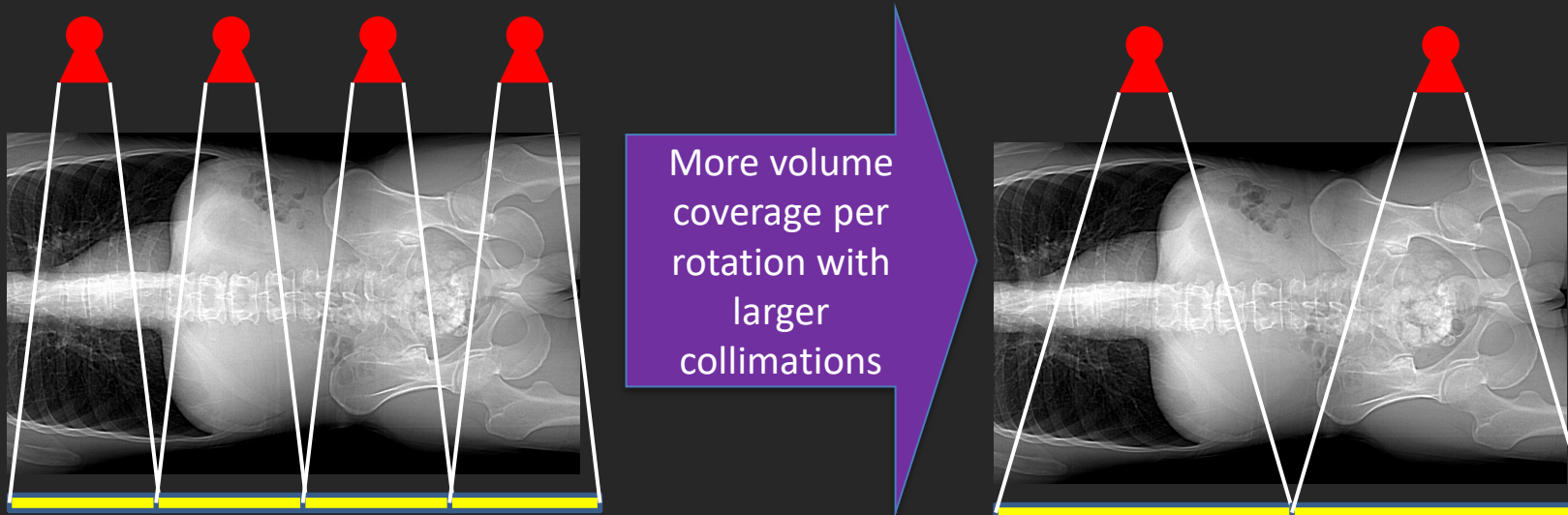
- Axial/sequential scan coverage
 - The scan coverage is going to be equal to the beam collimation for each rotation's worth of data. If multiple slabs are acquired, you just add up the collimation*number of slabs to get the total coverage. Note, the axial collimation may change from couch position to 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.



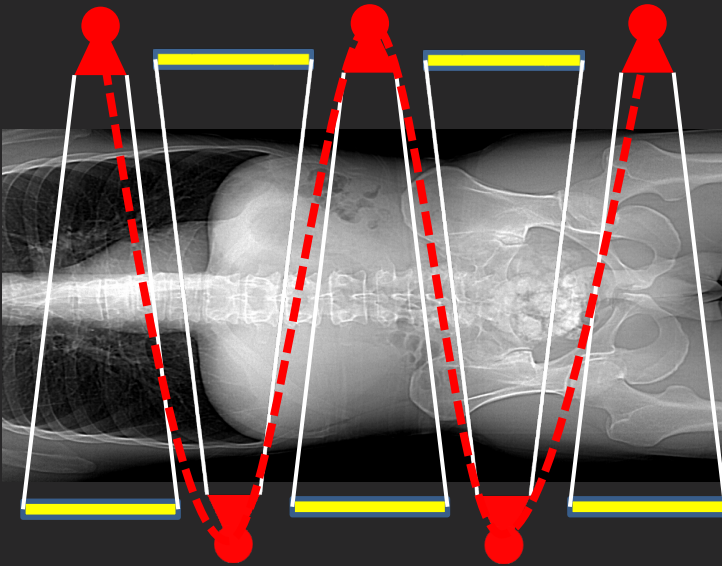
Single rotation's worth of data covers a beam collimation's worth of the patient

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.



Low pitch



high pitch



1 turn, moves a little

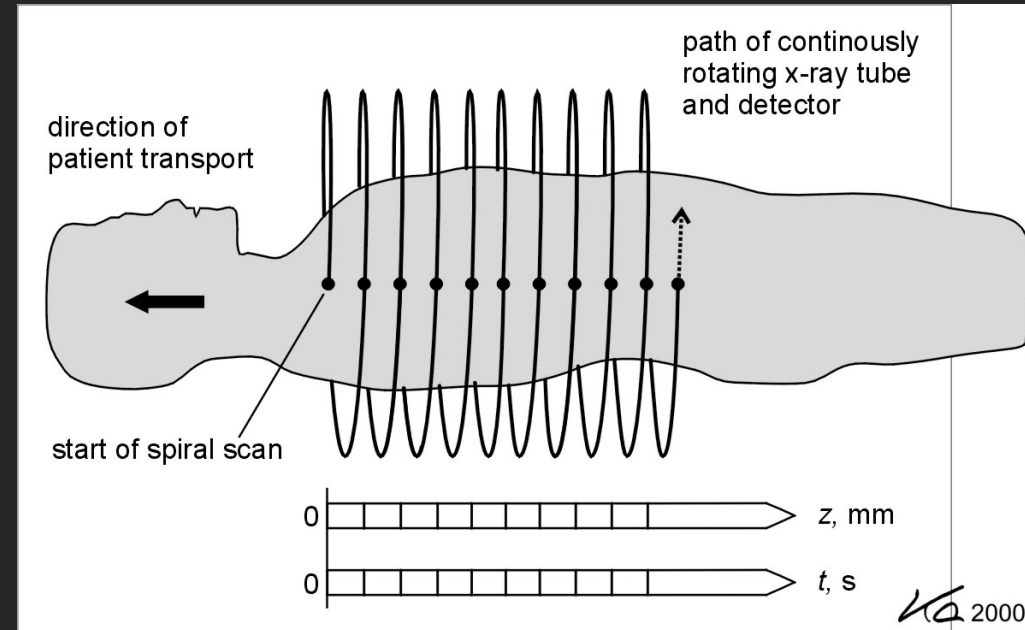
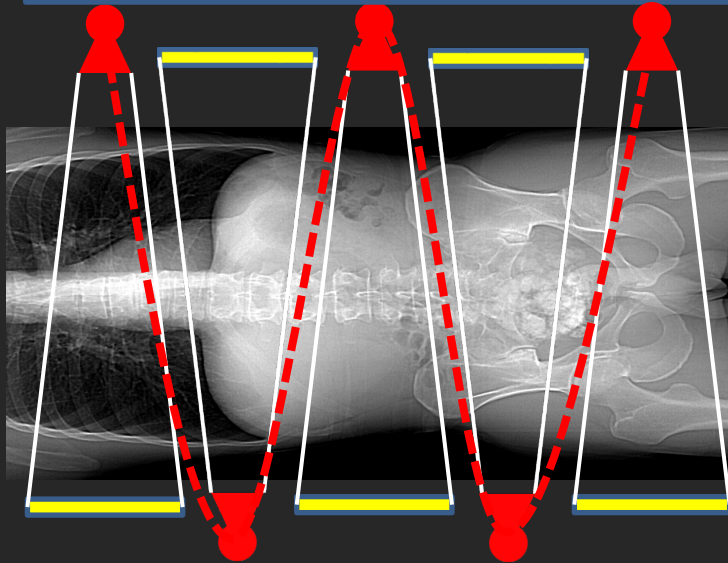
Slow and precise → brain
and MSK imaging (low
contrast tasks)

1 turn, moves a lot

Quick and sloppy (artifacts) → pediatric
scanning and chest scanning (high contrast
tasks)



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.

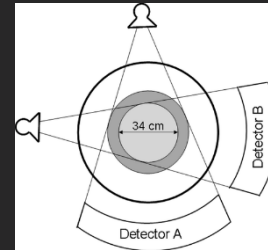
Pitch varies: ~ 0.1 -3.2 in diagnostic CT

Retrospectively
gated cardiac, and
respiratory gated
CT

Brain, MSK

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

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



$\sim[-0.1:1 \ 0.3:1] \ [0.5:1 \ 1:1]$

$\sim[1:1 \ 1.5:1]$

$\sim[1.75:1 \ 3.2:1]$

pitch

- Scan speed in axial scanning

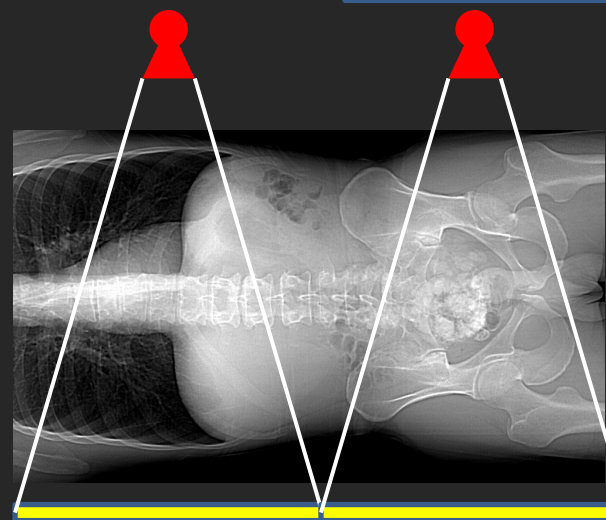
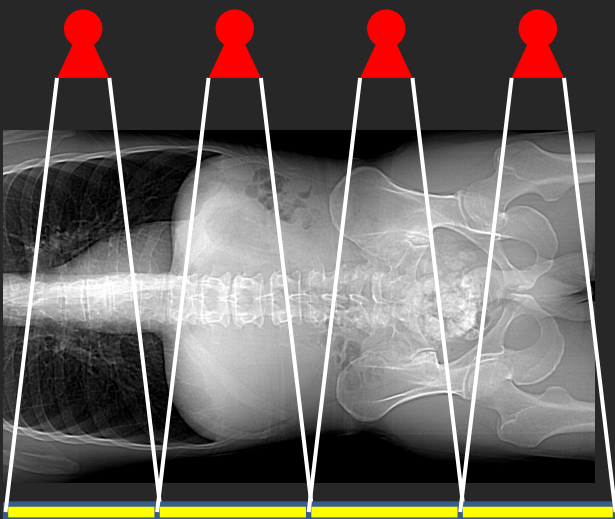
Time per slab location

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

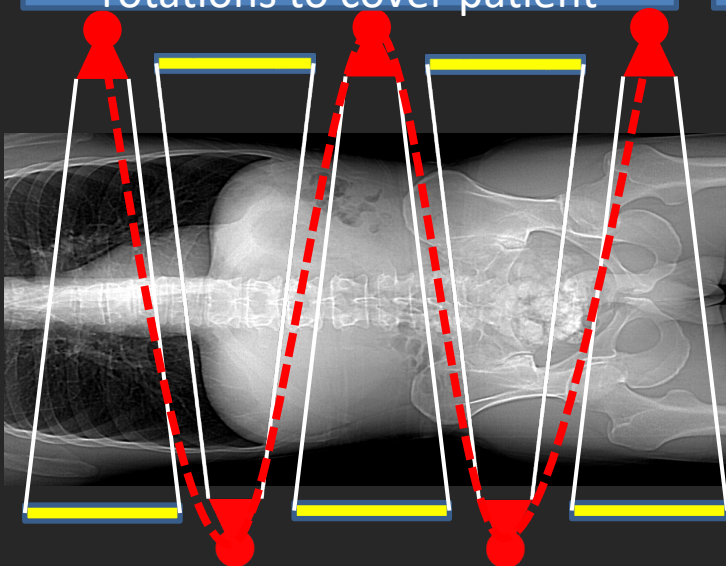
- Scan speed in helical scanning

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

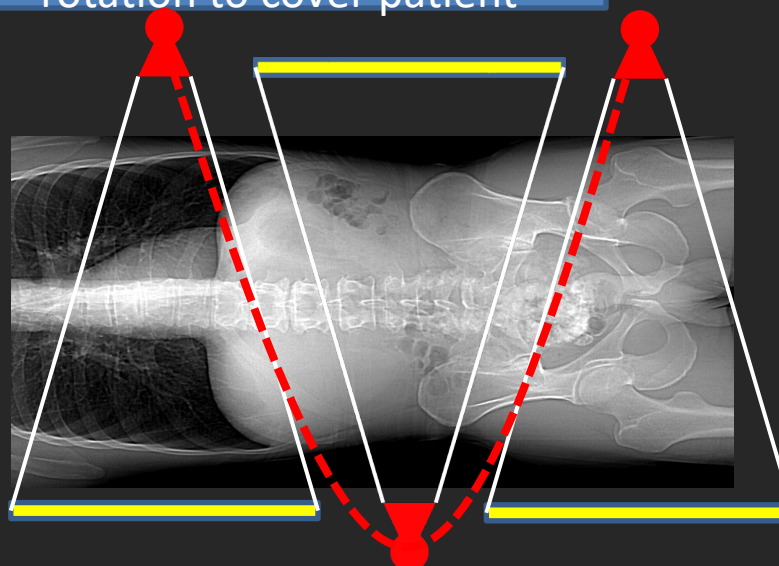
$$\text{Scan time per image} = \text{rotation time} * \text{weighting factor}$$

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

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



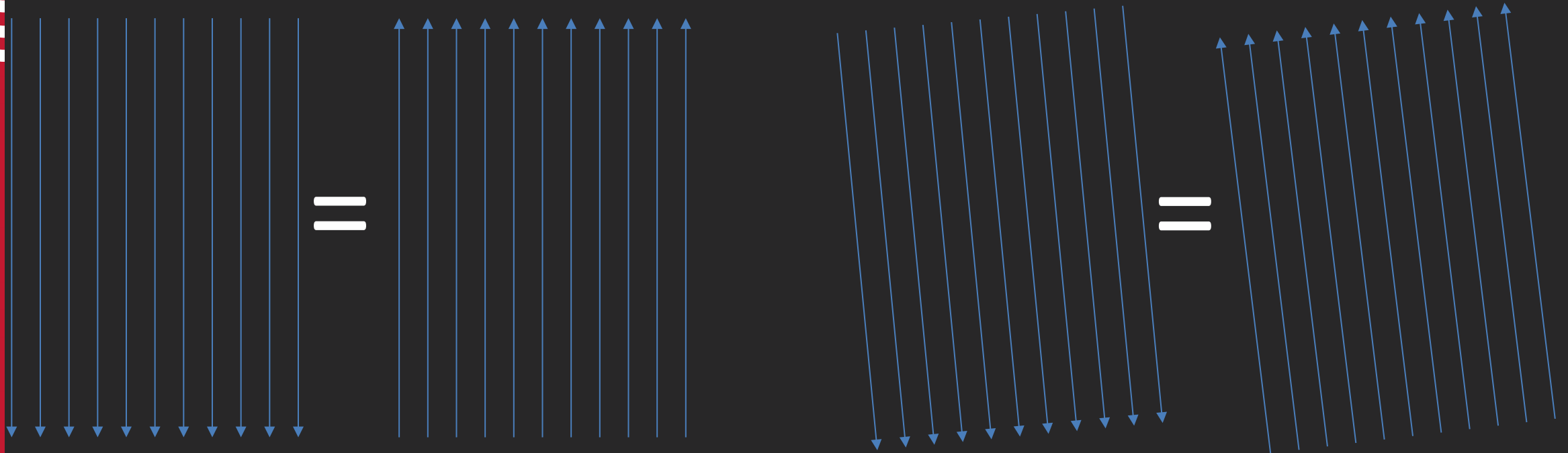
Pitch = 2:1 it takes 1 tube rotation to cover patient



~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.

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

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

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

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.



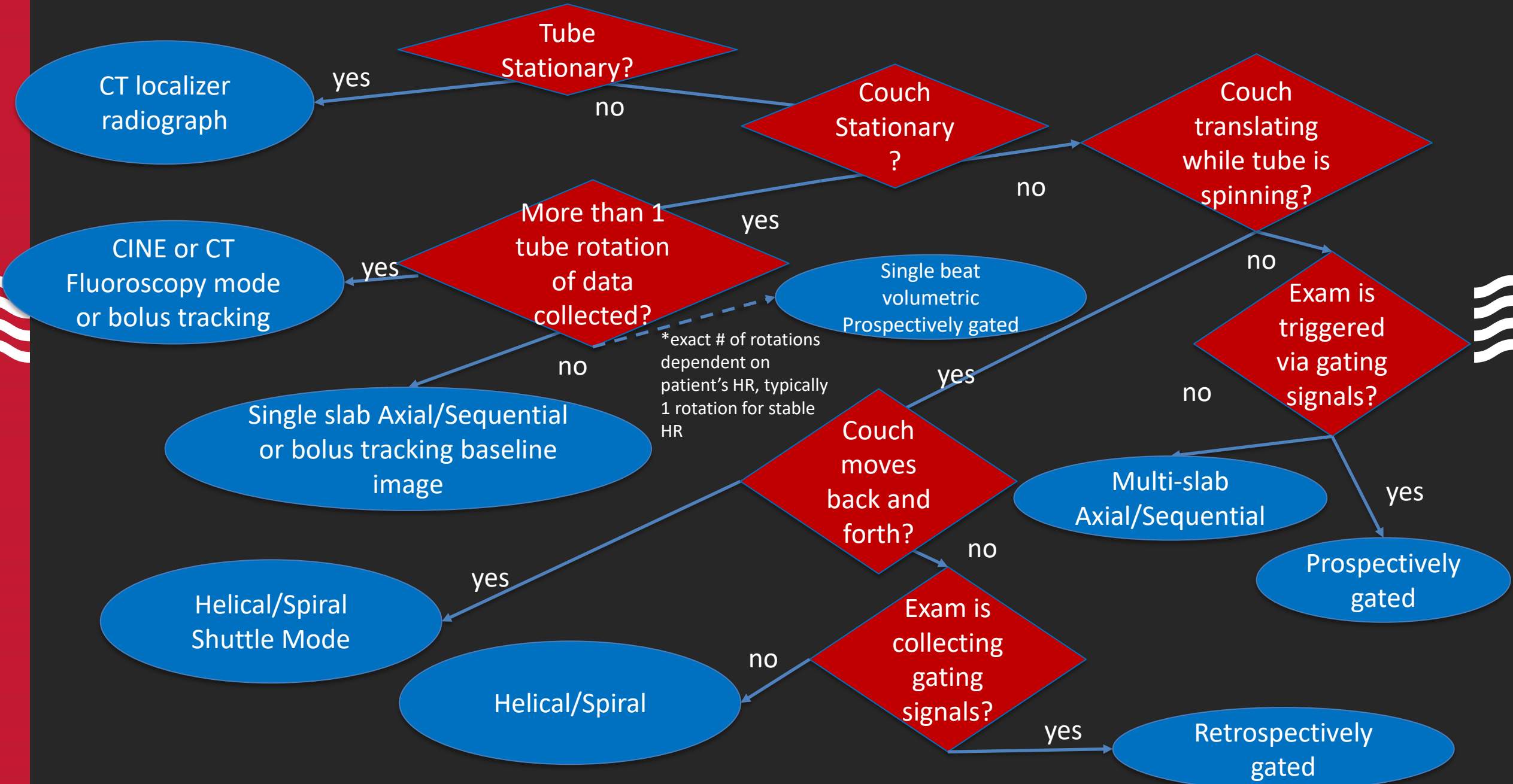
We have a lot of modes in CT when you consider we have a tube, optional filtration, a gantry, and a detector that all have different modes of operations. Lots of possible combinations we actually use clinically.

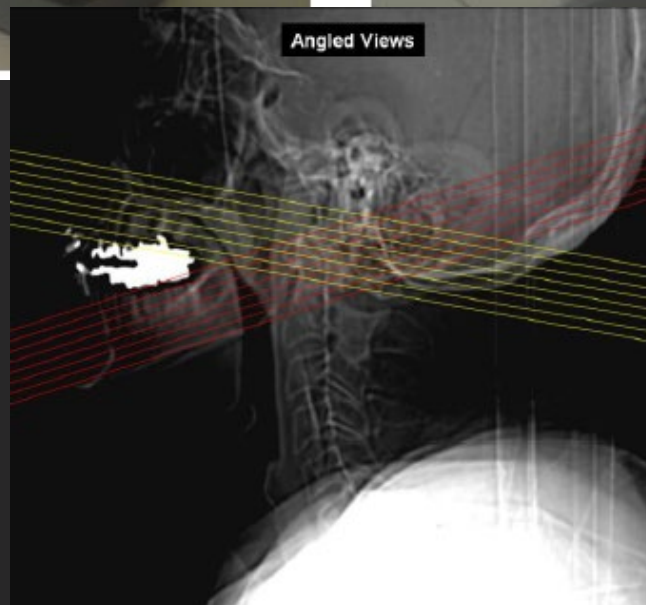
**A LOT
GOING ON
AT THE
MOMENT**

- 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







History of Medical (diagnostic) Computed Tomography



Focus on Speed

EARLY 1970S

16 A

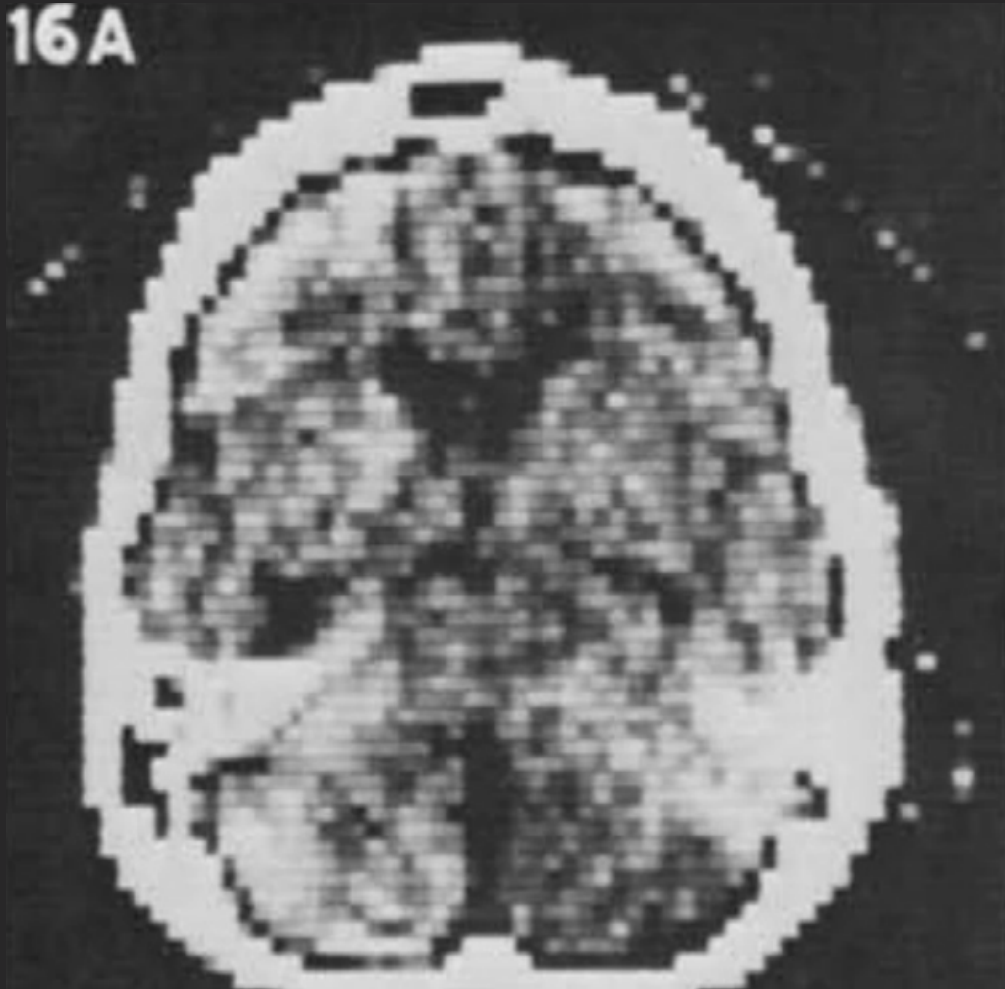


Image from 1974. 'shows a wedge-shaped zone of decreased attenuation in the right cerebellar hemisphere of a 60-year old man with sudden vertigo and inability to stand or walk 8 days prior to the examination'

80 pixels across image

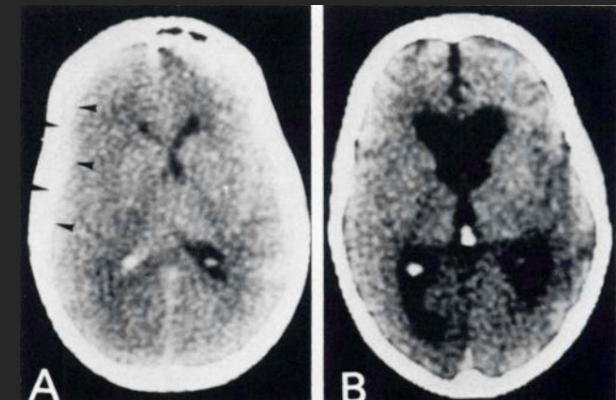
4.5 minute acquisition time (single slice)

160x160 matrix

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.

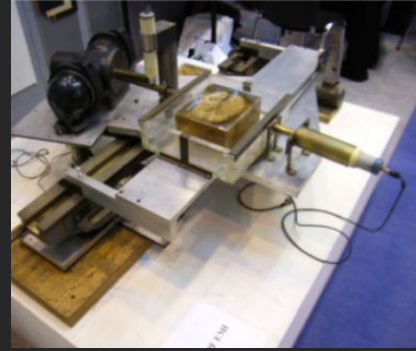
LATER 70S



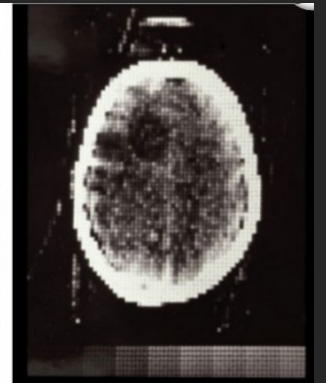
How CT happened: the early development of medical computed tomography

[Raymond A Schulz](#)^{a,*}, [Jay A Stein](#)^b, [Norbert J Pelc](#)^{c,✉}

On Friday, October 1, 1971, a new procedure was performed to image a live patient's brain. After a (lengthy) computer processing reconstruction delay, a remarkable image appeared on the screen of a monitor, sparking a revolution in medical imaging. Image "200.2A" was of a middle-aged female patient of Dr. James Ambrose at Atkinson Morley Hospital with a suspected tumor in the left frontal lobe, which was successfully excised and confirmed as a cystic astrocytoma.¹ The scanning process was painfully slow. But since each new image was



Look at the amazing progress from their benchtop system to their clinical system!

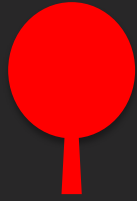


The first presentation of this early clinical data was held at the British Institute of Radiology conference in April 20, 1972,^{[13](#),[25](#)} by which time some 70 patients had been scanned. This

By RSNA 1973, five scanners had been installed beyond Atkinson-Morley, three in the UK (Manchester, London's Queen Square and Glasgow), and two in the United States. The Mayo Clinic EMI Mark-I system, delivered in early 1973, imaged the first patient outside the UK on June 18, 1973. About a month later, the MGH scanner was installed and operating. The first 10 EMI-scanners were partly hand built while manufacturing was ramping up.



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



...

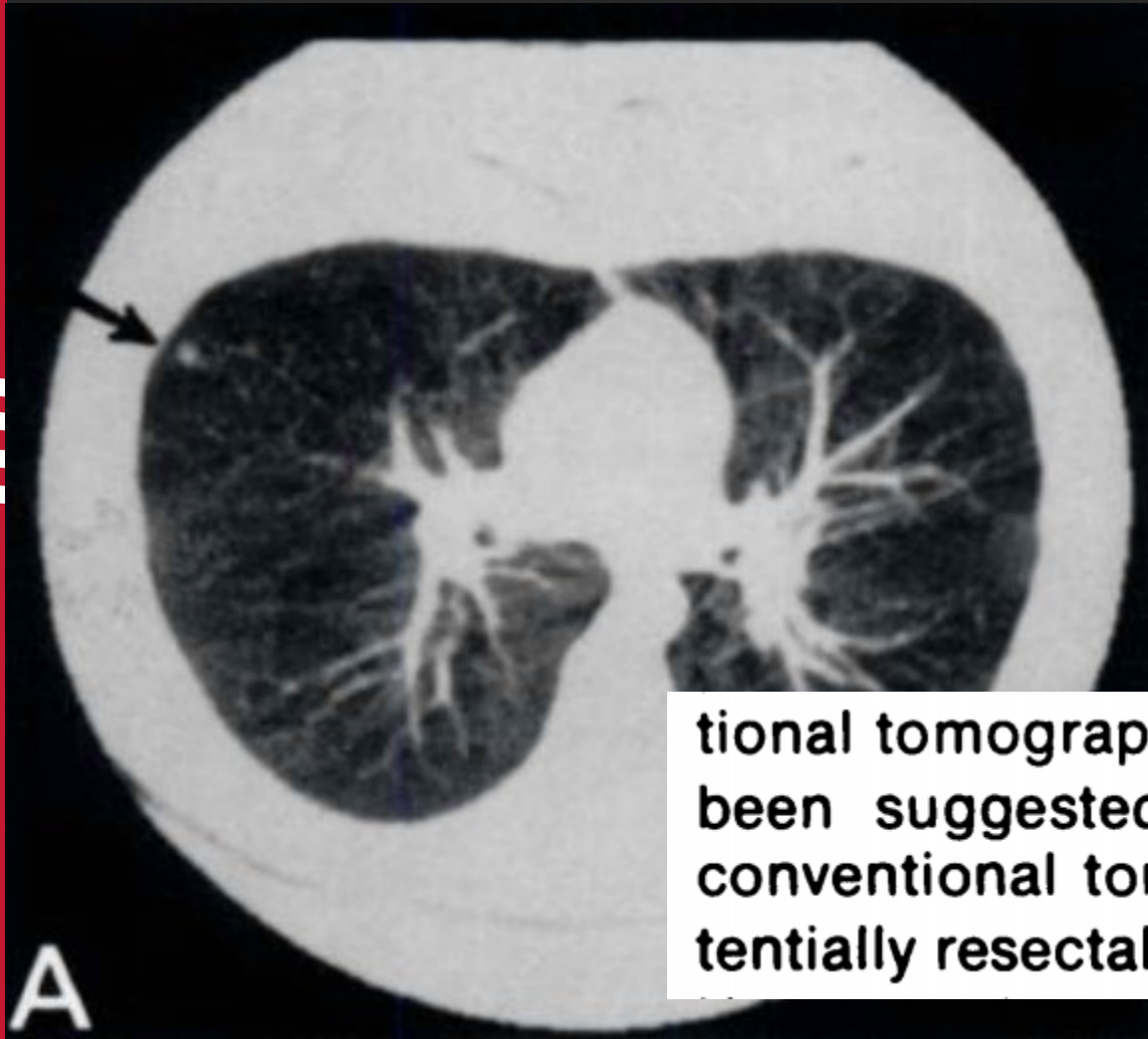


View angle 1,
detector position 1-2

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].

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



1st generation scanner



3rd generation scanner

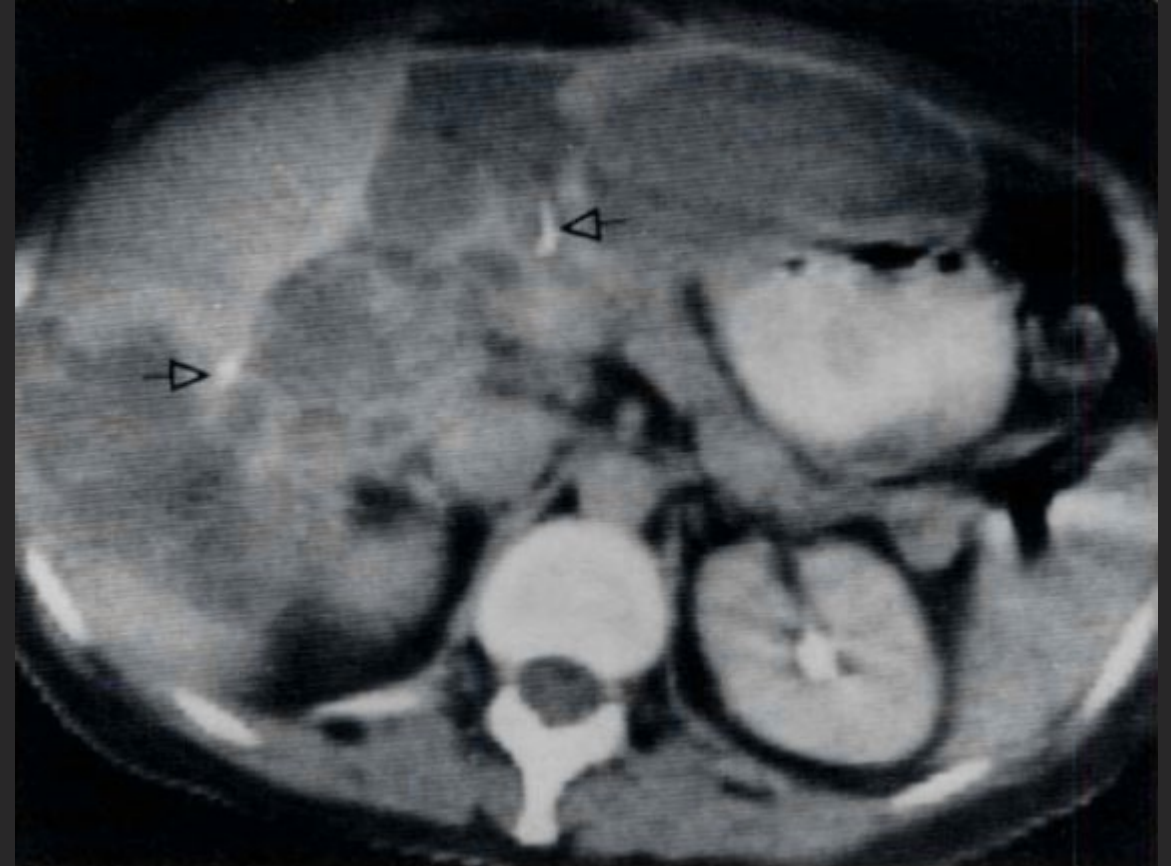


1980S



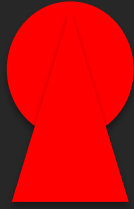
Cohen, R. A., Kaufman, R. A., Myers, P. A., & Towbin, R. B. (1986). Cranial computed tomography in the abused child with head injury. *American journal of roentgenology*, 146(1), 97-102.

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



3rd generation
scanner (~64 slice)

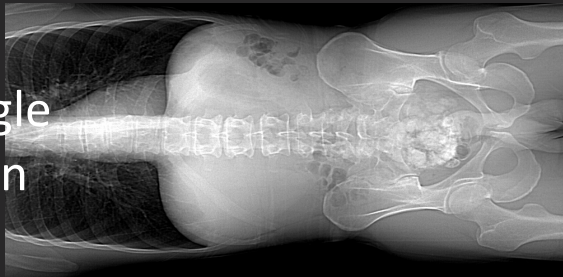


Fan angle
direction

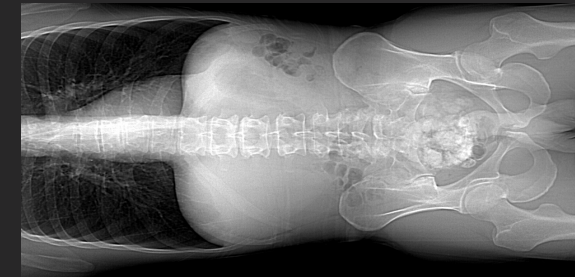


Total scan time = $\frac{\text{rotation time} \times \text{scan length}}{\text{pitch} \times \text{beam collimation}}$

Cone angle
direction



Cone angle
direction



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.140.6.1179

[Preview](#) | [Abstract](#) | [PDF \(726 KB\)](#) | [PDF Plus \(475 KB\)](#)



Computed tomography in hepatic echinococcosis



J de Diego Cholz, 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

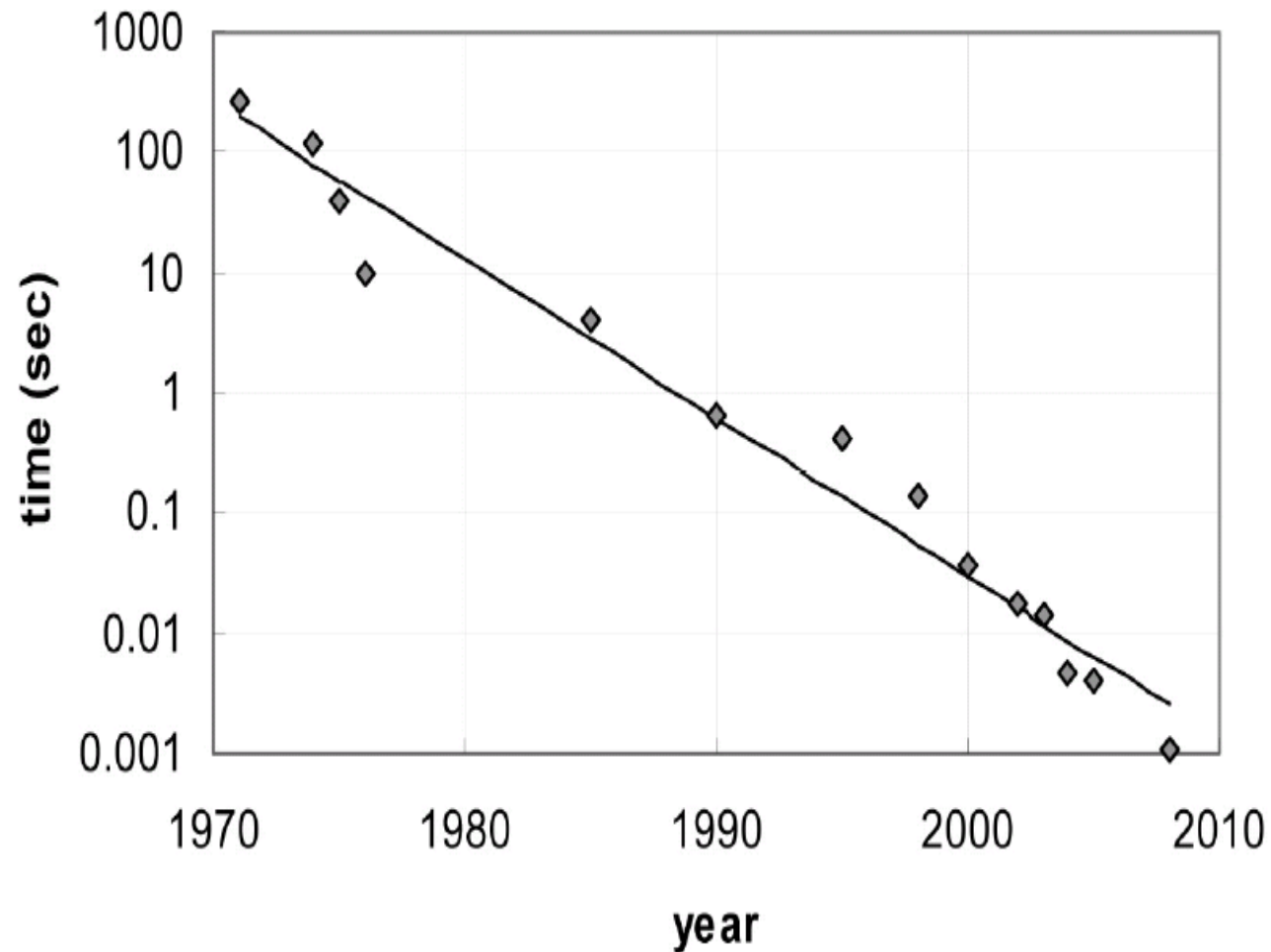


MP Frick, CW Maile, Crass, ME Goldberg, JP Delaney

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

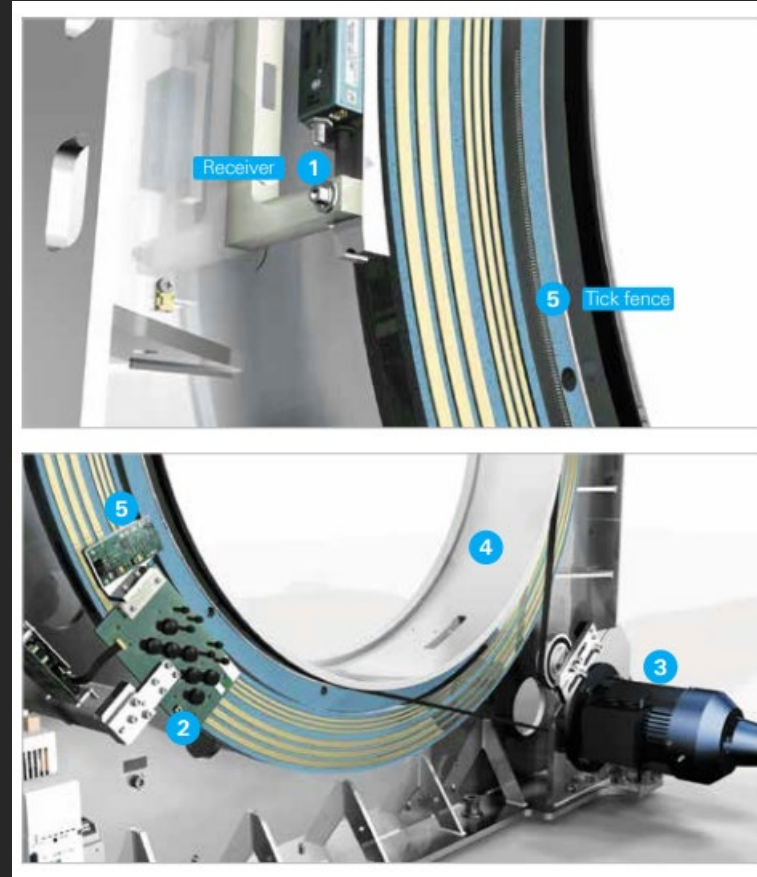
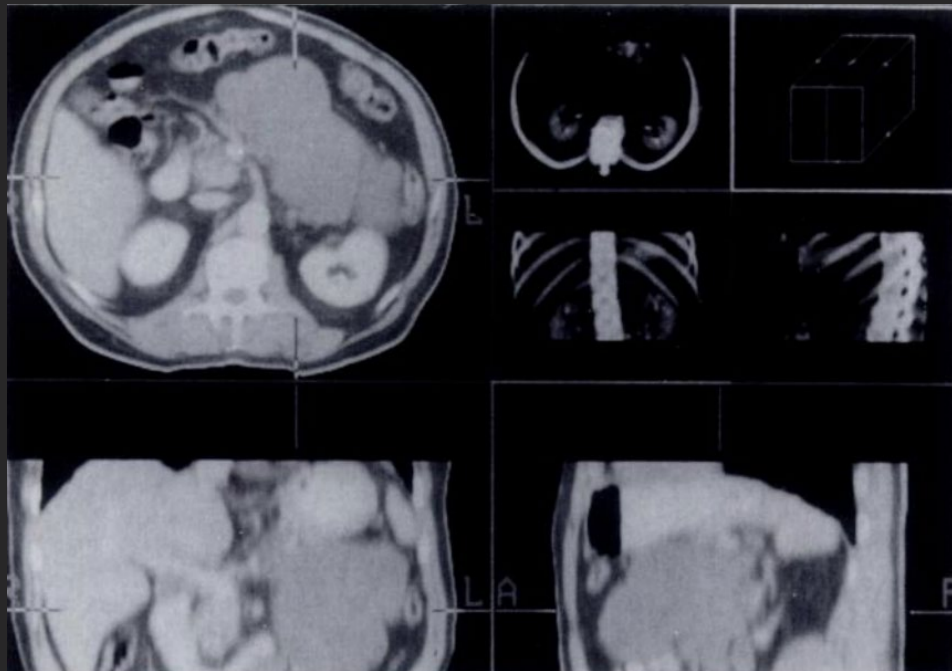


Hsieh, Jiang. *Computed tomography: principles, design, artifacts, and recent advances*. Vol. 114. SPIE press, 2003.

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”

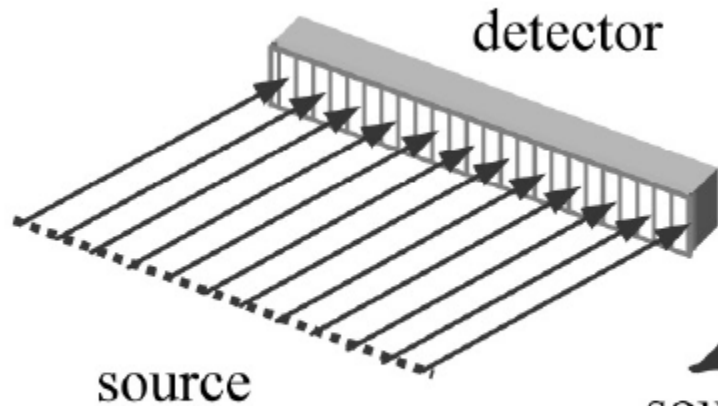
Images from first CT scanner with spiral/helical mode (Siemens Somatom-Plus)



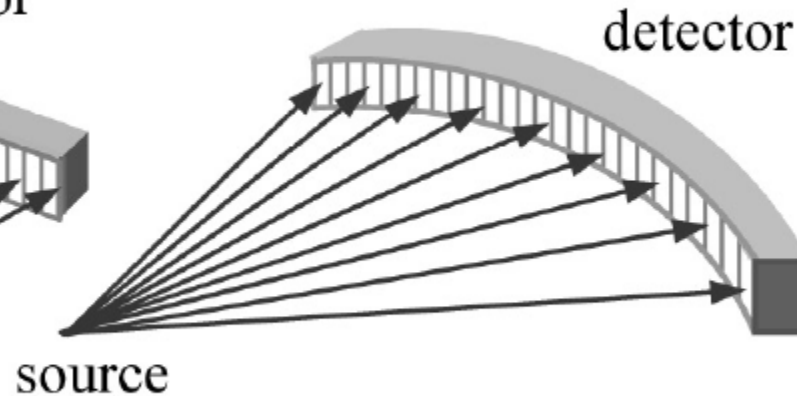
http://rsna2013.rsna.org/files/1678/SCHLEIFRING_CTAApplications.pdf

- In 1998 we had 4 slice CT scanners

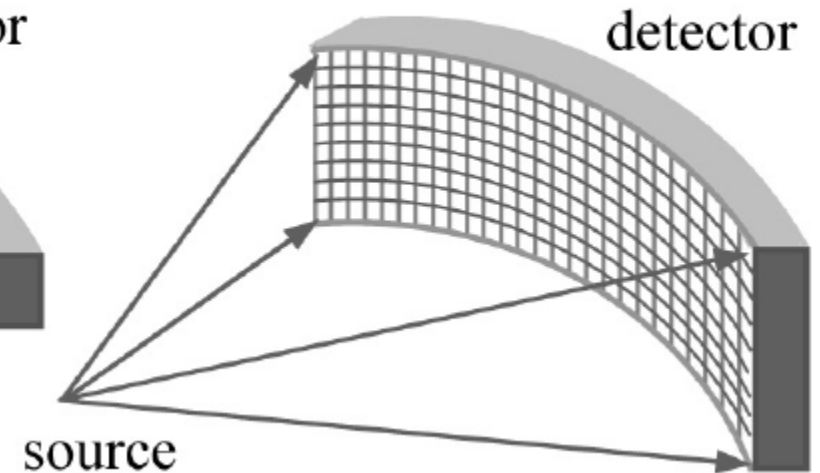
Single slice



Single slice

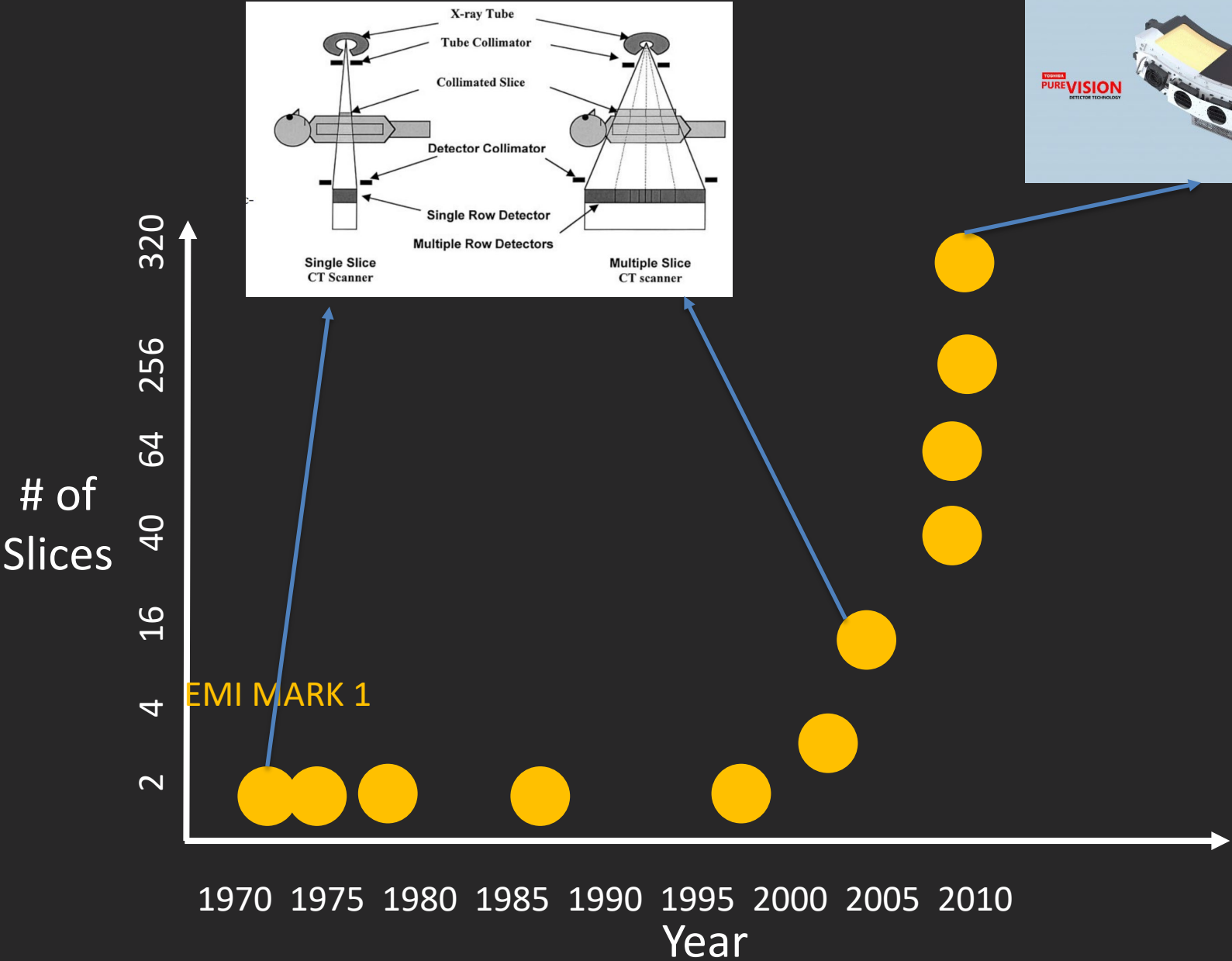


9 slices



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.

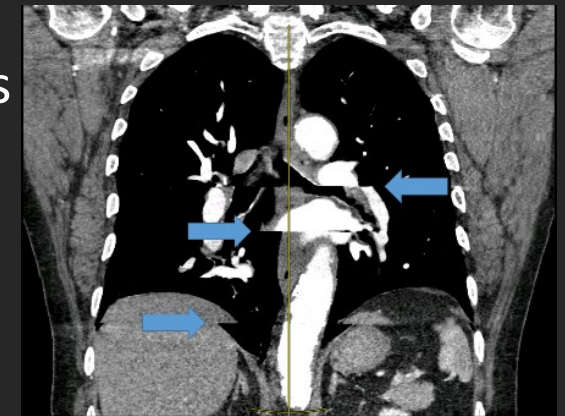
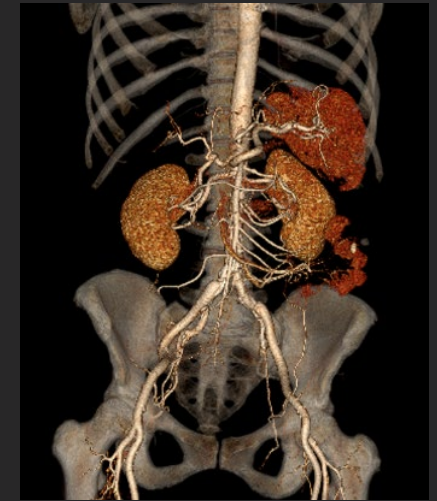


- Faster scanning helps

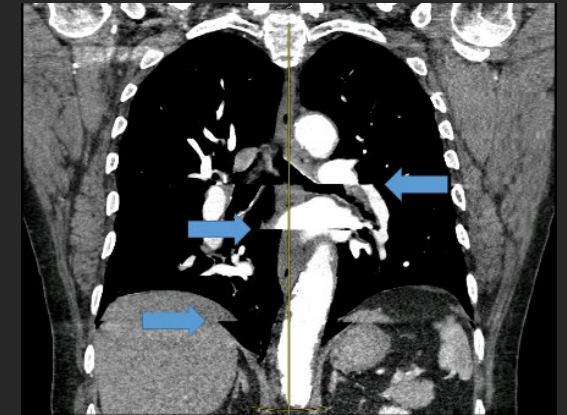
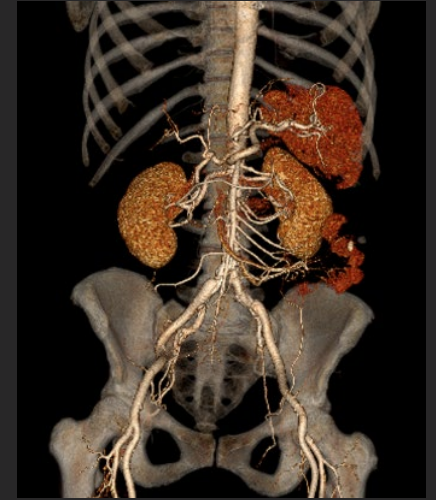
- Capture an entire organ with the same contrast dynamics (i.e. perfusion images without shuttle, cardiac imaging without gating, chest or abdomen CTA's of an organ group)
- The imaging of pediatrics who may not be capable of staying still for long periods
- Reduce cardiac motion artifacts
- Reduce respiratory motion artifacts
- Reduce swallowing/peristalsis motion artifacts

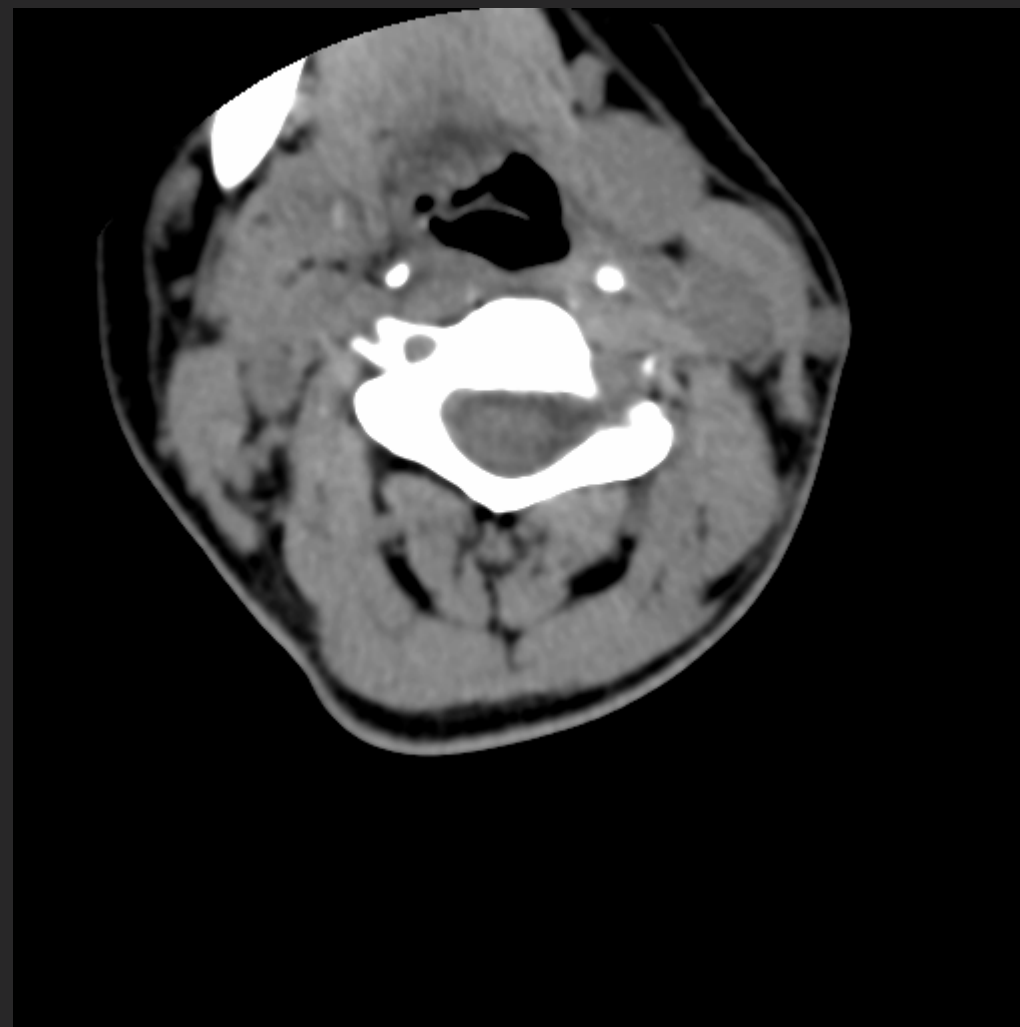
- Scan times for patient throughput consideration are not really an issue in CT

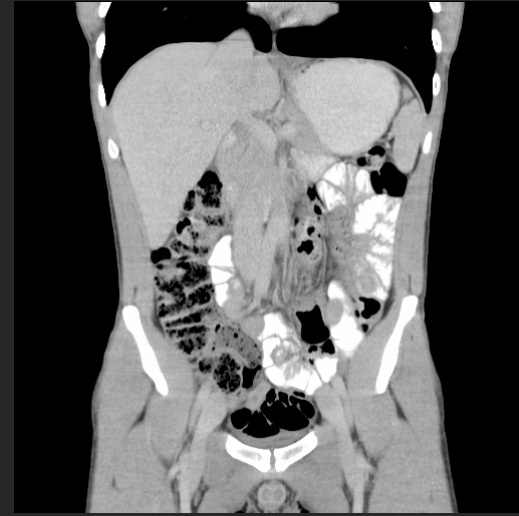
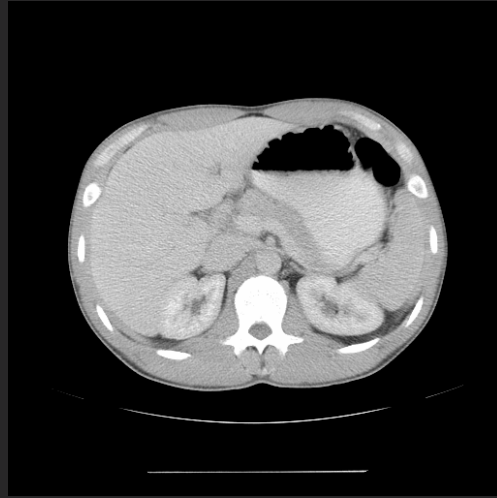
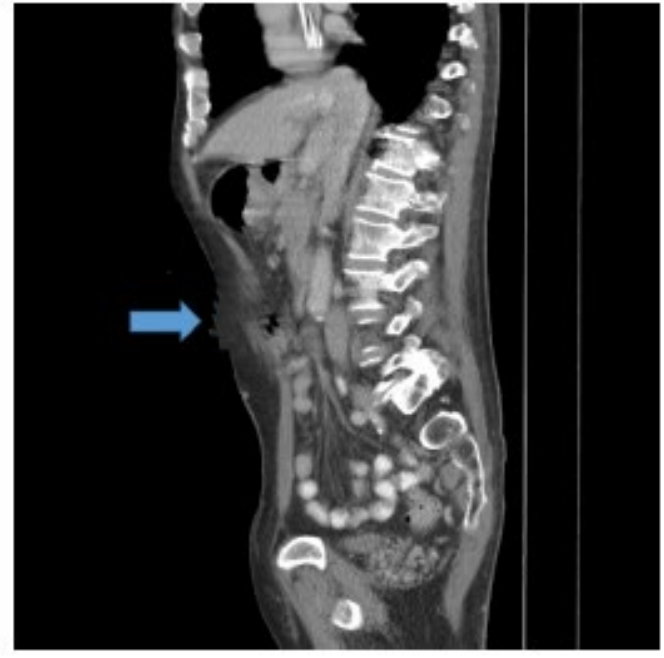
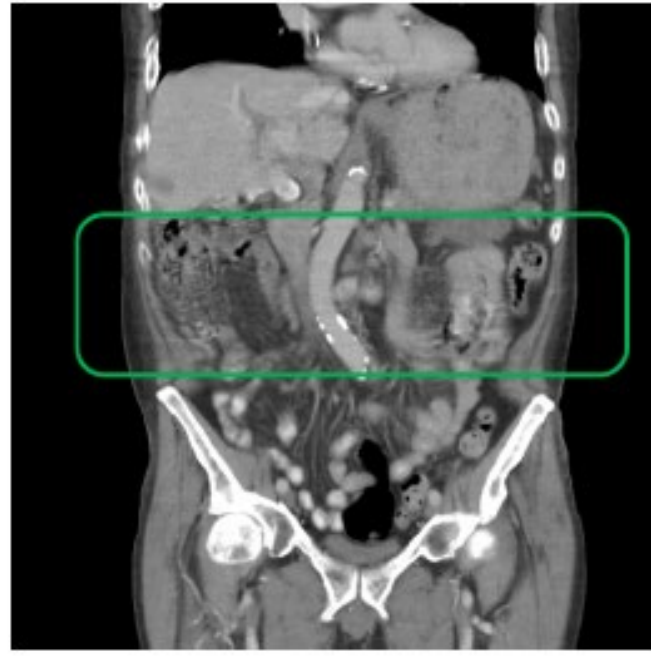
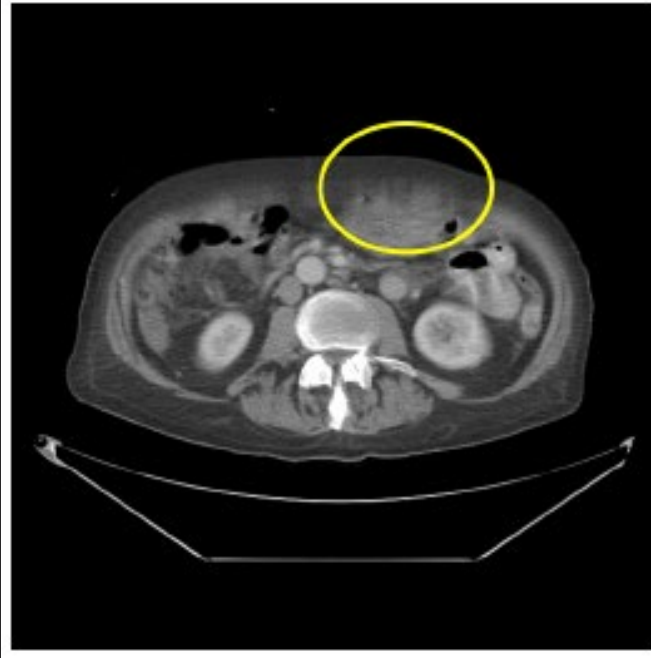
- In your typical 20 minute slot, the scanner is usually only acquiring data for ~10 seconds...

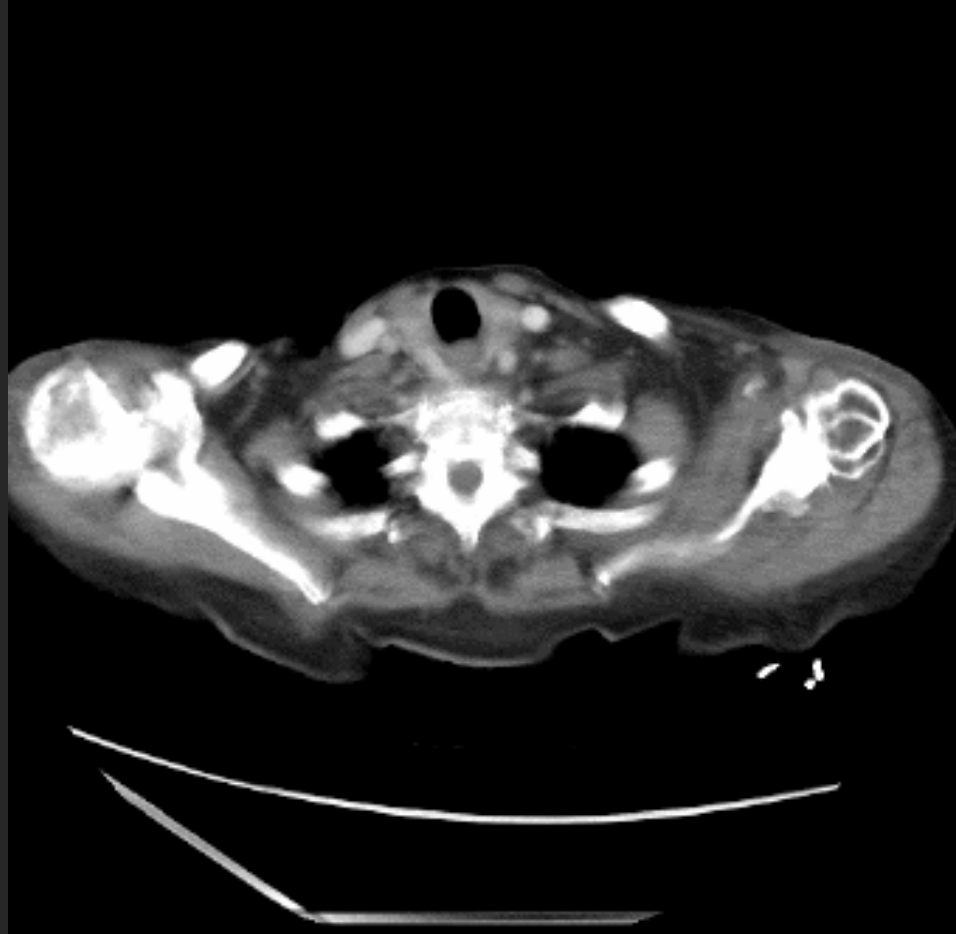


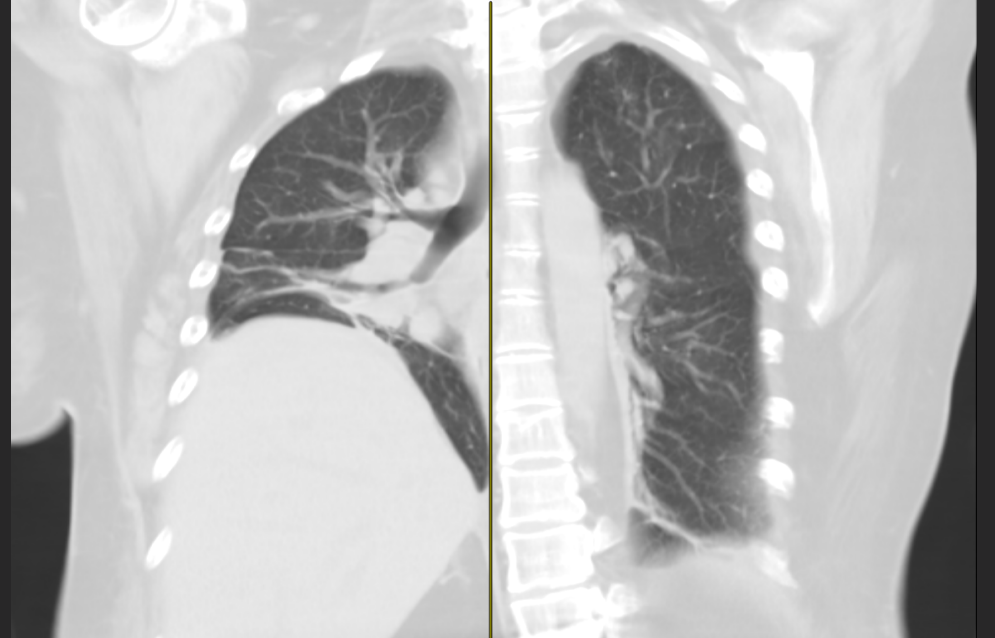
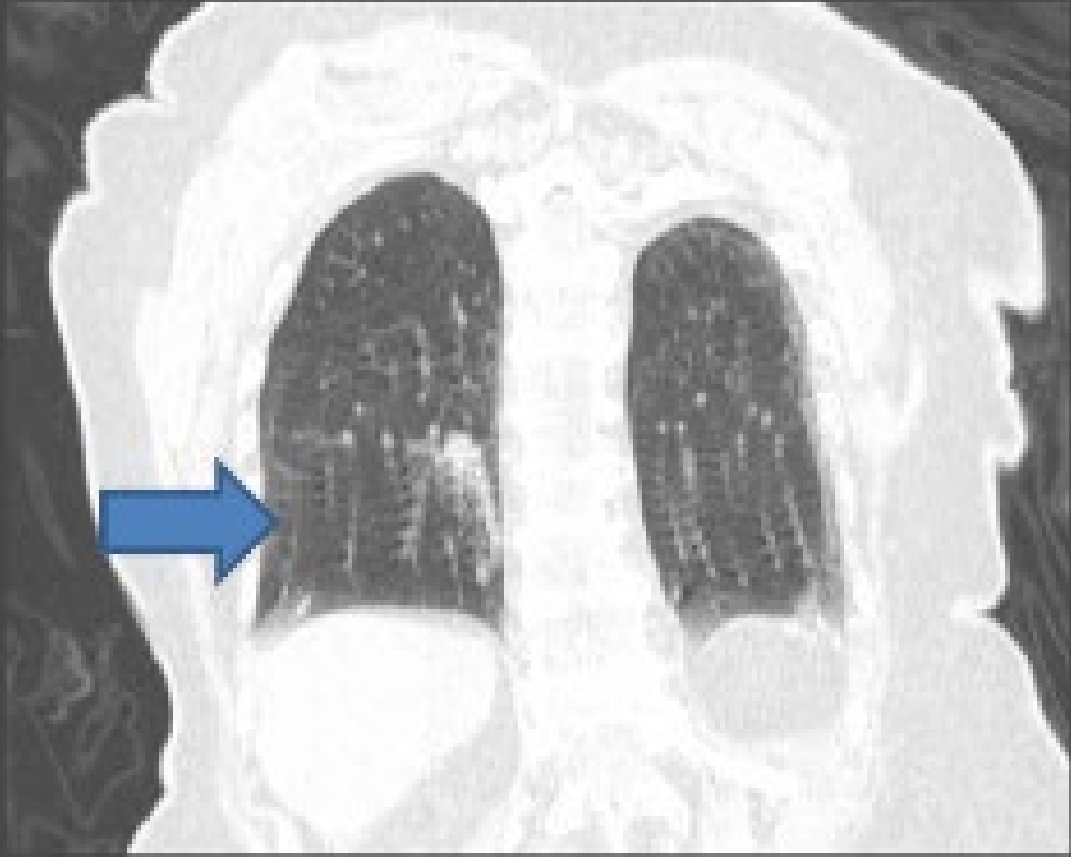
- Faster scanning helps
 - Things in our bodies that move
 - Patients that cannot help from moving

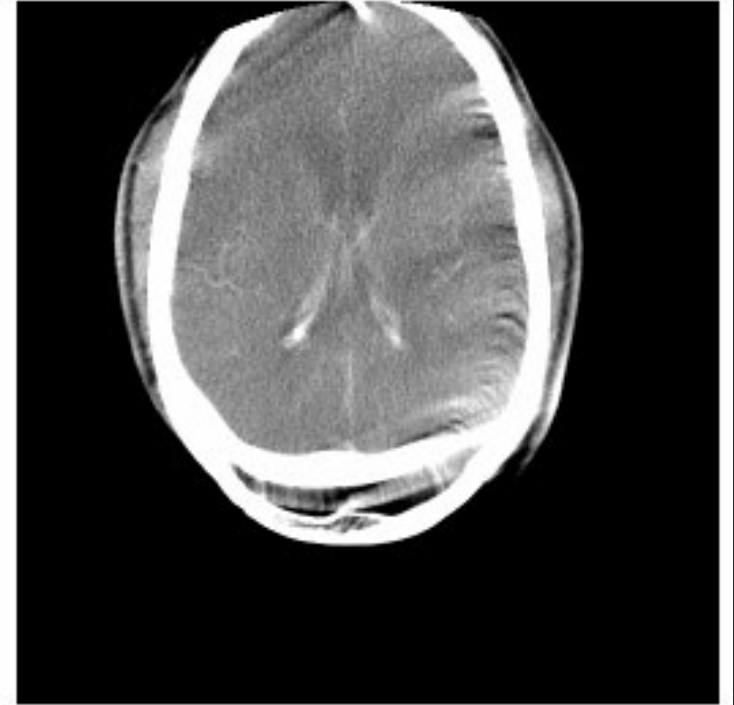
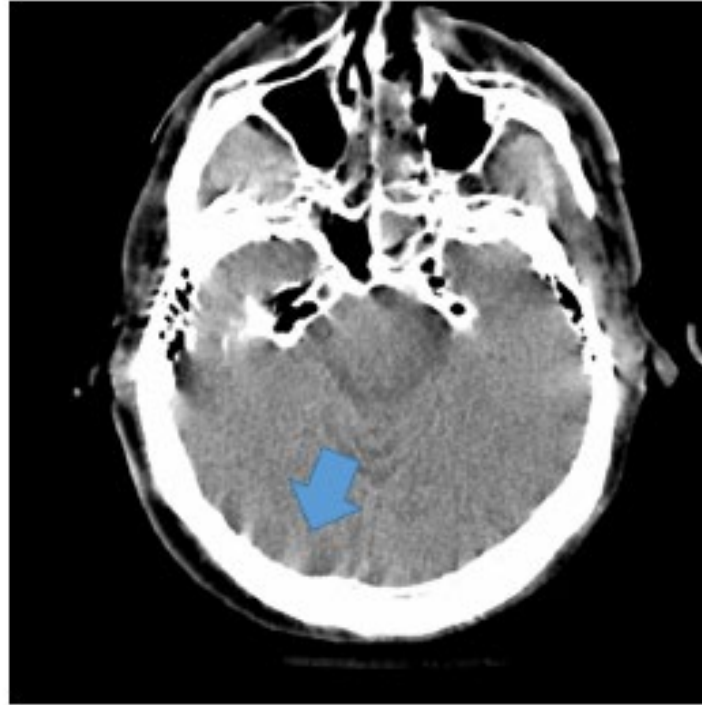
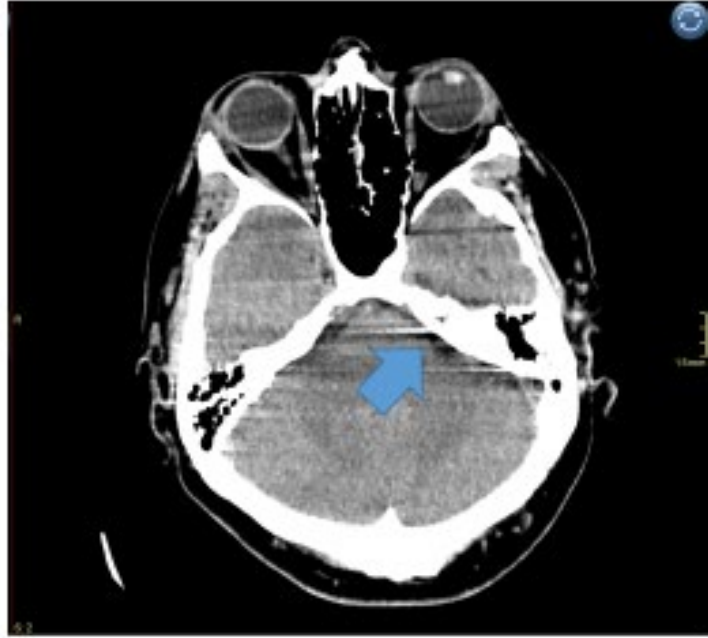












2 cm (i.e. 16 slice) CT scanner



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

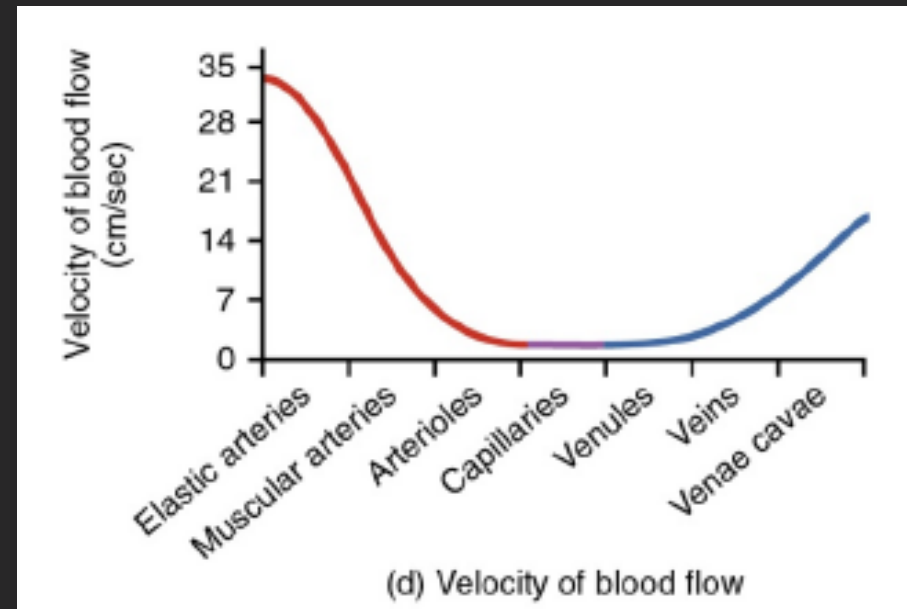
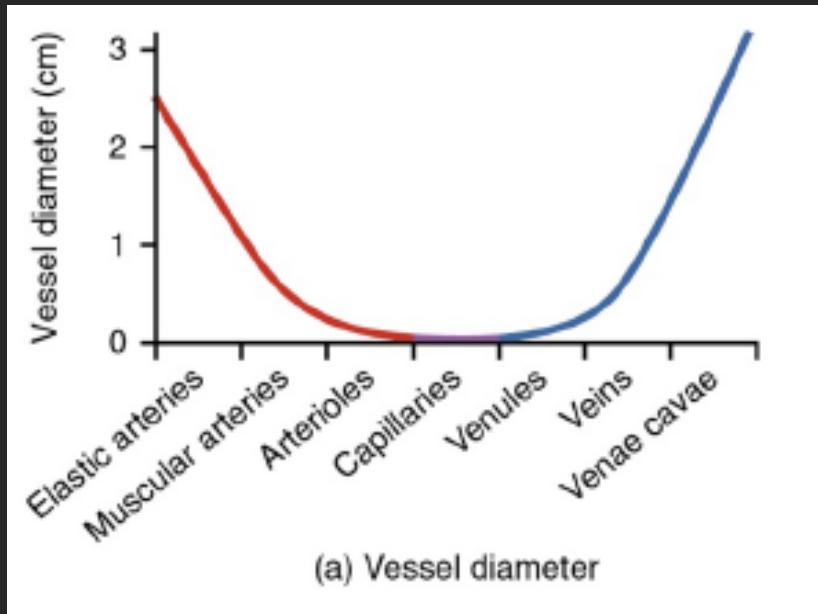


1.0 sec
breath hold

Scan speed: 283 mm/s

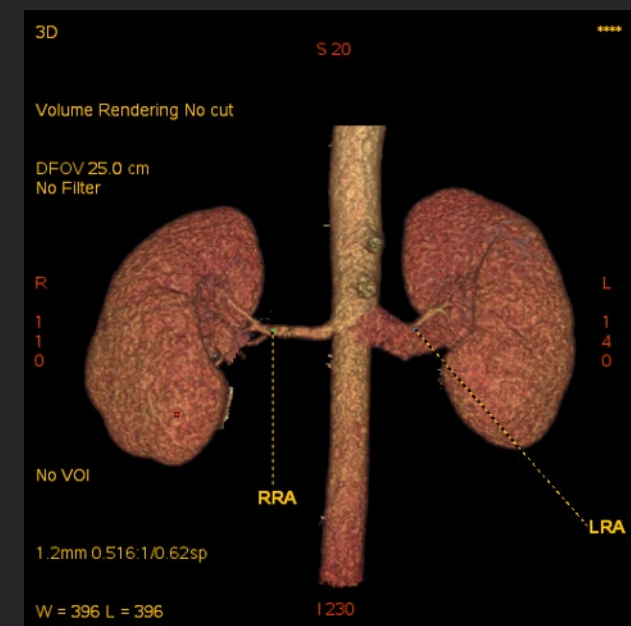
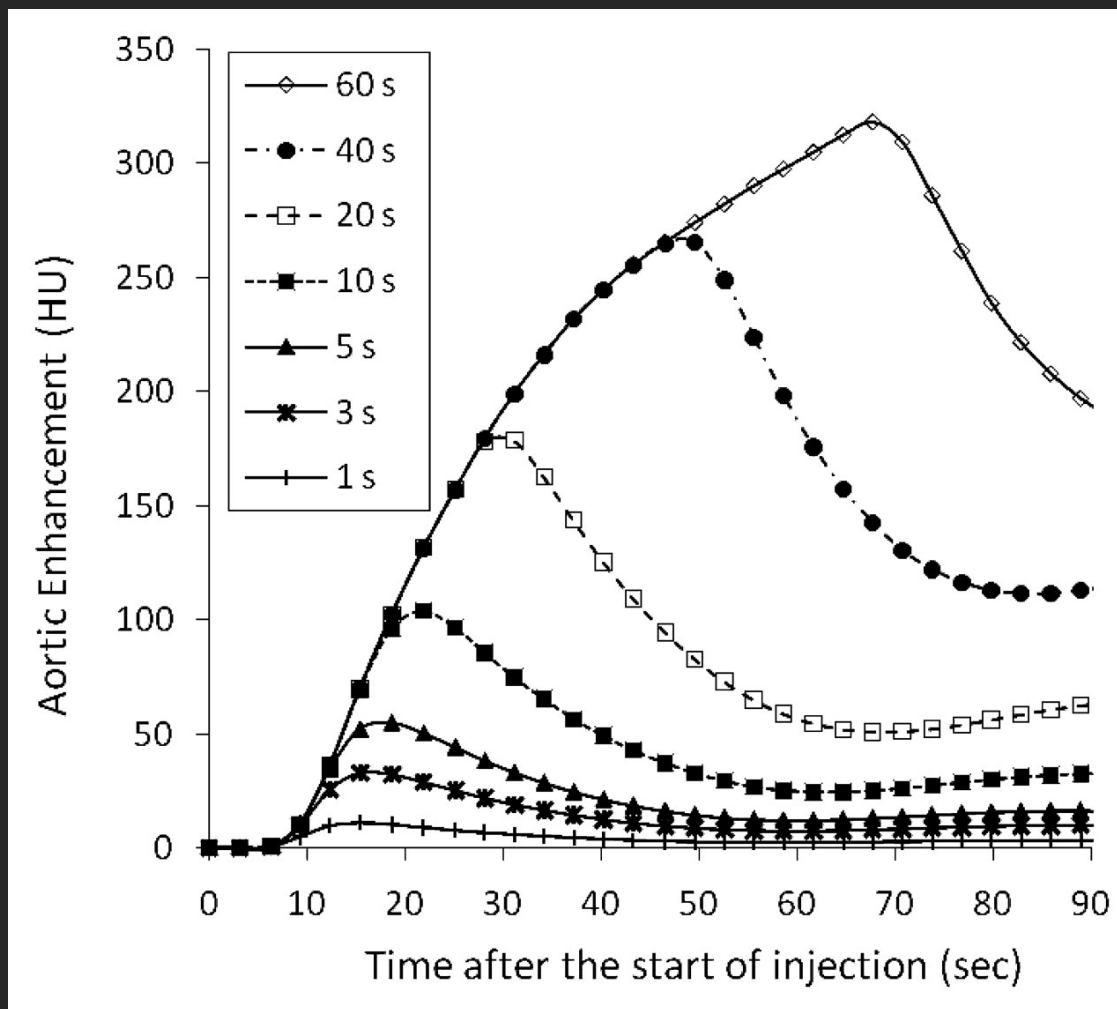
Scan range: 288 mm

Total scan time: 1.02 s





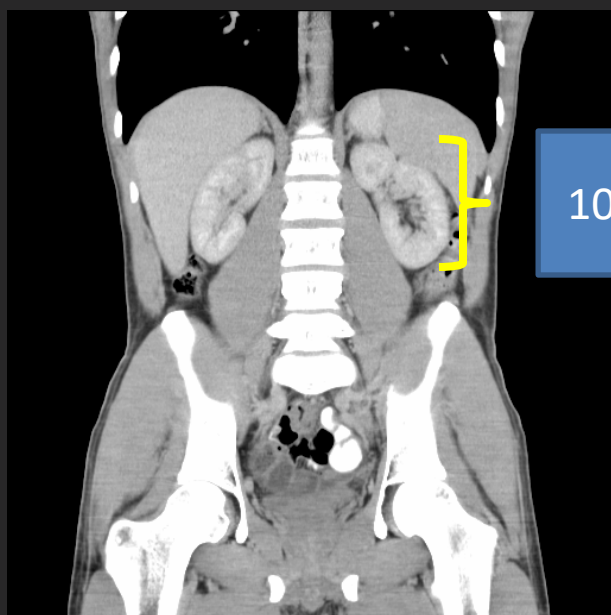
30 seconds



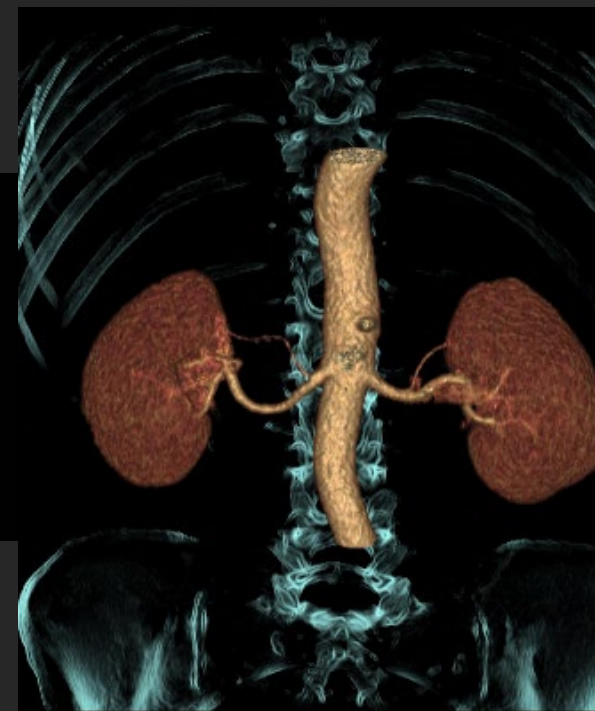
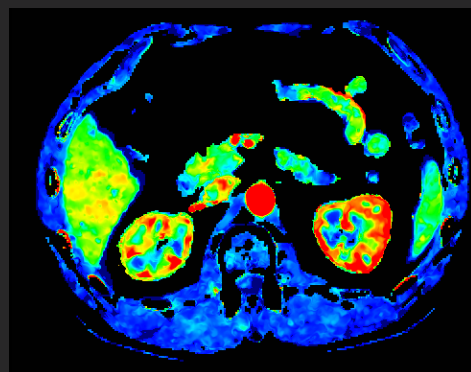
Plot: Bae, Kyongtae T. "Intravenous contrast medium administration and scan timing at CT: considerations and approaches." *Radiology* 256.1 (2010): 32-61.

Scan Coverage: Kidney perfusion applications for wide axial coverage

Wide axial coverage perfusion
scan of the kidneys

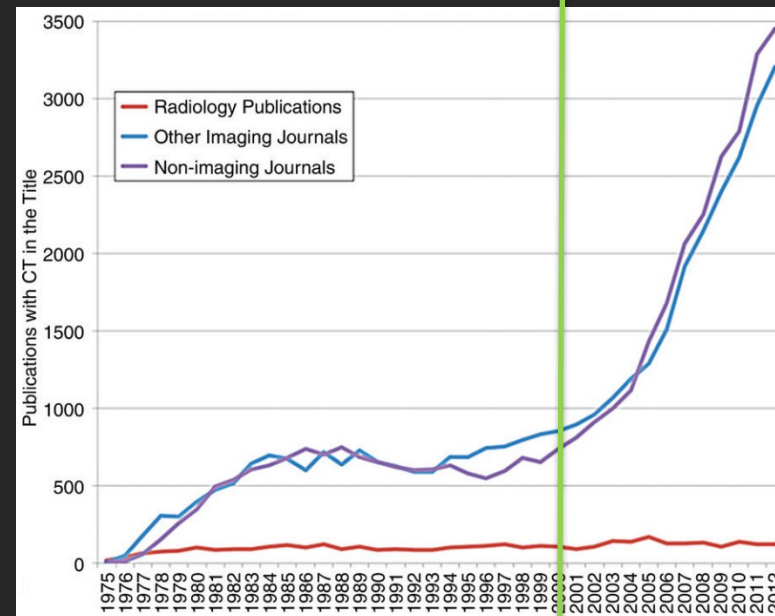
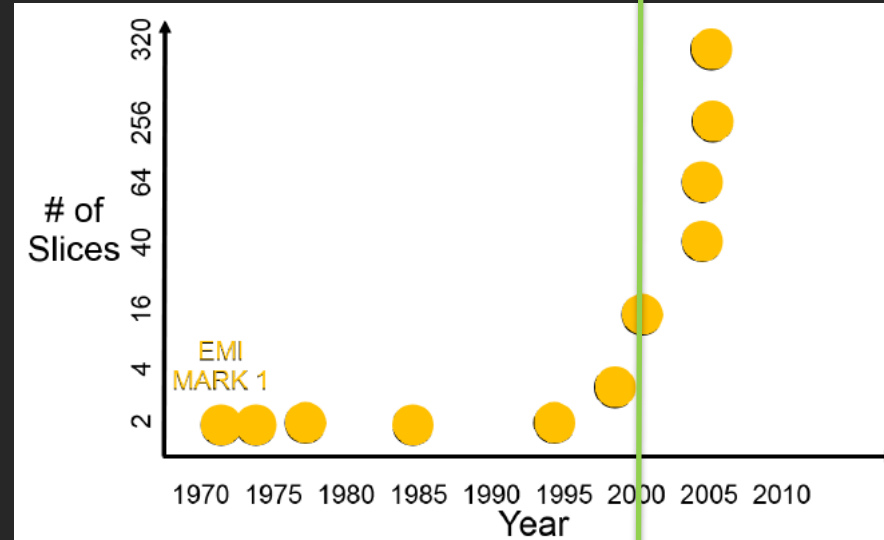


10 cm



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

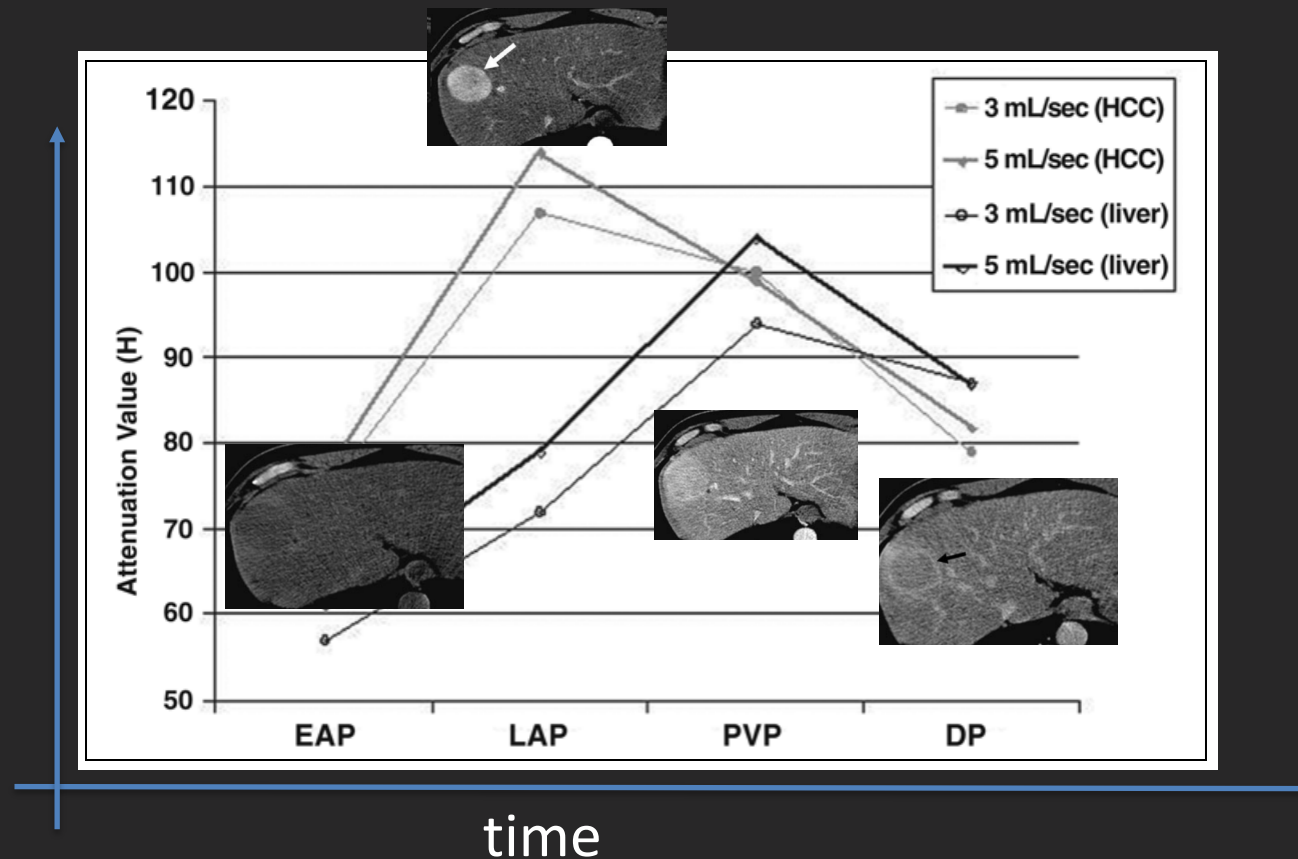


Bottom plot: Rubin, Geoffrey D. "Computed tomography: revolutionizing the practice of medicine for 40 years." *Radiology* 273.2S (2014): S45-S74.

Scan speed: The need and benefits of fast scanning

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

CT
number



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.

Speed

70

=

0.156586

Millimeter / Second

Miles per hour

Formula

divide the speed value by 447.04

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

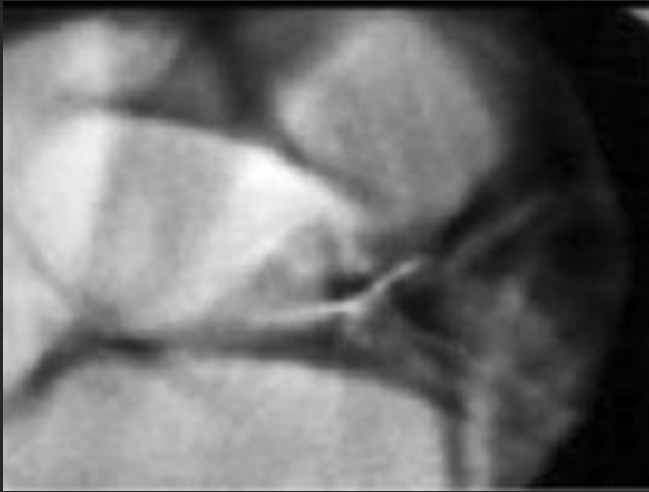
PURPOSE: To determine the speed of and changes in the speed of coronary arterial movement during the cardiac cycle with electron-beam computed tomography (CT).

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 $\pm$ 12.5 (SD). The mean velocity of right coronary arterial movement **69.5 mm/sec $\pm$ 22.5** was significantly faster than that of the left anterior descending (22.4 mm/sec $\pm$ 4.1) or the left circumflex coronary artery (48.4 mm/sec $\pm$ 15.0). The lowest mean velocity (27.9 mm/sec) was at 48% of the cardiac cycle.

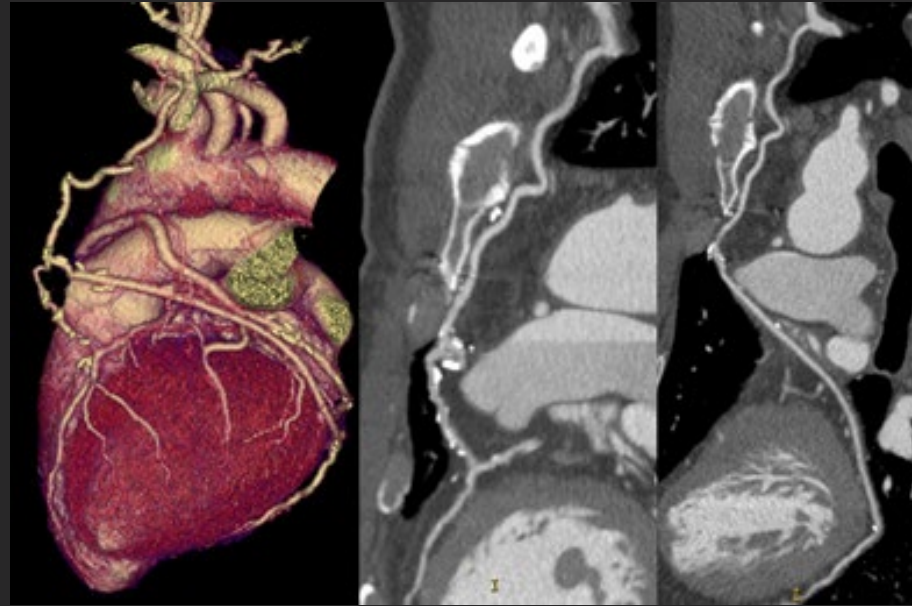
CONCLUSION: The lowest velocity of coronary arterial movement, which displays considerable temporal variation, was at 48% of the cardiac cycle.

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

4 MSCT



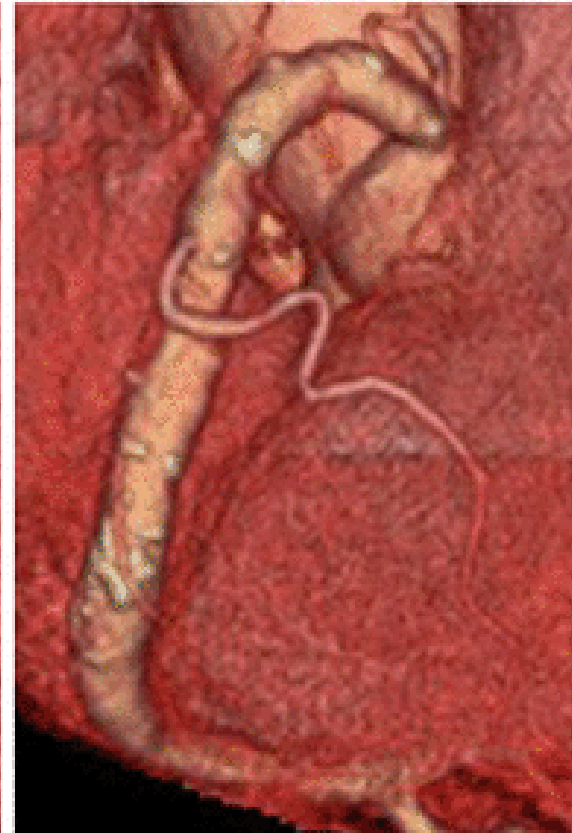
2002

16 MSCT



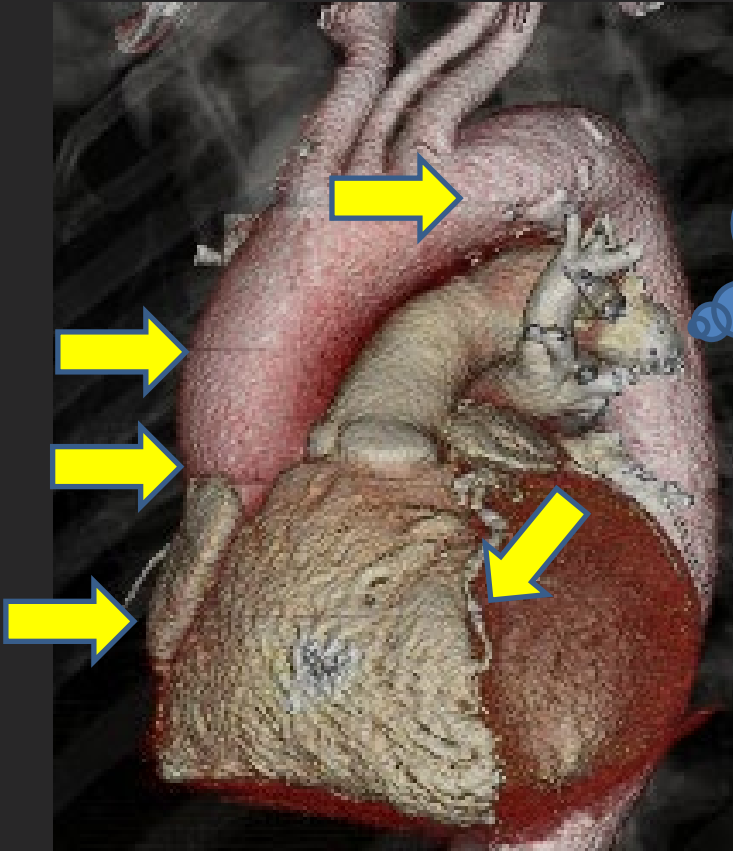
2004

64 MSCT



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



Prospective gating, 4 cm beam collimation

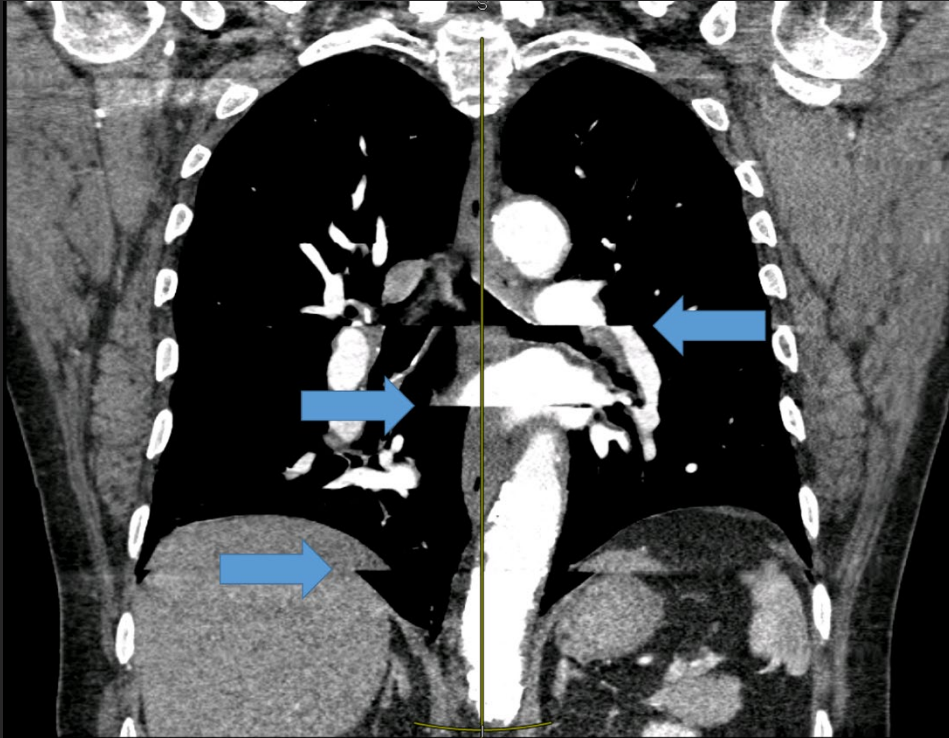
The artifacts appear every 4 cm...

2014



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

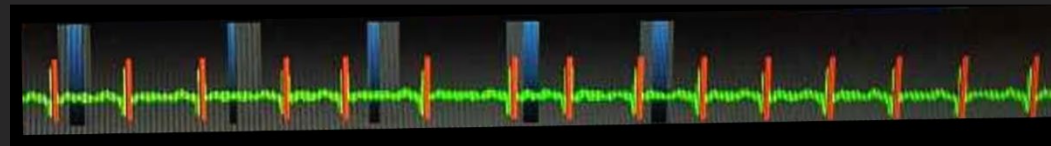
Benz, Dominik C., et al. "Minimized Radiation and Contrast Agent Exposure for Coronary Computed Tomography Angiography: First Clinical Experience on a Latest Generation 256-slice Scanner." *Academic radiology* 23.8 (2016): 1008-1014.

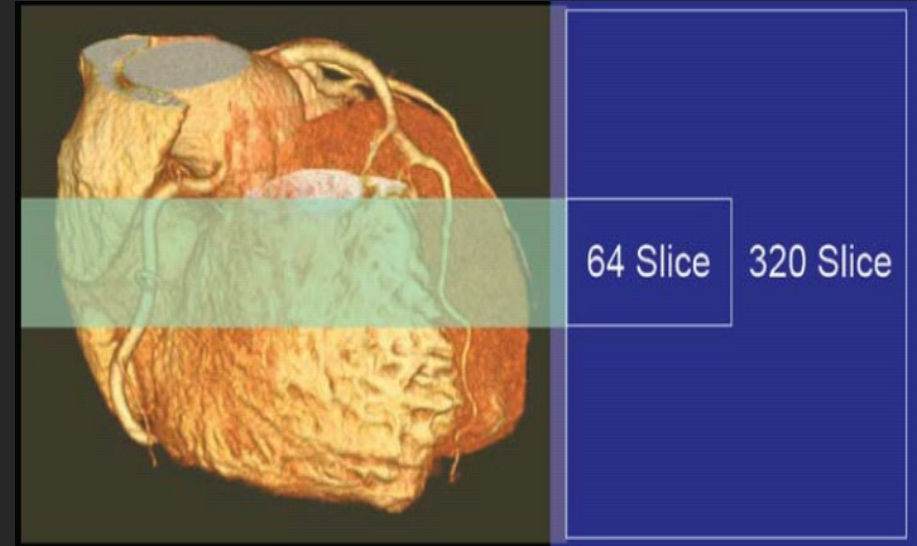
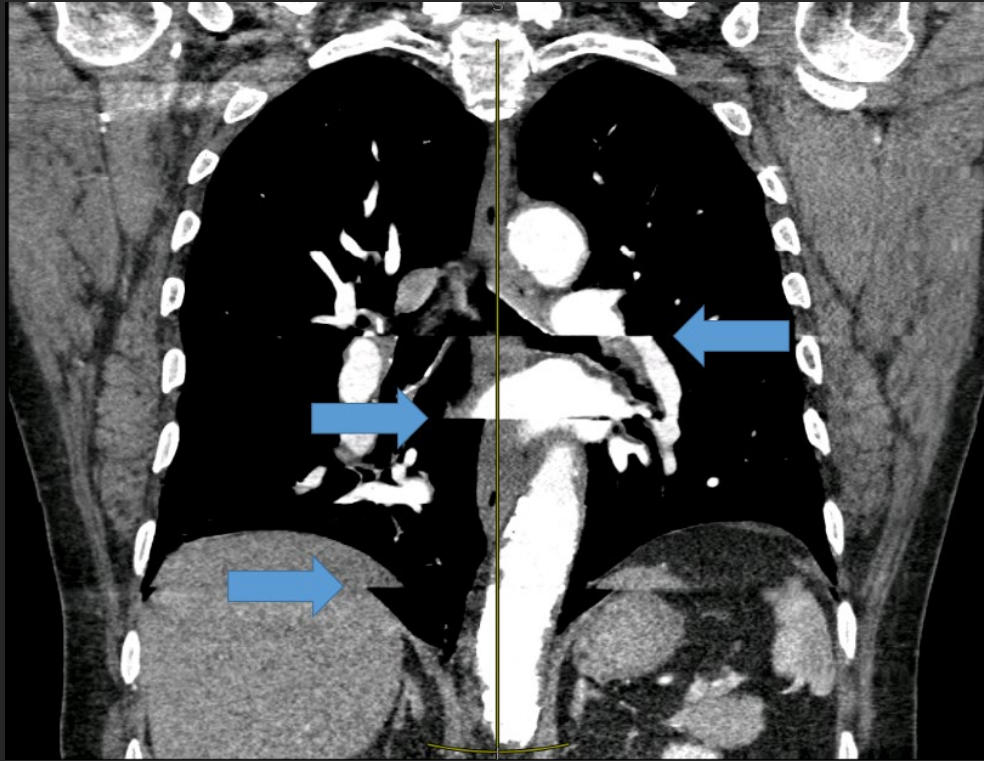


average heart rate of 70 bpm

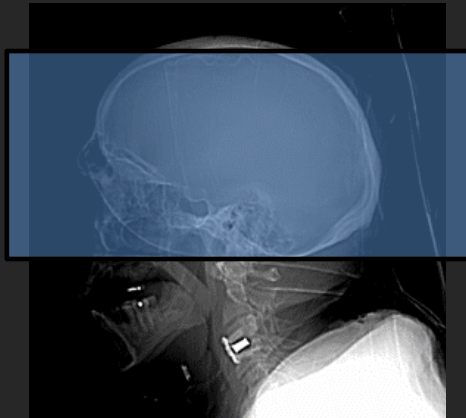
varied from a minimum of 51 to a maximum of 79 during the exam

3 irregular heart beats during the prospective cardiac acquisition

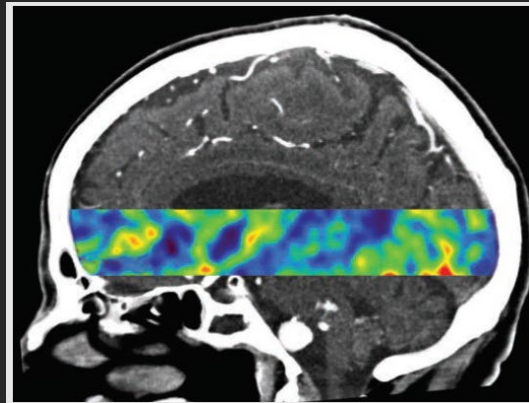




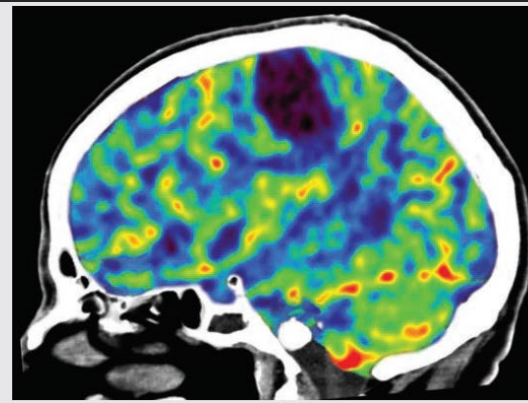
Choi, S.I., George, R.T., Schuleri, K.H. et al. Int J Cardiovasc Imaging (2009) 25(Suppl 1): 23. doi:10.1007/s10554-009-9443-4



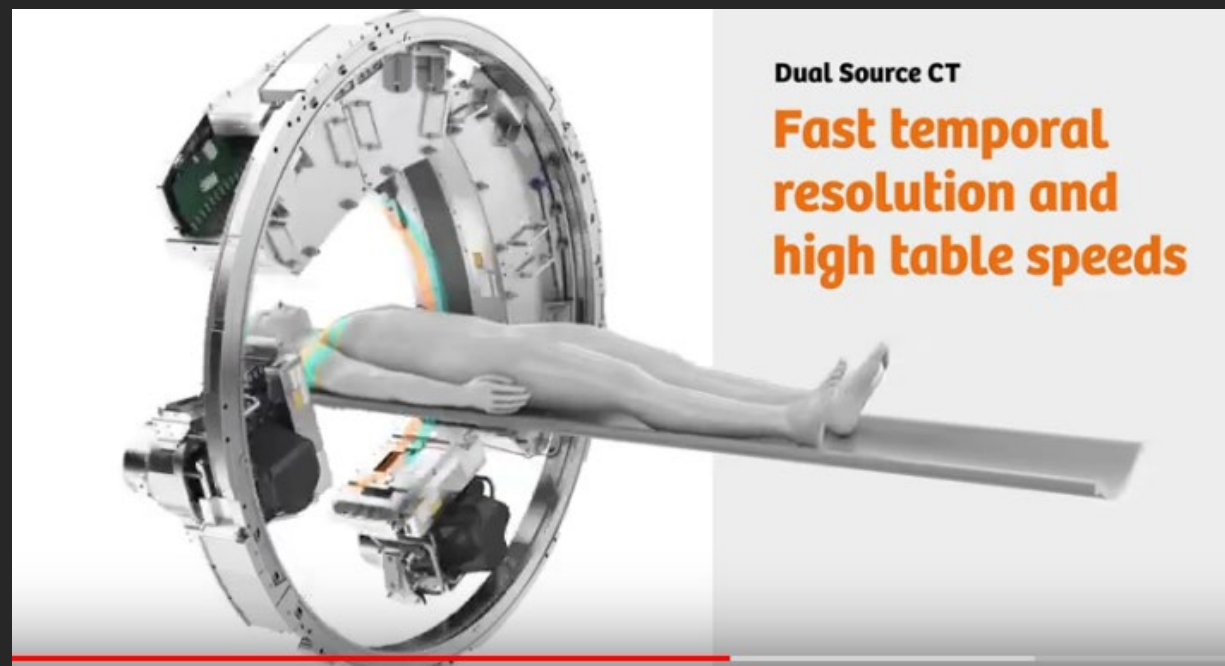
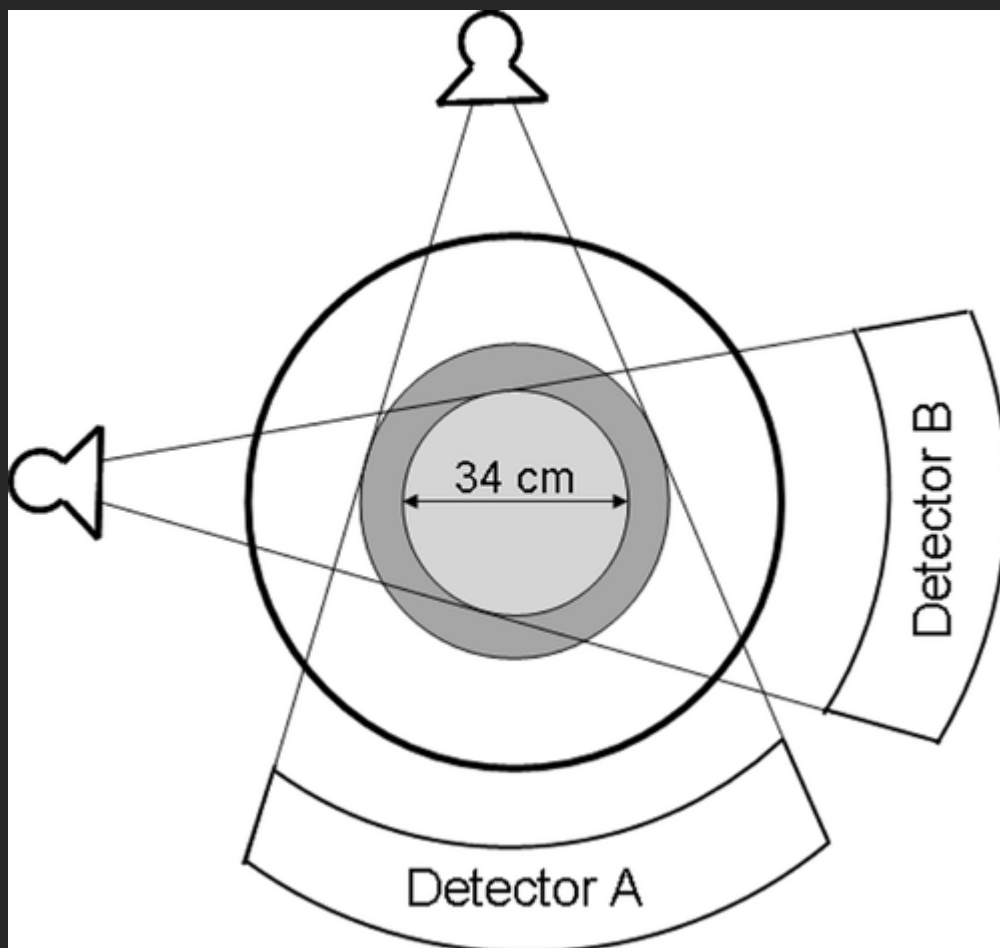
Limited coverage



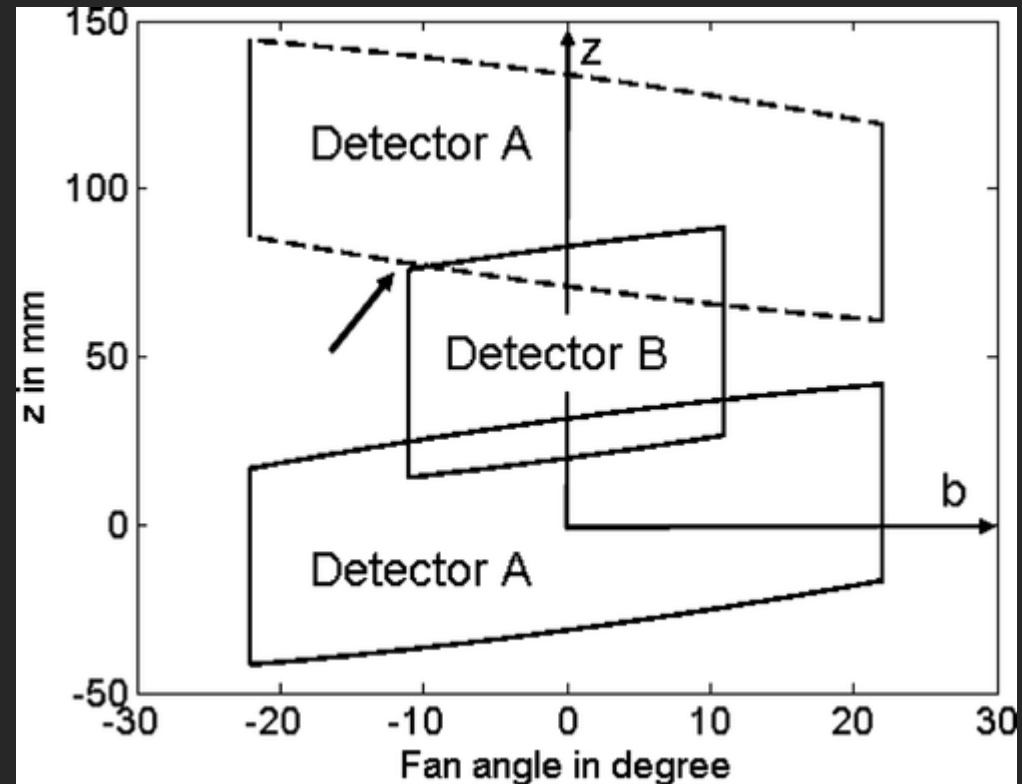
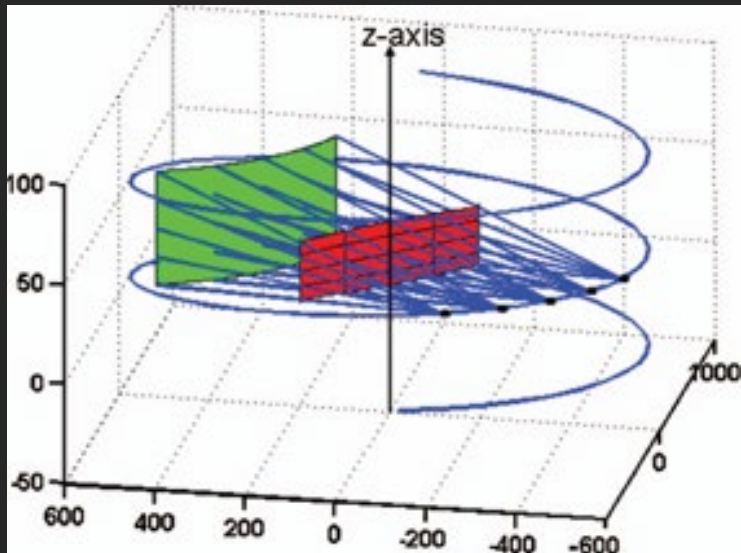
Wide axial coverage



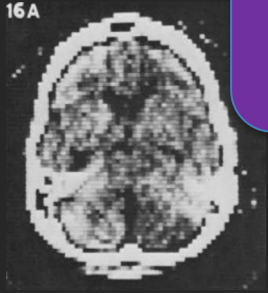
Right Images: Image from “Neuro and acute stroke imaging with dynamic volume CT” by Richard Mather Toshiba Medical Systems whitepaper 2008



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.



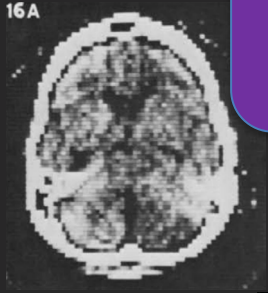
Flohr, T. G., Leng, S., Yu, L., Allmendinger, T., Bruder, H., Petersilka, M., ... & McCollough, C. H. (2009). Dual-source spiral CT with pitch up to 3.2 and 75 ms temporal resolution: image reconstruction and assessment of image quality. *Medical physics*, 36(12), 5641-5653.



Actually imaging the
entire body- head to feet

70s

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



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



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

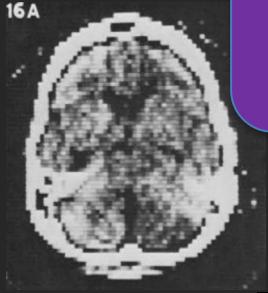
Actually imaging the entire body- head to feet

70s

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

70-80s



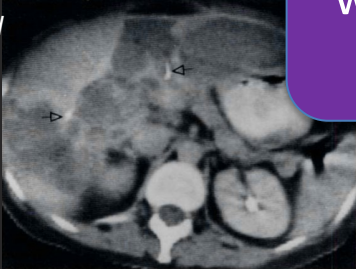


Actually imaging the
entire body- head to feet

70s

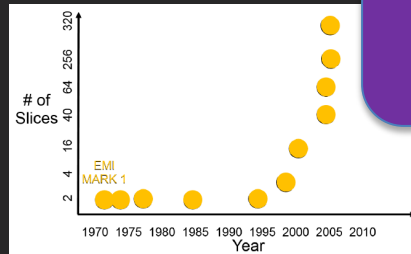
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Rubin, Geoffrey D. "Computed tomography: revolutionizing the practice of medicine for 40 years." *Radiology* 273.2S (2014): S45-S74.

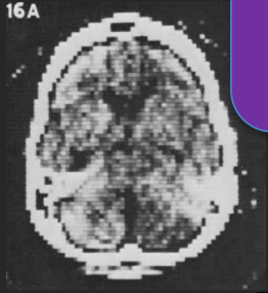
Kunstlinger, Francis, et al. "Computed tomography of hepatocellular carcinoma." *American Journal of Roentgenology* 134.3 (1980): 431-437.



Imaging blood vessels

00s

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



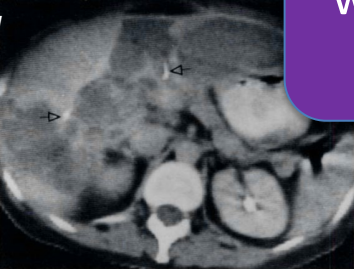
Actually imaging the
entire body- head to feet

70s

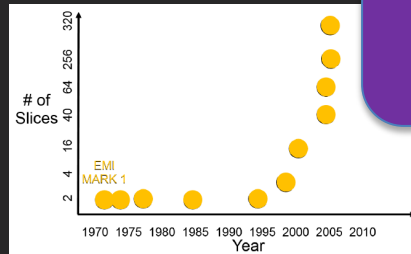
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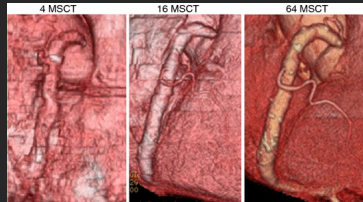


Imaging blood vessels

00s

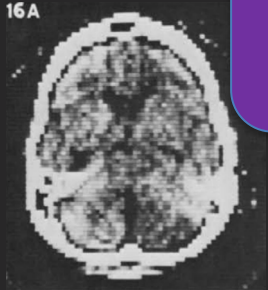
"The CT Handbook: Optimizing Protocols for Today's feature-rich scanners" By Tim Szczykutowicz. Medical Physics Publishing 2020

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.



Imaging the heart

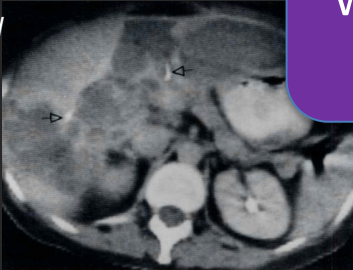
00s



Actually imaging the
entire body- head to feet

70s

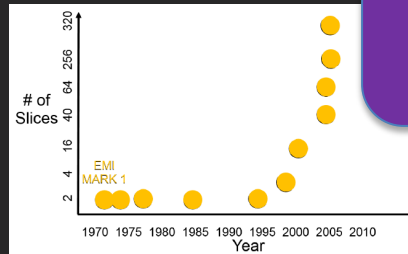
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70-80s

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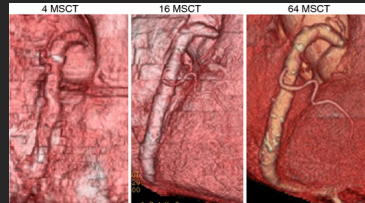


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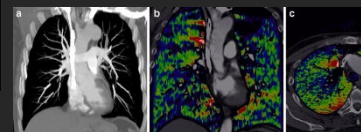
Hurlock, Gregory S., Hiroshi Higashino, and Teruhito Mochizuki. "History of cardiac computed tomography: single to 320-detector row multislice computed tomography." *The international journal of cardiovascular imaging* 25.1 (2009): 31-42.



Imaging the heart

00s

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.



More than just CT
number?

teens



Thanks!

**Feel free to contact me at
tszczykutowicz@uwhealth.org**

