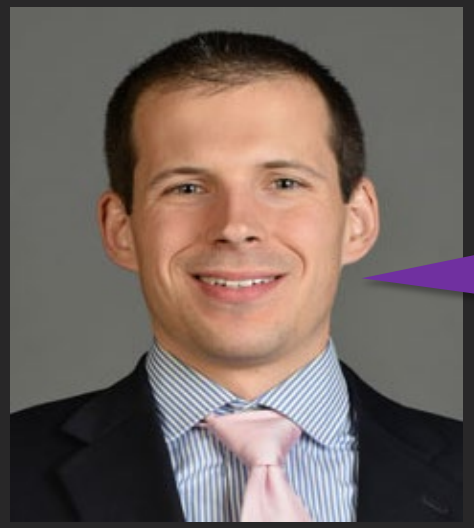


Thanks for watching!

CT Contrast Parameters for the Medical Physicist

Timothy P. Szczykutowicz PhD, DABR

@Prof_TimStick

Associate Professor

University of Wisconsin Madison Departments of Radiology, Medical Physics and Biomedical Engineering

Conflict of Interest

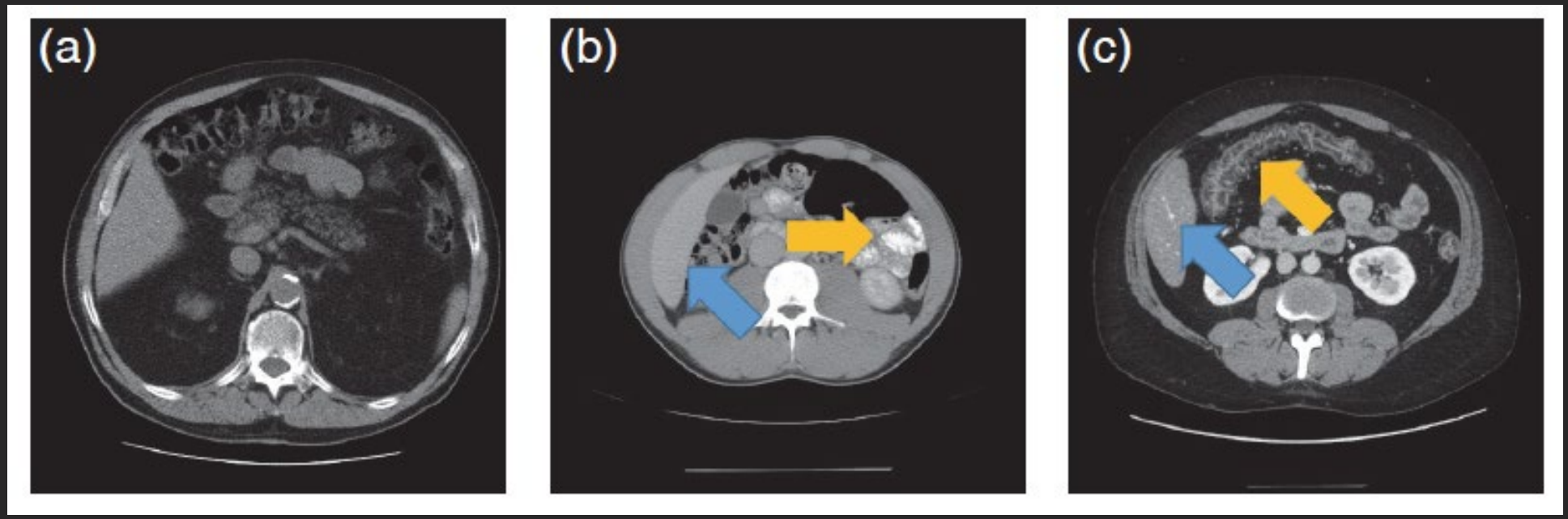
- TPS supplies CT protocols to GE Healthcare under a licensing agreement, TPS is a consultant and on an advisory board to GE Healthcare, TPS receives research support from GE Healthcare
- TPS is on the MAB of Imalogix LLC
- TPS is a consultant to AstoCT LLC, and cybermed.ai (DBA RadFlow), AiDoc, iSchemaView
- TPS receives book royalties from Medical Physics Publishing

CT CONTRAST 101

No contrast

Positive Oral and IV contrast (parenchymal phase)

Negative Oral and IV contrast (liver arterial phase)



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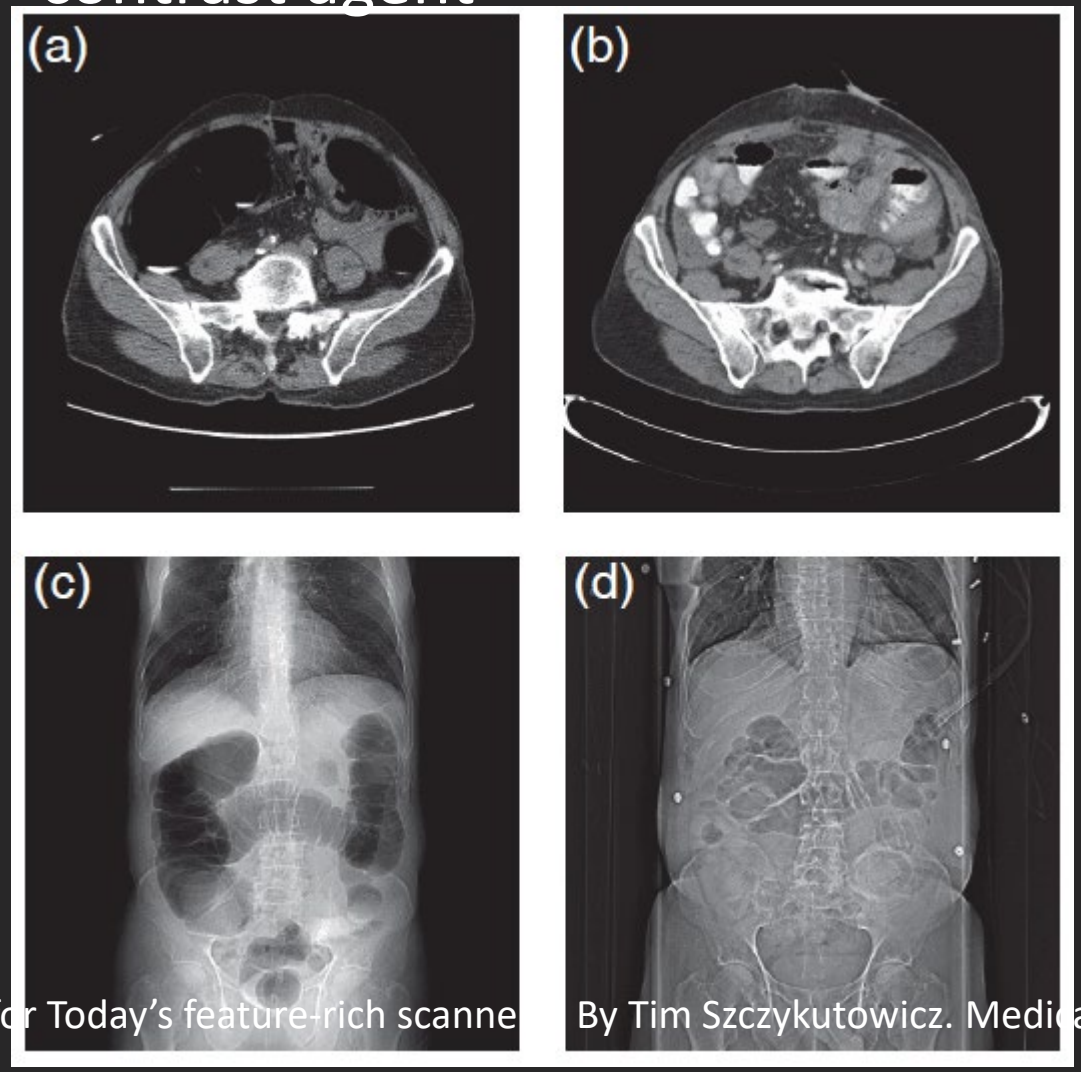
CT CONTRAST 101

CO2 gas contrast agent

Same pt no CO2



Both scans have positive oral agent

Note: the localizers even show the CO2

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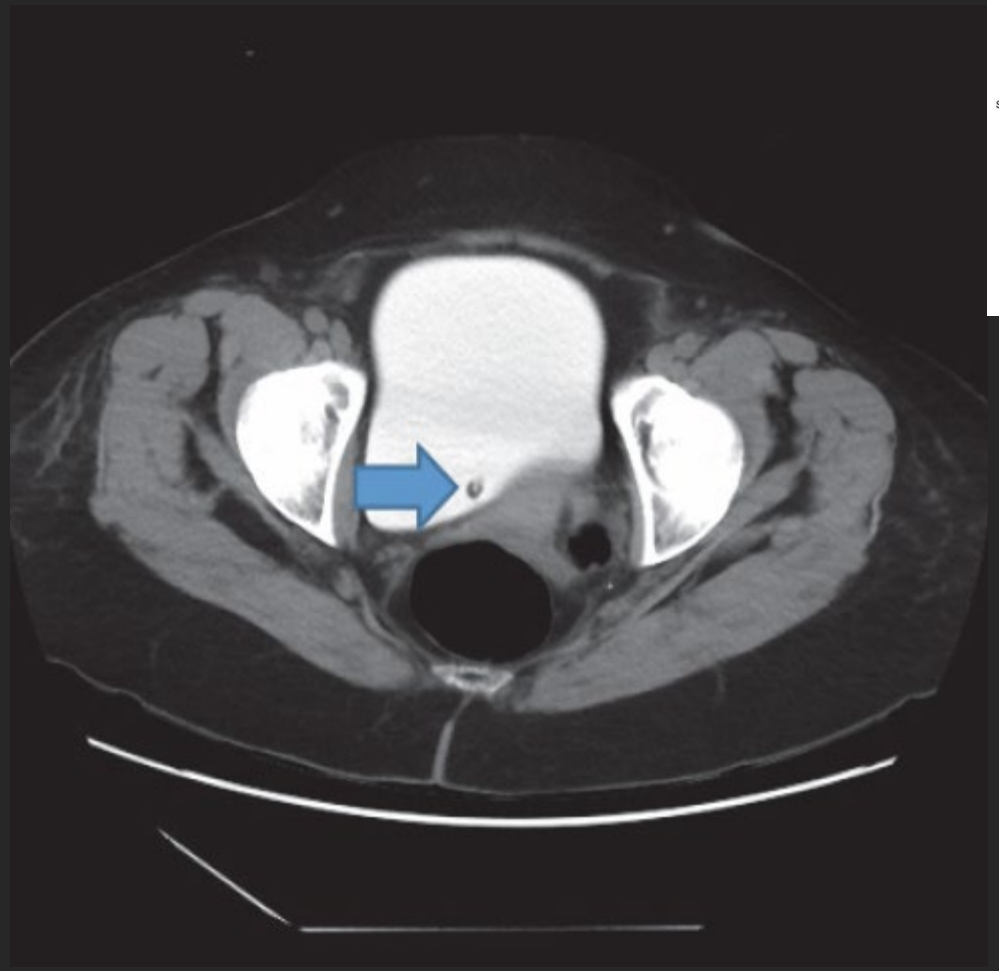
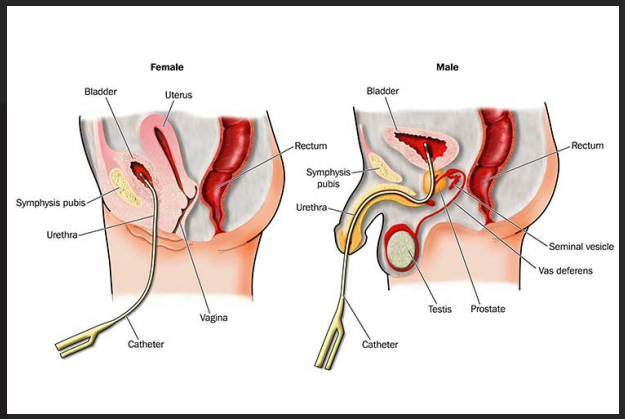
CT CONTRAST 101

Positive oral contrast introduced via Foley catheter

(arrow shows catheter, don't confuse this with an artifact)





https://www.ausmed.com/cpd/articles/urinary-catheter

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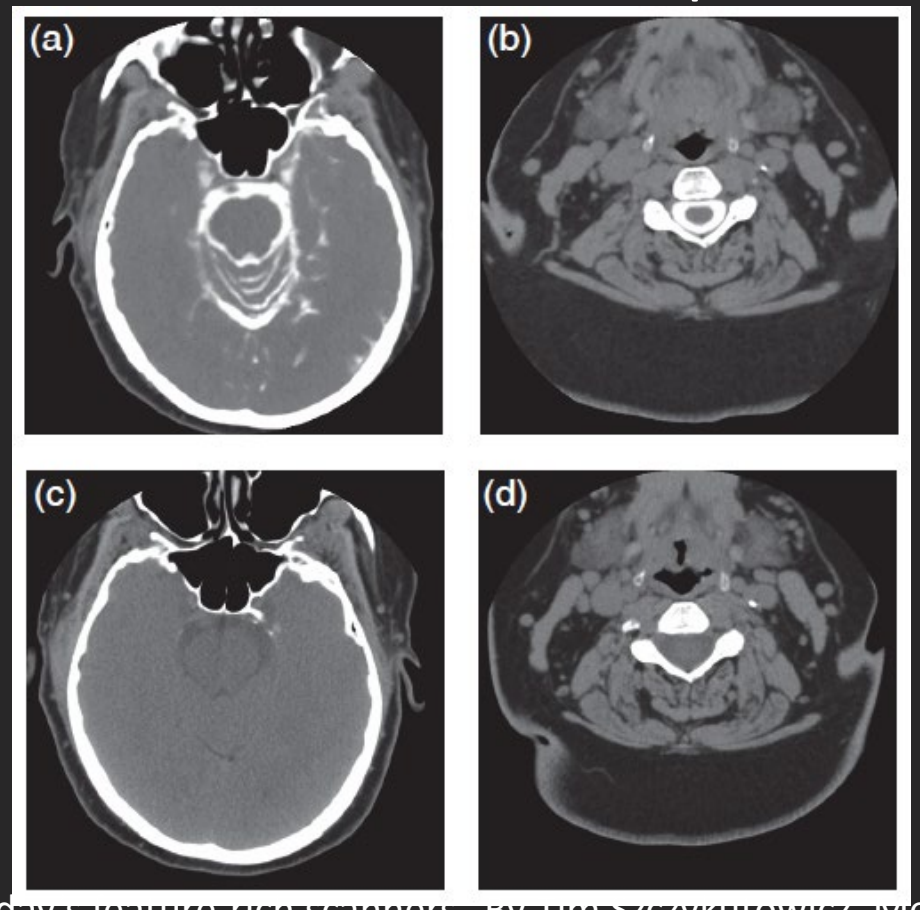
CT CONTRAST 101

Introducing contrast agent into the spinal column is called CT Myelography

(into joint space is called arthrogram)

Positive contrast agent in spinal column

Native (non con) scan for comparison



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CT CONTRAST 101

General Guidance

Patient with moderate or severe allergy to Iodine based contrast

- Give these patients Barium Readicat, or perform the scan without oral contrast. Consult the attending radiologist for guidance.
- If the patient is going to surgery post imaging, then give them Iohexol, surgery prefers this, please consult the attending radiologist for approval.

Outpatients: 1 dose = 4mL of Iohexol in 200 mL of clear liquid.

- Abd CT: 2 doses (400 mL of oral contrast)
- Abd/Pel CT: 4 doses (800 mL of oral contrast)
- Last dose on CT table: 8mL of Iohexol in 200 mL of clear liquid.
  - X-Large cups = 800 mL-(1x q 1 hour)
  - Large cups = 400 mL-(2x q 30)
  - Small cups = 200 mL- (4x q 15)
  - Patients have their choice of to mix the Iohexol with lemonade or water.
- Billing = All oral contrast (including COT)

Inpatients: 1 dose = 4mL of Iohexol in 200 mL of clear liquid.

- Abd CT: 2 doses q 30 minutes
- Abd/Pel CT: 4 doses q 30 minutes
- Billing = None (Patient is billed on the floor)

Bariatric Oral

- If the patient is a bariatric post-op patient they will not drink up on the floor. Rather, they will get one 2x concentrated dose on CT table: 8mL of Iohexol in 200 mL of clear liquid. If you have questions please ask the protocolling radiologist.
- Billing = 8 ml of Iohexol

CT CONTRAST 101

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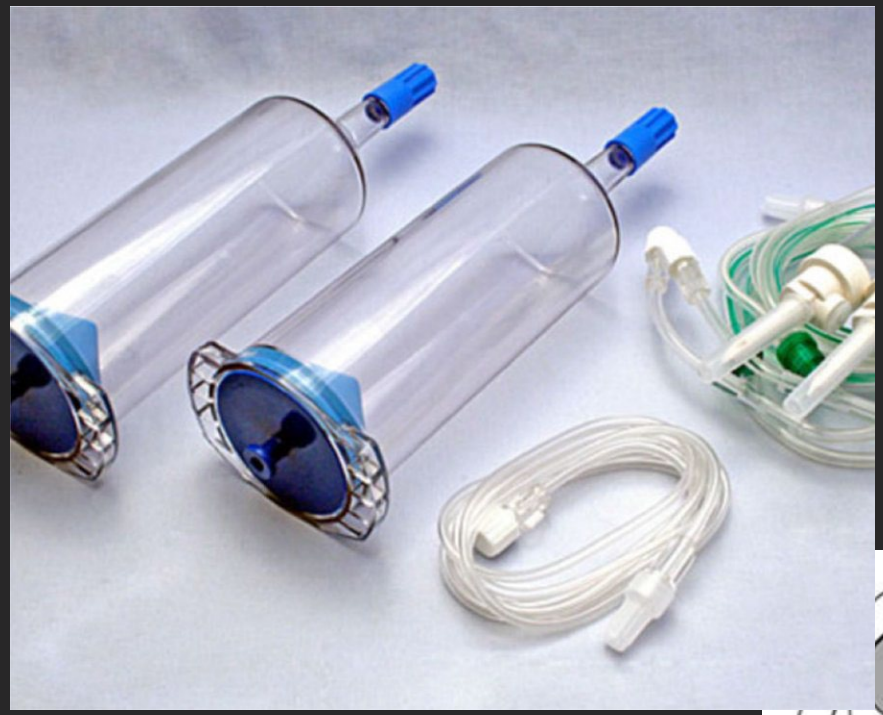
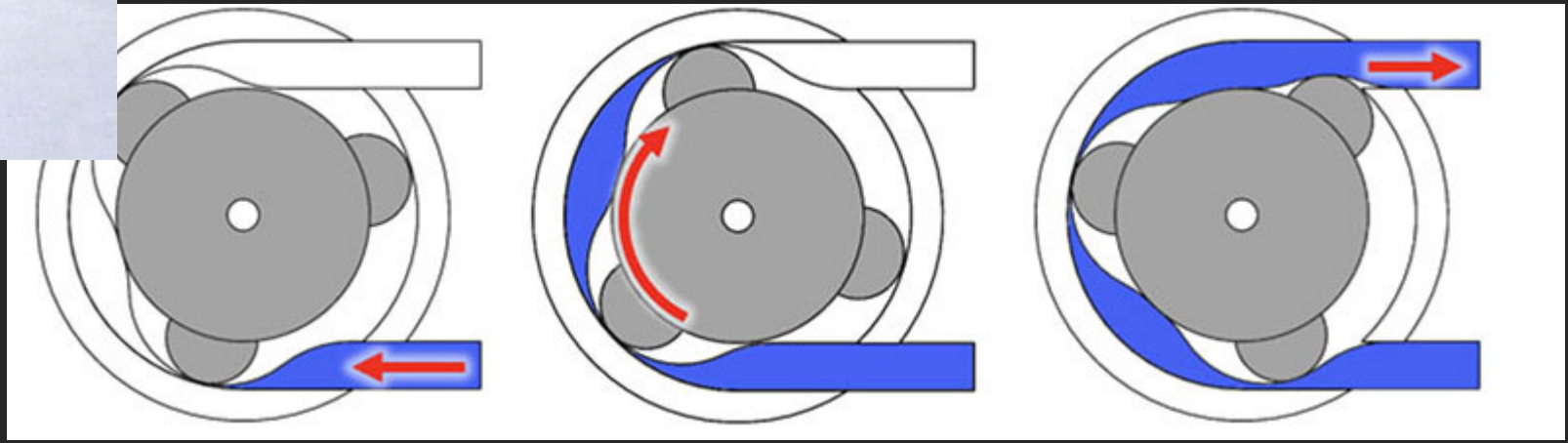
CT CONTRAST 101

CT CONTRAST 101



Piston based pump… simple, the plunger pushes the agent out

Peristaltic pump, the rotating action pushes agent along a flexible tube



https://dienerprecisionpumps.com/positive-displacement-pumps/

CT CONTRAST 102

Air/CO_2

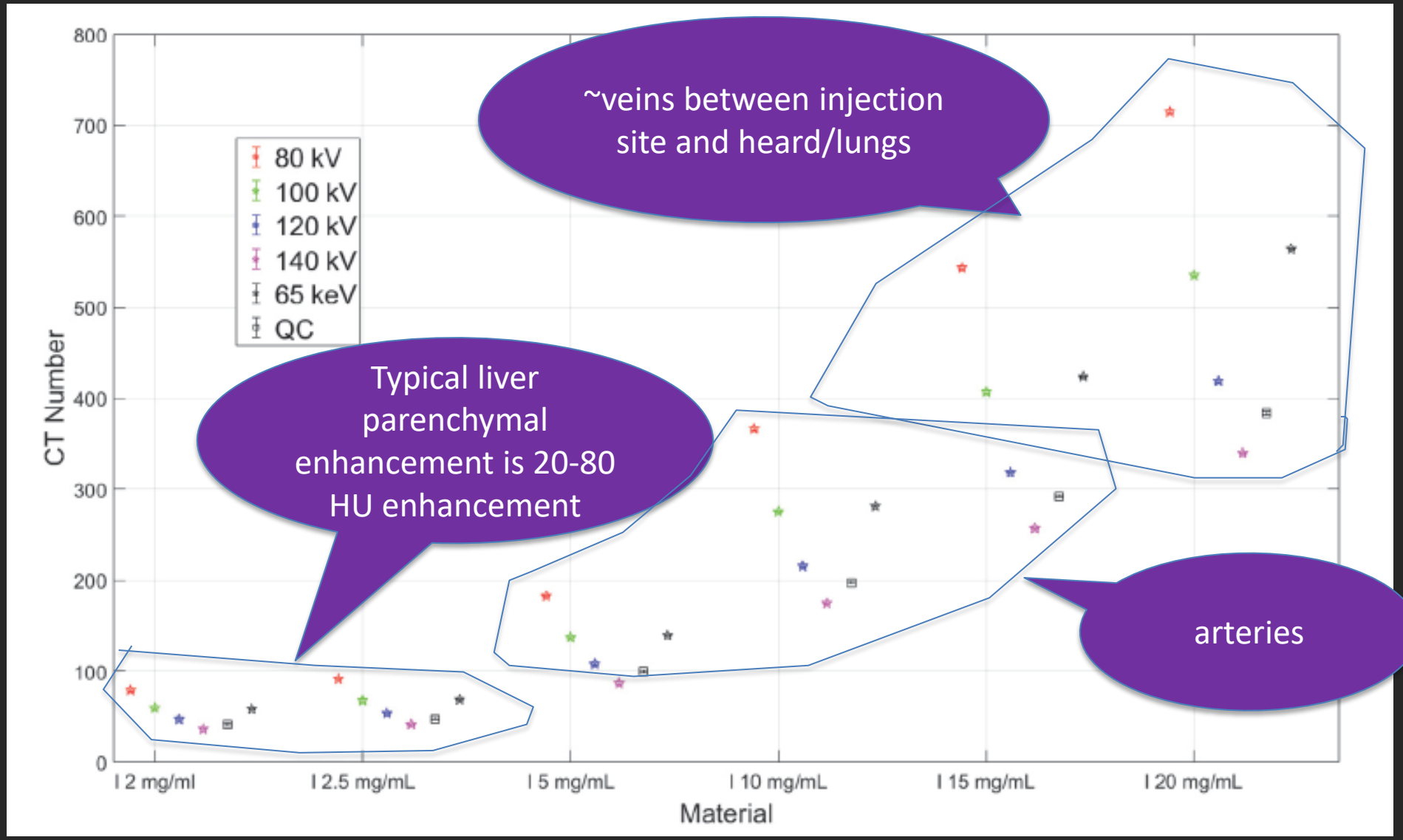
Generates CT number ~-1000, “usually doesn’t get diluted”

Used for CTC

Iodine

Workhorse for CT. Usually it will always be diluted by blood (IVC administration) or water (oral) or urine (catheter injection)

CT CONTRAST 102



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CT CONTRAST 102

Material	80 kV	100 kV	120 kV	140 kV	N/A
Water	0	0	0	0	[–4 4]**
Air	–1,000	–1,000	–1,000	–1,000	[–1005 –995]**
Fat	–152*	–111*	–89*	–69*	[–100 –80]**
Brain	47*	43*	39*	37*	
Soft Tissue	62*	58*	54*	52*	
Solid Cortical Bone	3,760*	2,590*	1,940*	1,330*	[≈200 > 1000]**
Pure Calcium	9,570*	5,960*	3,950*	2,090*	
Pure Iodine	405,000*	267,000*	180,000*	93,200*	
Iodine Contrast	See footnote a	See footnote a	See footnote a	See footnote a	
Relative Iodine Enhancement[b]	1.68	1.27	1	0.826	
Relative Iodine Enhancement[c]	1.70	1.28	1	0.81	
Kidney					[20 40]**
Pancreas					[30 50]**
Blood					[50 60]**
Liver					[50 70]**
PMP					–200***
Low-Density Polyethylene					–100***
Polystyrene					–35***
Acrylic					120***
Delrin®					340***
Teflon®					990***

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CT CONTRAST 102

$$\mu(E) = a_1 \times \frac{1}{E^3} + a_2 \times f_{KN}(E)$$

$$a_1(x,y) = C \times \rho_e \times Z^{n-1},$$

$$a_2(x,y) = \rho_e ,$$

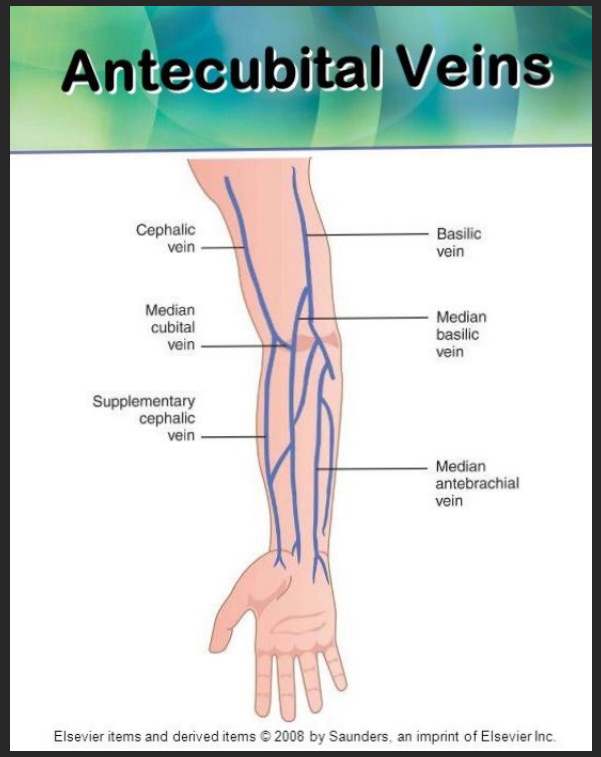
Z is 5-7 for soft tissue

Z is 53 for Iodine

Become familiar with these equations… and you can understand every “lower kV equals dose reduction for CTA” paper ever written

CT CONTRAST 103

1. Inject via antecubital vein

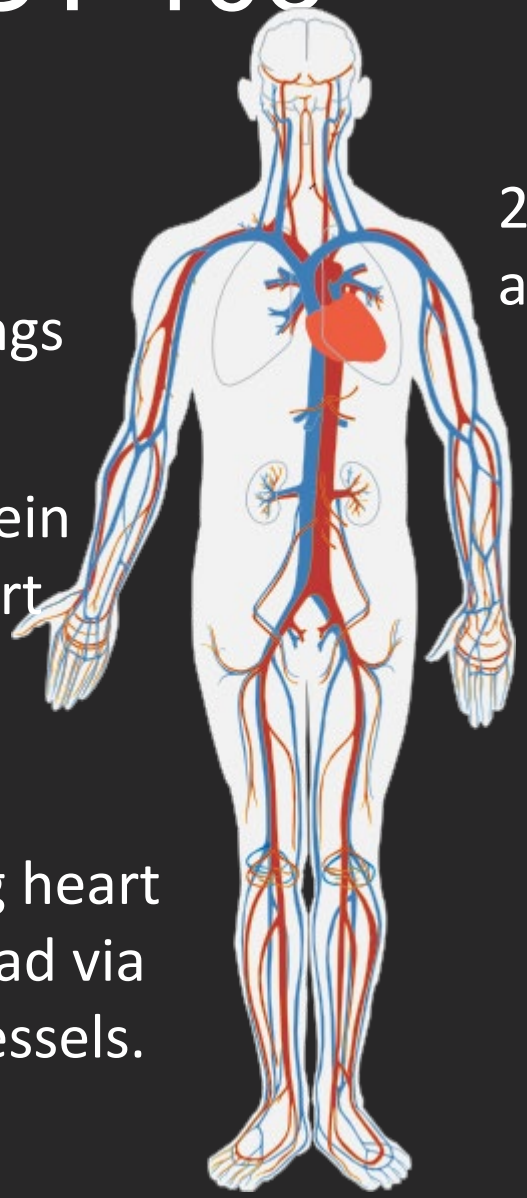


CT CONTRAST 103

3. Blood goes to right ventricle and goes out pulmonary artery to lungs

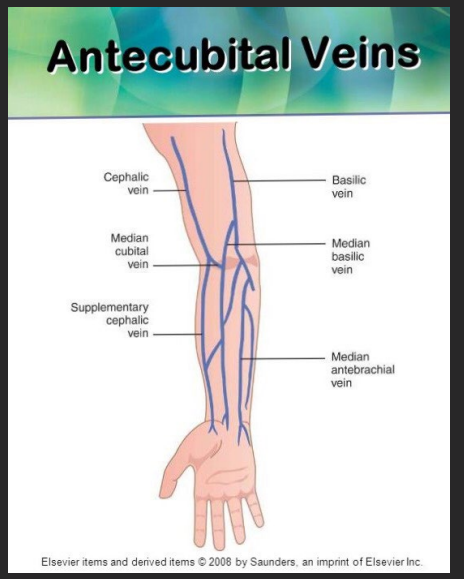
4. Returns via pulmonary vein and goes to left side of heart to be pushed out aorta via left ventricle.

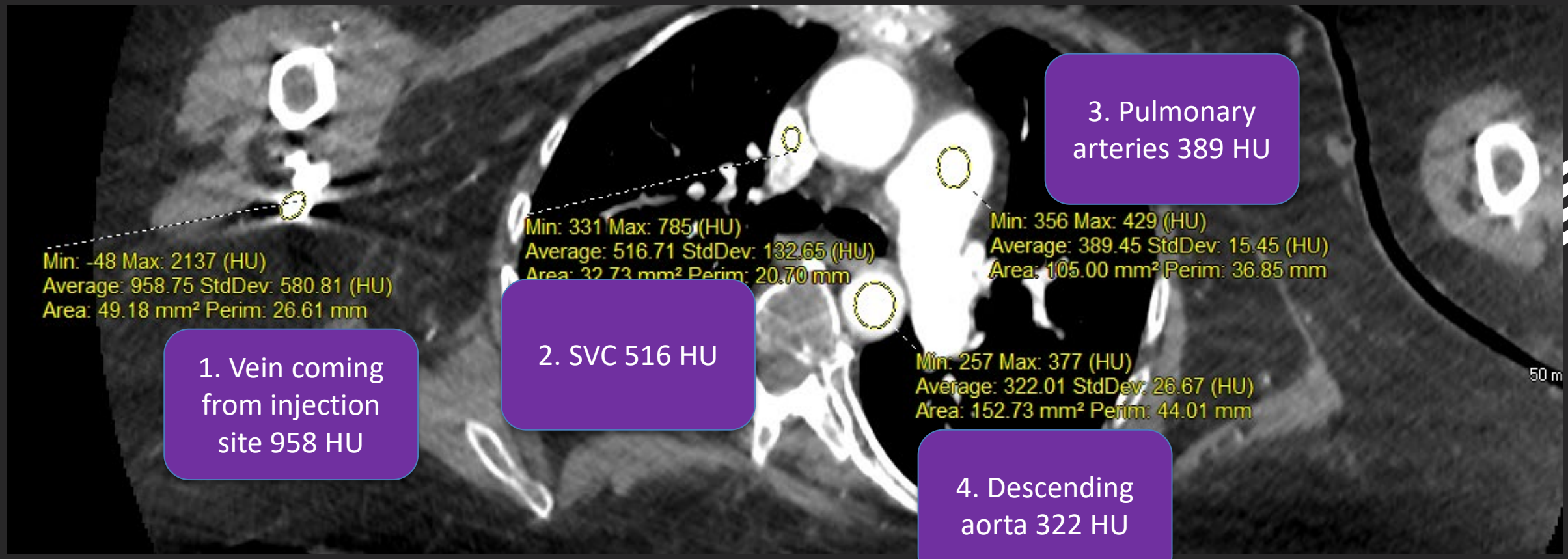
5. First stop is supplying heart via coronaries. Then head via carotid and vertebral vessels.



2. Blood goes into SVC and then into right atrium

1. Inject via antecubital vein





Numbers increase with ROI locations via path blood follows from injection site → blood/I mix HU goes down as we move from site because of blood mixing diluting agent

CT CONTRAST 103

Contrast time of arrival will vary from person to person, but assuming an antecubital injection, values will generally be in the range of 7 to 10 seconds for the pulmonary artery, 12 to 15 seconds for the ascending aorta, 15 to 18 seconds for the abdominal aorta, and 30 to 40 seconds for hepatic parenchyma.

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

Another reference Bae, K. T., J. P. Heiken, and J. A. Brink. (1998). “Aortic and hepatic contrast medium enhancement at CT. part i. prediction with a computer model.” *Radiology* 207(3):647–55.

Radiology

Reviews and Commentary
State of the Art

Free Access

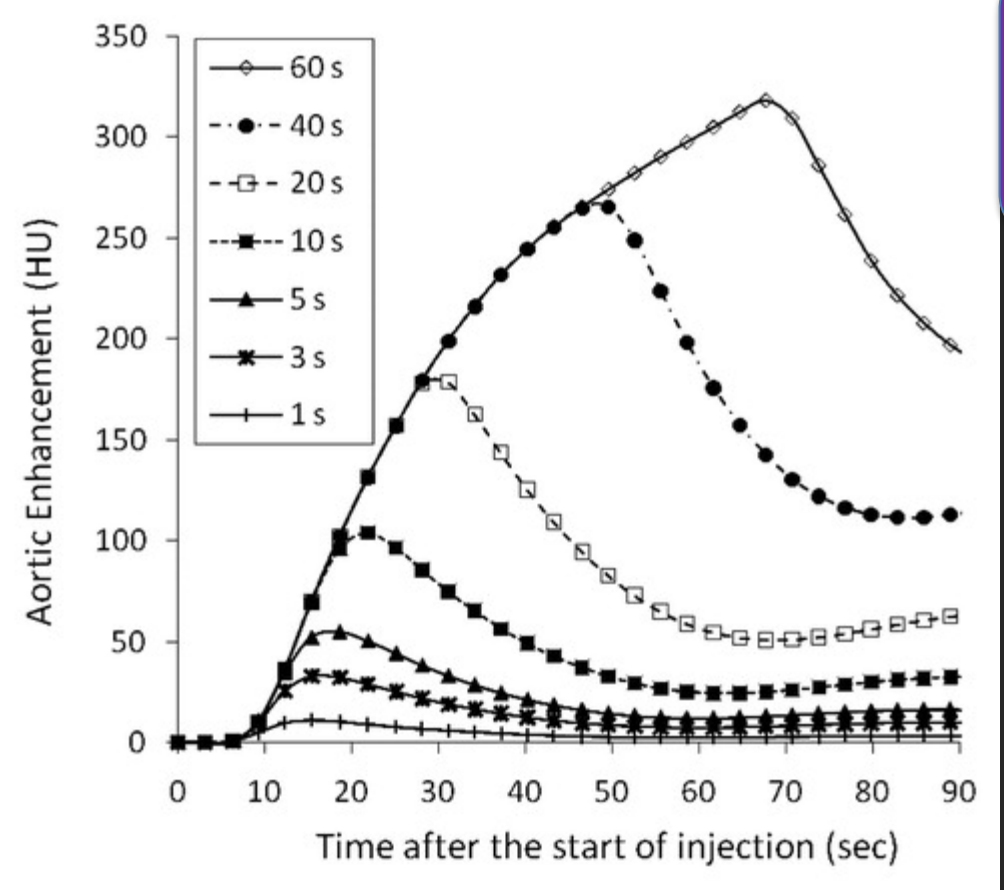
Intravenous Contrast Medium Administration and Scan Timing at CT: Considerations and Approaches

Kyongtae T. Bae

Author Affiliations

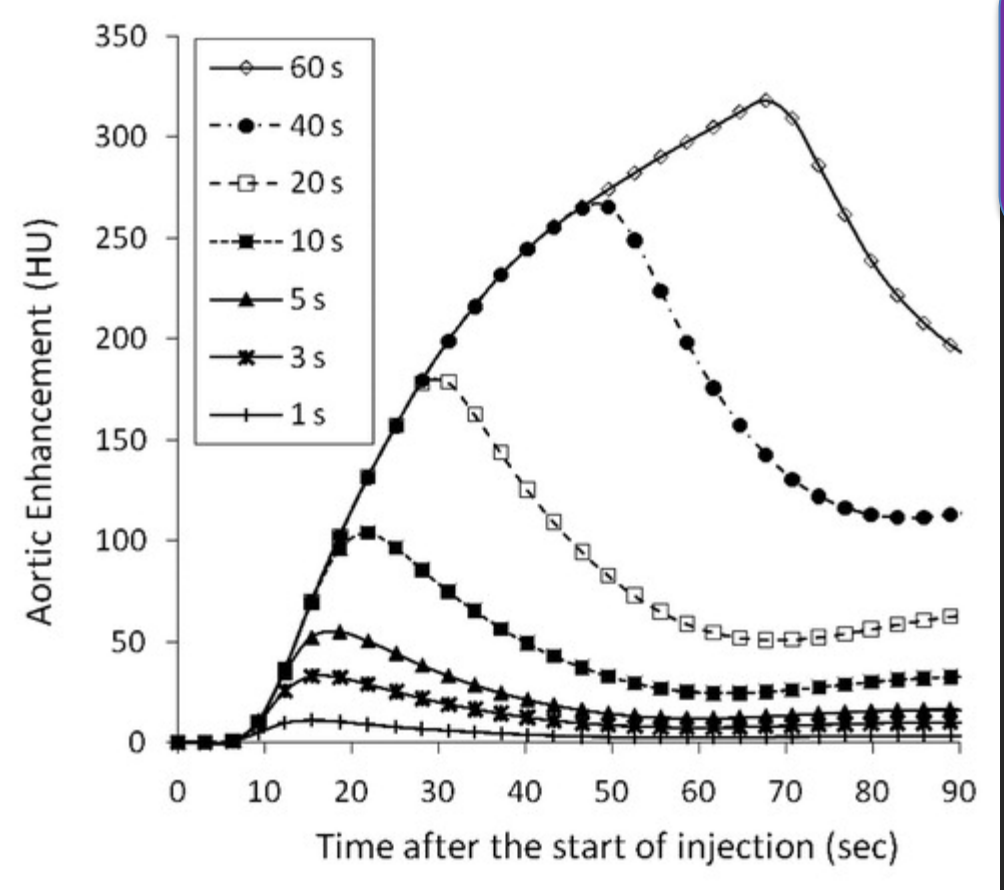
Published Online: Jul 1 2010 | https://doi.org/10.1148/radiol.10090908

CT CONTRAST 104



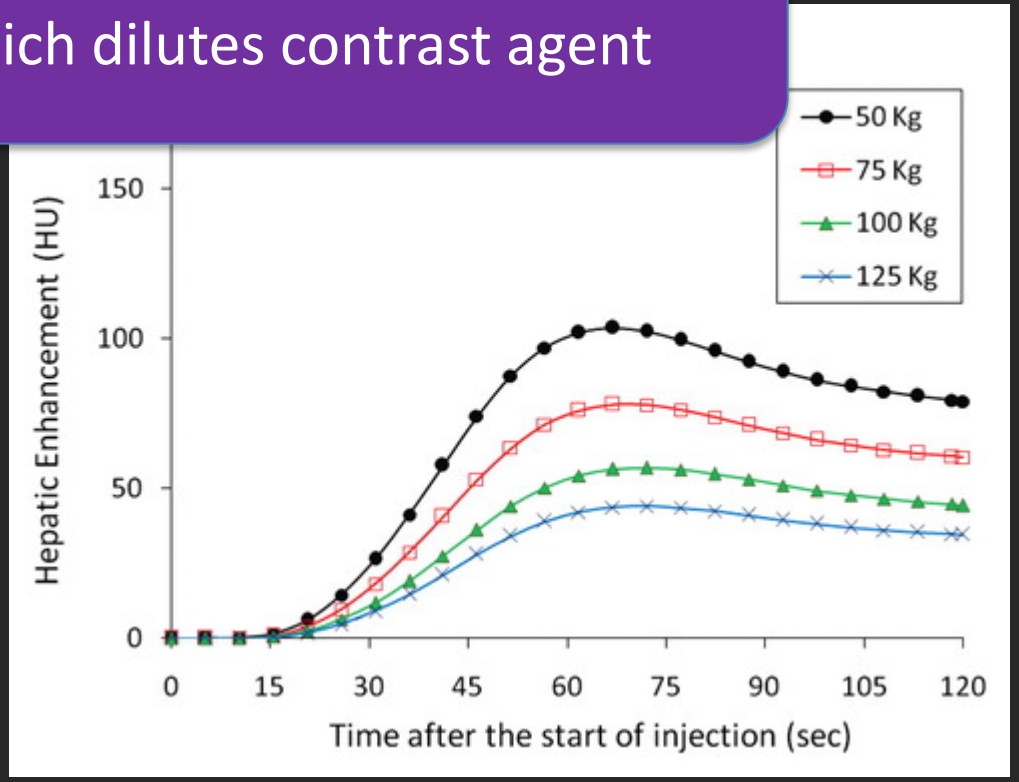
Longer and longer injections push CT enhancement up and delay peak enhancement

CT CONTRAST 104

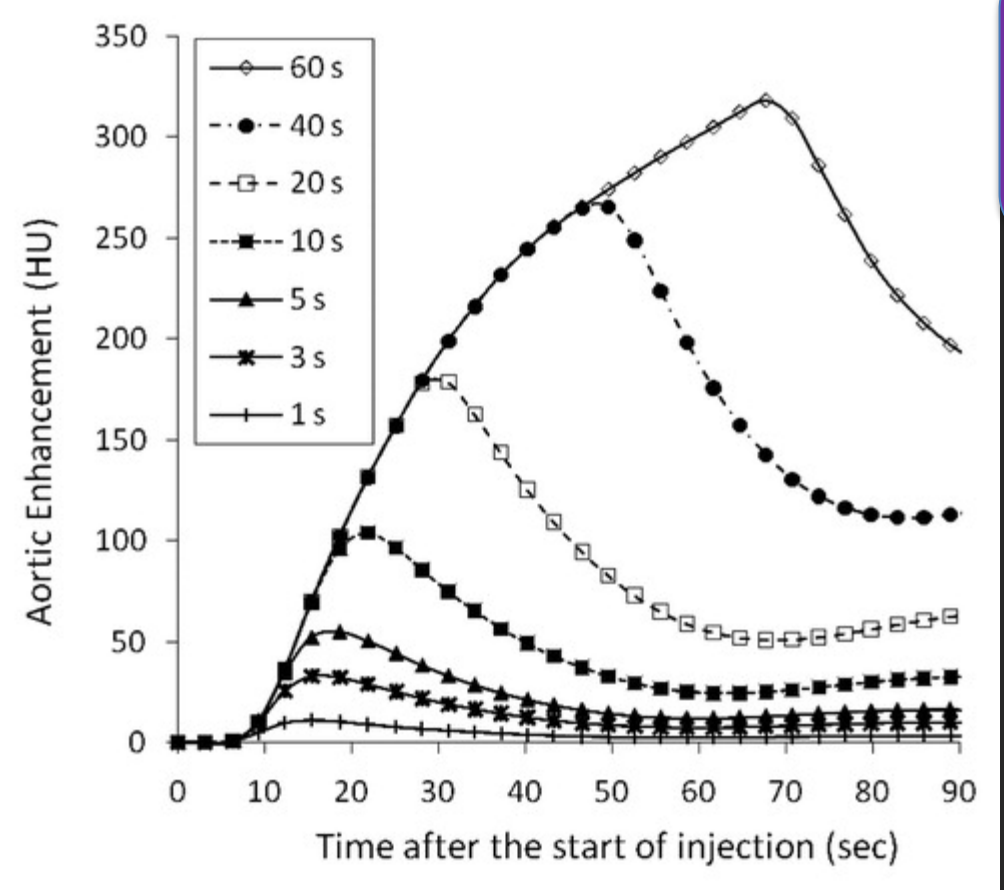


Longer and longer injections push CT enhancement up and delay peak enhancement

Bigger people have more blood… which dilutes contrast agent



CT CONTRAST 104



Longer and longer injections push CT enhancement up and delay peak enhancement

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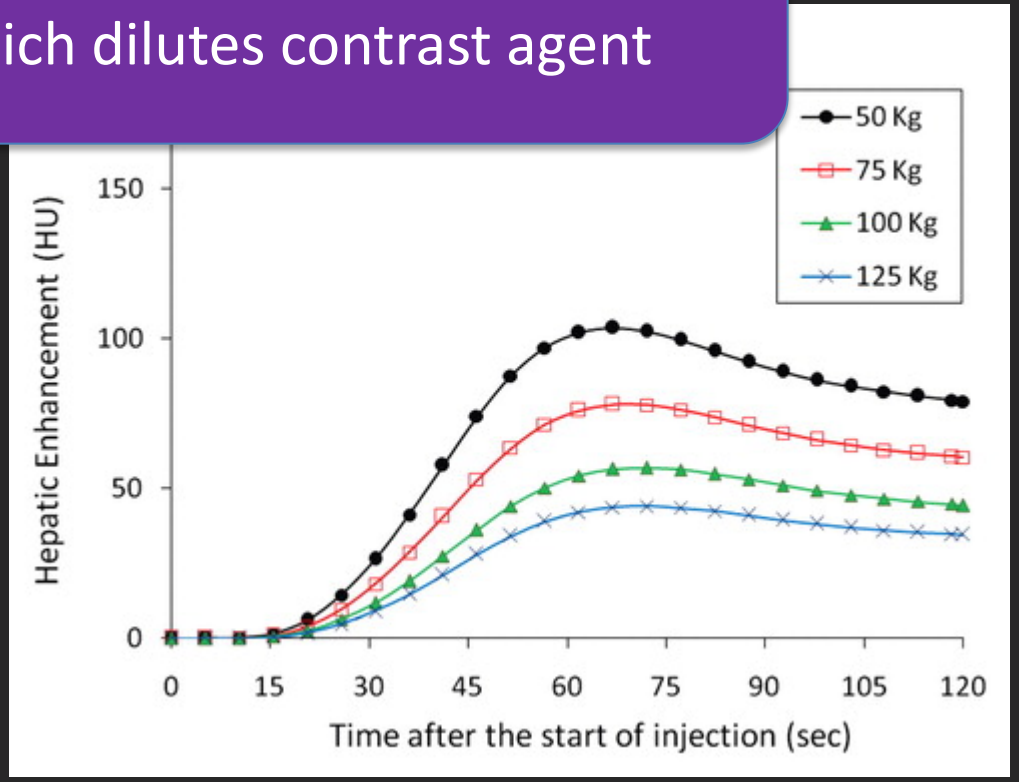

Arterial enhancement is “in and out” faster relative to parenchymal

CT CONTRAST 104

Equations Governing the Major Facets of Contrast Delivery

$$Volume_{arbitrary\ strength}\,(ml) = \frac{Strength_{reference}\,(mg\,I\,/\,ml)}{Strength_{arbitrary}\,(mg\,I\,/\,ml)}\,Volume_{reference\ strength\,(ml)} \quad [See\ Table\ 8.2]$$

$$Volume\,(ml) = Duration\,(s) \times Injection\ flow\ rate\,(ml\,/\,s) \quad [See\ Table\ 8.3]$$

$$Total\ iodine\ load\,(mg\,I) = Contrast\ concentration\,(mg\,I\ per\ ml) \times Contrast\ volume\,(ml)$$

$$Scan\ delay = Time\ to\ optimal\ enhancement - \tfrac{1}{2}\,Scan\ duration$$

$$Scan\ speed\,(mm/s) = \frac{Collimation\,(mm) \times Pitch}{Rotation\ time\,(s)}$$

$$Scan\ duration\,(s) = \frac{Scan\ range\,(mm)}{Scan\ speed\,(mm\,/\,s)}$$

$$= \frac{Scan\ range\,(mm) \times Rotation\ time\,(s)}{Collimation\,(mm) \times Pitch}$$

Contrast volume as a function of patient weight and contrast strength is shown in Table 8.3 for routine abdominal parenchymal enhancement.

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CT CONTRAST 104

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$$Total\ iodine\ load\,(mg\,I) = Contrast\ concentration\,(mg\,I\ per\ ml) \times Contrast\ volume\,(ml)$$

Iodine load versus contrast volume

All volumes are not created equal… a lower volume of high concentration agent can deliver the same total Iodine as a larger volume of less concentrated agent

Want more enhancement?
Increasing volume can give more enhancement, but change contrast timing

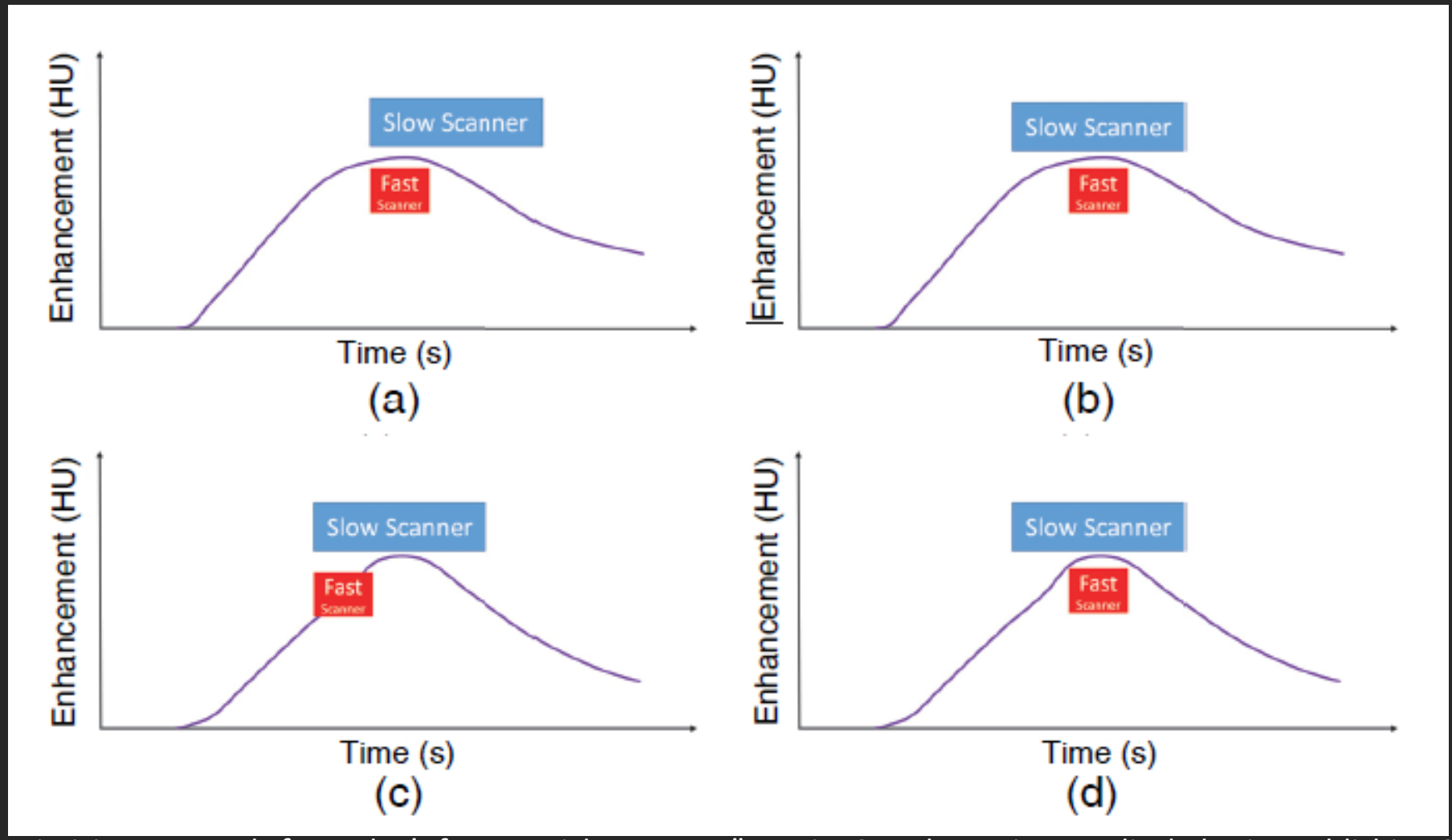
Increasing concentration will increase enhancement and usually wont change timing

CT CONTRAST 104

$$\textbf{Scan delay} = \text{Time to optimal enhancement} - \tfrac{1}{2}\,\text{Scan duration}$$

CT CONTRAST 104

$$\textit{Scan delay} = \textit{Time to optimal enhancement} - \tfrac{1}{2}\,\textit{Scan duration}$$



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CT CONTRAST 104

$$\text{Scan speed (mm/s)} = \frac{\text{Collimation (mm)} \times \text{Pitch}}{\text{Rotation time (s)}}$$

$$\text{Scan duration (s)} = \frac{\text{Scan range (mm)}}{\text{Scan speed (mm / s)}}$$

$$= \frac{\text{Scan range (mm)} \times \text{Rotation time (s)}}{\text{Collimation (mm)} \times \text{Pitch}}$$

@Prof_TimStick's Actionable information

- As a physicist, you should "own" scan duration. You can get scan length from dose report (DLP/CTDIvol).
  - Yes I know about overscanning. It doesn't matter here…
- As a physicist, you can suggest scanner specific scan delays differences based on scan speed.
  - Faster scanners usually need longer delays
- Physicists are good at multiplying and dividing numbers… so do site specific volume calcs for your sites having different strength agents.

CT Contrast 201…graduating to the clinic ;)

Radiology

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PREVIOUS

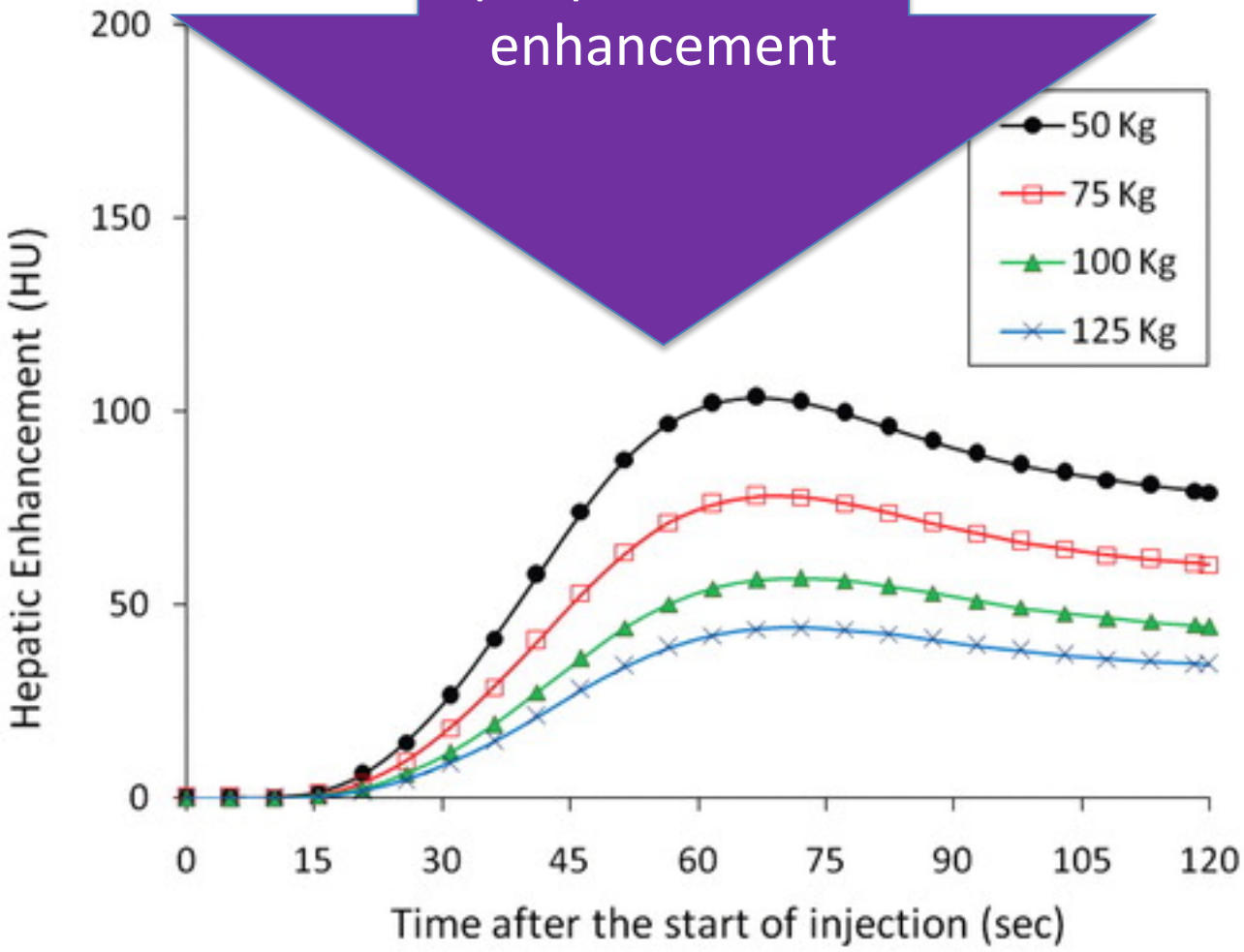
Reviews and Commentary
State of the Art

Intravenous Contrast Medi
Scan Timing at CT: Conside

Kyongtae T. Bae

Author Affiliations

If every ones gets 125 mls…big people see less enhancement



- Typical IV contrast prescription. Most sites around the world will have increases in I contrast with weight.

Example CTPA (PE) contrast prescription

IV Contrast Parameters

Patient weight < 140 kilos.(Less than 300 lbs.)

- 100 mL Iohexol (Omnipaque) 300 MG/ML @ 5 mL/sec
- 10 mL Sodium Chloride 0.9% @ 5 mL/sec

Patient weight 140-160 kilos.(300-350 lbs.)

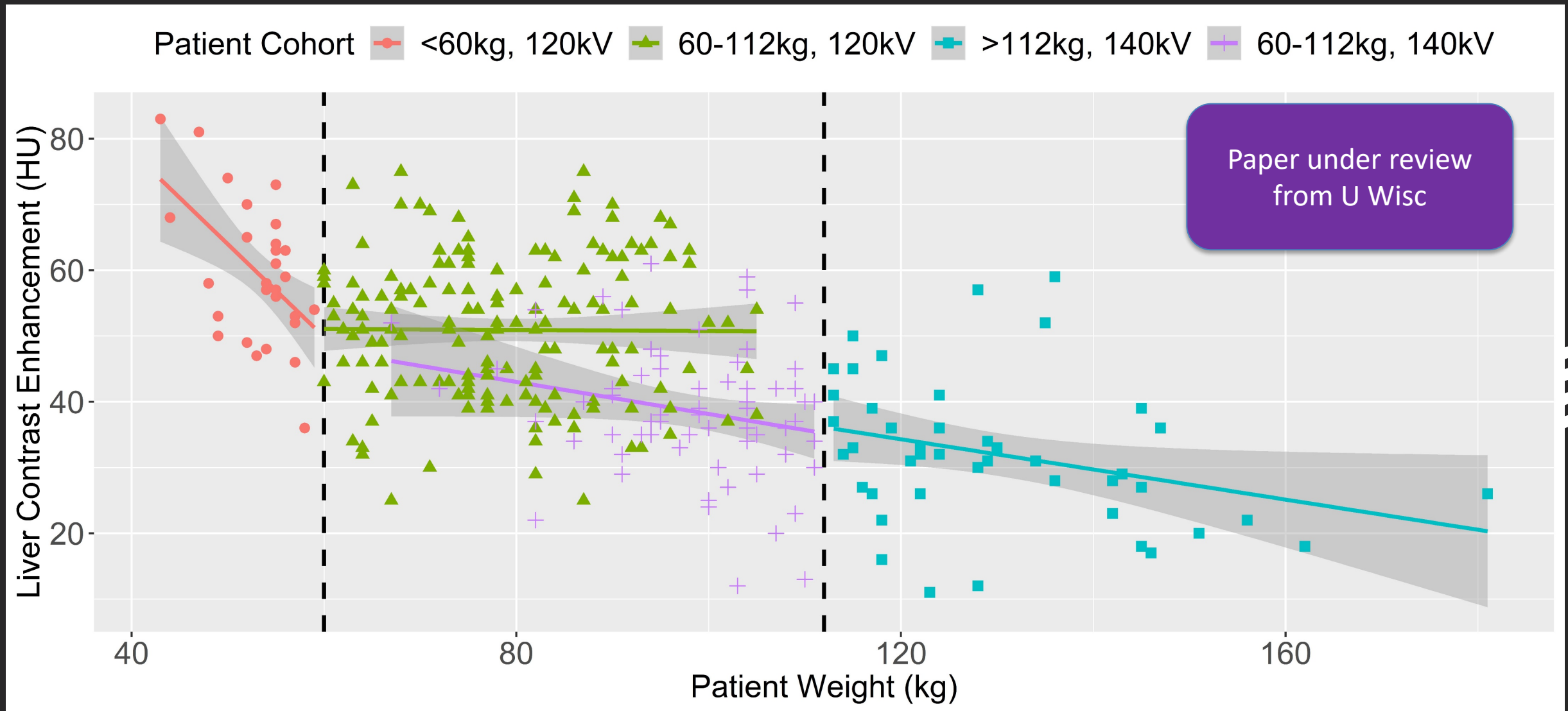
- 100 mL Iopamidol (Isovue 370) 370 mgI/ml @ 5 mL/sec
- 10 mL Sodium Chloride 0.9% @ 5 mL/sec

Patient weight > 160 kilos.(More than 350 lbs.)

- 150 mL Iopamidol (Isovue 370) 370 mgI/ml @ 5 mL/sec
- 10 mL Sodium Chloride 0.9% @ 5 mL/sec

Example routine parenchymal phase torso contrast prescription

Patient Weight (lbs)	Contrast Volume (ml or cc)
130 and less	80 (minimum amount to load)
140	86
150	92
160	98
165	101
170	104
175	107
180	110
190	116
200	122
210	129
220	135
230	141
240	147
250 and larger	150 (max amount to load)

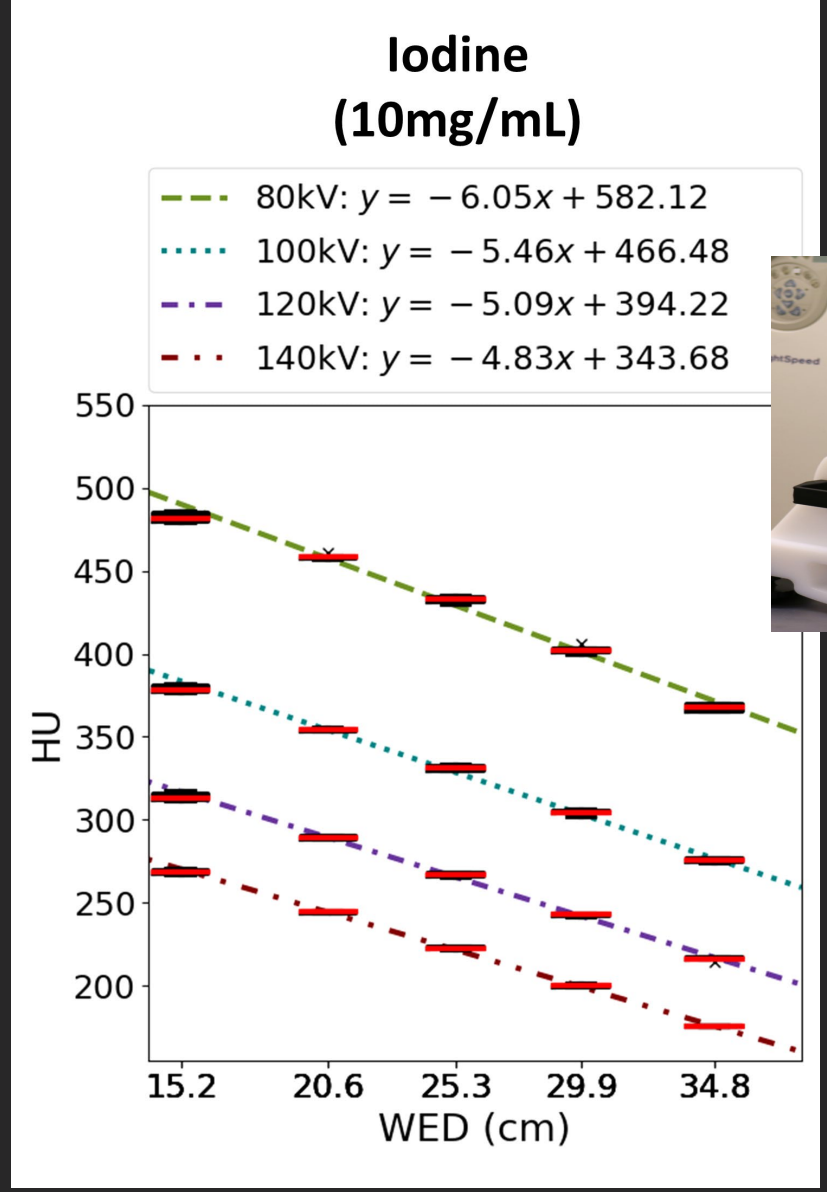


Smaller people see big increase in enhancement (opposite effect and rationale for large people)

Within black lines we use weight based dosing

Large patient see quick fall off in enhancement due to **blood volume increase** and **beam hardening**

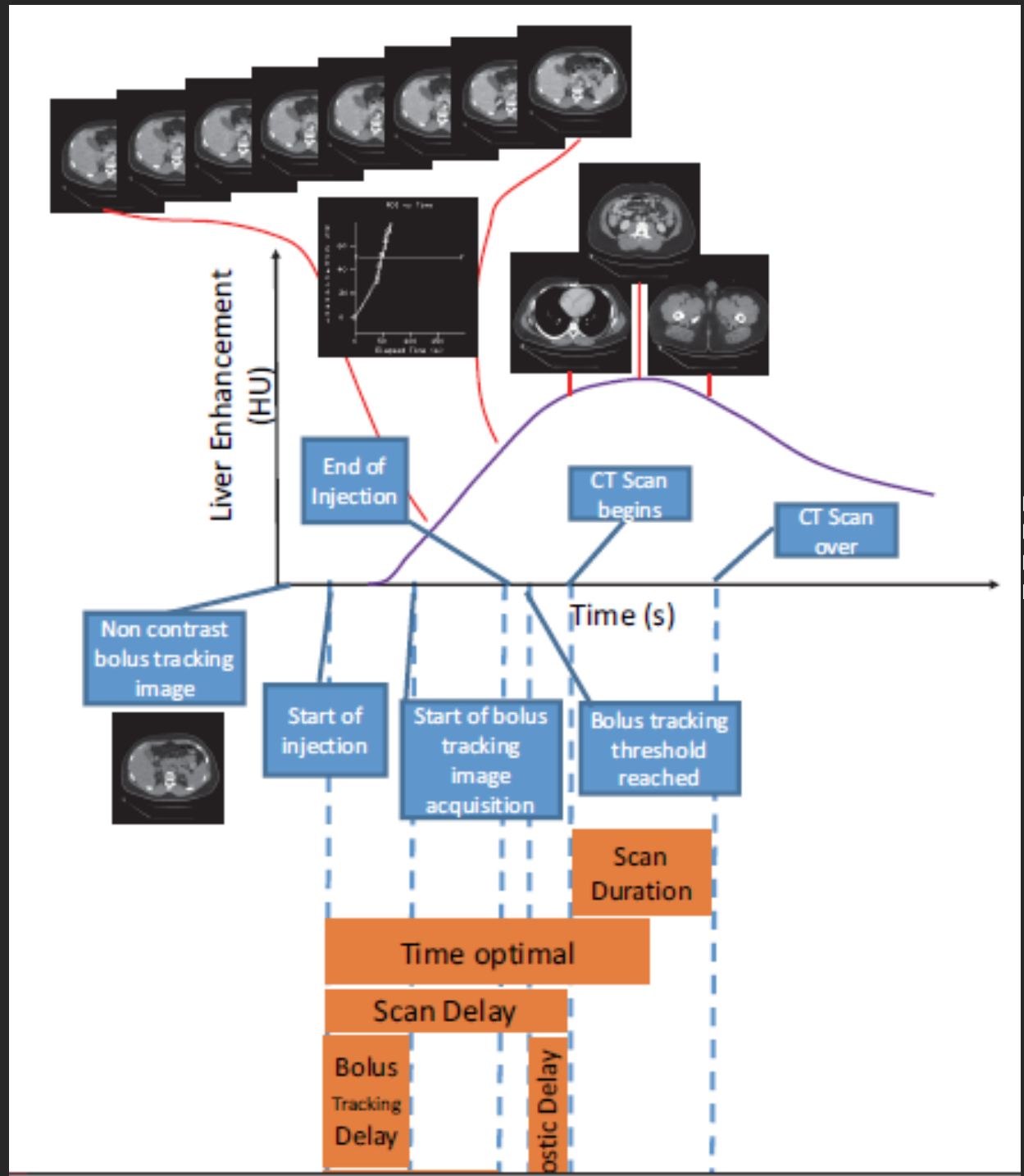
- Just due to beam hardening, we see a HUGE reduction in CT number with increasing patient size
  - -5 HU per cm of WED!



Parameterizing Size-Based Variations in CT Number
AAPM ePoster Library. Rose S. 07/12/20; 302594; BReP-SNAP-I-36 Topic: Multi-detector CT

BOLUS TRACKING

Allows for CT protocol acquisition tuned to patient specific cardiac output and flow dynamics



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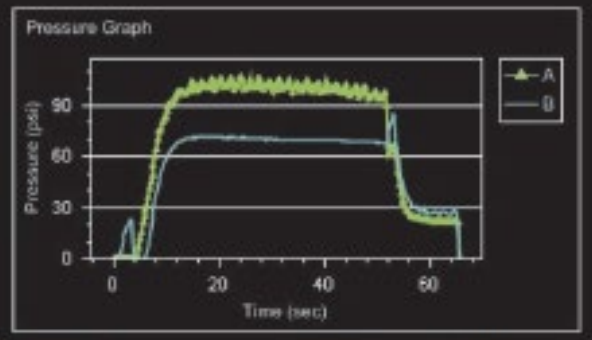
Administered 140.8 ml of 300 mg/ml using P3T Abdomen.

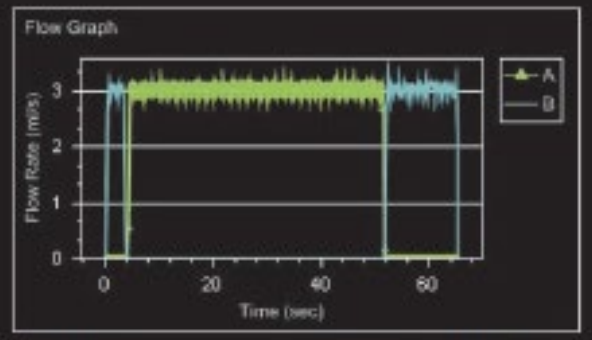
Injection Start: October 26, 1985 6:53 AM Image Created: October 26, 1985 6:55 AM

P3T Abdomen

Programmed		ml/s	ml	Actual		ml/s	ml
1	B	3.0	10	1	B	2.8	9.8
2	Hold			2	Hold		
3	A	3.0	141	3	A	3.0	140.8
4	B	3.0	40	4	B	3.0	39.9

Total Contrast (A):	141 ml	Total Contrast (A):	140.8 ml
Total Saline (B):	50 ml	Total Saline (B):	49.7 ml
Delay:	None		
Pressure Limit:	300 psi		



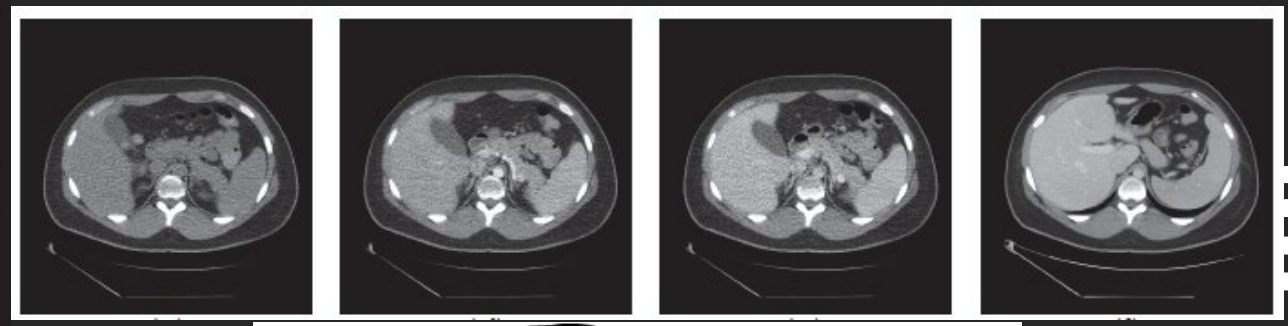


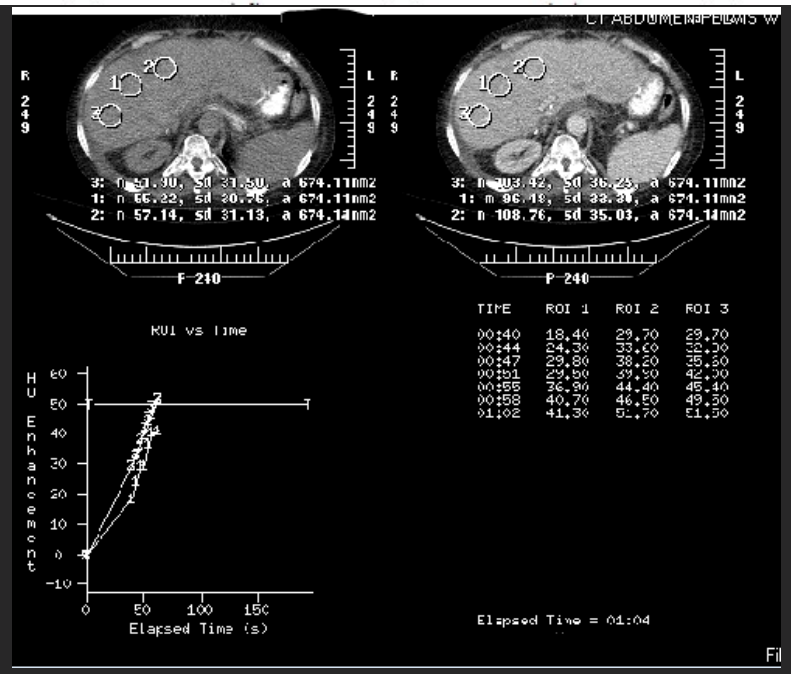
Injection	Contrast	Saline	Fluid Usage	Contrast	Saline
Peak Pressure:	107 psi	84 psi	Loaded:	158.7 ml	52.0 ml
Peak Flow Rate:	3.2 ml/s	3.2 ml/s	Used:	140.8 ml	49.7 ml
			Remaining:	17.9 ml	2.3 ml

Injection Completed: YES
Transient Events: NO

Total Fluid: 190.5 ml
Total Iodine: 42.2 gI

Bolus tracking time series





@Prof_TimStick's Actionable information

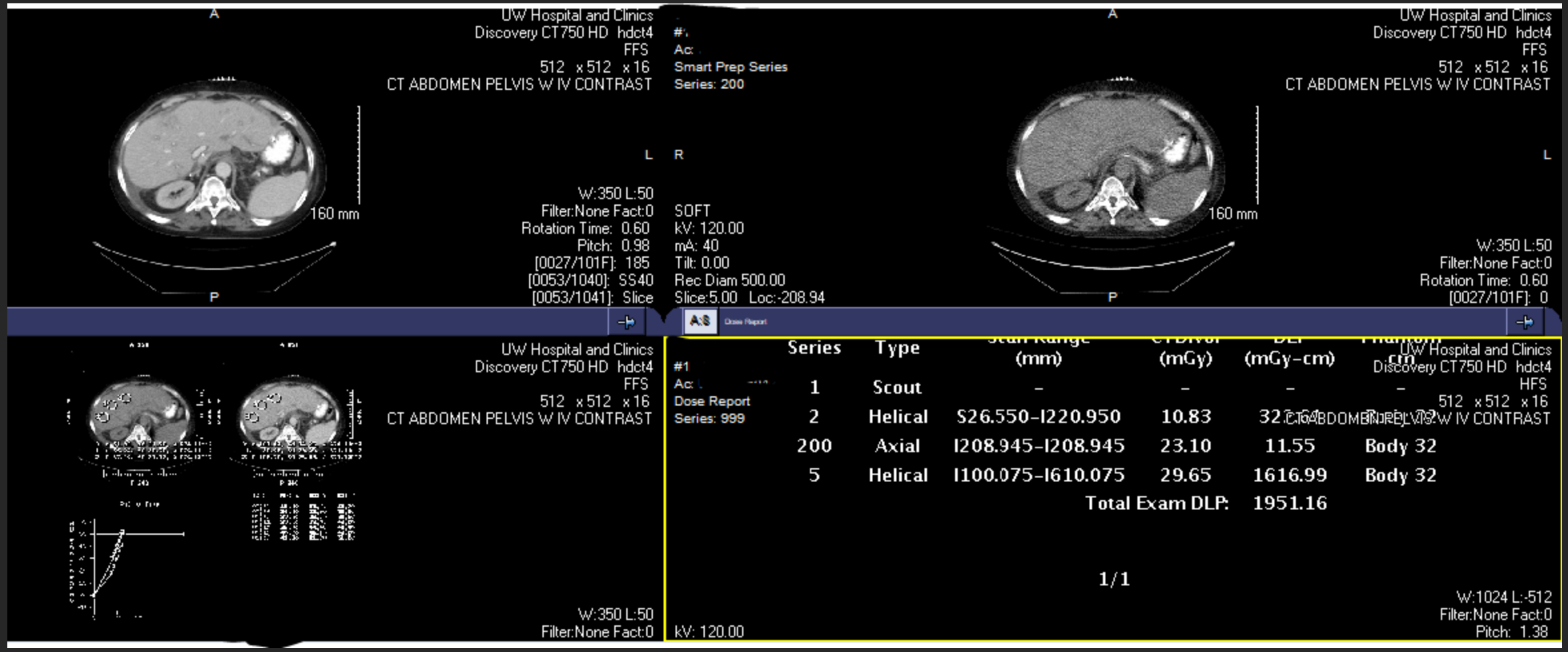
- If your site isn't using weight-based dosing…they will see large changes in enhancement with weight (and are probably wasting a lot of money)
- If your site isn't using bolus tracking… also badness, not enough time today to get into that. But sick patients really benefit from BT as they usually need longer (tens of seconds) delays w.r.t. healthy people

@Prof_TimStick's Actionable information

- Homework time!
  - Go to PACS and figure out the scan timing as I have done on the following slides
    - There will be site and vendor specific limitations and nuances you'll need to understand…

Parenchymal liver scan

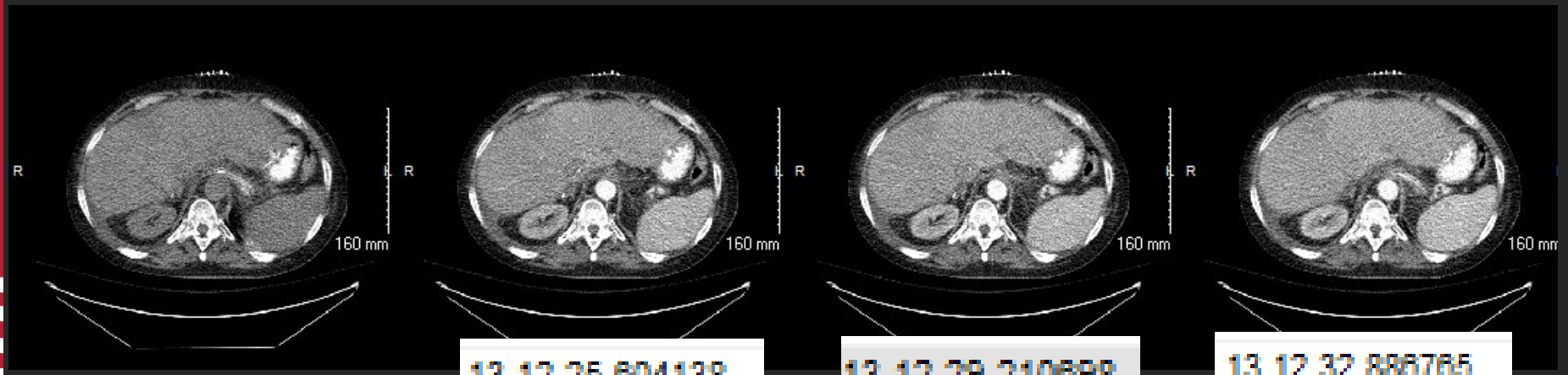
Baseline bolus tracking image



Scanner generated bolus tracking report

Dose slide. Series 200 on GE is the bolus tracking phase. (this study had a chest and a AP)

0008 0032 | ID Acquisition Time | 13 11 26 504627



...

We have a story. At 1:11:26 the tech took the non contrast baseline image for ROI placement

At 1:12:25 they started acquiring CINE images to monitor enhancement , taking an image every ~3-4 seconds… The pt hit enhancement threshold at 1:12:47

It took ~7 seconds to move from bolus tracking position to start of scan (1:12:54-1:12:47)

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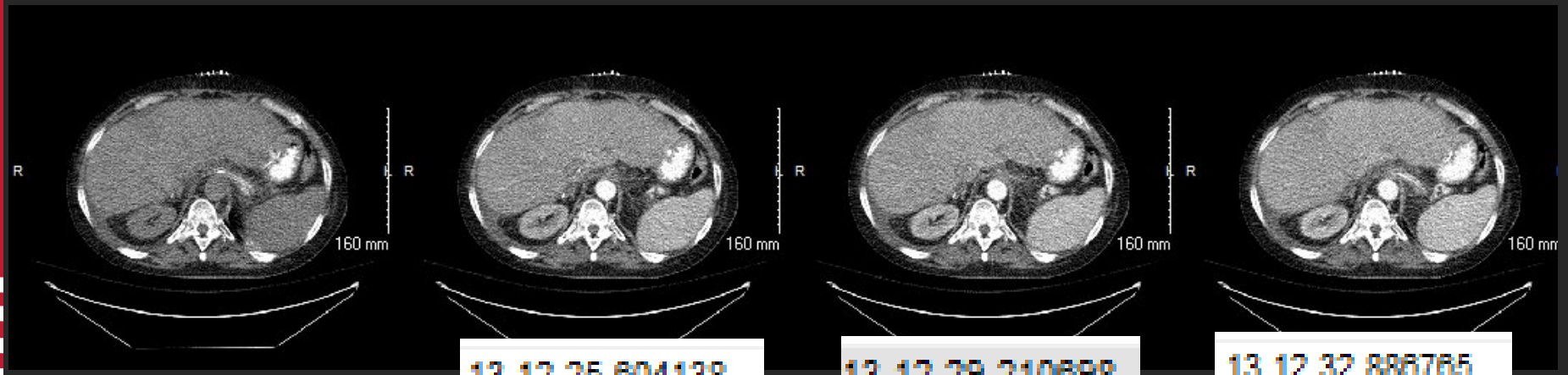
0008 0032 | ID Acquisition Time | 13 11 26 504627



13 12 25 604138

13 12 29 210698

13 12 32 886765

...

13 12 47 305386

I know we use a 40 second delay before acquiring the first bolus tracking image, so we started injection at 1:12:25 – 40 seconds.

1:11:45 was injection start

So time of scan from injection start was 1:12:54 – 1:11:45 = 69 seconds

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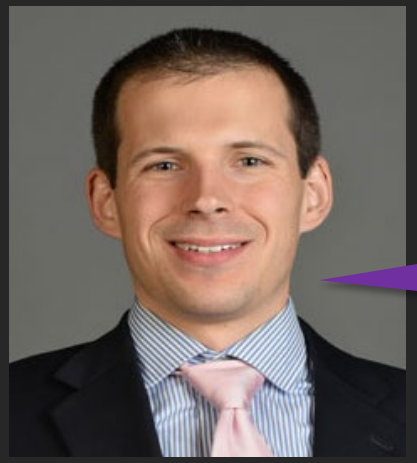

Thanks for your attention!

Please feel free to reach out to me with questions

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