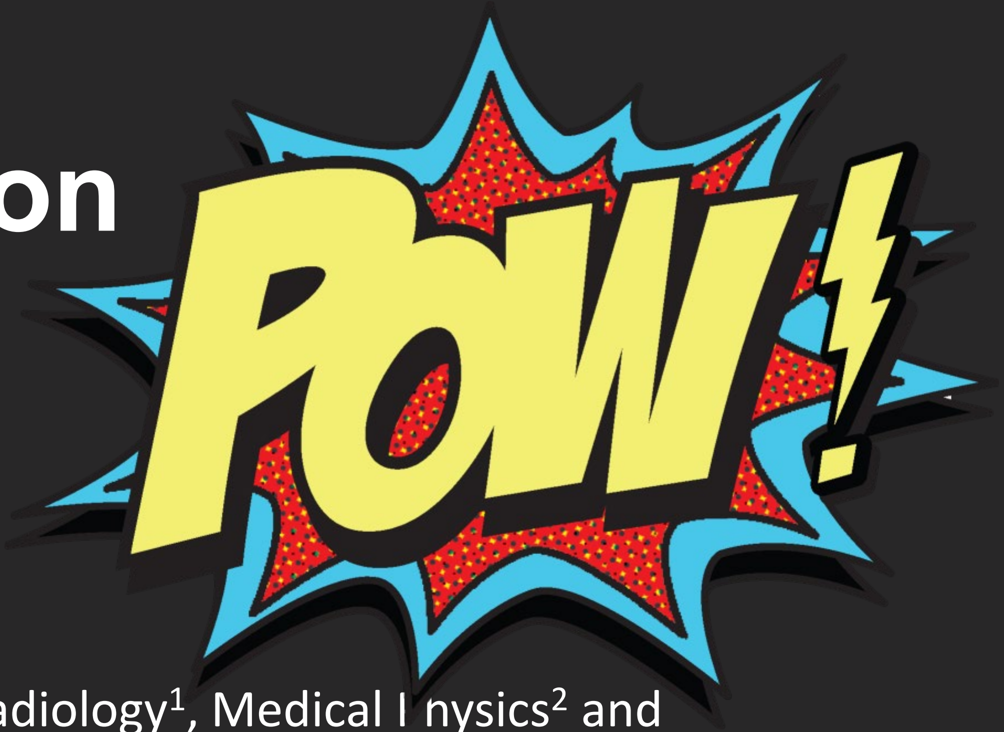
Protocol Optimization



Timothy P. Szczykutowicz Ph.D., DABR

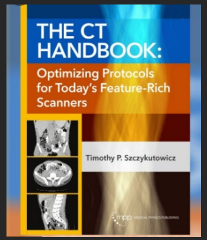
Professor

University of Wisconsin Madison Departments of Radiology[1], Medical Physics[2] and Biomedical Engineering[3]

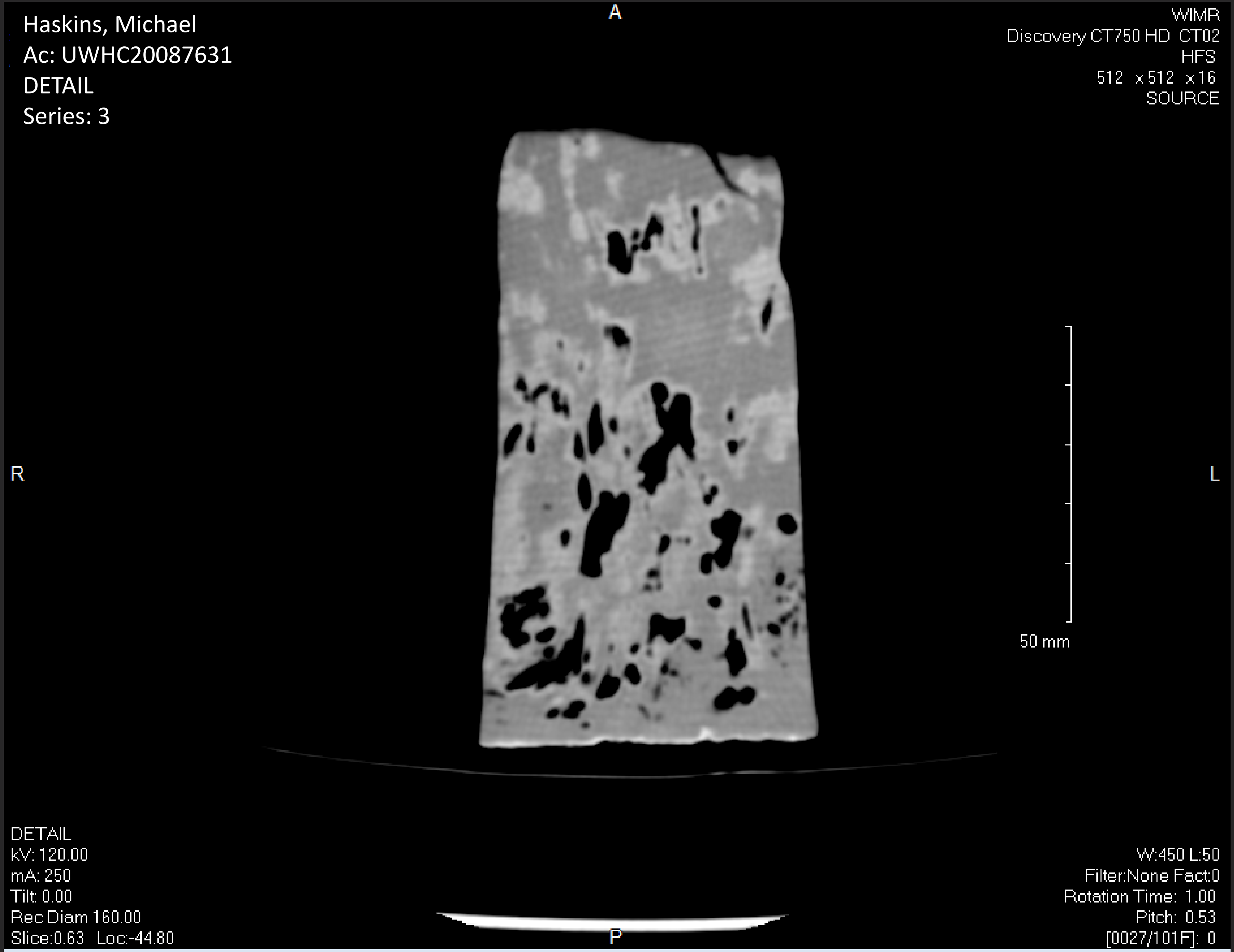
Disclosures/COI

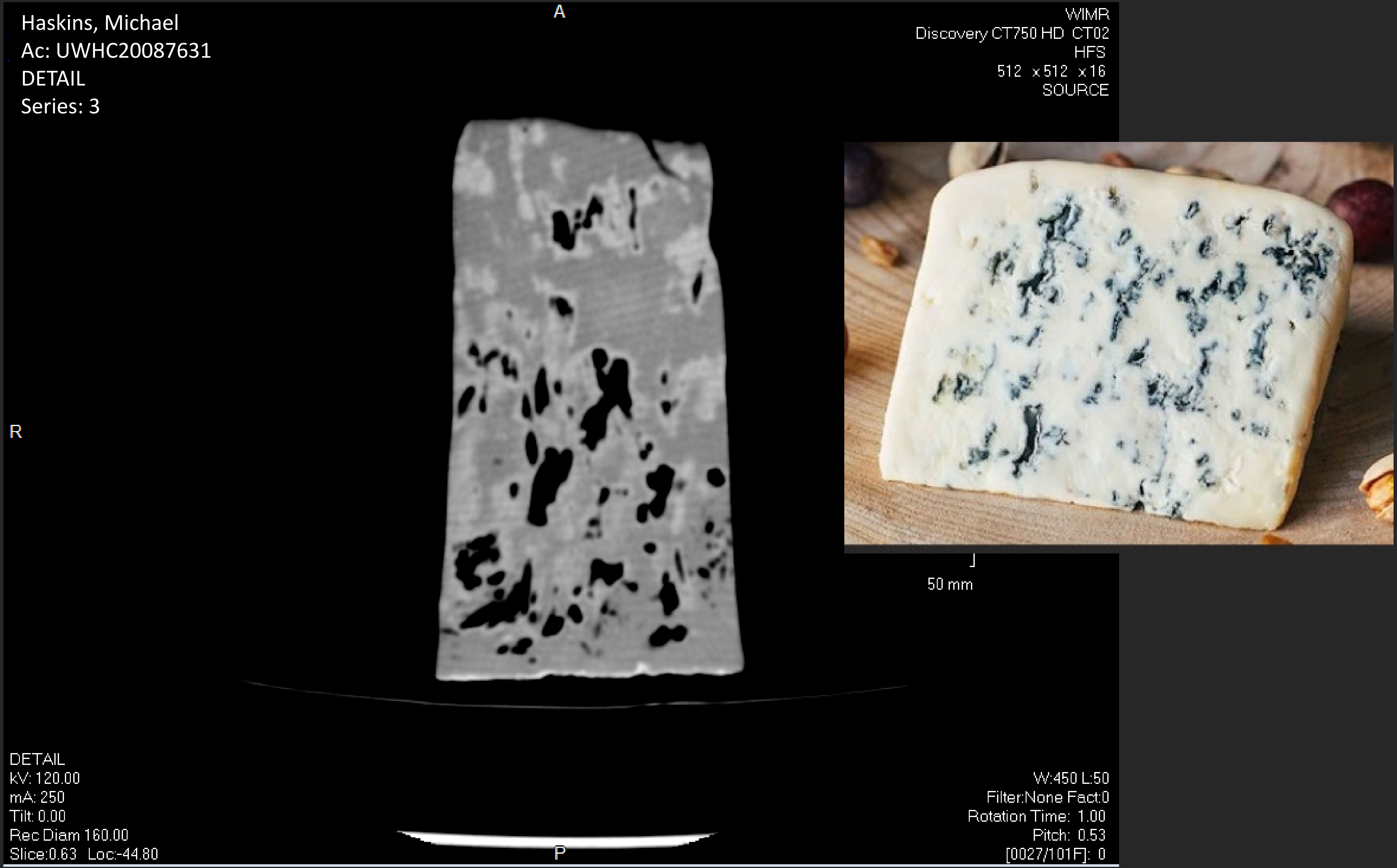
- # Tim Stick's Disclosures
  - Funds or equipment to UW-Madison
    - Supplies CT protocols to GE Healthcare under a licensing agreement
    - Research support from GE Healthcare
    - Receives research support from Canon Medical Systems USA
  - Personal
    - Medical Advisory Board of iMALOGIX LLC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

RadUnity



No personal $ from GE/Canon


Haskins, Michael
Ac: UWHC20087631
DETAIL
Series: 3
A
WIMR
Discovery CT750 HD CT02
HFS
512 x512 x16
SOURCE
R
L
50 mm
DETAIL
kV: 120.00
mA: 250
Tilt: 0.00
Rec Diam 160.00
Slice:0.63 Loc:-44.80
P
W:450 L:50
Filter:None Fact:0
Rotation Time: 1.00
Pitch: 0.53
[0027/101F]: 0


Haskins, Michael
Ac: UWHC20087631
DETAIL
Series: 3
A
WIMR
Discovery CT750 HD CT02
HFS
512 x 512 x 16
SOURCE
R
50 mm
DETAIL
kV: 120.00
mA: 250
Tilt: 0.00
Rec Diam 160.00
Slice:0.63 Loc:-44.80
P
W:450 L:50
Filter:None Fact:0
Rotation Time: 1.00
Pitch: 0.53
[0027/101F]: 0

Learning Objectives

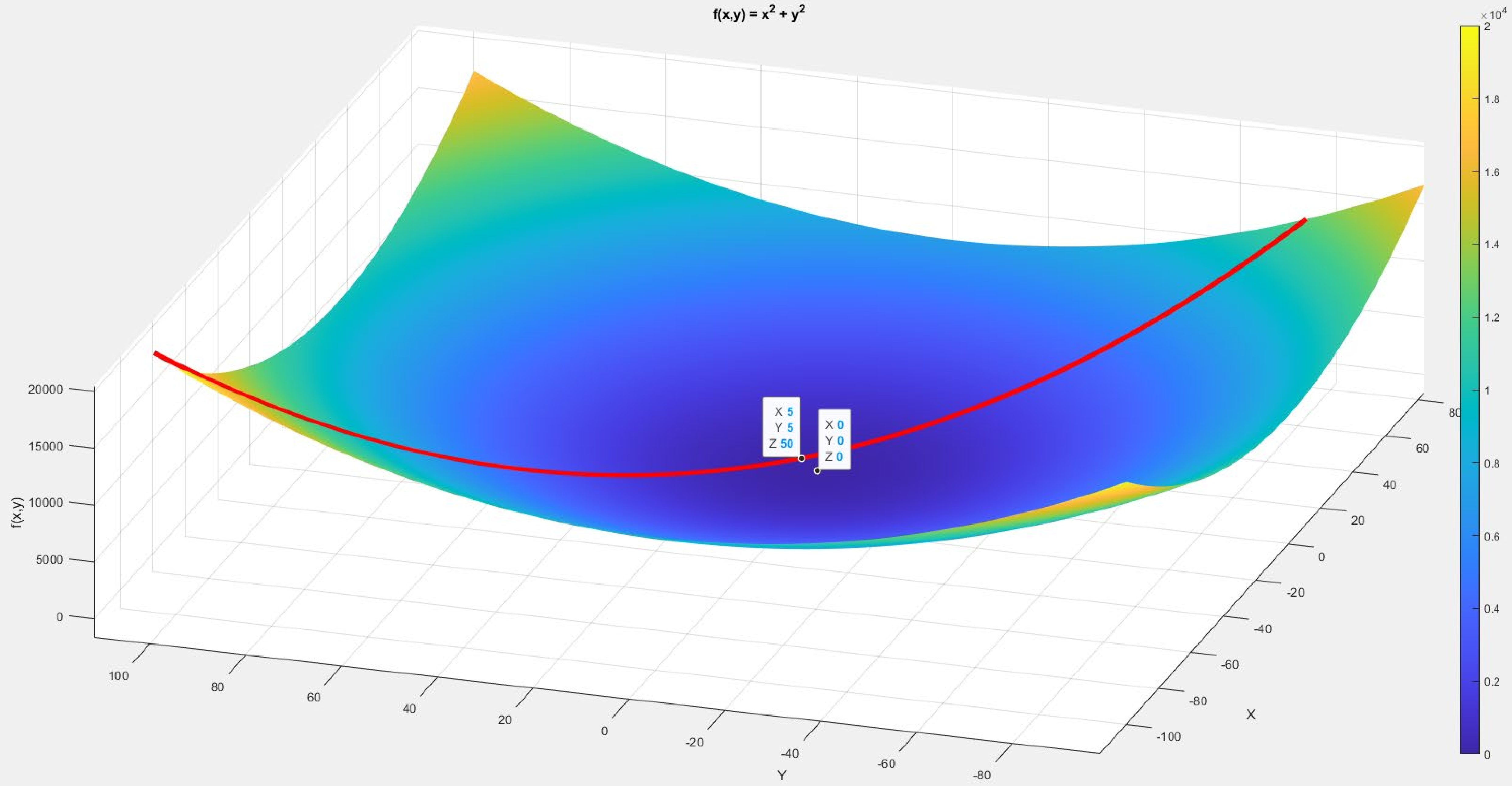
- Grasp the fundamental tradeoff between scan speed and radiation dose.

- Learn how modern automatic exposure control (AEC) systems manage image quality and dose.

$$f(x, y) = x^2 + y^2$$

$$f(x, y) = x^2 + y^2$$

Where $x + y = 10$



f(x,y) = x^2 + y^2
f(x,y)
20000
15000
10000
5000
0
Y
100
80
60
40
20
0
-20
-40
-60
-80
X
80
60
40
20
0
-20
-40
-60
-80
-100
X 5
Y 5
Z 50
X 0
Y 0
Z 0
×10^4
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

$$f(x, y) = x^2 + y^2$$

Where $x + y = 10$

You cannot start an optimization problem until you understand what you are trying to **optimize** (minimize or maximize) and what are your **constraints**

Reduce average length of stay in a hospital

Reduce average length of stay in a hospital

While still treating lung transplants, NICU babies, complex stroke patients…etc

Reduce average length of stay in a hospital

While still treating lung transplants, NICU babies, complex stroke patients…etc

You cannot start an optimization problem until you understand what you are trying to **optimize** (minimize or maximize) and what are your **constraints**

Objective: fast scanning for pediatrics

Constraint: must scan indicated range of lung apices to bases

Constraint: cannot rely on coaching instructions to freeze voluntary motion

Constraint: cannot use over 100 kV

Constraint: available tube rotation times are [0.35 0.4 0.5 0.6 0.8 0.9 1] sec

Constraint: available beam collimations are [10, 20, 40] mm

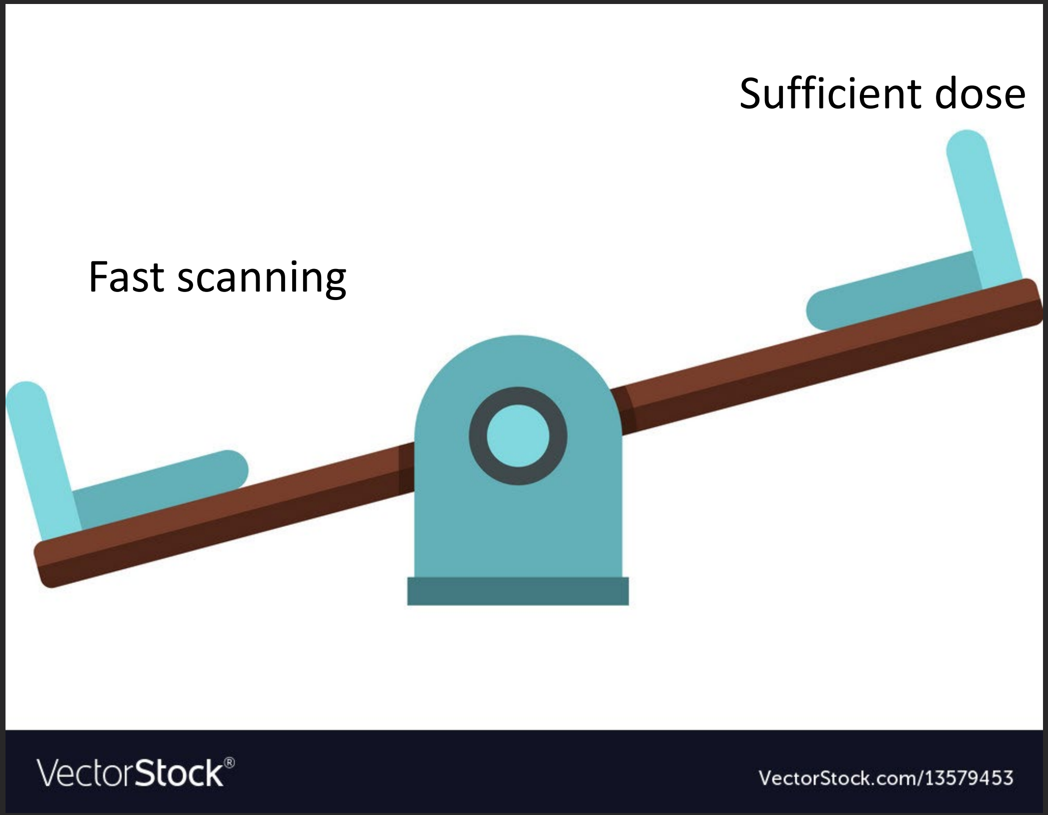
Constraint: need dose dynamic range of 0-5 mGy

Constraint: available pitches are [0.5 1 1.4]:1

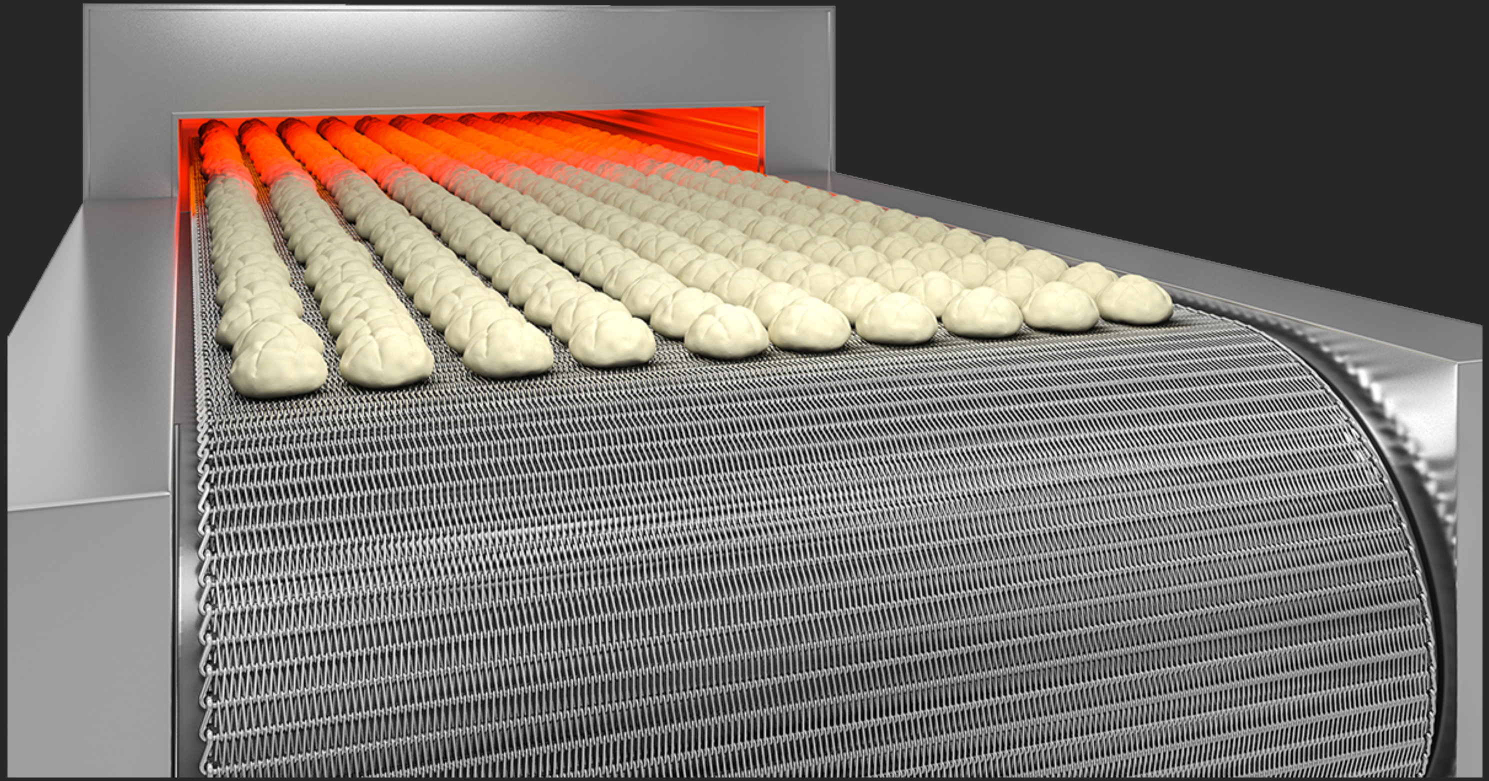
Constraint: can only make 1 protocol for all pediatrics for this task

If you are not considering this tradeoff, you don’t have optimized protocols!

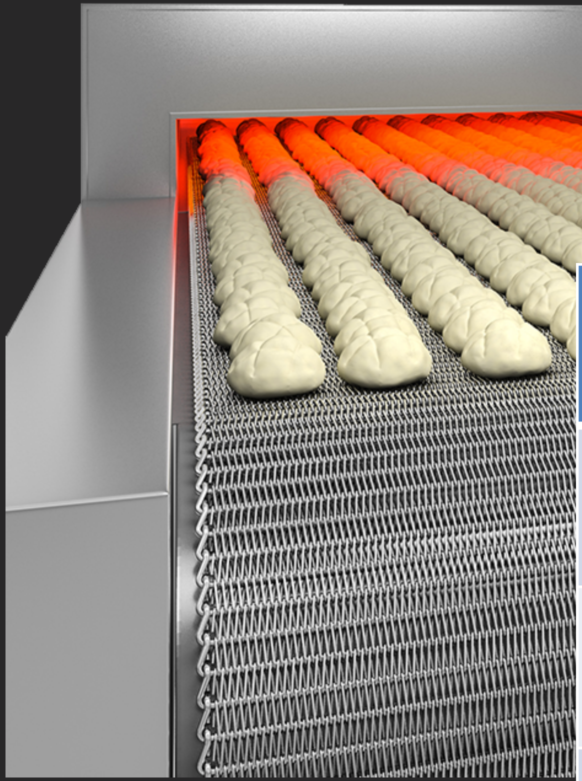
$$\text{Speed} = \frac{\text{pitch} * \text{collimation}}{\text{Rotation time}}$$



$$\text{Effective mAs} = \frac{\text{mA} * \text{Rotation Time}}{\text{Pitch}}$$



Dr. Stick's lil bread bun factory



	Slow belt	Medium Speed	Fast belt
Low heat			
Med Heat			
High Heat			

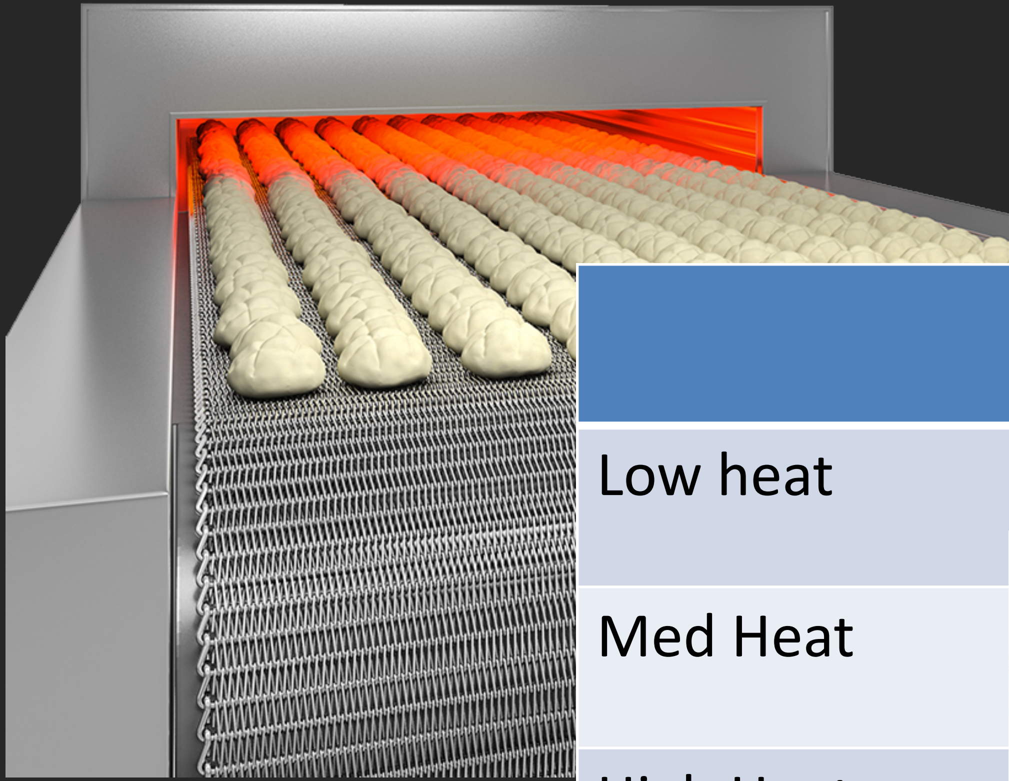








Dr. Stick’s lil bread bun factory



	Slow belt	Medium Speed	Fast belt
Low heat			
Med Heat			
High Heat			

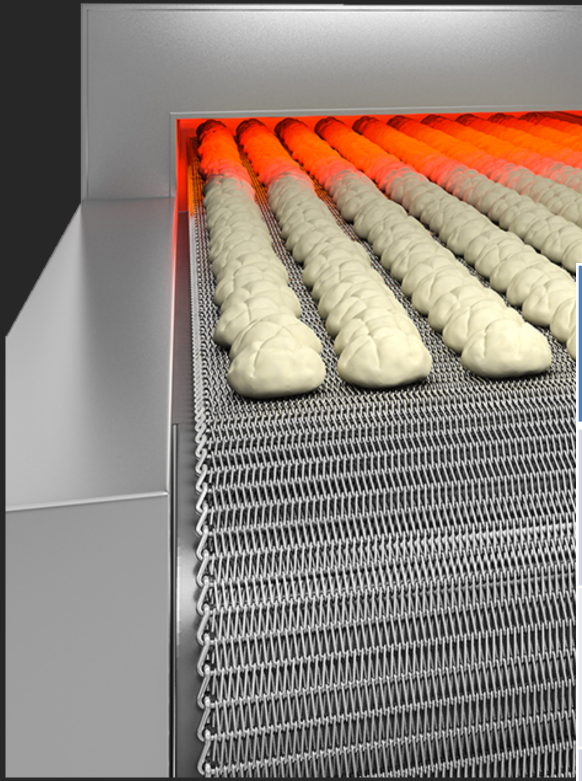








Dr. Stick's lil bread bun factory

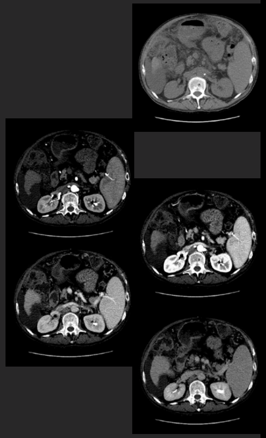


Speed = $\frac{\text{pitch} * \text{collimation}}{\text{Rotation time}}$

	Slow belt	Medium Speed	Fast belt
Low heat			
Med Heat			
High Heat			

Scanner Output (i.e., effective mAs) = $\frac{\text{mA} * \text{Rotation Time}}{\text{Pitch}}$

Scan speed: The need and benefits of fast scanning



Exam Description: CT ANGIO ABDOMEN

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Helical	S78.750-I179.250	5.91	176.97	Body 32
3	Axial	I50.250-I50.250	60.71	30.35	Body 32
4	Helical	S78.750-I179.250	16.00	478.60	Body 32
4	Helical	I179.250-S78.750	6.29	188.40	Body 32
4	Helical	S78.750-I431.250	6.91	381.26	Body 32
6	Helical	S78.750-I179.250	9.10	272.37	Body 32
		Total Exam DLP:		1527.95	

258 mm

258 mm

258 mm

510 mm

258 mm

Just liver coverage

Diaphragm to pubic synthesis

Scan speed: The need and benefits of fast scanning

258 mm imaged @ 0.516 pitch @ 40 mm collimation @ 0.4 sec rotation time → 5 sec

258 mm imaged @ 0.516 pitch @ 40 mm collimation @ 0.6 sec rotation time → 7.5 sec

510 mm imaged @ 0.516 pitch @ 40 mm collimation @ 0.4 sec rotation time → 9.9 sec

258 mm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 26 sec

510 mm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 51 sec

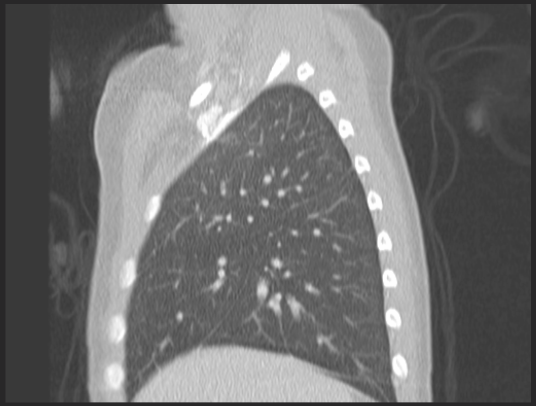
510 mm imaged with GE hyperdrive mode (80 mm collimation, 0.28 s rotation, 1.531 pitch) → 1.2 sec
510 mm imaged in Siemens Flash Mode (737 mm/s) → 0.7 seconds

US American College of Radiology guidelines specify scan times <15 seconds for lung cancer screening. These may be appropriate for healthy patient scanning, but you will see a lot of cardiac motion. For any diseased population, 15 seconds is far too long.

ADULT LUNG CANCER SCREENING TECHNICAL SPECIFICATIONS		
Adult Chest for Lung Cancer Screening		
Technique Parameters (Items in bold are designation requirements. Failure to meet these requirements will result in deferral of Designation)		
Scan Parameter	**Parameter Specification**	**Comments**
Scanner type	**multidetector helical (spiral) detector rows ≥ 4**	non helical and single detector scanners are not appropriate for lung cancer screening CT
Required Series		No IV or oral contrast should be used
kV	100 to 140 acceptable for standard sized patient	Should be set in combination with mAs to meet CTDIvol specifications
mAs	Should be set in combination with kVp to meet CTDIvol specifications.	The mAs selected should result in diagnostic-quality images of the lungs Should take into account the patient's body habitus and age, slice width, kVp, and unique attributes of the scanner and acquisition mode
Max.Tube Rotation Time	≤ 0.5 seconds	0.75 second is acceptable if a single breath hold ≤15 seconds can be achieved for scanners that cannot perform 0.5 second rotation time
Pitch (IEC Definition)	Between 0.7 and 1.5	Should be set with other technical parameters to achieve single breath hold scan and CTDIvol specifications
Respiration	**single breath hold full inspiration**	
Scan duration/ Acquisition time	≤ 15 seconds	e to acquire the scan though entire s within a single breath
Reconstructed image width (nominal width of reconstructed image along z-axis)	**≤ 2.5 mm**	≤ 1 mm preferred
Reconstructed image spacing (Distance between two reconstructed images)	≤ slice width	Overlapping reconstructions are not necessary but are acceptable

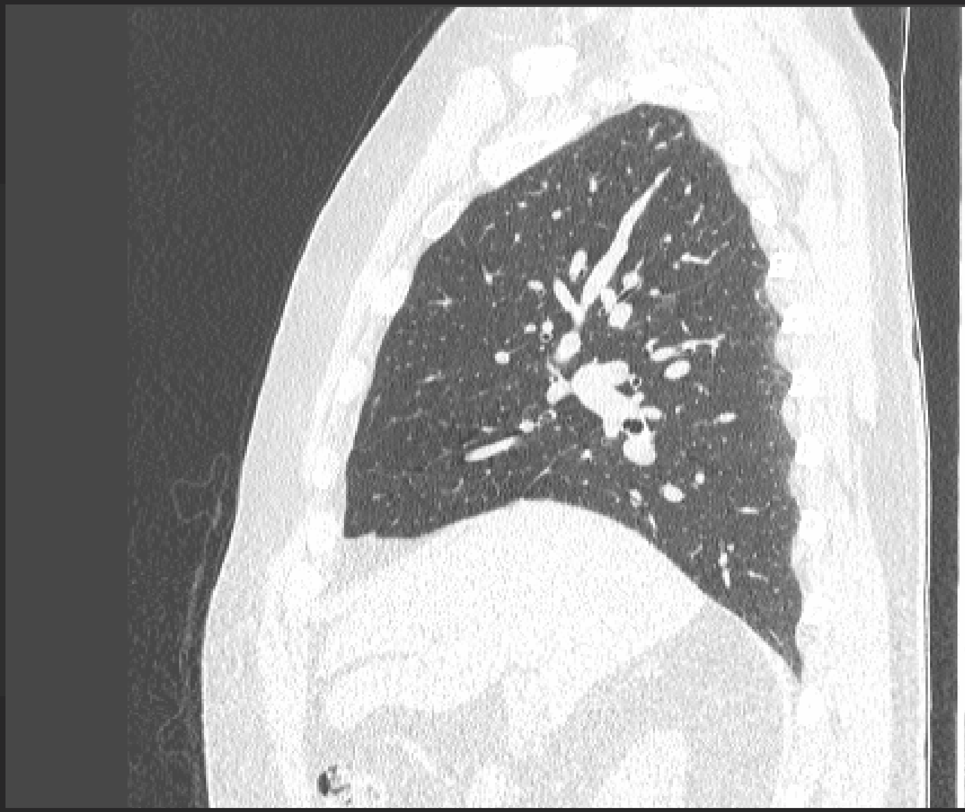
Scan speed: The need and benefits of fast scanning

2 YO M, 15 cm coverage



51 YO F, 23 cm coverage

55 YO M, 34 cm coverage



Scan speed: The need and benefits of fast scanning

15 cm imaged @ 1.5 pitch @ 40 mm collimation @ 0.4 sec rotation time → 1 sec
23 cm imaged @ 1.5 pitch @ 40 mm collimation @ 0.4 sec rotation time → 1.5 sec
34 cm imaged @ 1.5 pitch @ 40 mm collimation @ 0.4 sec rotation time → 2.3 sec

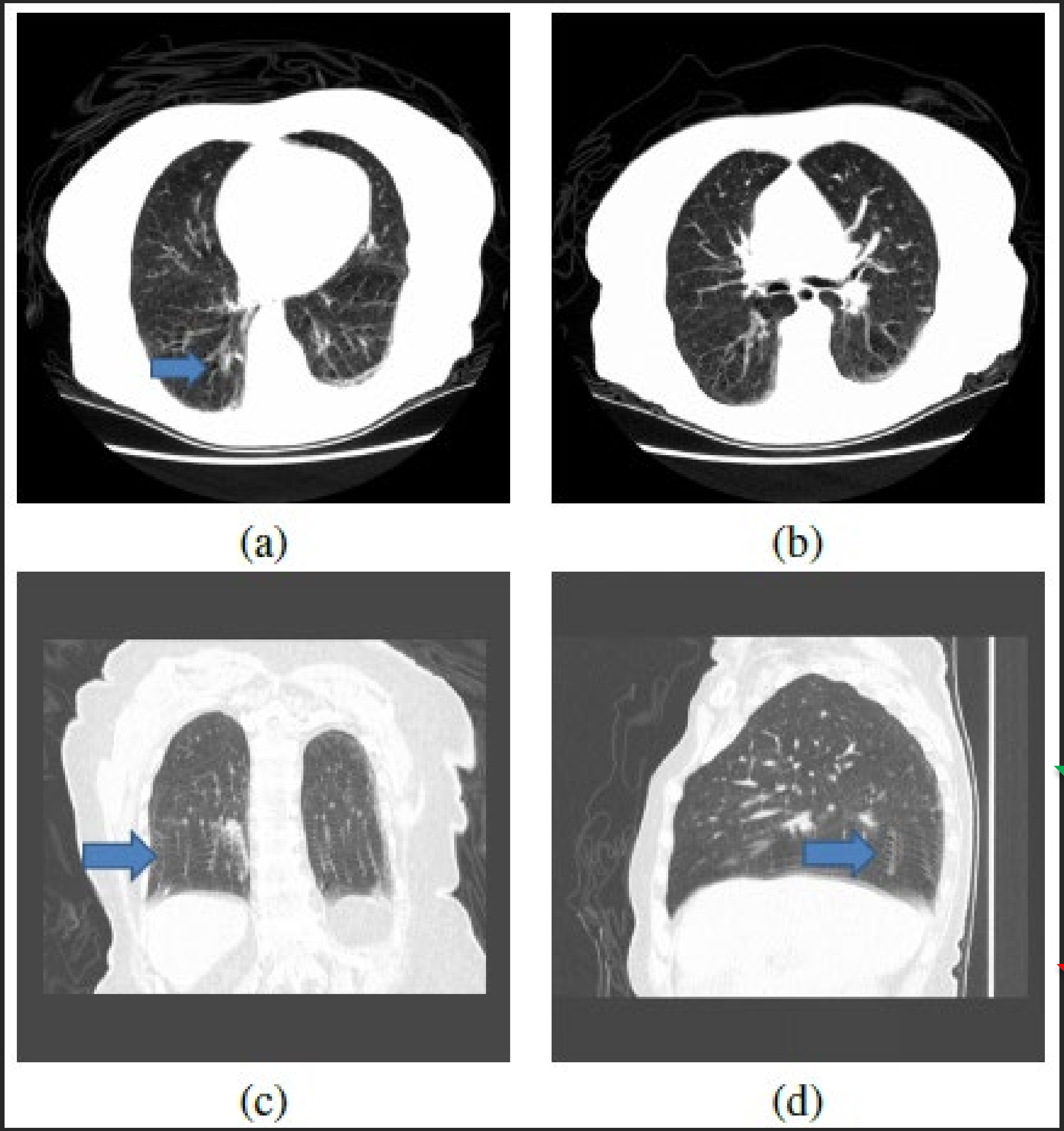
15 cm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 15 sec
23 cm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 23 sec
34 cm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 34 sec

340 mm imaged with GE hyperdrive mode (80 mm collimation, 0.28 s rotation, 1.531 pitch) → 0.78 sec
340 mm imaged in Siemens Flash Mode (737 mm/s) → 0.46 seconds

Scan speed: The need and benefits of fast scanning

Cancer patients, people presenting with PE, or other respiratory diseases cannot hold their breaths for more than a couple seconds.

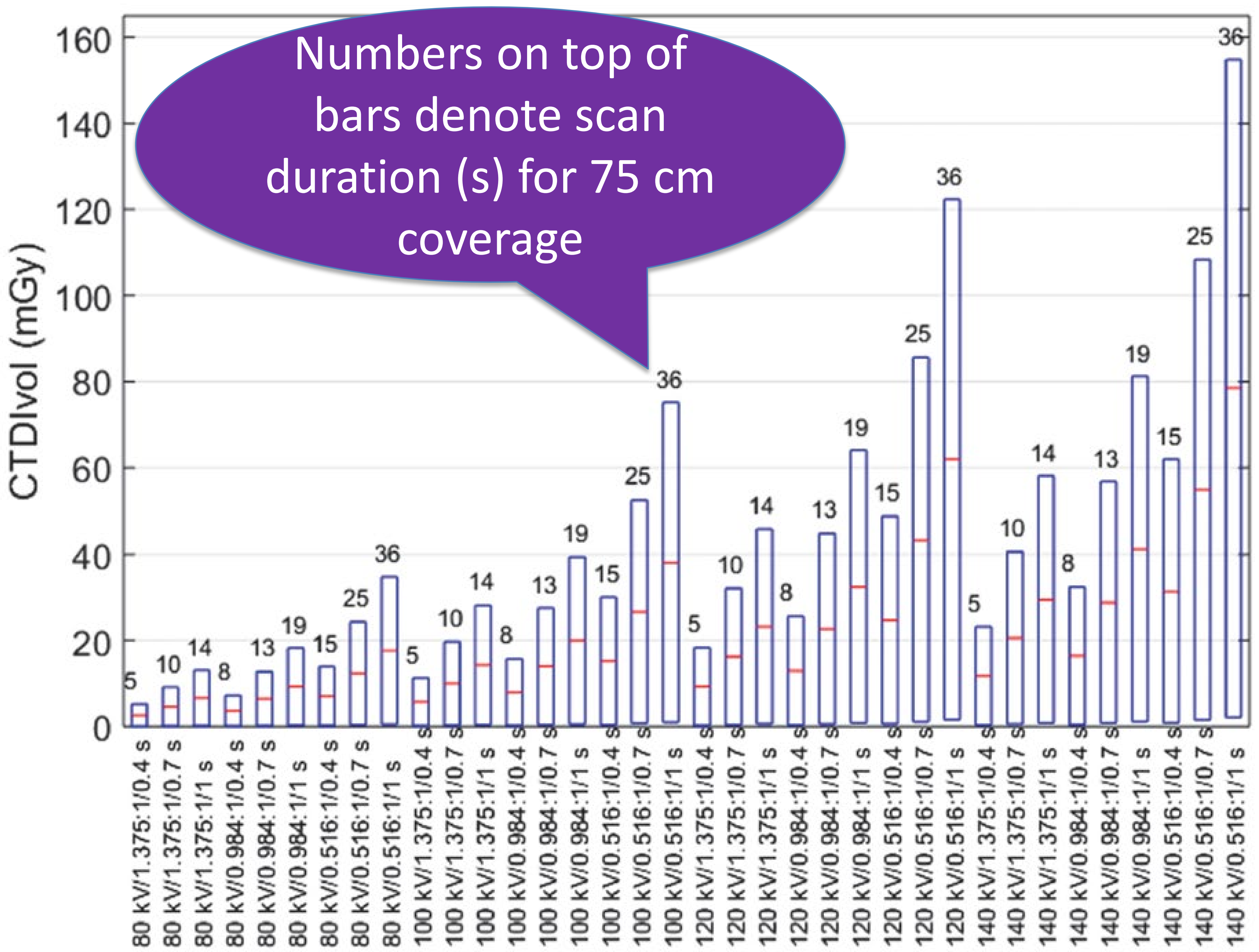
With these patients, we often get these “half motion contaminated” scans. If we could have scanned faster, this scan would have been fine.



Able to hold breath

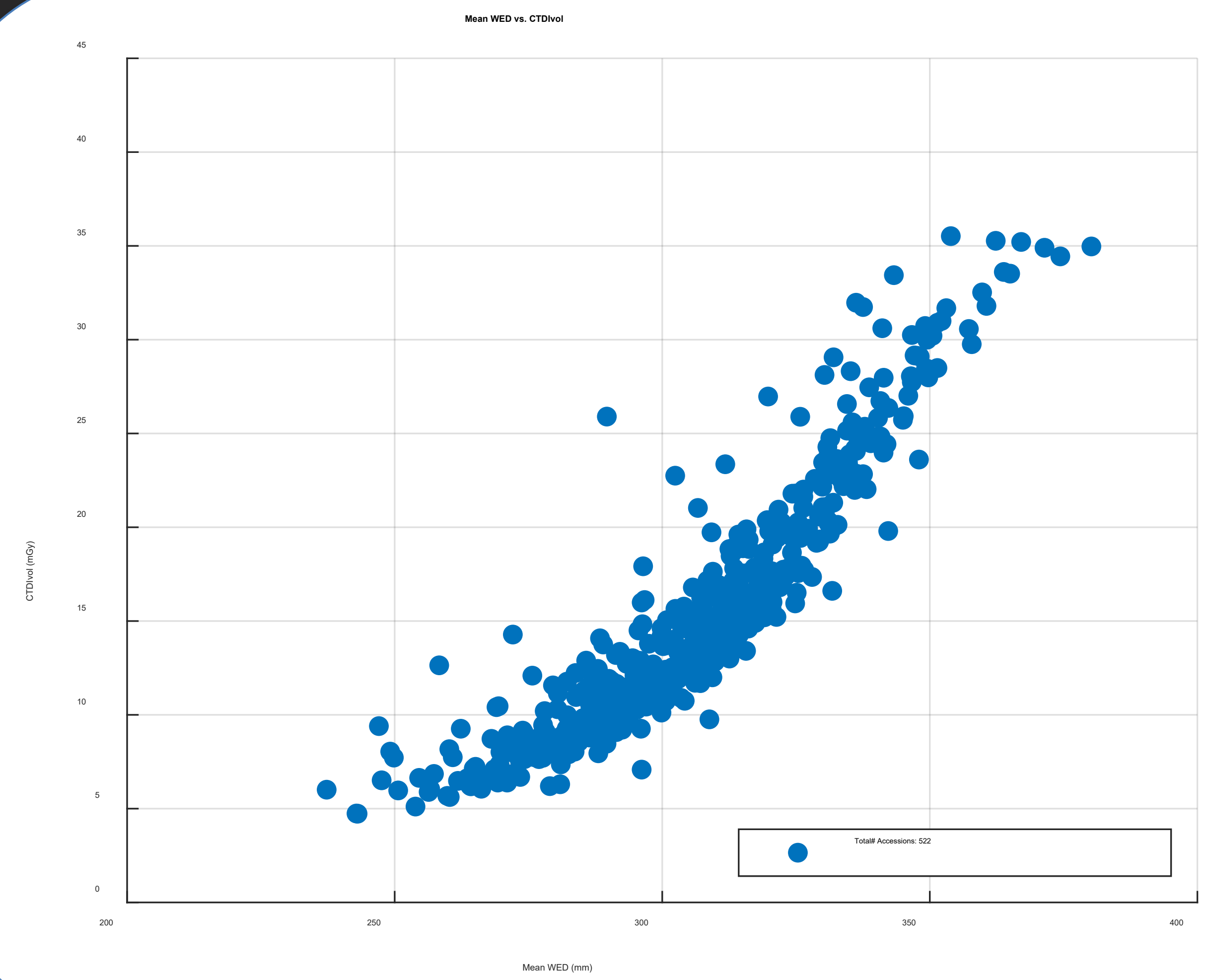
Had to breath while scan was in progress

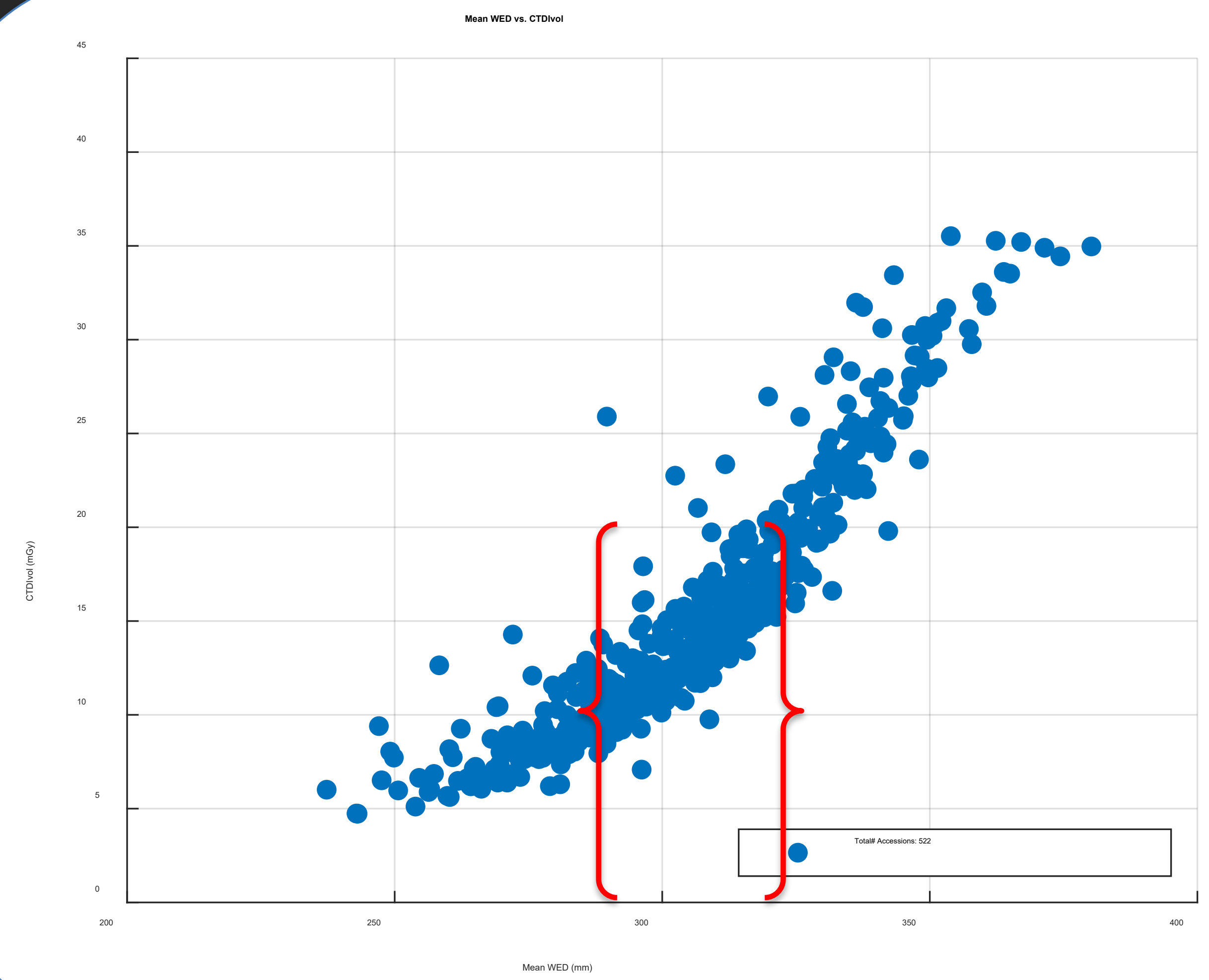
Figure from “CT Handbook” By Tim Szczykutowicz


Numbers on top of bars denote scan duration (s) for 75 cm coverage
CTDIvol (mGy)
80 kV/1.375:1/0.4 s
80 kV/1.375:1/0.7 s
80 kV/1.375:1/1 s
80 kV/0.984:1/0.4 s
80 kV/0.984:1/0.7 s
80 kV/0.984:1/1 s
80 kV/0.516:1/0.4 s
80 kV/0.516:1/0.7 s
80 kV/0.516:1/1 s
100 kV/1.375:1/0.4 s
100 kV/1.375:1/0.7 s
100 kV/1.375:1/1 s
100 kV/0.984:1/0.4 s
100 kV/0.984:1/0.7 s
100 kV/0.984:1/1 s
100 kV/0.516:1/0.4 s
100 kV/0.516:1/0.7 s
100 kV/0.516:1/1 s
120 kV/1.375:1/0.4 s
120 kV/1.375:1/0.7 s
120 kV/1.375:1/1 s
120 kV/0.984:1/0.4 s
120 kV/0.984:1/0.7 s
120 kV/0.984:1/1 s
120 kV/0.516:1/0.4 s
120 kV/0.516:1/0.7 s
120 kV/0.516:1/1 s
140 kV/1.375:1/0.4 s
140 kV/1.375:1/0.7 s
140 kV/1.375:1/1 s
140 kV/0.984:1/0.4 s
140 kV/0.984:1/0.7 s
140 kV/0.984:1/1 s
140 kV/0.516:1/0.4 s
140 kV/0.516:1/0.7 s
140 kV/0.516:1/1 s

@Prof_TimStick's Actionable information

- An elephant gun "1 size fits all" CT protocol will need to be slow enough have enough output to image bariatric patients, which means it is too slow for smaller patients


Mean WED vs. CTDIvol
CTDIvol (mGy)
Mean WED (mm)
Total# Accessions: 522
0
5
10
15
20
25
30
35
40
45
200
250
300
350
400



Every ~4 cm in CT, dose needs to double to keep noise fixed

A collection of routine abdomen pelvis patients scanned at my institution

CTDIvol	2.72 mGy	5.4 mGy	10.8 mGy	22.01 mGy	58.5 mGy
APxLat	25x20 cm size	30x23 cm size	36x25cm size	39x30cm size	~50x39cm size

Double dose for a ~8cm size increase
(if diameter increases by 4, adding
diameter plus diameter increases by 8)

A collection of routine abdomen pelvis patients scanned at my institution

2.72 mGy
25x20 cm size

5.4 mGy
30x23 cm size

10.8 mGy
36x25cm size

22.01 mGy
39x30cm size

58.5 mGy
~50x39cm size

Double dose for a ~8cm size increase
(if diameter increases by 4, adding
diameter plus diameter increases by 8)

A collection of routine abdomen pelvis patients scanned at my institution

2.72 mGy
25x20 cm size

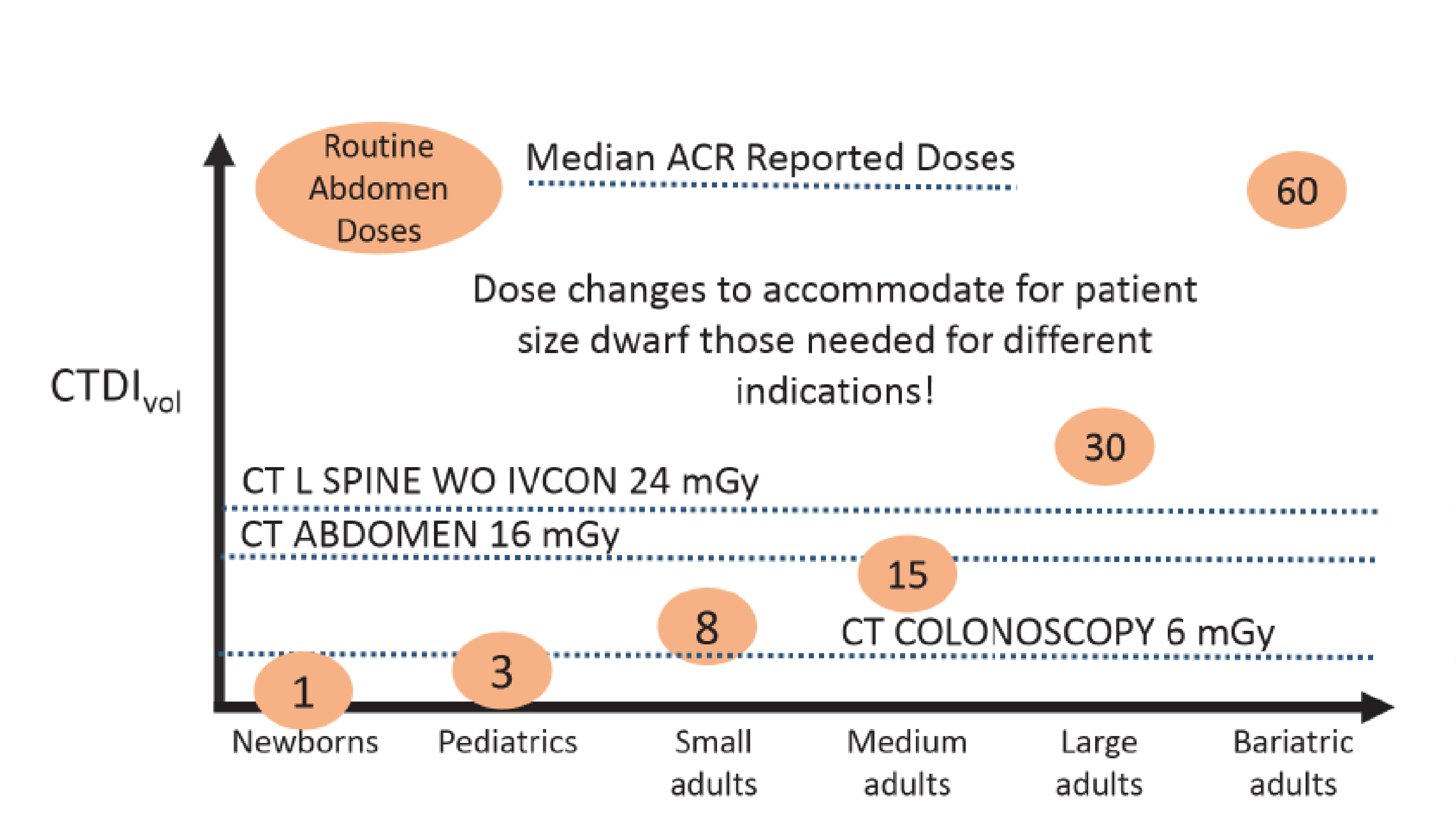
5.4 mGy
30x23 cm size

10.8 mGy
36x25cm size

22.01 mGy
39x30cm size

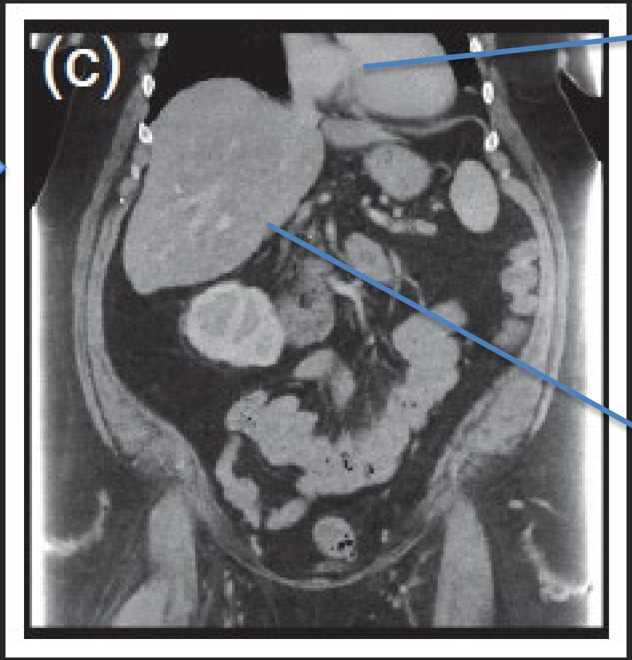
58.5 mGy
~50x39cm size

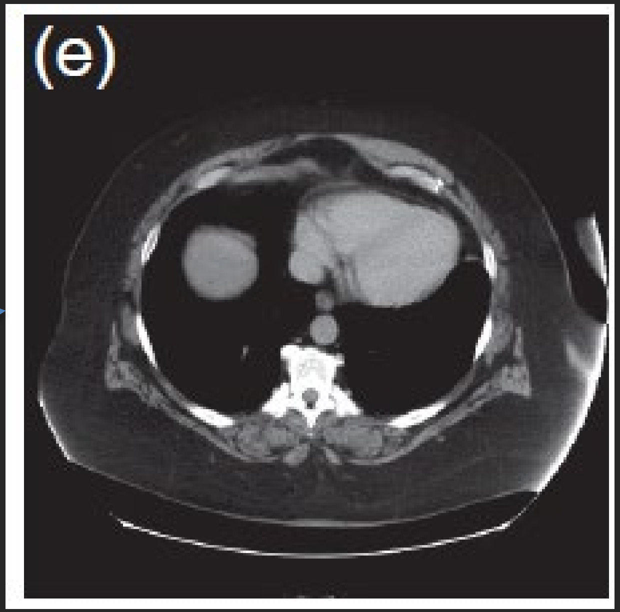
Double dose for a ~8cm size increase
(if diameter increases by 4, adding
diameter plus diameter increases by 8)



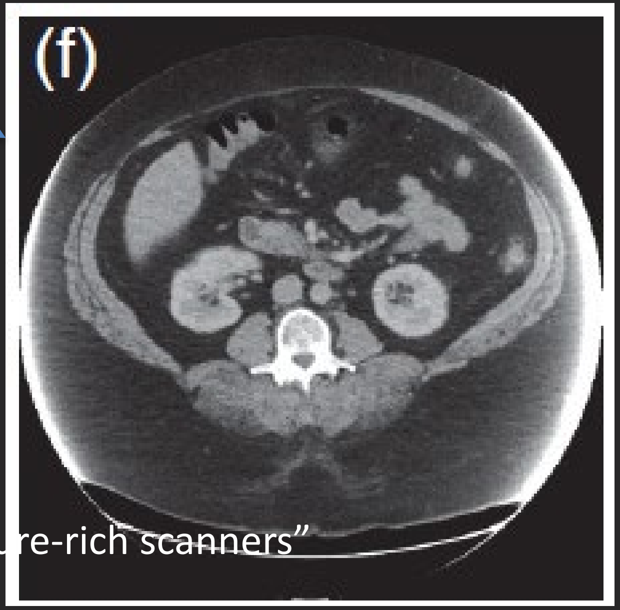
Dose variation to account for size for a single indication is much larger than indication to indication dose changes for the same size patient!

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



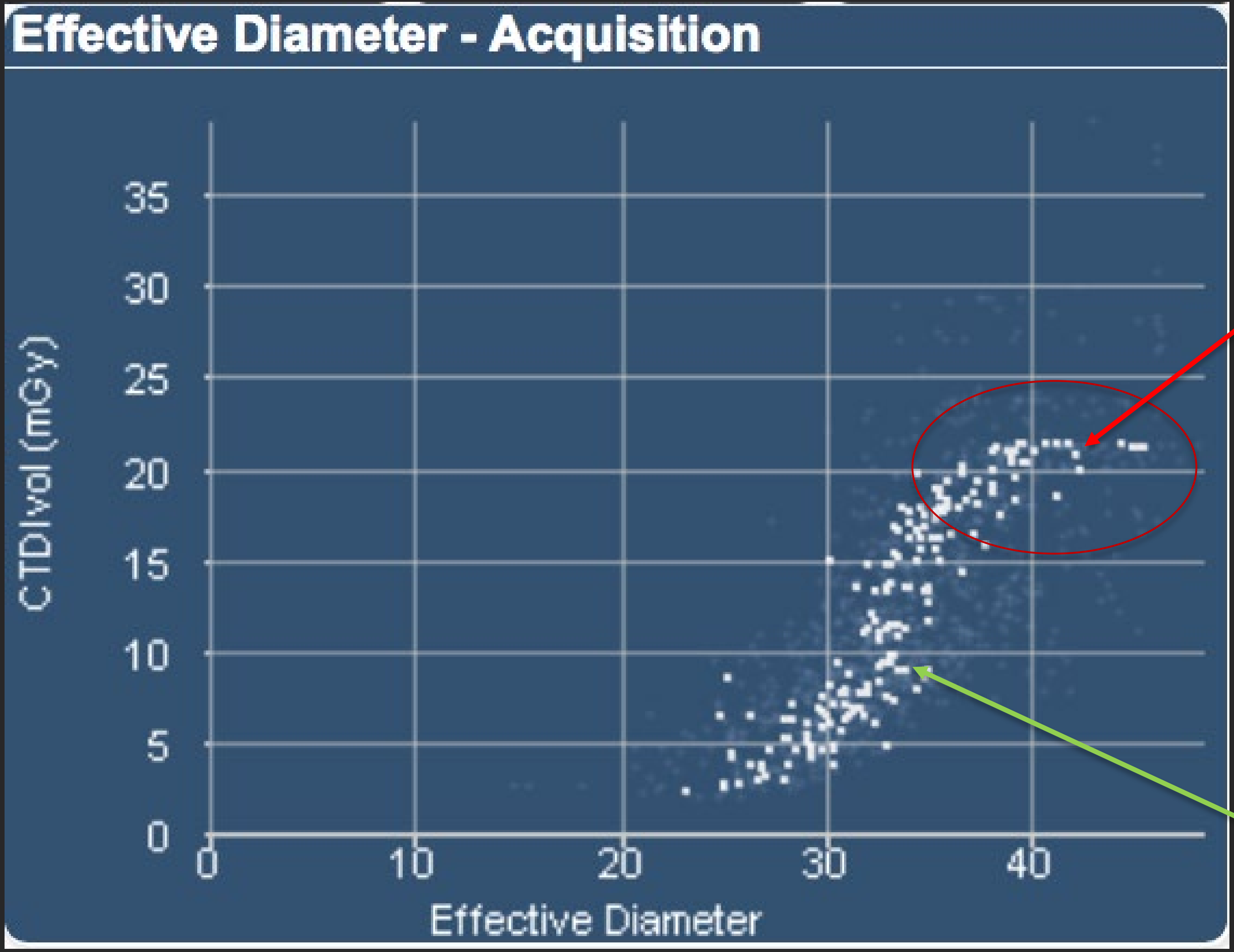


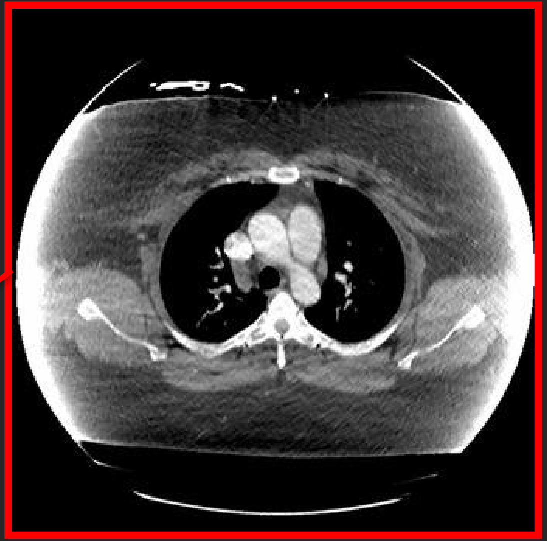
At this level we are just about to hit our mA max, noise still reasonable



At this level we have hit our mA max, noise increases a lot!

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


Effective Diameter - Acquisition
CTDIvol (mGy)
35
30
25
20
15
10
5
0
0
10
20
30
40
Effective Diameter



Predicting Image Quality Issues with Bariatric Patients Based on Scanner Characterization

Authors:

Aria M. Salyapongse, MS. Departments of Medical Physics and Radiology, University of Wisconsin – Madison. asalyapongse@wisc.edu

Giuseppe V. Toia, MS, MD. Departments of Medical Physics and Radiology, University of Wisconsin – Madison. gtoia@uwhealth.org

Matthew R. Smith, MD, PhD. Department of Radiology, University of Wisconsin – Madison. msmith20@uwhealth.org

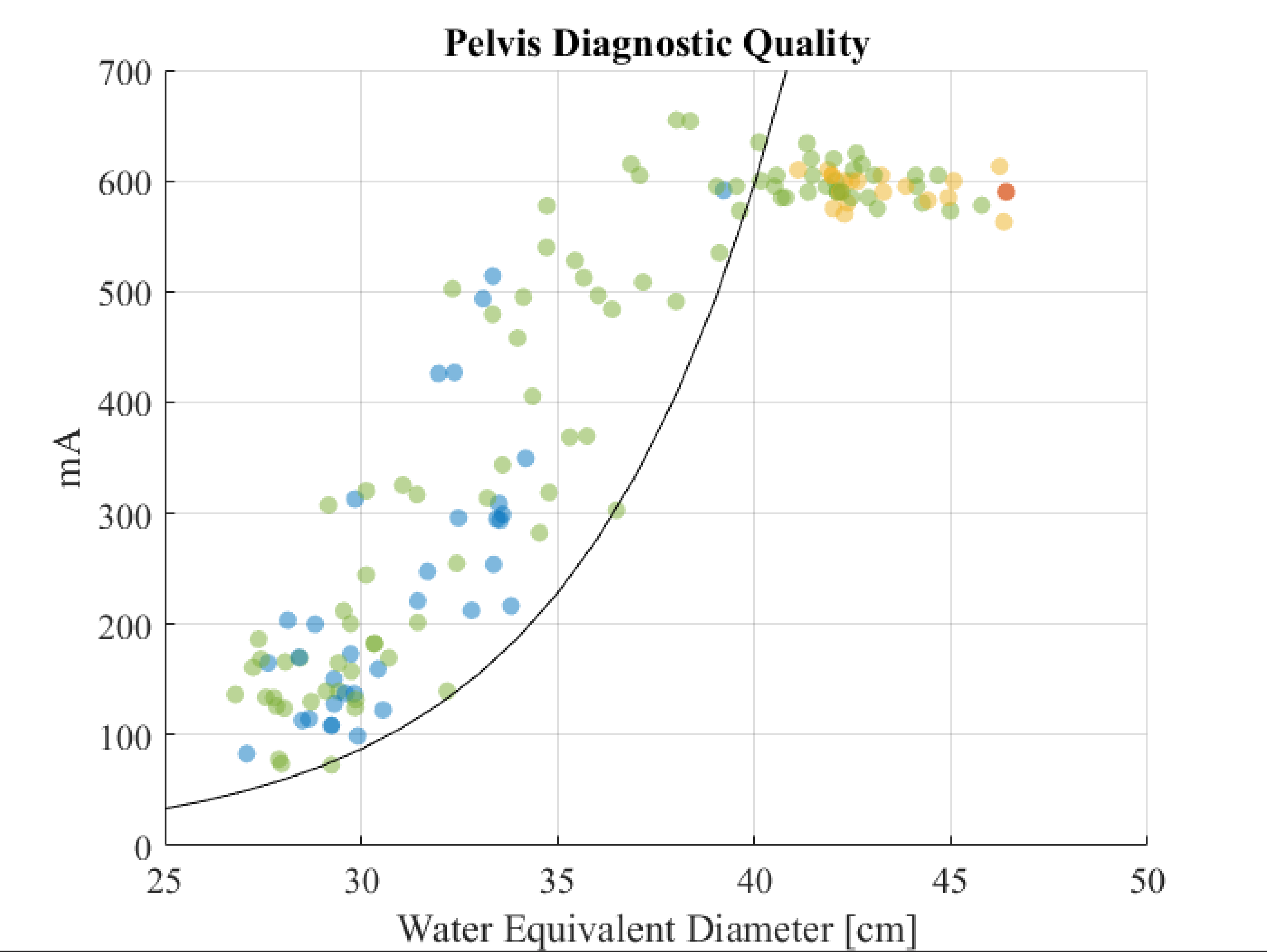
Hiroki Kawashima, PhD.

Martin Wagner, PhD. Departments of Medical Physics and Radiology, University of Wisconsin – Madison. mwagner9@wisc.edu

Timothy P. Szczykutowicz, PhD. Departments of Biomedical Engineering, Medical Physics, and Radiology, University of Wisconsin – Madison. tzczykutowicz@uwhealth.org

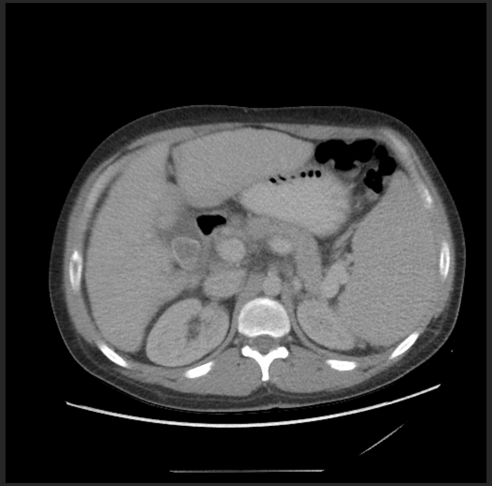
Corresponding author: Timothy Szczykutowicz, PhD, 1005 Wisconsin Institute for Medical Research, 1111 Highland Avenue, Madison, WI 53705; e-mail: tszczykutowicz@uwhealth.org @Prof_TimStick

We should care about mA maxxing out



2.72 mGy
25x20 cm size

10.8 mGy
36x25cm size



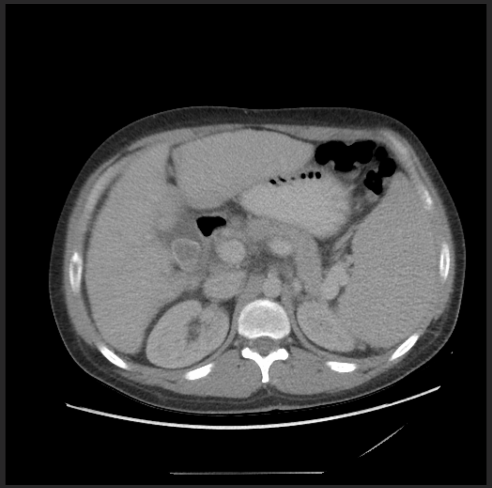
58.5 mGy
~50x39cm size

100 kV
1.531:1 pitch
0.28 s rotation
437 mm/s

2.72 mGy
25x20 cm size

120 kV
0.992:1 Pitch
0.28 s rotation
283 mm/s

10.8 mGy
36x25cm size



140 kV
0.508:1 Pitch
0.5 s rotation
81 mm/s

58.5 mGy
~50x39cm size

100 kV
1.531:1 pitch
0.28 s rot
437 mm

120 kV
0.992:1 Pitch
0.28 s rotation
283 mm/s

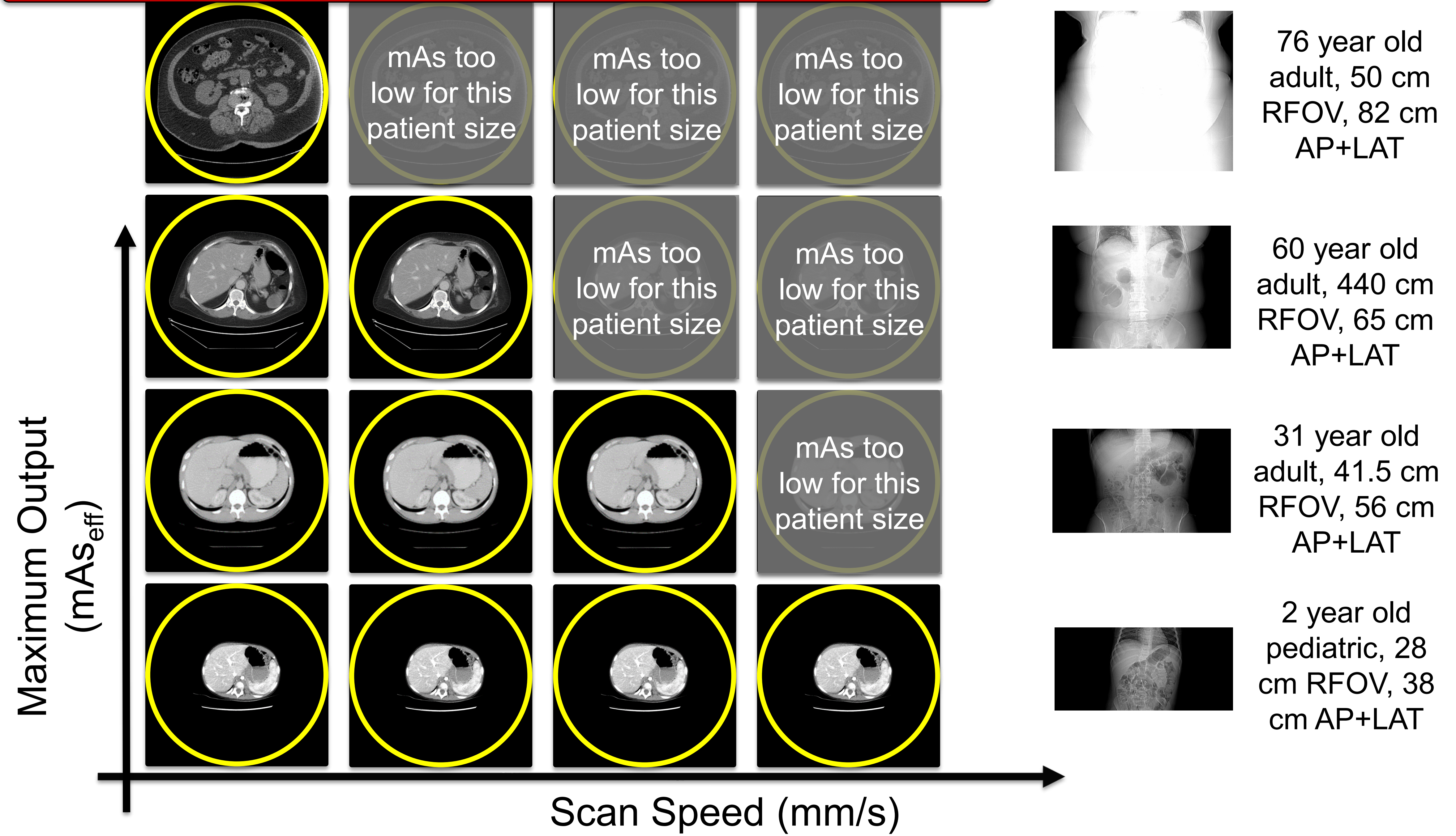
140 kV
.508:1 Pitch
s rotation
mm/s

2.72 mGy
25x20 cm size

speed

58.5 mGy
~5 x39cm size

Wide axial scanner technology (GE, Canon, Philips, United Imaging)



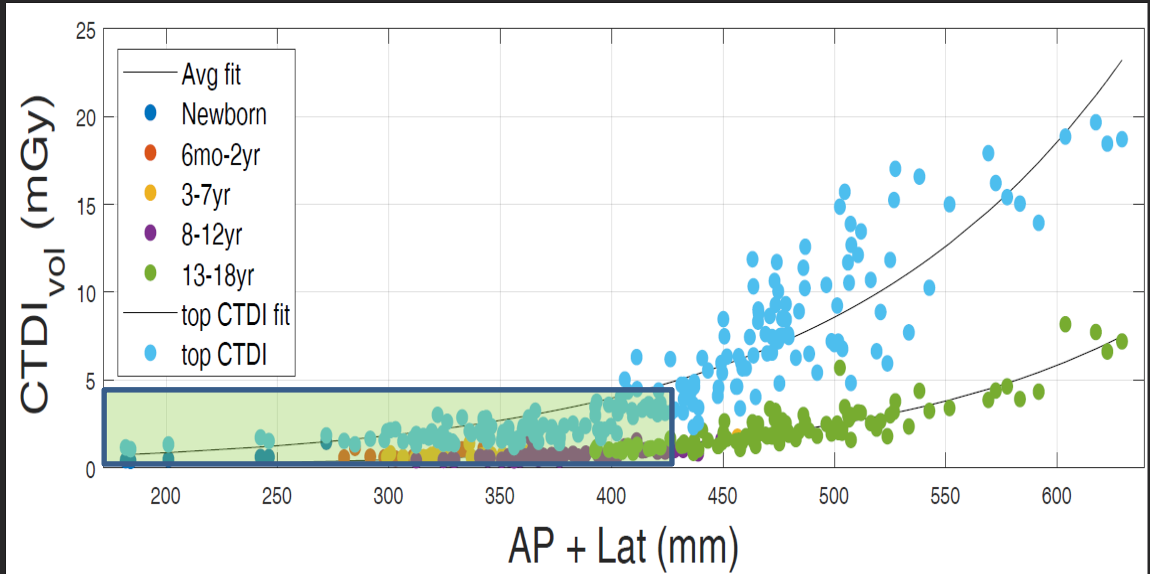
Highest scanner output corresponds to lowest pitch and longest rotation time

Output

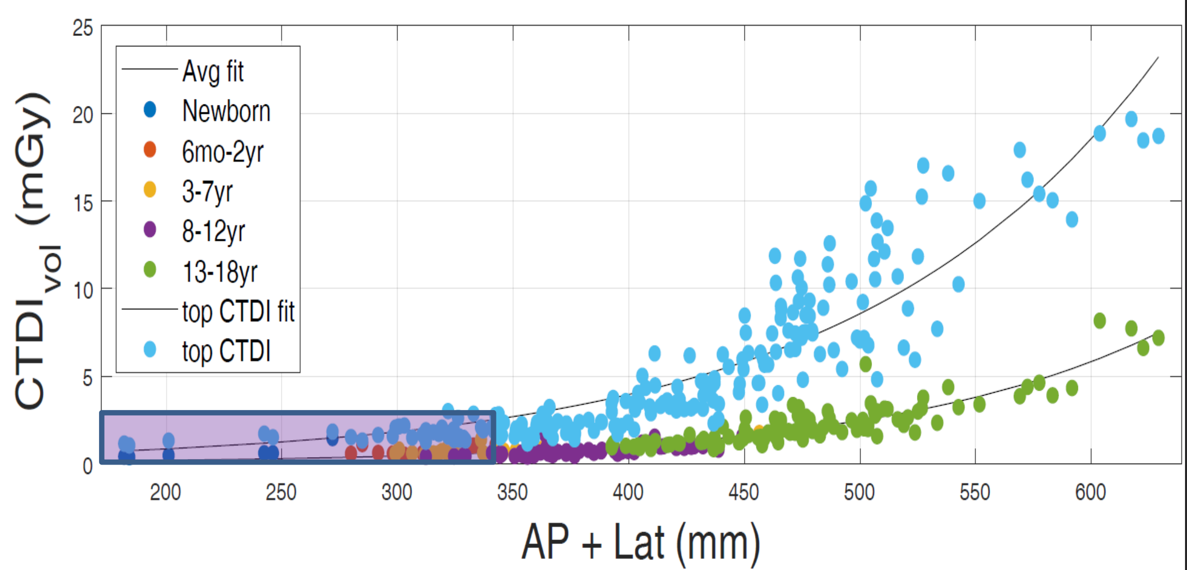
- So what do I want, a protocol set up to scan super fast, or have a lot of output?
  - Perhaps easy to answer for adult bariatrics, but what about for adult bariatric lung scanning?
  - Naïve to think this is easy for kids, we just want fast scanning, but some super fast scan modes can get dose limited pretty fast.

- So what do I want, a protocol set up to scan super fast, or have a lot of output?
  - Perhaps easy to answer for adult bariatrics, but what about for adult bariatric lung scanning?
  - Naïve to think this is easy for kids, we just want fast scanning, but some super fast scan modes can get dose limited pretty fast.

This example is for a single source, 1.4 pitch, 40 mm collimation scanner. It has a CTDIvol max corresponding to a 12 year old. It would take 3 seconds to scan 41 cm.



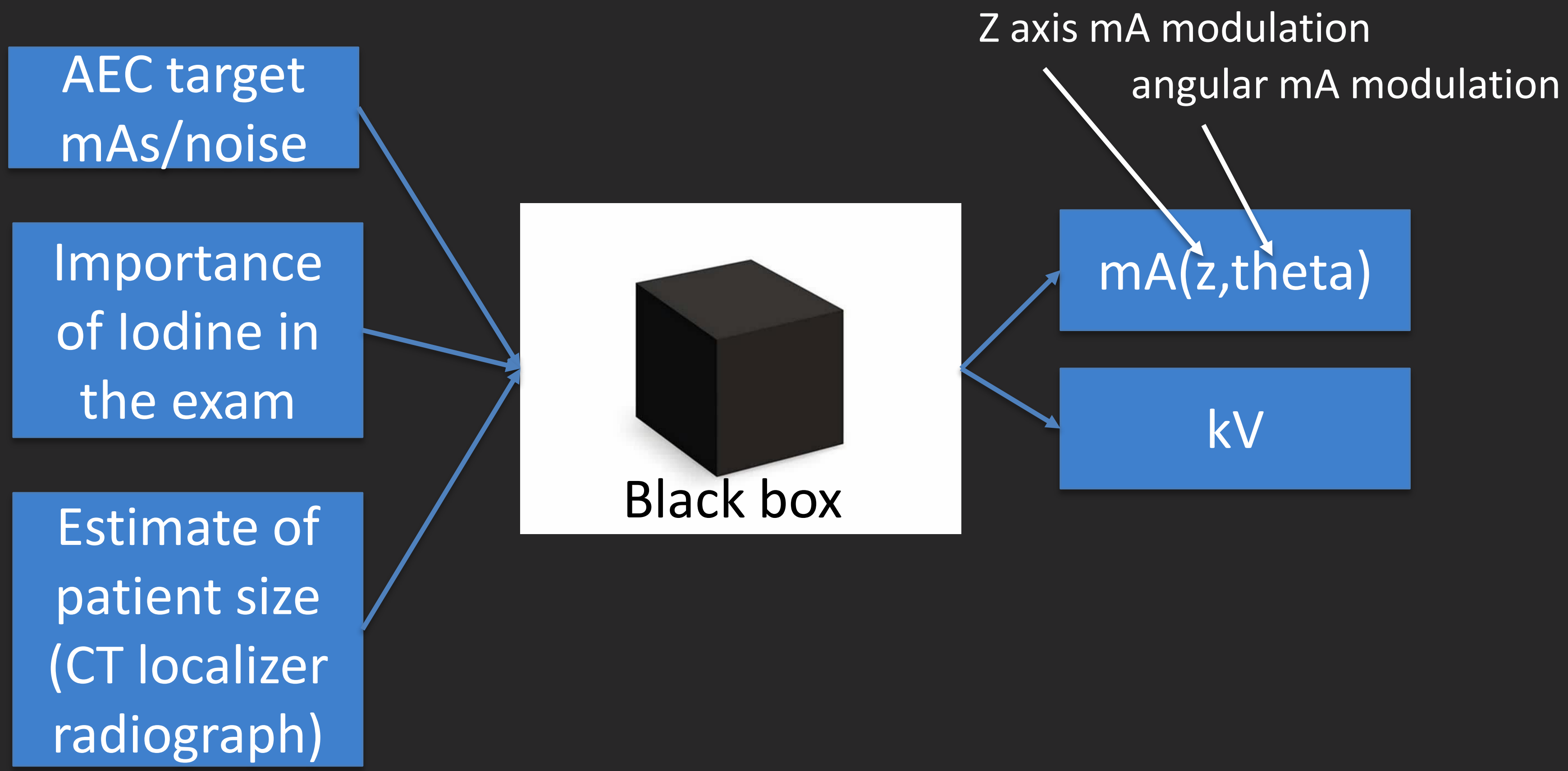
This example is for a dual source, 3.2 pitch, 58 mm collimation scanner. It has a CTDIvol max corresponding to a 2 year old. But it can scan 35 cm in only 0.5 seconds.



@Prof_TimStick's Actionable information

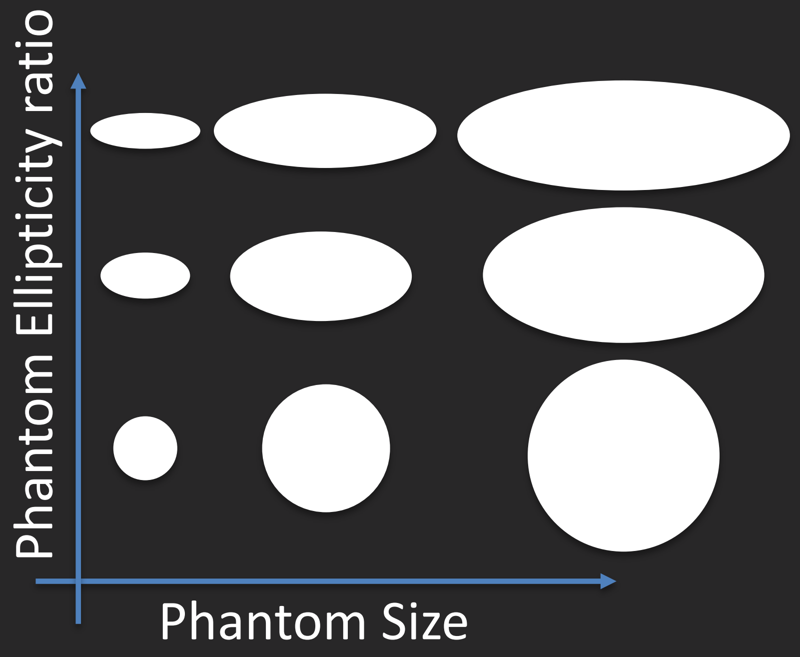
- You will need multiple beam energy, rotation time combinations to have optimized protocols across patient size.
- You must consider tradeoff in protocol complexity with making more protocols… this will be a site-specific considerations.

- All Vendor's AEC systems operate like this



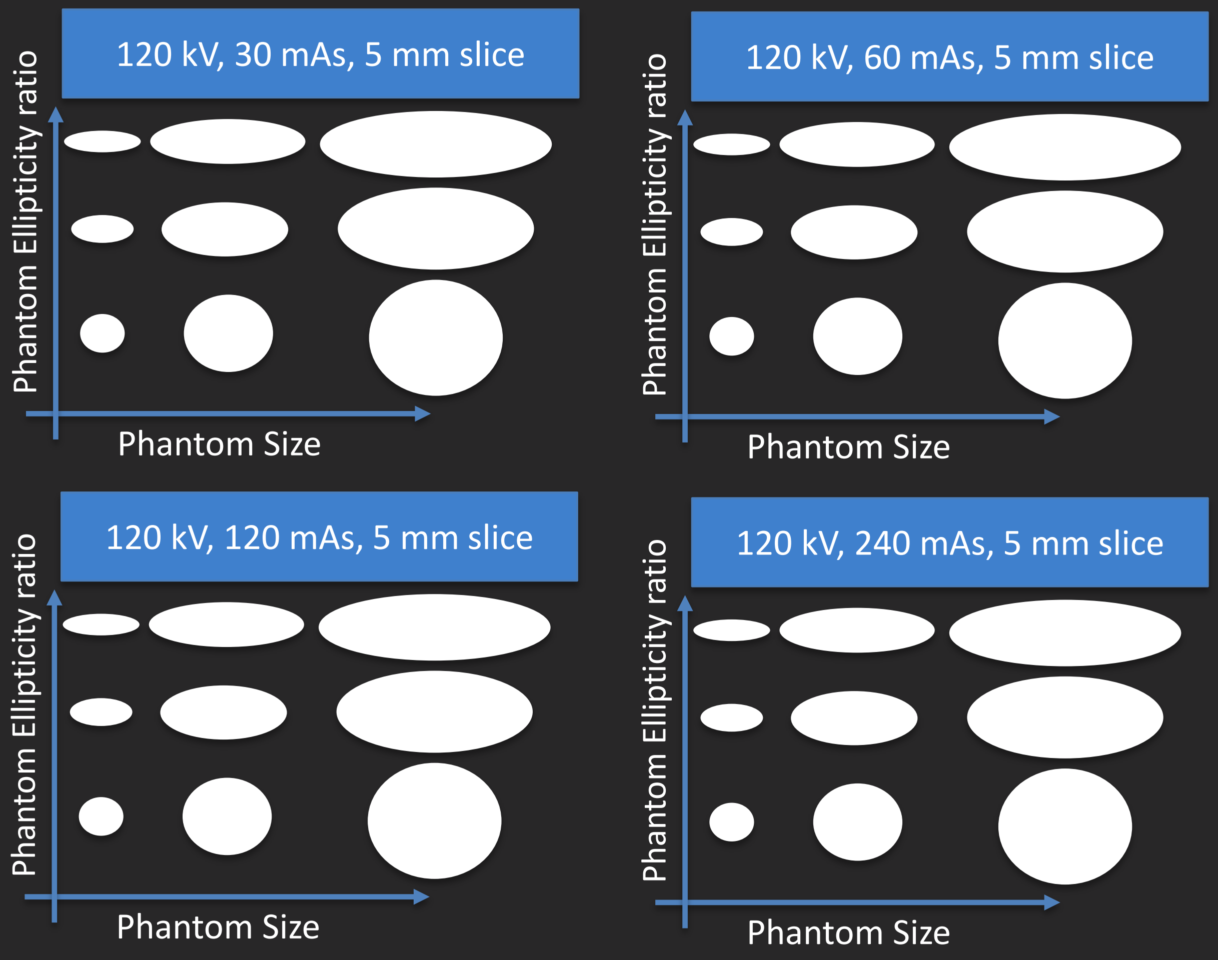
- "Homebrew" AEC system
  - To understand how vendors could implement an AEC system, lets make our own "black box"!

Start by gathering a bunch of different size and shaped phantoms



Overview of AEC in MDCT

Then scan these phantoms under the same conditions of mAs, kV, slice thickness, reconstruction kernel, iterative denoising level, etc.



Measure the image noise for each combination of scan settings for each phantom

Noise Standard Deviation (HU)

mA	30 mAs	60 mAs	120 mAs	240 mAs
Phantom				
Small 1:1	20	14	10	7
Medium 1:1	25	18	13	9
Large 1:1	35	25	18	12
Small 2:1	26	18	13	9
Medium 2:1	33	23	16	11
Large 2:1	46	32	23	16
Small 3:1	40	28	20	14
Medium 3:1	50	35	25	18
Large 3:1	70	49	35	25

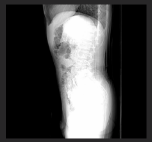
Overview of AEC in MDCT

I want 17 HU SD

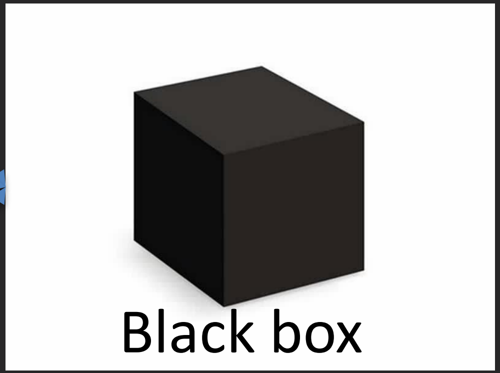
AEC target mAs/noise

Iodine contrast not important

Importance of Iodine in the exam



Estimate of patient size (CT localizer radiograph)



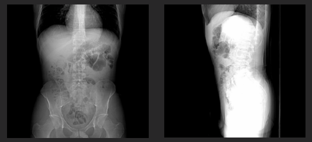
Overview of AEC in MDCT

I want 17 HU SD

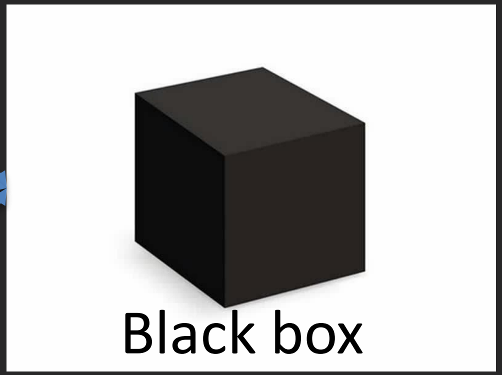
AEC target mAs/noise

Iodine contrast not important

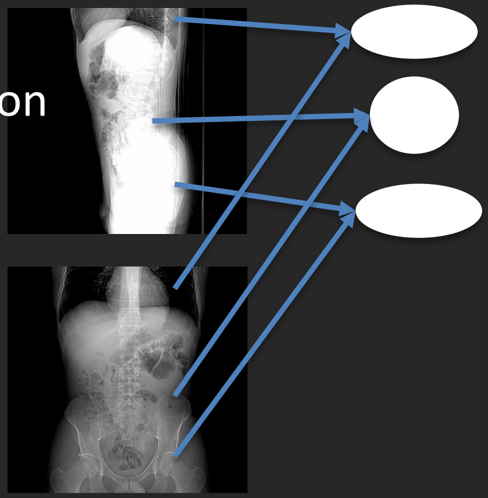
Importance of Iodine in the exam



Estimate of patient size (CT localizer radiograph)



Our black box can compare our CT localizers to localizers of our phantoms and find the closet phantom match for each z position



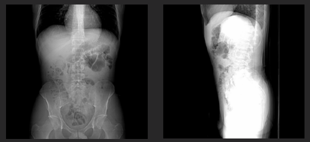
Overview of AEC in MDCT

I want 17 HU SD

AEC target mAs/noise

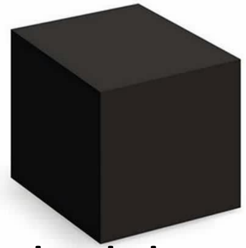
Iodine contrast not important

Importance of Iodine in the exam



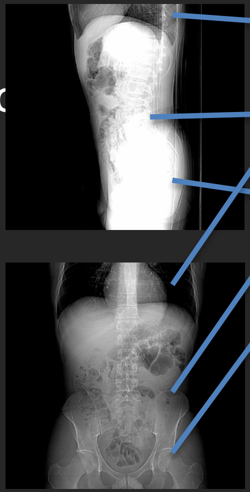
Estimate of patient size (CT localizer radiograph)

Our black box can compare our CT localizers to localizers of our phantoms and find the closet phantom match for each z positic



Black box

Then our black box can use our look up table of measurements to see what mA is needed to achieve the noise target we requested



Phantom	30 mAs SD (HU)	60 mAs SD (HU)	120 mAs SD (HU)	240 mAs SD (HU)
Medium 1:1	25	18	13	9
Medium 2:1	33	23	16	11

CT EDUCATION AND COLLABORATION COLLECTIVE

Thanks!

Feel free to contact me at tszczykutowicz@uwhealth.org