Personalized CT Imaging: Decision support and optimization techniques for age, habitus, and diagnostic task

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Disclosures

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No disclosures

Outline

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Personalized CT Imaging: Decision support and optimization techniques for age, habitus, and diagnostic task

I. Pediatric Considerations

II. Bariatric Considerations

III. Size-Specific Dose Estimate

IV. Image Gently/Wisely and Choose Wisely

Pediatric considerations

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I. Challenges
    a. Radiation Sensitivity
    b. Anatomic & Physiologic features
    c. "Uncooperative" Patients

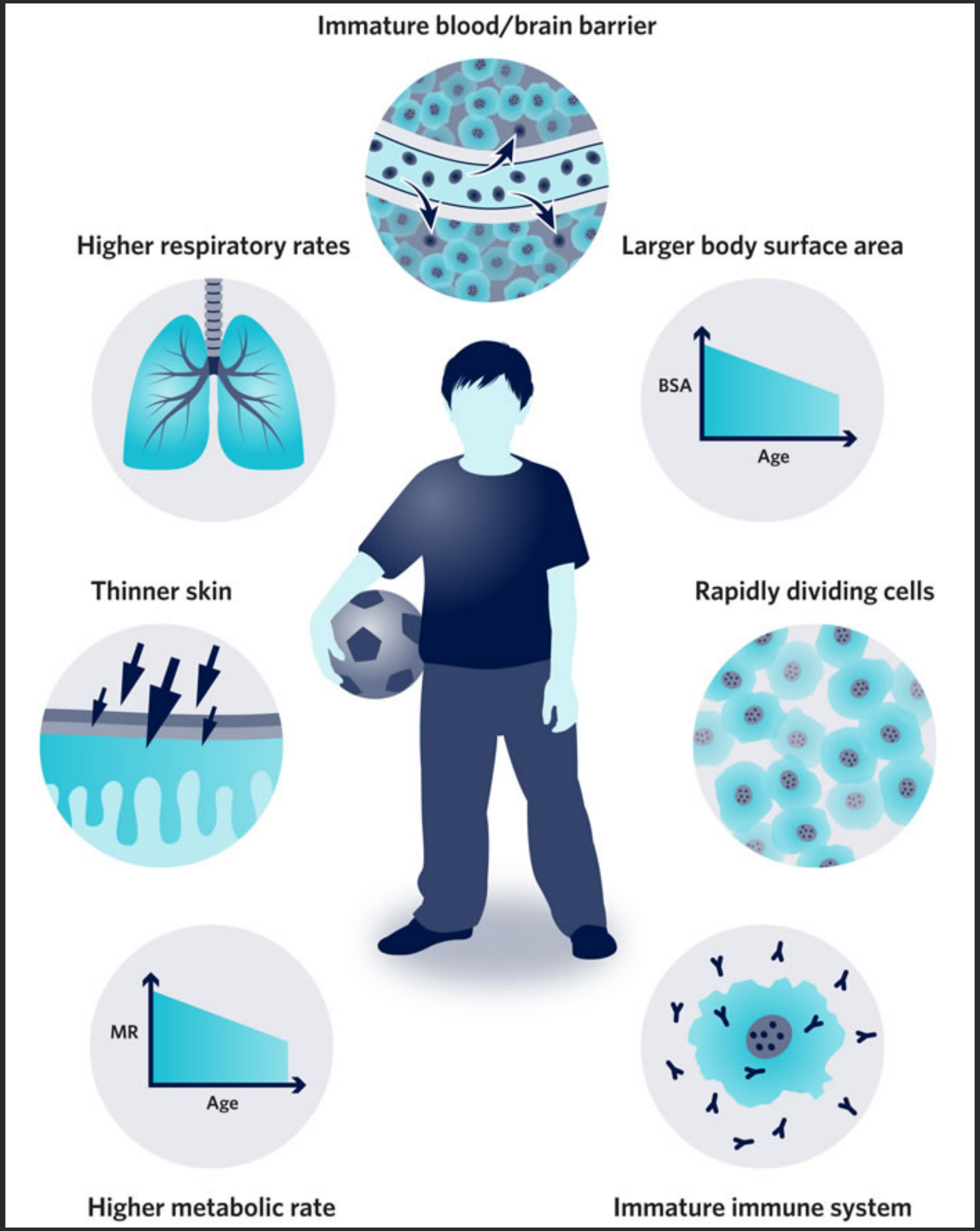
II. Unique to pediatrics

III. Imaging Tips

Differences between Pediatrics & Adults

- Immature blood/brain barrier
- Larger body surface area
- Rapidly dividing cells
- Immature immune system
- Higher metabolic rate
- Thinner skin
- Higher respiratory rates

Cristina Dodge, *Optimizing Pediatric CT in the ED*. AAPM Annual Meeting, 2016



http://www.rch.org.au/studentorientation/Differences_between_children_and_adults/

Challenges to Pediatric Imaging: Radiation Sensitivity

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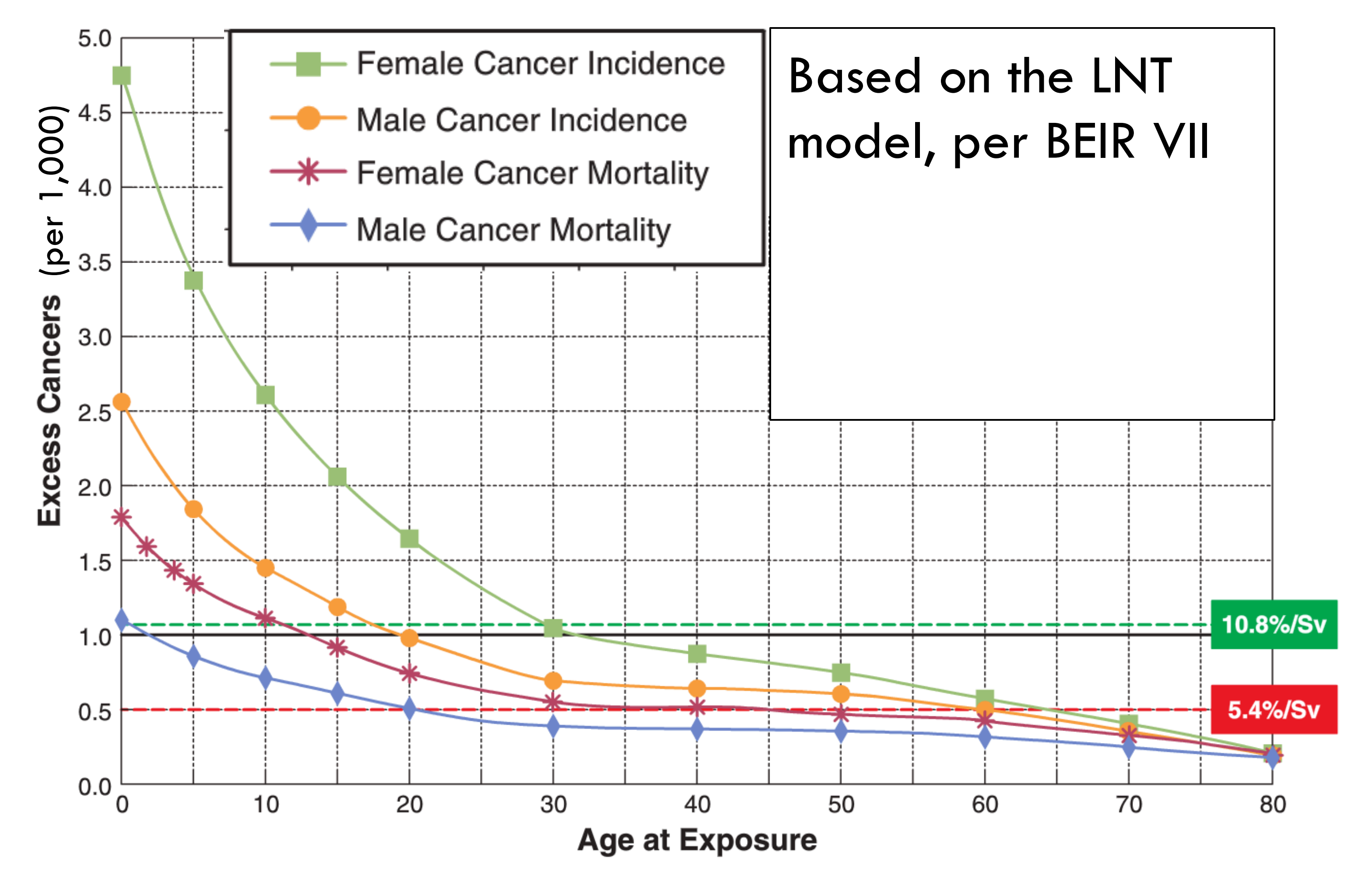

Based on the LNT model, per BEIR VII

Effect of Age At Exposure M&F	
Risk at 1 vs 30 yrs	
Female Cancer Incidence	~4.3
Male Cancer Incidence	~3.3
Female Cancer Mortality	3.2
Male Cancer Mortality	2.8

Bushberg, et al. (2012) The Essential Physics of Medical Imaging. Lippincott Williams &Wilkins, Philadelphia, 3rd edition.

Challenges to Pediatric Imaging: Radiation Sensitivity

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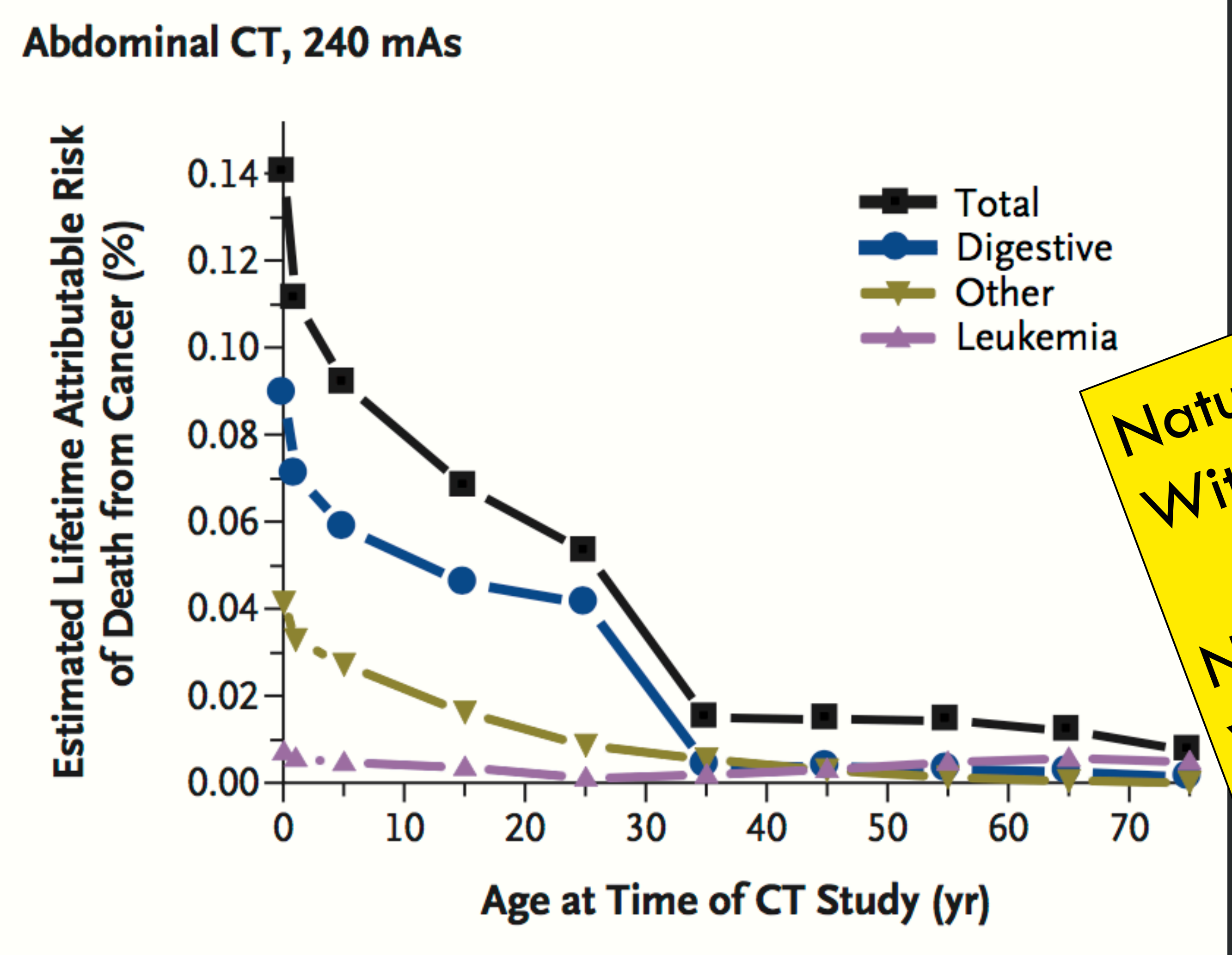

Natural Cancer Incidence: 22%
With an ABD CT at birth: 22.14%

Natural Cancer Mortality: 41%
With an ABD CT at birth: 41.14%

Brenner and Hall (2007). Computed tomography – an increasing source of radiation exposure. N Engl J Med. Fig 3.

Radiation Sensitivity: Carcinogenesis Risk for Children vs. Adults

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Cancer Site	More	No Difference	Less	Level of Evidence
Breast	✓			Strong
Brain	✓			Strong
Thyroid	✓			Strong
Leukaemia non-CL L	✓			Strong
Stomach (mortality)	ERR	EAR		Moderate
Lung			✓*	Moderate
Skin non-melanoma	✓			Moderate
Bladder		✓		Moderate
Colon (incidence)	EAR	ERR		Weak
Colon (mortality)	EAR & ERR			Weak
Liver		✓		Weak
Myelodysplasia	✓			Weak

* Limited data on radon and lung cancer indicate approximately same risk after exposure at pre-adult and adult age

UNSCEAR, 2013. Sources, Effects and Risks of Ionizing Radiation. UNSCEAR Report 2013 to the General Assembly with Scientific Annexes. Volume II, Scientific Annex B: Effects of Radiation Exposure of Children. E.14.IX.2. United Nations, New York.

Radiation Sensitivity: UNSCEAR 2013 Annex B

Cancer Site	More	No Difference	Less	Level of Evidence
				Strong
				Strong
				Strong
Colon (incidence)				
Colon (mortality)	E			
Liver				
Myelodysplasia	✓			Weak

* Limited data on radon and lung cancer indicate approximately same risk after exposure at pre-adult and adult age

Not enough sufficient data for cancer of…

- Kidney
- Myeloma
- Non-Hodgkin's lymphoma
- Oesophagus
- Ovary
- Parathyroid
- Uterus

Tumor not definitely shown to be increased by radiation exposure for…

- Cervix
- Hodgkin's lymphoma
- Pancreas
- Prostate
- Rectum
- Small intestine

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Challenges to Pediatric Imaging: Anatomic & Physiologic Features

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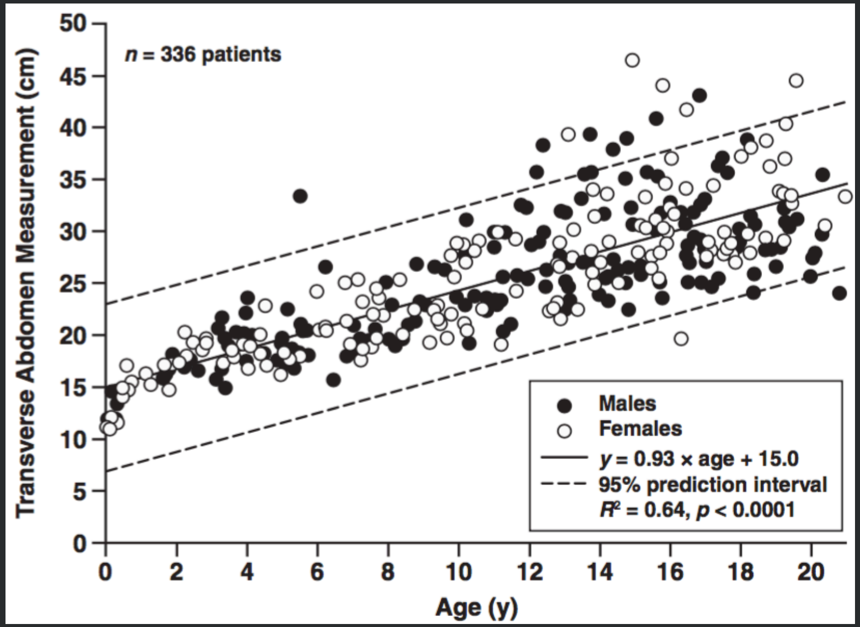
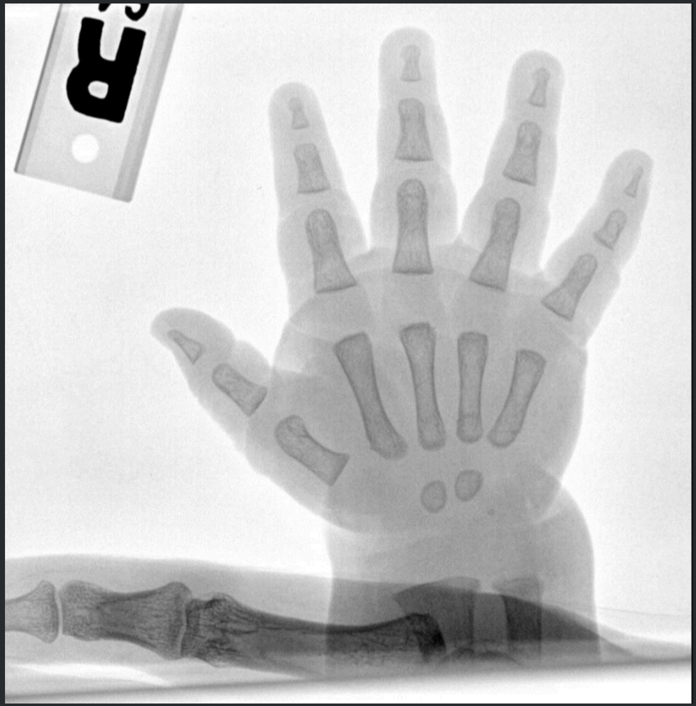
Wide spectrum of patient sizes



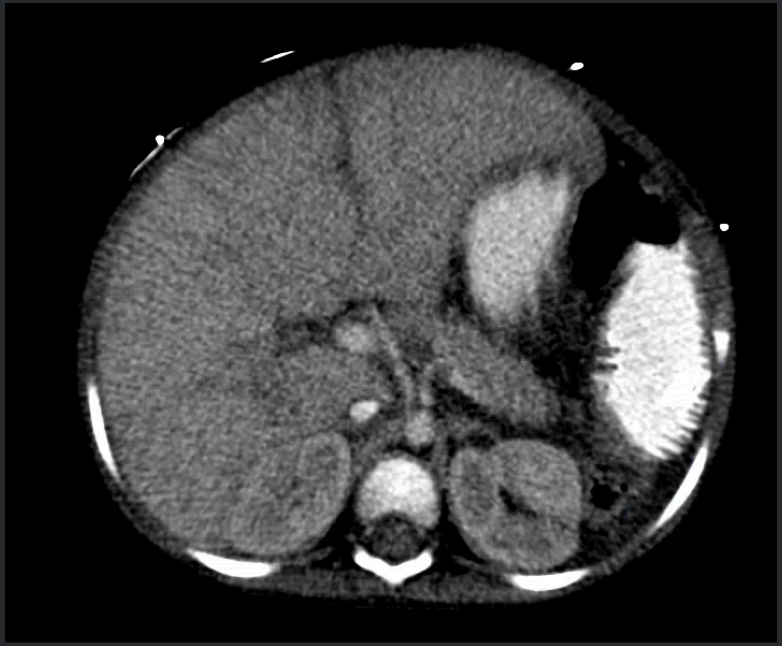
Kleinman, Patricia L., Keith J. Strauss, David Zurakowski, Kevin S. Buckley, and George A. Taylor. "Patient Size Measured on CT Images as a Function of Age at a Tertiary Care Children's Hospital." *American Journal of Roentgenology* 194, no. 6 (June 1, 2010): 1611–19. doi:10.2214/AJR.09.3771.

Low calcium content (flexible & lower con)



Slide Courtesy of Cristina Dodge, *Optimizing Pediatric CT in the ED.* AAPM Annual Meeting 2016

Small features & low body fat



Challenges to Pediatric Imaging: The "Uncooperative Patient"

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http://www.growingyourbaby.com/wp-content/uploads/2010/11/6635745_s.jpg

- Highly expressive
- Mistrust of health professionals
- Limited communication abilities
- Limited concentration & control

Pediatric considerations

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I. Challenges

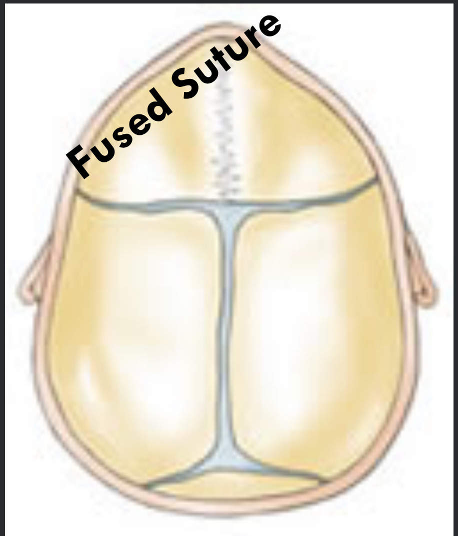
II. Unique to pediatrics
   a. Specialized protocols
   b. Patient Comfort
   c. When to use shielding

III. Imaging Tips

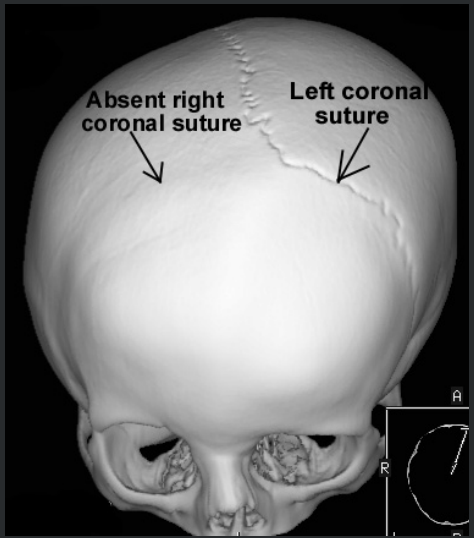
Unique to Pediatrics: Specialized Protocols

Ultra low-dose CT for boney congenital disease

- Craniosynostosis

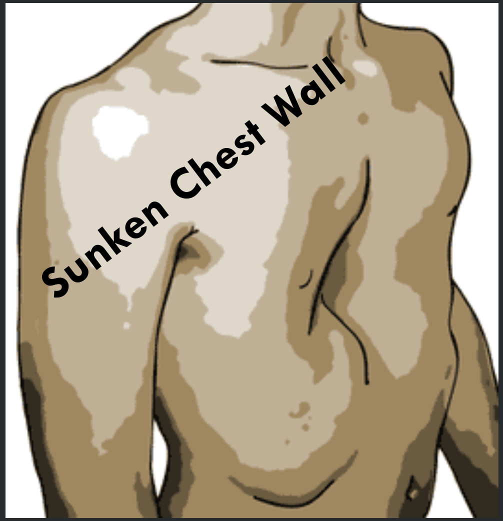


https://neurosurgery.ufl.edu/patient-care/diseases-conditions/pediatric-craniosynostosis/

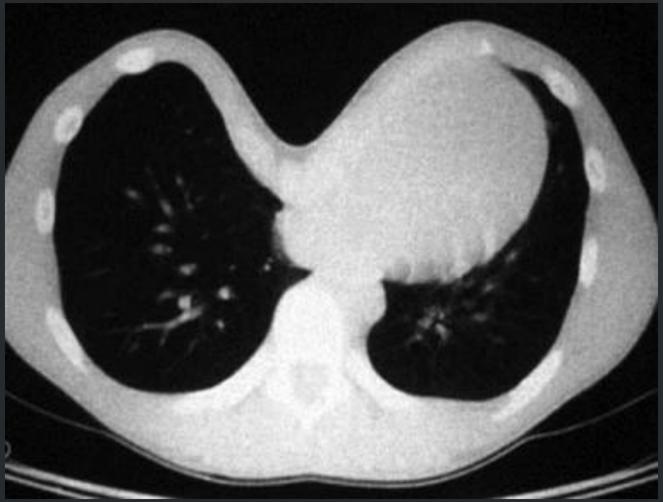


http://www.fetalultrasound.com/online/text/1-021.HTM

- Pectus excavatum



http://pedsurg.ucsf.edu/conditions--procedures/pectus-excavatum.aspx#a1



http://img.medscapestatic.com/pi/meds/ckb/89/26189tn.jpg

Unique to Pediatrics: Specialized Protocols

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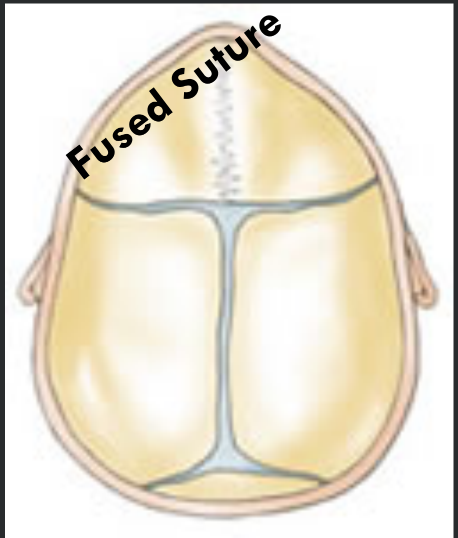
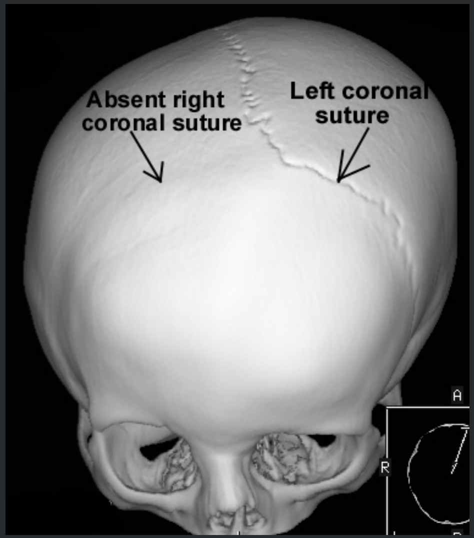
Ultra low-dose CT for boney conge[...]al disease

- Craniosynostosis
- [...]ctus excavatum

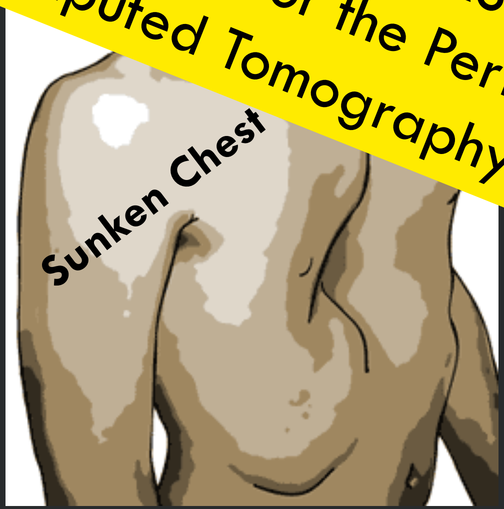
More at the ACR–ASER–SCBT-MR–SPR Practice Parameter for the Performance of Pediatric Computed Tomography



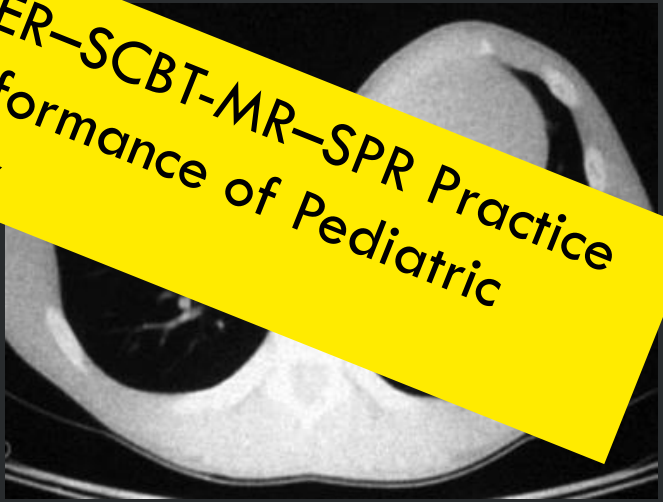
https://neurosurgery.ufl.edu/patient-care/diseases-conditions/pediatric-craniosynostosis/



http://www.fetalultrasound.com/online/text/1-021.HTM



http://pedsurg.ucsf.edu/conditions--procedures/pectus-excavatum.aspx#a1



http://img.medscapestatic.com/pi/meds/ckb/89/26189tn.jpg

Unique to Pediatrics: Patient Comfort

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Cooperation requires patience and age-appropriate…

- Education
- Communication
- Distraction tools
- Patient restraints

http://elhardfamily.blogspot.com/2010/

https://childrensnational.org/~/media/cnhs-site/images/brand-images/diagnostic-imaging-and-radiology-_18305.ashx?h=800&la=en&w=1200

Improved with Child Life Specialists

Unique to Pediatrics: Use of Shielding

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AAPM statement for use of Bismuth shields

POLICY NUMBER	POLICY NAME	POLICY DATE	SUNSET DATE
PP 26-A	Use of Bismuth Shielding for the Purpose of Dose Reduction in CT Scanning	2/7/2012	12/31/2017

Policy source

AAPM Board Vote - Closed on February 7, 2012

Policy text

Bismuth shields are easy to use and have been shown to reduce dose to anterior organs in CT scanning. However, there are several disadvantages associated with the use of bismuth shields, especially when used with automatic exposure control or tube current modulation. Other techniques exist that can provide the same level of anterior dose reduction at equivalent or superior image quality that do not have these disadvantages. The AAPM recommends that these alternatives to bismuth shielding be carefully considered, and implemented when possible.

Outline

I. Pediatric considerations
   a. Challenges
   b. Unique to pediatrics
   c. Imaging Tips
      a. General considerations
      b. Technique considerations
      c. AD's, DRR's & DRL's

Baseline Pediatric Protocols

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Protocols for a spectrum of CT makes & models
http://www.aapm.org/pubs/CTProtocols/

- Head
- Chest
- Abdomen/Pelvis

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

THE ALLIANCE FOR QUALITY COMPUTED TOMOGRAP

Purpose | FDA Award | Questions | Role of the QMP | CT Dose-Check | Protocols | Le

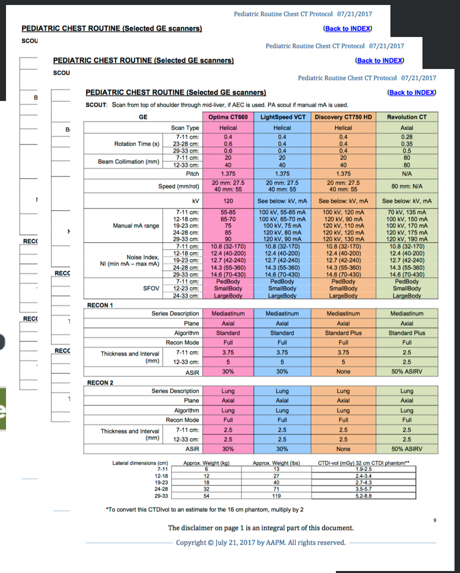
Available Protocols

Adult Protocols

- Lung Cancer Screening CT (updated 02/23/2016) [Give Feedback]
- Routine Adult Chest-Abdomen-Pelvis CT (added 02/20/2014) [Give Feedback]
- Routine Adult Chest CT (updated 05/04/2016) [Give Feedback]
- Routine Adult Abdomen/Pelvis CT (updated 08/07/2015) [Give Feedback]
- Routine Adult Head CT (updated 03/01/2016) [Give Feedback]
- Routine Adult Brain Perfusion (updated 03/01/2016) [Give Feedback]

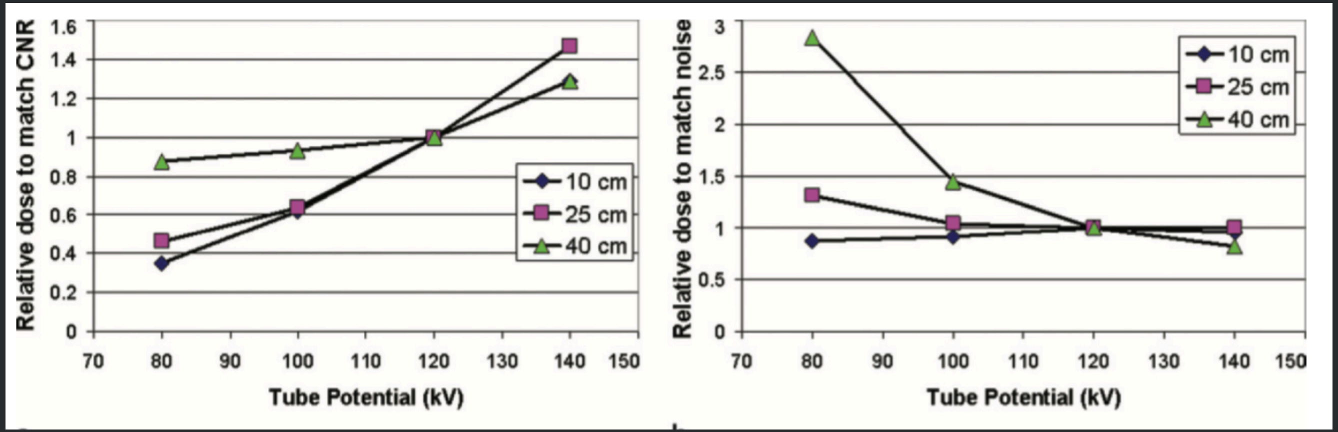
Pediatric Protocols

- Routine Pediatric Chest CT (added 07/21/2017) [Give Feedback]
- Routine Pediatric Abdomen and Pelvis CT (added 07/21/2017) [Give Feedback]
- Routine Pediatric Head CT (updated 12/14/2015) [Give Feedback]



Technique Tips: When to Reduce Tube Potential

- Lower tube potential improves contrast & lowers dose to small patients



Yu, Lifeng, Michael R. Bruesewitz, Kristen B. Thomas, Joel G. Fletcher, James M. Kofler, and Cynthia H. McCollough. “Optimal Tube Potential for Radiation Dose Reduction in Pediatric CT: Principles, Clinical Implementations, and Pitfalls.” *RadioGraphics* 31, no. 3 (May 1, 2011): 835–48. doi:10.1148/rg.313105079.

- Educate before you implement!

Table 2 Hounsfield Unit values as a function of CT X-ray tube voltages (kV) [Relative HU values normalized to unity at 120 kV]

Tube voltage (kV)	80	100	120	140
Nominal average photon energy (keV)	40	50	60	80
Fat	−152	−111	−89	−69
	[1.70]	[1.25]	[1.00]	[0.77]
Brain	47	43	39	37
	[1.20]	[1.08]	[1.00]	[0.93]
Soft tissue	62	58	54	52
	[1.14]	[1.06]	[1.00]	[0.96]
Cortical bone	3760	2590	1940	1330
	[1.94]	[1.34]	[1.00]	[0.69]
Calcium	9,570	5,960	3,950	2,090
	[2.42]	[1.51]	[1.00]	[0.53]
Iodine	405,000	267,000	180,000	93,200
	[2.24]	[1.48]	[1.00]	[0.52]

Huda, W. CT Radiation Exposure: An Overview. Curr Radiol Rep (2015) 3:80

Technique Tips:
When to Use AEC & TCM

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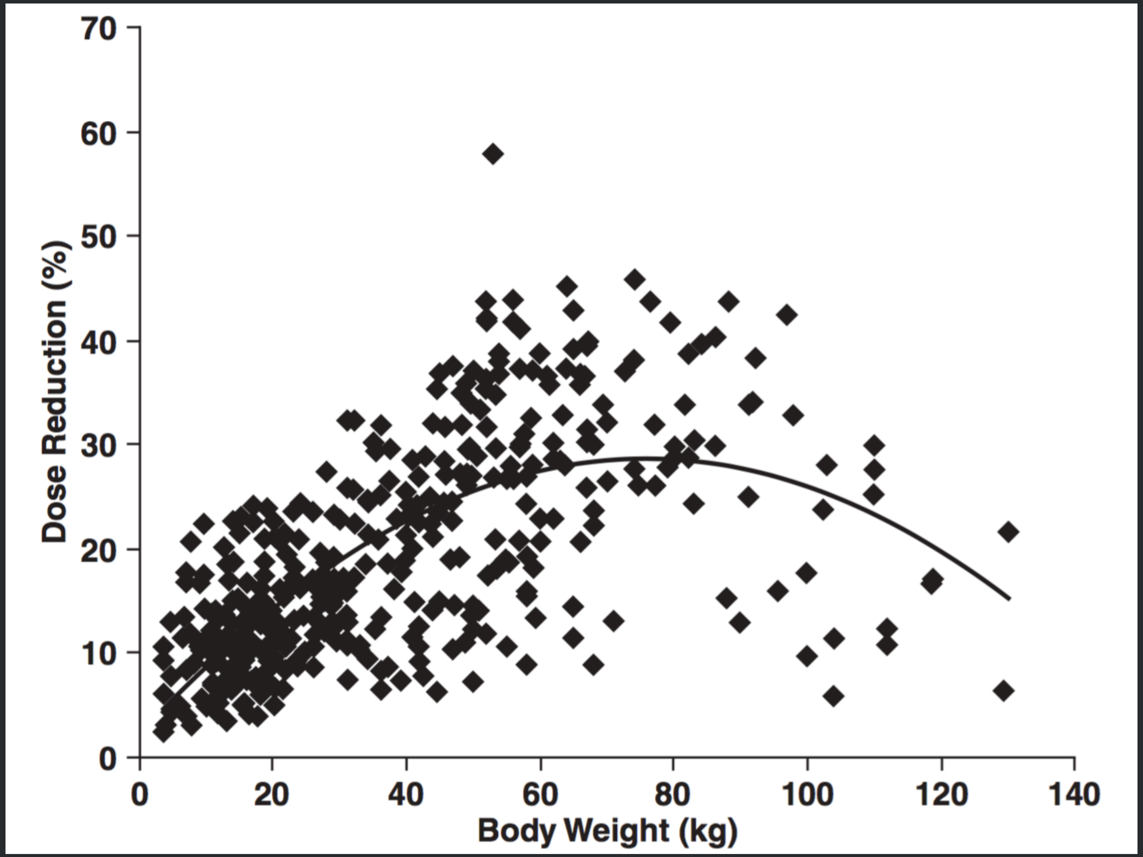
Automatic Exposure Control & Tube Current Modulation

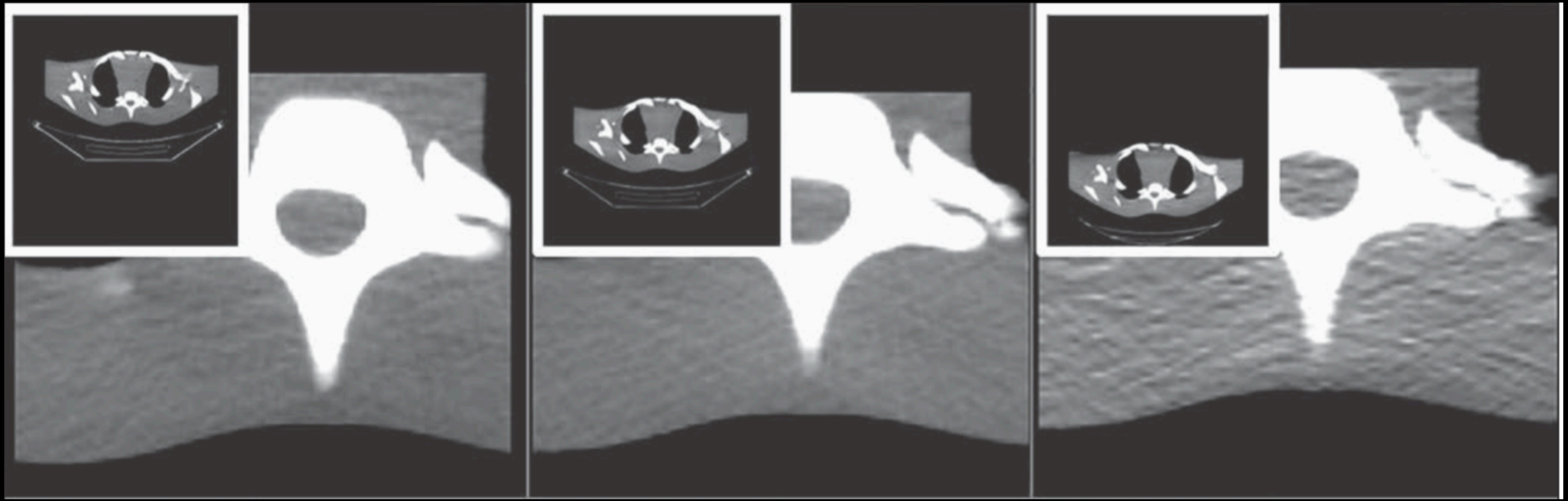
- Greater dose savings for mid-sized patients
- Greatest gains if AEC changes with size-dependent protocols



Karmazyn, Boaz, Huisi Ai, Yun Liang, Paul Klahr, George J. Eckert, and S. Gregory Jennings. "Effect of Body Size on Dose Reduction With Longitudinal Tube Current Modulation in Pediatric Patients." *American Journal of Roentgenology* 204, no. 4 (March 20, 2015): 861–64. doi:10.2214/AJR.14.12762.

Technique Tips: Appropriate Bow Tie Filter & Patient Positioning

- Greater patient positioning effects observed at low kV
- Positioning at the “center of mass” (attenuation) not the geometric center of a patient



Szczykutowicz, Timothy P., Andrew DuPlissis, and Perry J. Pickhardt. “Variation in CT Number and Image Noise Uniformity According to Patient Positioning in MDCT.” *American Journal of Roentgenology* 208, no. 5 (March 7, 2017): 1064–72. doi:10.2214/AJR.16.17215.

Technique Tips:
Methods to Reduce Scan time

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Collimation	Rotation Time	Pitch	Tube Current
↑	↓	↑	↑

AD's, DRR's, & DRL's

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- Achievable Dose: Median Dose
- Dose Reference Levels: 75th percentile
- Dose Reference Ranges: 25th - 75th percentile

Chest CT

Distribution of SSDEs with 32-cm CTDI Phantom

Effective Diameter (cm)	No. of Examinations	Mean SSDE (mGy)	Standard Error of the Mean (mGy)	Median (mGy)*	PDRF
<15	20	2.7	0.34	2.1 (1.8–3.9)	<0.44
15–19	147	3.4	0.15	3.0 (2.2–4.5	0.44–0.60
20–24	165	4.3	0.20	3.4 (2.7–5.1)	0.64–0.80
25–29	134	5.3	0.21	4.7 (3.6–6.6)	0.84–1.0
≥30	52	7.4	0.43	6.3 (5.5–8.4)	≥1.0

* Data in parentheses are the DRR (25th and 75th percentiles).

Strauss, Keith J., Marilyn J. Goske, et al. "Pediatric Chest CT Diagnostic Reference Ranges: Development and Application." *Radiology* 284, no. 1 (February 17, 2017): 219–27. doi:10.1148/radiol.2017161530.

AD's, DRR's, & DRL's

Children's National™

- Achievable Dose: Median Dose
- Dose Reference Levels: 75th percentile
- Dose Reference Ranges: 25th - 75th percentile

Abdomen CT

Table 3

Distribution of SSDE

BW Group	No. of Scans	Mean	Standard Error	Lower DRR, 25th Percentile	Median, 50th Percentile	Upper DRR, 75th Percentile	$SSDE/SSDE_{adult}$ Ratio
<15 cm	21	8.6	0.9	5.8	8.0	12.0	0.52
15–19 cm	153	10.0	0.5	7.3	8.7	12.2	0.61
20–24 cm	286	11.4	0.7	7.6	9.8	13.4	0.69
25–29 cm	326	13.5	0.3	9.8	13.0	16.4	0.82
⩾30 cm	168	16.5	0.4	13.1	15.6	19.0	1.00

Goske, Marilyn J., Keith J. Strauss, Laura P. Coombs, Keith E. Mandel, Alexander J. Towbin, David B. Larson, Michael J. Callahan, et al. "Diagnostic Reference Ranges for Pediatric Abdominal CT." *Radiology* 268, no. 1 (July 1, 2013): 208–18. doi:10.1148/radiol.13120730.

Outline

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I. Bariatric Considerations
   a. Challenges
      a. Table limits
      b. Bore limits
      c. Radiation output limits

   (Hardware)

   b. Technique Tips

Challenges to Bariatric Imaging: Table Limits

- Label weight limits on <u>all</u> imaging tables during acceptance

CT scanners

Manufacturer	Model	Internal bore diameter	Weight capacity
GE Healthcare	LightSpeed RT 4	80 cm	500 lb
	LightSpeed RT 16	80 cm	500 lb
	LightSpeed CT750 HD, VCT, VCT XT	70 cm	500 lb
Philips Healthcare	Brilliance CT (Big Bore system), iCT	85 cm	450 lb, optional 650 lb
	Brilliance CT (other)	70 cm	450 lb, optional 650 lb

More limits available at: https://www.itnonline.com

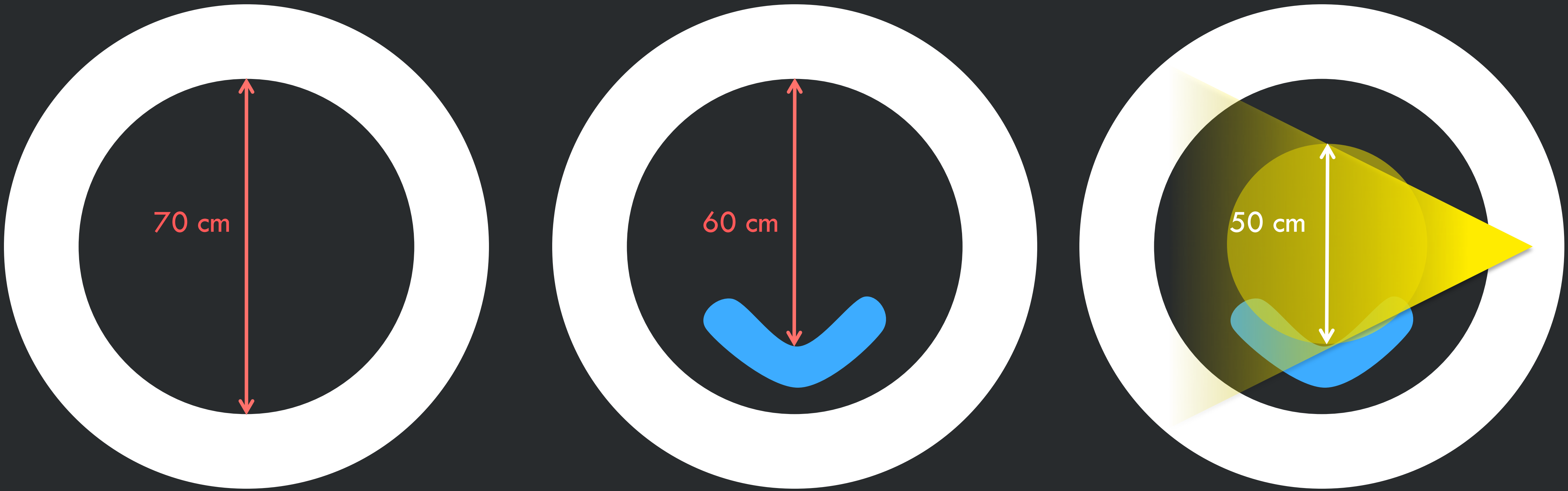
CT scanners

Manufacturer	Model	Internal bore diameter	Weight capacity
Siemens Healthcare	Somatom Sensation 40, 64	70 cm	450 lb, optional 650 lb
	Somatom Definition AS and Somatom Dual Source	78 cm	450 lb, optional 660 lb
	Somatom Sensation Open	82 cm	450 lb, optional 650 lb
Toshiba America Medical Systems	Aquilion 16	72 cm	450 lb
	Aquilion 32, 64	72 cm	450 lb, optional 660 lb
	AquilionOne	72 cm	660 lb

"When Zoos Refuse: Obese Patients Face Shortage of Large-Capacity Scanners." *AuntMinnie.Com*, n.d. http://www.auntminnie.com/index.aspx?sec=ser&sub=def&pag=dis&ItemID=82543.

Challenges to Bariatric Imaging: Bore Diameter & Field of View

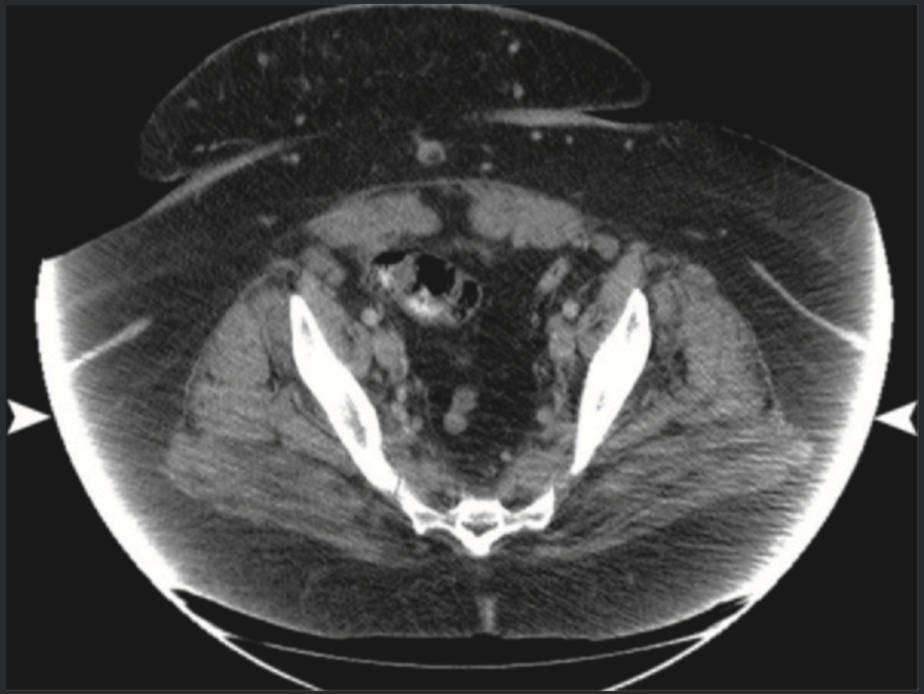
Aperture Specification | Useable Vertical Diameter | Scan FOV

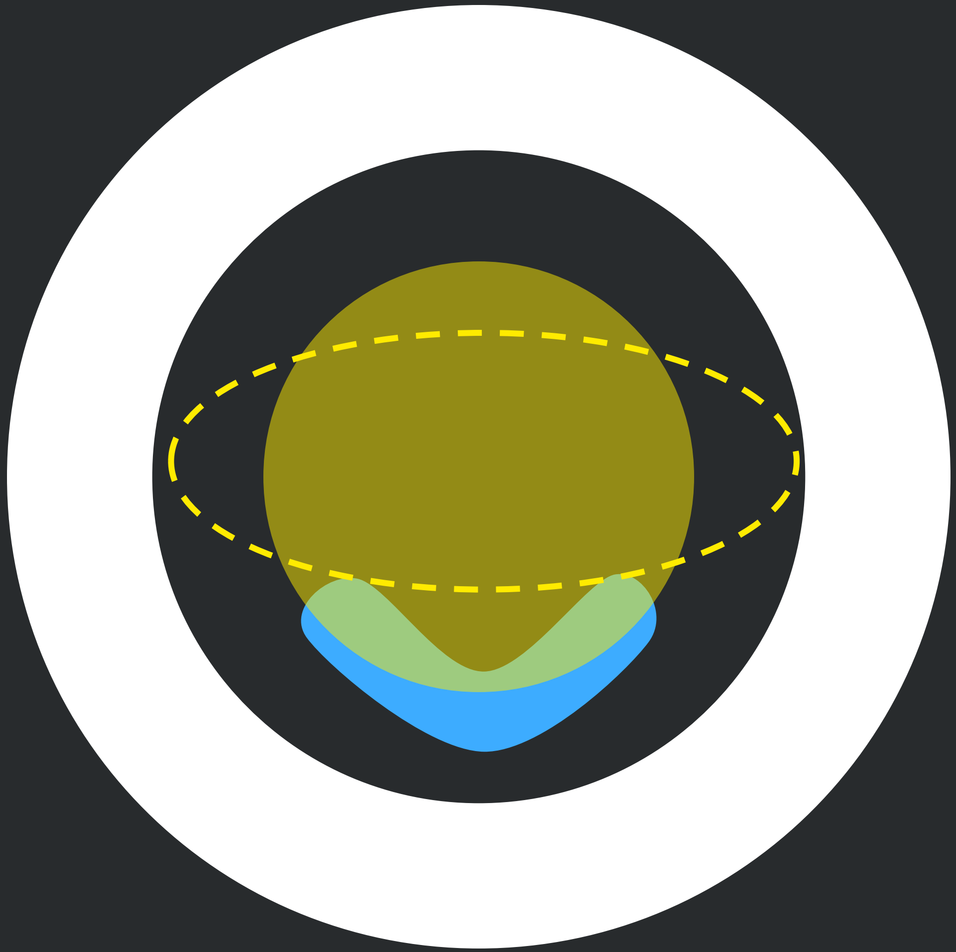


Modica, Michael J., Kalpana M. Kanal, and Martin L. Gunn. "The Obese Emergency Patient: Imaging Challenges and Solutions." *RadioGraphics* 31, no. 3 (May 1, 2011): 811–23. doi:10.1148/rg.313105138.

Challenges to Bariatric Imaging: Truncation Artifacts

Incomplete lateral data collection





Modica, Michael J., Kalpana M. Kanal, and Martin L. Gunn. "The Obese Emergency Patient: Imaging Challenges and Solutions." *RadioGraphics* 31, no. 3 (May 1, 2011): 811–23. doi:10.1148/rg.313105138.

Challenges to Bariatric Imaging: Patient Bundling

Without Bundle

With Bundle

Modica, Michael J., Kalpana M. Kanal, and Martin L. Gunn. "The Obese Emergency Patient: Imaging Challenges and Solutions." *RadioGraphics* 31, no. 3 (May 1, 2011): 811–23. doi:10.1148/rg.313105138.

Outline

I. Bariatric Considerations
   a. Challenges

   b. Technique Tips
      a. How to increase tube output
      b. When to use AEC

Challenges to Bariatric Imaging: Radiation Output & Photon Starvation

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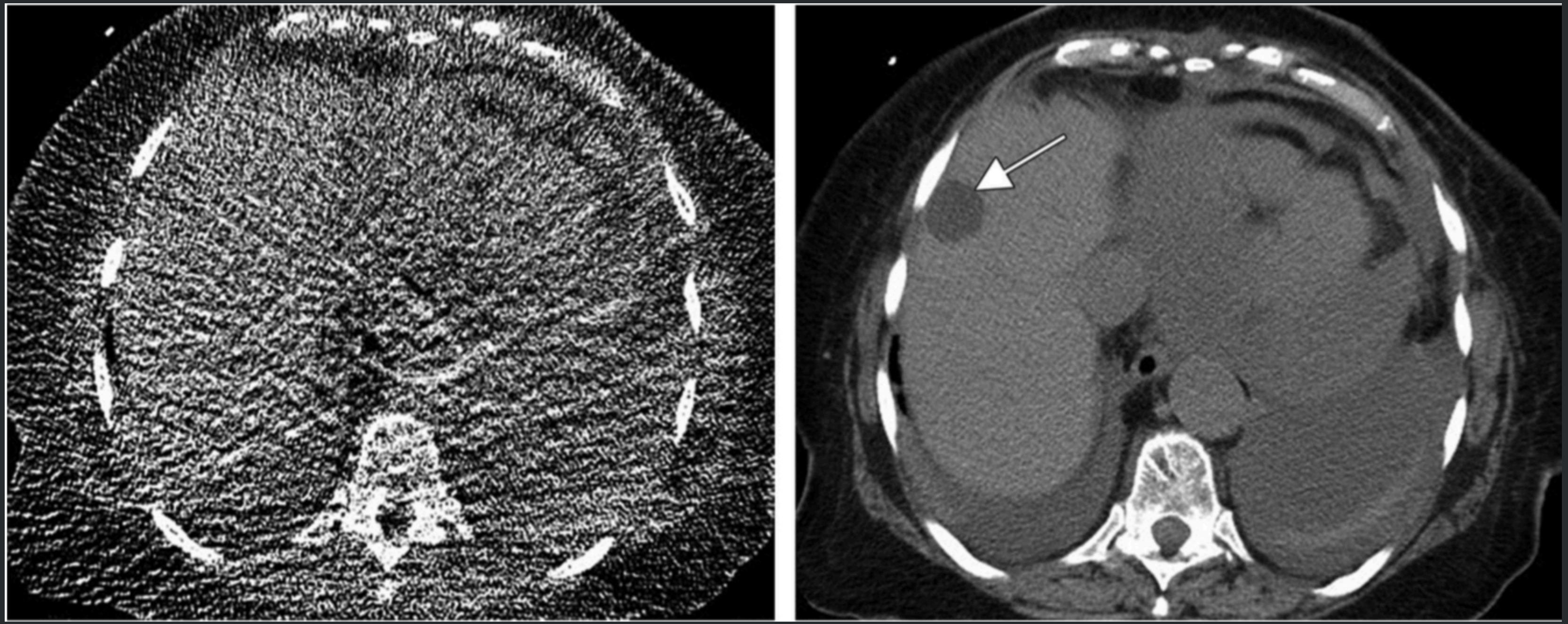

Radiation output depends on

1. Generator power
   - Ranges from 50-100 kW
2. Technique selection

Fursevich, Dzmitry M., Gary M. LiMarzi, Matthew C. O'Dell, Manuel A. Hernandez, and William F. Sensakovic. "Bariatric CT Imaging: Challenges and Solutions." *RadioGraphics* 36, no. 4 (May 27, 2016): 1076–86. doi:10.1148/rg.2016150198.

Technique Tips:
How to Increase Tube Output

Tube Current	Rotation Time	Pitch	kV
↑	↑	↓	↑

For BMI >40, increase tube potential to 140 kV

Improve image noise with increased thickness & iterative reconstruction

Slide from Mannudeep Kalra, *CT in Obesity: Tips and Tricks.* 3rd CT Dose Summit, 2013

Technique Tips:
Use AEC with Care!

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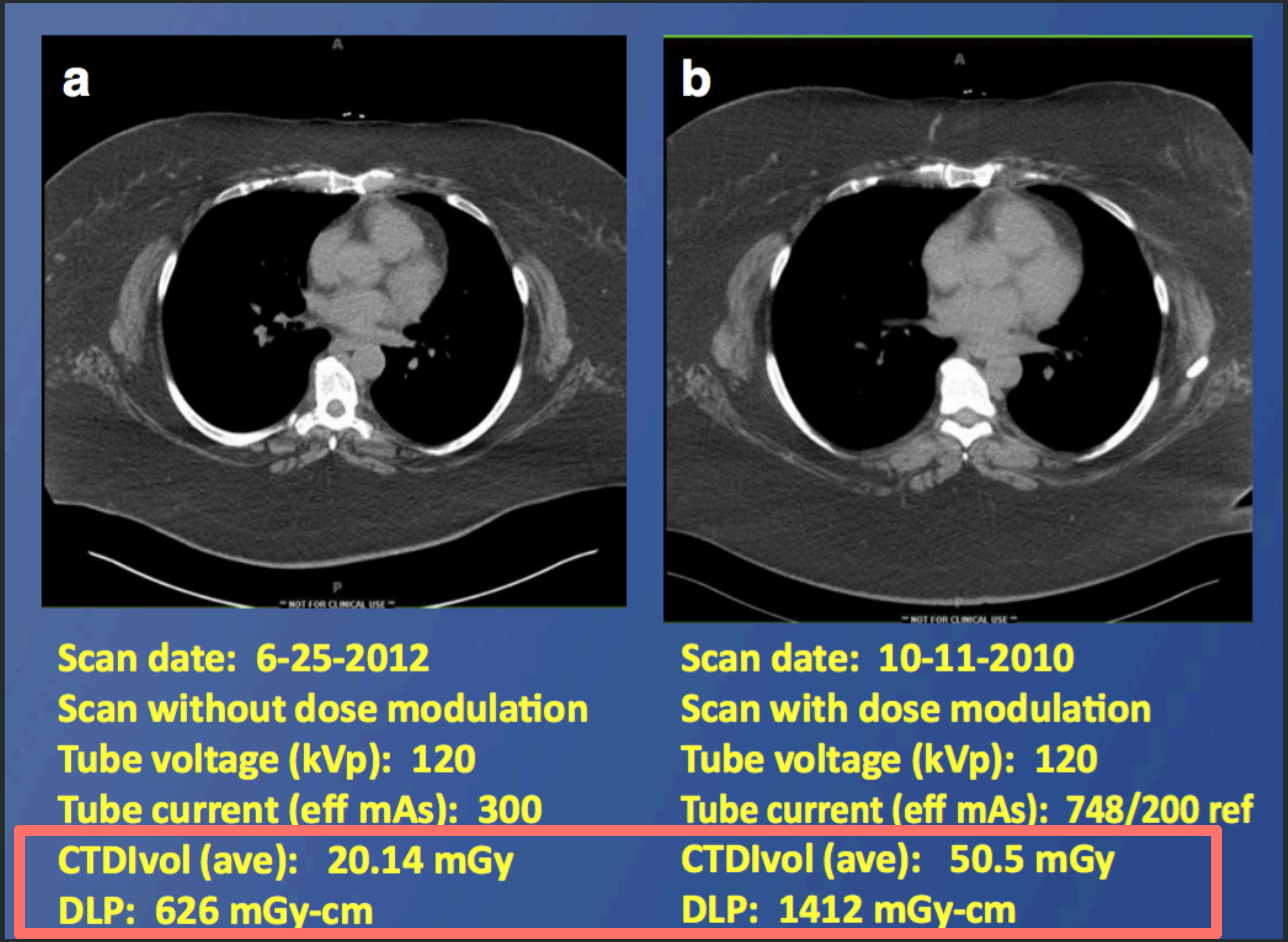
- Review maximum tube current for bariactric protocols
- Manual techniques may be adequate



Mahesh, Mahadevappa, and Elliot K. Fishman. "CT Dose Reduction Strategy: To Modulate Dose or Not in Certain Patients?" *Journal of the American College of Radiology* 9, no. 12 (December 1, 2012): 931–32. doi:10.1016/j.jacr.2012.09.021.

Unique to Bariatric Imaging: Dose Distribution

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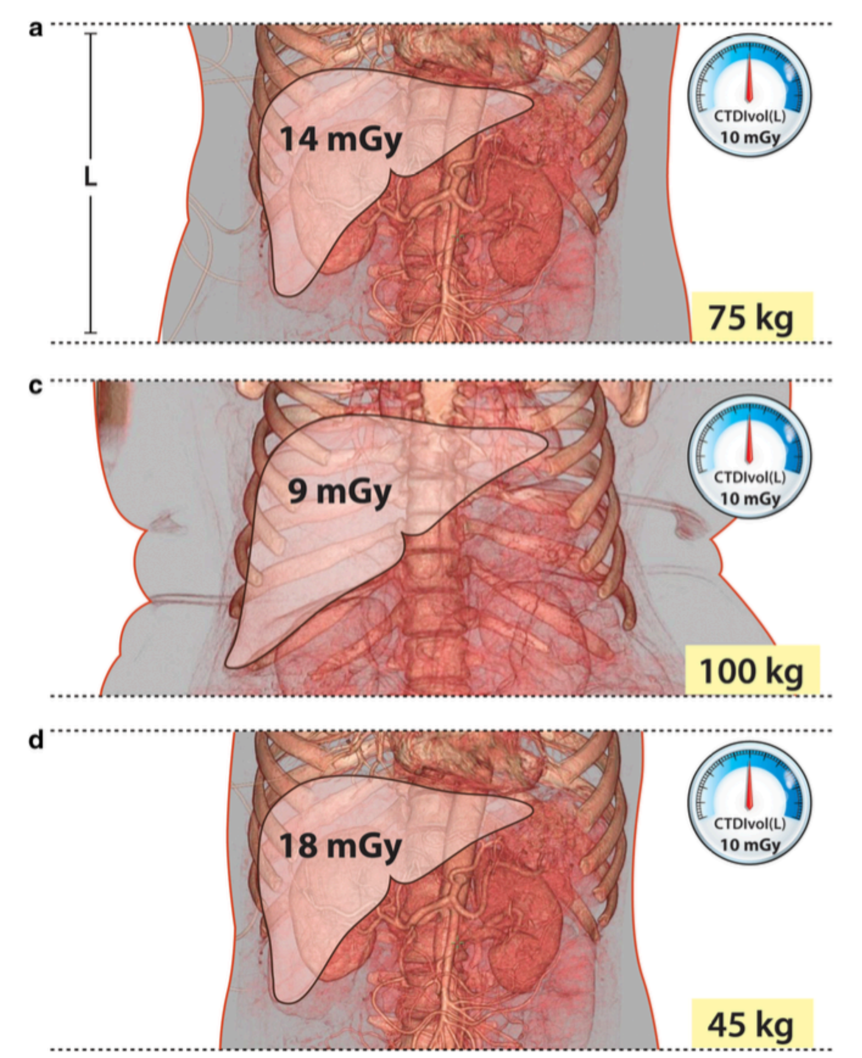
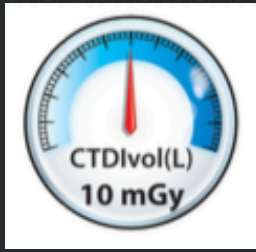




- Decreased radiation dose to internal organs
- Increased radiation dose to skin, breast tissue, and thyroid

Deak, Paul, Marcel van Straten, Paul C. Shrimpton, Maria Zankl, and Willi A. Kalender. "Validation of a Monte Carlo Tool for Patient-Specific Dose Simulations in Multi-Slice Computed Tomography." *European Radiology* 18, no. 4 (April 1, 2008): 759–72. doi:10.1007/s00330-007-0815-7.

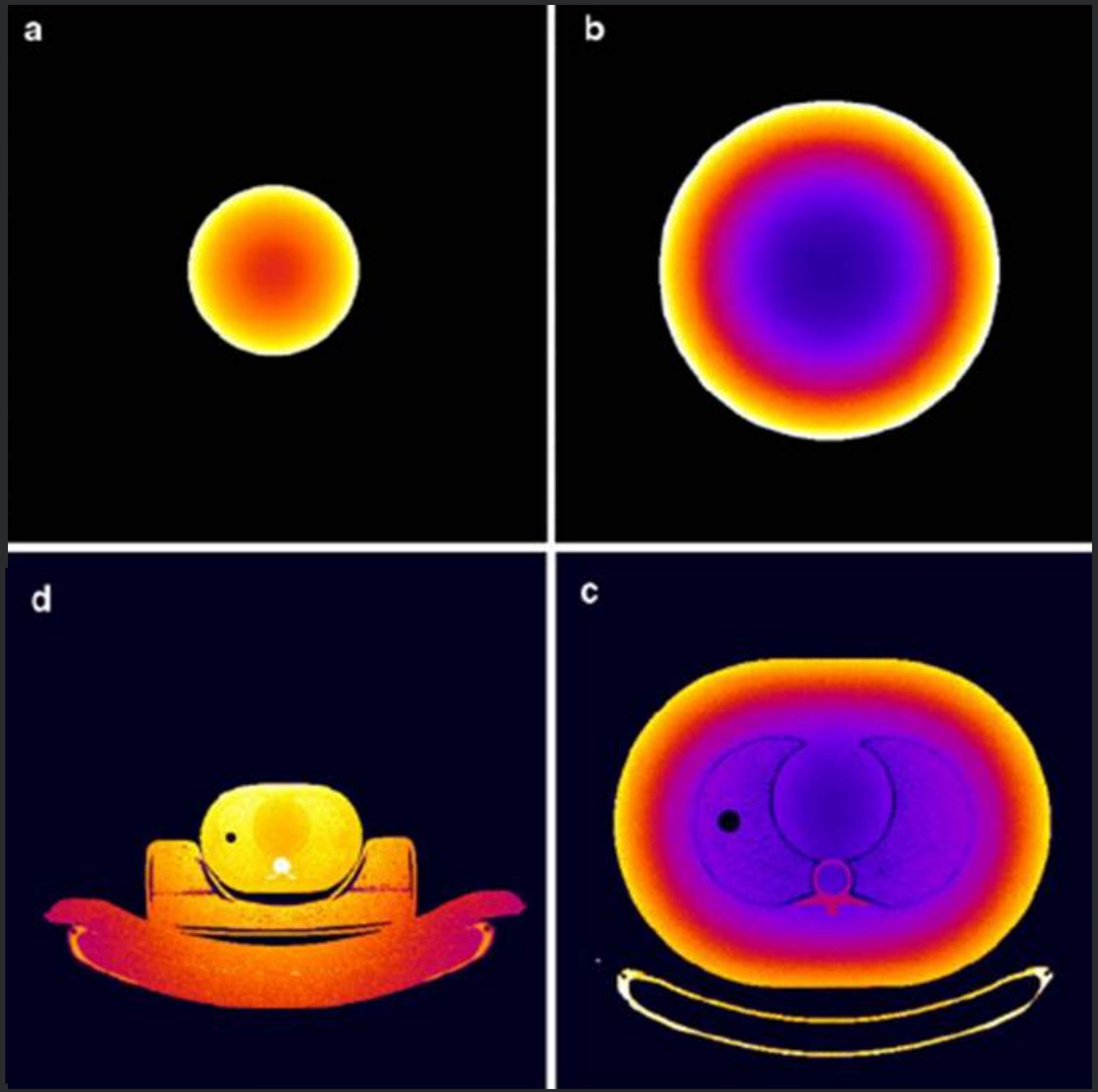
Huda, W. CT Radiation Exposure: An Overview. Curr Radiol Rep (2015) 3:80 [Fig 5]

TG204:
The Size-Specific Dose Estimate

The same CT output results in different dose distributions

Useful for

- Prospective evaluation of CT technique
- Size-specific protocol development



Deak, et al. "Validation of a Monte Carlo Tool for Patient-Specific Dose Simulations in Multi-Slice Computed Tomography." *European Radiology* 18, no. 4 (April 1, 2008): 759–72.

Outline

I. Image Gently/Wisely and Choose Wisely
   a. Image Wisely
      1. Description of coalition and goals
      2. Educational material
   b. Image Gently
   c. Choosing Wisely

Image Wisely: Coalition & Goals

Image Wisely offers resources and information to radiologists, medical physicists, other imaging practitioners, and patients to:

1. Lower the amount of radiation used in medically necessary imaging studies
2. Eliminate unnecessary procedures

Image Wisely: Educational Material

Children's National

Outline

Children's National™

I. Image Gently/Wisely and Choose Wisely
   a. Image Wisely
   b. Image Gently
      1. Description of alliance and goals
      2. Educational material
   c. Choosing Wisely

Image Gently: Alliance & Goals

Children's National™

- To change practice by raising awareness of the opportunities to lower radiation dose in the imaging of children via information and free educational materials to every member of the care team.

Image Gently: Scope & Reach

The Image Gently Alliance: How far we have come together!

2008 –

- 13 Alliance Organizations reaching ~ 400,000
- 200 pledges on the Campaign's 1st day

2015 –

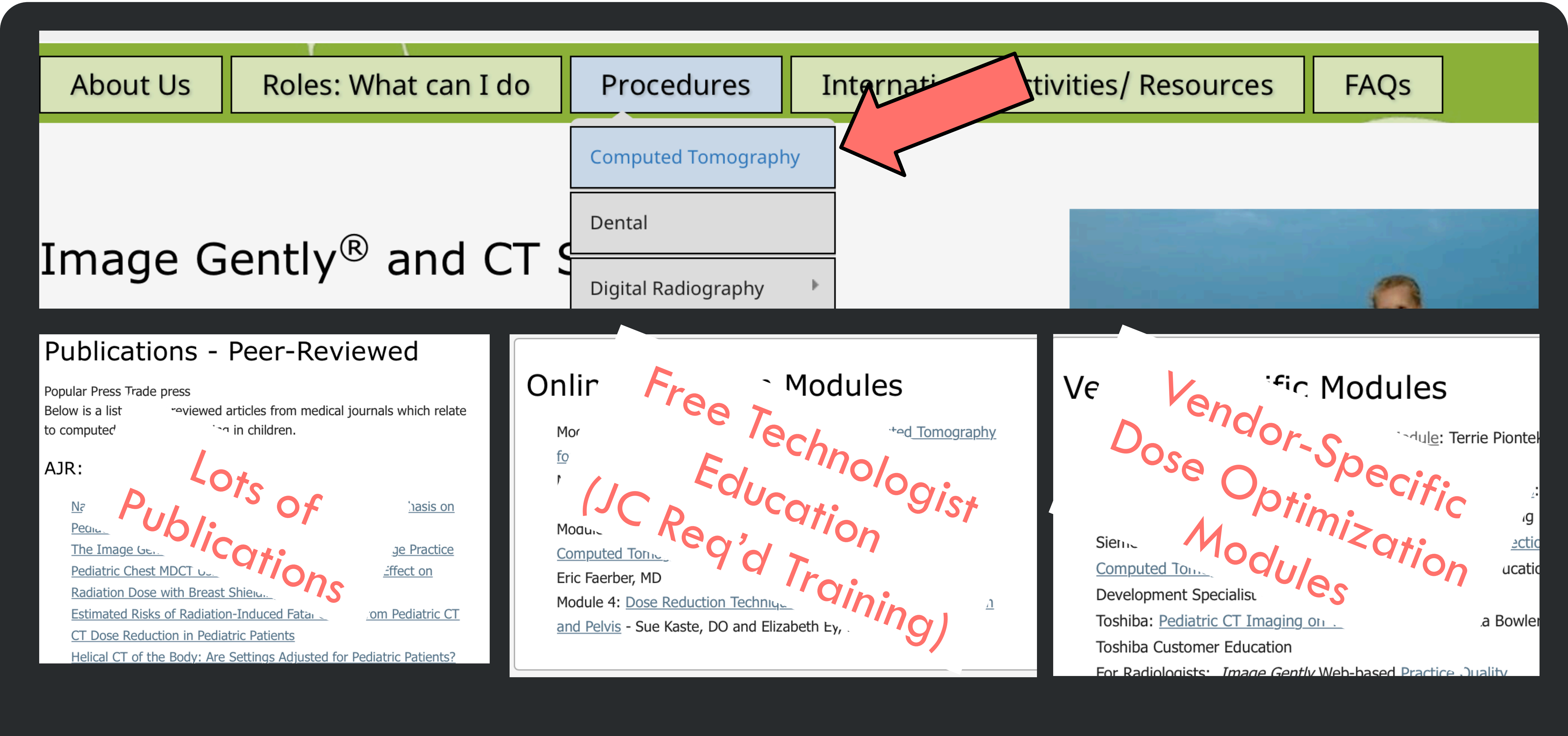
- 91 Alliance Organizations – reaching millions
- ~35,000 pledges to date

Thanks to the Founding Organizations representing the members of the Image Team: SPR, ACR, ASRT and AAPM

http://www.imagegently.org/portals/6/Banner/2Noras.png

Image Gently: Educational Material

Children's National™



Outline

Children's National ™

I. Image Gently/Wisely and Choose Wisely
   a. Image Wisely
   b. Image Gently
   c. Choosing Wisely
      1. Description of foundation and goals
      2. Resources

Choosing Wisely: Appropriateness Criteria & Decision support

Children's National™

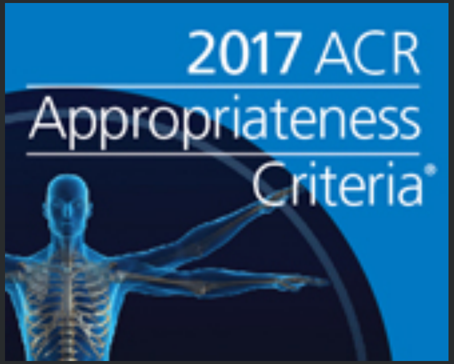
To promote conversations between clinicians and patients by helping patients choose care that is:

- Supported by evidence
- Not duplicative of other tests or procedures already received
- Free from harm
- Truly necessary

Choosing Wisely®

An initiative of the ABIM Foundation

Choosing Wisely:
ACR Recommendations



Ever-growing list of indications

- Narrative & Rating Table
- Evidence Table
- Literature Search

1 **Don't do imaging for uncomplicated headache.**

Imaging headache patients absent specific risk factors for structural disease is not likely to change management or improve outcome. Those patients with a significant likelihood of structural disease requiring immediate attention are detected by clinical screens that have been validated in many settings. Many studies and clinical practice guidelines concur. Also, incidental findings lead to additional medical procedures and expense that do not improve patient well-being.

2 **Don't image for suspected pulmonary embolism (PE) without moderate or high pre-test probability of PE.**

While deep vein thrombosis (DVT) and PE are relatively common clinically, they are rare in the absence of elevated blood d-Dimer levels and certain specific risk factors. Imaging, particularly computed tomography (CT) pulmonary angiography, is a rapid, accurate and widely available test, but has limited value in patients who are very unlikely, based on serum and clinical criteria, to have significant value. Imaging is helpful to confirm or exclude PE only for such patients, not for patients with low pre-test probability of PE.

3 **Avoid admission or preoperative chest x-rays for ambulatory patients with unremarkable history and physical exam.**

Performing routine admission or preoperative chest x-rays is not recommended for ambulatory patients without specific reasons suggested by the history and/or physical examination findings. Only 2 percent of such images lead to a change in management. Obtaining a chest radiograph is reasonable if acute cardiopulmonary disease is suspected or there is a history of chronic stable cardiopulmonary disease in a patient older than age 70 who has not had chest radiography within six months.

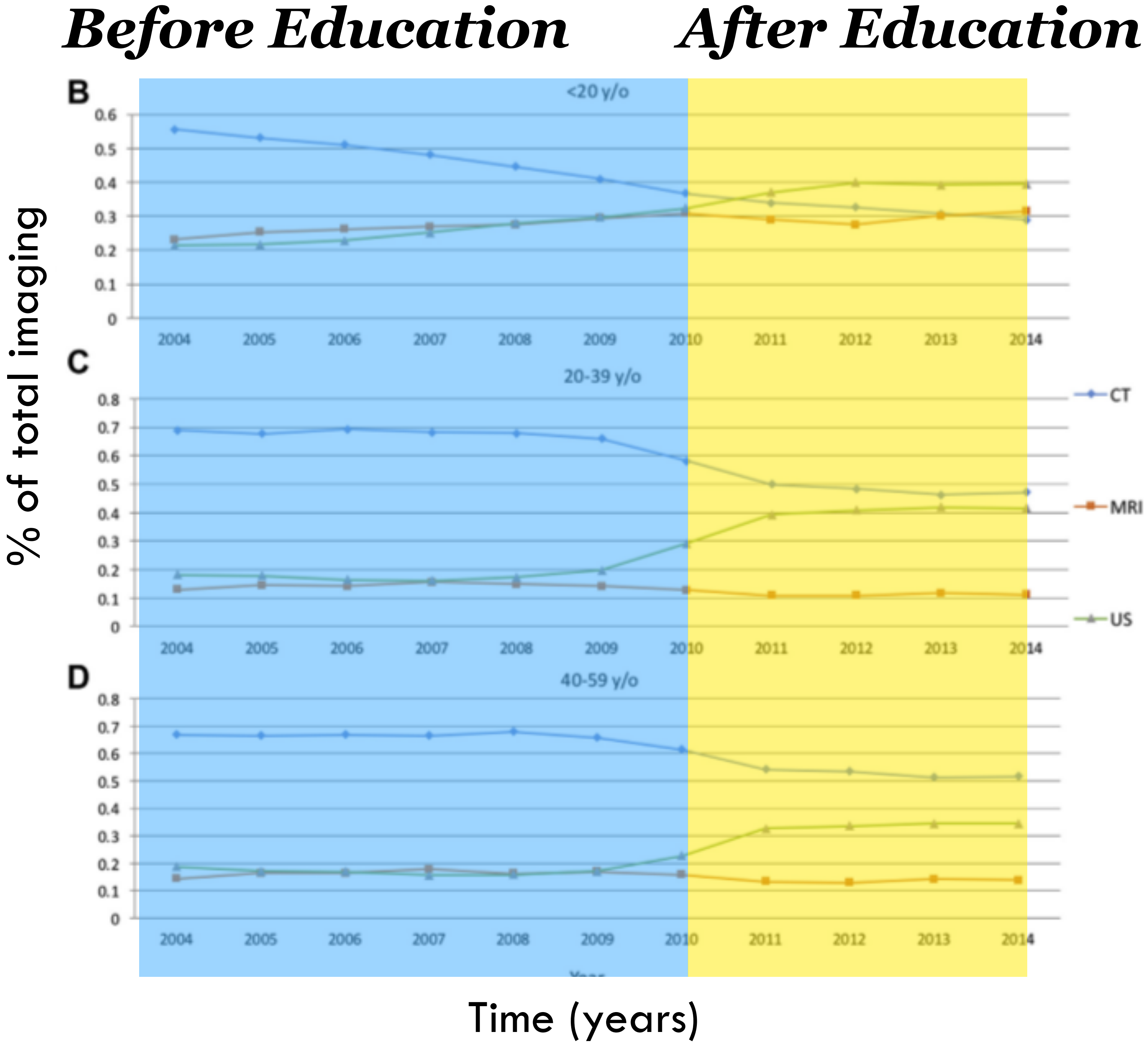
4 **Don't do computed tomography (CT) for the evaluation of suspected appendicitis in children until after ultrasound has been considered as an option.**

Although CT is accurate in the evaluation of suspected appendicitis in the pediatric population, ultrasound is nearly as good in experienced hands. Since ultrasound will reduce radiation exposure, ultrasound is the preferred initial consideration for imaging examination in children. If the results of the ultrasound exam are equivocal, it may be followed by CT. This approach is cost-effective, reduces potential radiation risks and has excellent accuracy, with reported sensitivity and specificity of 94 percent.

5 **Don't recommend follow-up imaging for clinically inconsequential adnexal cysts.**

Simple cysts and hemorrhagic cysts in women of reproductive age are almost always physiologic. Small simple cysts in postmenopausal women are common, and clinically inconsequential. Ovarian cancer, while typically cystic, does not arise from these benign-appearing cysts. After a good quality ultrasound in women of reproductive age, don't recommend follow-up for a classic corpus luteum or simple cyst <5 cm in greatest diameter. Use 1 cm as a threshold for simple cysts in postmenopausal women.

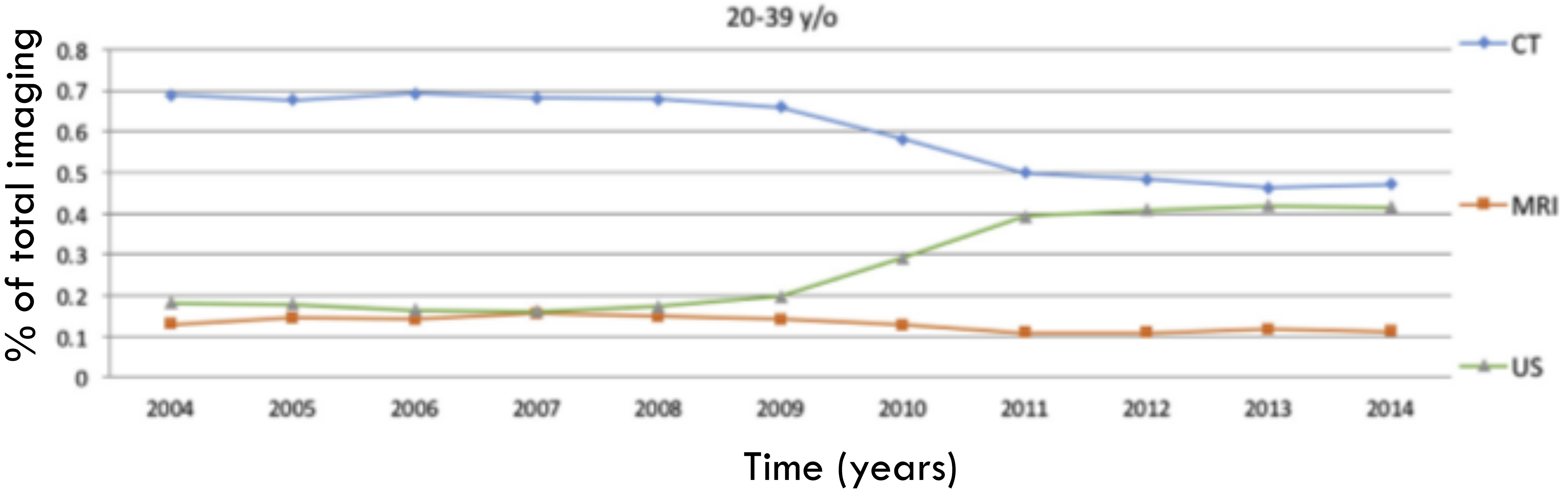
What happens with Gently/ Wisely education?



Fernandes, Kevin, Terry L. Levin, Todd Miller, Alan H. Schoenfeld, and E. Stephen Amis. "Evaluating an Image Gently and Image Wisely Campaign in a Multihospital Health Care System." *Journal of the American College of Radiology* 13, no. 8 (August 1, 2016): 1010–17. doi:10.1016/j.jacr.2016.04.025.

What happens with Gently/Wisely education?

Before Education ***After Education***



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Thank You


https://ce4rt.com/images/pigg-o-stat1.jpg


“When Zoos Refuse: Obese Patients Face Shortage of Large-Capacity Scanners.” *AuntMinnie.Com*, n.d. http://www.auntminnie.com/index.aspx?sec=ser&sub=def&pag=dis&ItemID=82543.