Pediatric CT Protocol Development

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UCDAVIS

Disclosures

No disclosures

https://goo.gl/kyfUxf

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Outline: Pediatric CT Protocol Development

https://goo.gl/kyfUxf

I. Challenges

II. Unique to pediatrics

III. Protocol Development & Optimization Tips

IV. Resources

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Pediatric considerations

https://goo.gl/kytuxt

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

II. Unique to pediatrics

III. Protocol Development & Optimization Tips

IV. Resources

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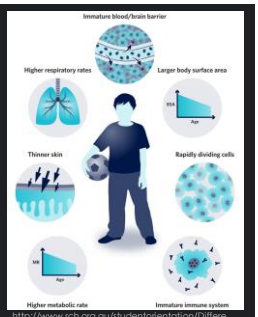
Pediatrics & Adults are Physiologically Different

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

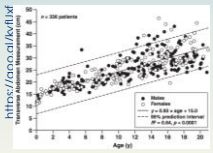
Cristina Dodge, *Optimizing Pediatric CT in the ED*. AAPM Annual Meeting, 2016



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

Challenges to Pediatric Imaging: Anatomic & Physiologic Features

Wide spectrum of patient sizes



https://doi.org/10.2214/ajr.09.3771

Kleinman, P. L., et al. "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

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Challenges to Pediatric Imaging: The "Uncooperative Patient"

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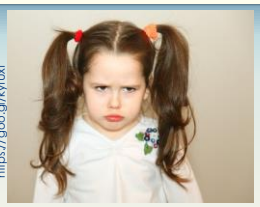

- Highly expressive
- Mistrust of health professionals
- Limited communication abilities
- Limited concentration & control

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

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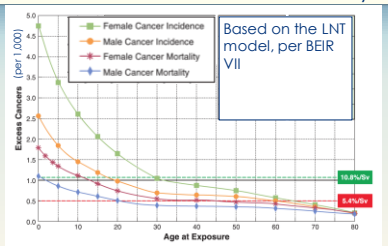
Challenges to Pediatric Imaging: Radiation Sensitivity

https://goo.gl/kyfUxf



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.

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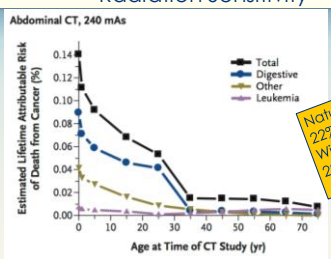
Challenges to Pediatric Imaging: Radiation Sensitivity

https://goo.gl/kyfUxf



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

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

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Radiation Sensitivity: Carcinogenesis Risk for Children vs. Adults

https://goo.gl/kyfUxf

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.

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Radiation Sensitivity: UNSCEAR 2013 Annex B

https://goo.gl/kyfUxf

Not enough sufficient data for cancer of…

- Kidney
- Myeloma
- Non-Hodgkin's lymphon
- 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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Radiation Sensitivity: UNSCEAR 2013 Annex B

https://goo.gl/kyfUxf

Prioritize efforts to reduce dose to …

- Breast
- Brain
- Thyroid
- Leukemia

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Pediatric considerations

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I. Challenges

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

III. Protocol Development & Optimization Tips

IV. Resources

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Unique to Pediatrics: Specialized Protocols

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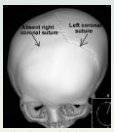
Ultra low-dose CT for boney congenital disease

- Craniosynostosis
- Pectus excavatum



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

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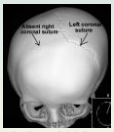
Unique to Pediatrics: Specialized Protocols

https://goo.gl/kyfUxf

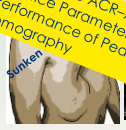
Ultra low-dose CT for boney congenital disease

- Craniosynostosis
- 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

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Unique to Pediatrics: Patient Comfort

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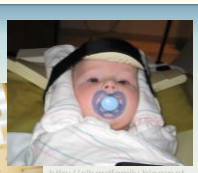
Cooperation requires patience and age-appropriate…

- Education
- Communication
- Distraction tools
- Patient restraints

Improved with Child Life Specialists

https://amicus.radiology.com/media/cms-site/images/brand-images/diagnostic-imaging-and-radiology-18305.ashx?h=800&la=en&w=1200



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

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Unique to Pediatrics: Use of Shielding

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.

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Pediatric considerations

https://goo.gl/kyfUxf

I. Challenges

II. Unique to pediatrics

III. Protocol Development & Optimization Tips
   a. General considerations
   b. Variable patient size
   c. AD's, DRR's & DRL's

I. Resources

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Why bother?

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Dedicated pediatric facilities consistently out perform adult facilities:

- SSDE is 65% less
- Higher concordance w/ final diagnosis

	n (%)		P-value[a]
	CH scans	OSI scans	
Size-specific dose estimate (SSDE) (median, IQR)[b]	8.68 (6.44, 15.0), n = 48	13.29 (8.33, 15.6), n = 42	0.03
Anatomical coverage			
Insufficient	0 (0%)	1/50 (2%)	<0.001
Sufficient	45/50 (90%)	29/50 (58%)	
Over-coverage	5/50 (10%)	20/50 (40%)	
Thin-section images sufficient for multiplanar reconstruction provided			
Yes	50/50 (100%)	47/50 (94%)	0.08
No	0 (0%)	3/50 (6%)	
Optimal phases			
Yes	47 (94%)	44 (88%)	0.32
No	3 (6%)	6 (12%)	
Unnecessary phases performed			
Yes	1 (2%)	1 (2%)	0.99
No	49 (98%)	49 (98%)	
IV contrast agent administered	46 (92%)	43 (86%)	0.48
IV contrast agent indicated (n = 89)	46/46 (100%)	43/43 (100%)	0.99
Oral contrast agent administered	13 (26%)	31 (62%)	0.002
Oral contrast agent indicated (n = 44)	13/13 (100%)	8/31 (26%)	0.05

CH children's hospital, *IQR* interquartile range, *IV* intravenous, *OSI* outside institution, *SD* standard deviation

[a] *P*-value from Cochran Mantel-Haenzel test accounting for matched pairs unless otherwise noted; $P < 0.05$ was used to determine statistical significance

[b] *P*-value from signed rank test

Snow, Aisling, et al. "Quality of Pediatric Abdominal CT Scans Performed at a Dedicated Children's Hospital and Its Referring Institutions: A Multifactorial Evaluation." *Pediatric Radiology* 47, no. 4 (April 1, 2017): 391–97. https://doi.org/10.1007/s00247-016-3768-7.

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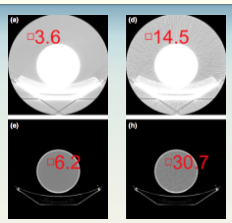
Evaluating Image Noise

https://goo.gl/kyfUxf



- Protocol optimization must be based on image quality.
- Ideally the metric is independent of patient size & condition

Malkus, Annelise, and Timothy P. Szczykutowicz. "A Method to Extract Image Noise Level from Patient Images in CT." *Medical Physics* 44, no. 6 (2017): 2173–84. https://doi.org/10.1002/mp.12240.

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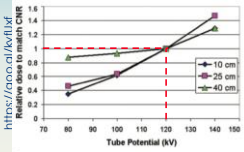
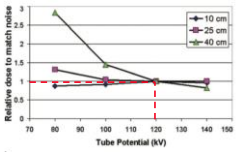
General Considerations: When to Reduce Tube Potential

https://goo.gl/kyfUxf

Lower kV lowers dose at matched iodine CNR



Lower kV <u>may</u> decrease dose at matched noise levels



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.

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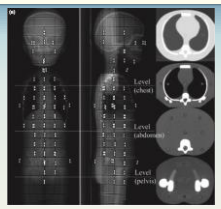
Tube Potential & TCM: Modest Dose Reductions

https://goo.gl/kyfUxf

Relative effective dose (mSv) for Chest CT

	80 kV	100 kV	120 kV
New born	88%	96%	100%
1 yo	75%	91%	100%
5 yo	81%	91%	100%



Masuda, Takanori, et al. "Relationship between the Radiation Doses at Nonenhanced CT Studies Using Different Tube Voltages and Automatic Tube Current Modulation during Anthropomorphic Phantoms of Young Children." *Journal of Applied Clinical Medical Physics* 18, no. 6 (n.d.): 232–43. https://doi.org/10.1002/acm2.12192.

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General Considerations: Tube Potential, Educate Before You Implement!

https://goo.gl/kyfUxf

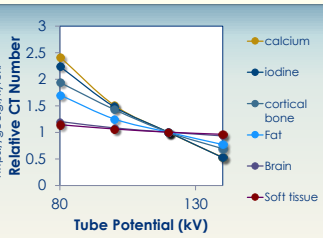

Table 2 Hounsfield Unit values as a function of CT X-ray tube voltages (kV) (Relative HU values normalized to unity at 120 kV)

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

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

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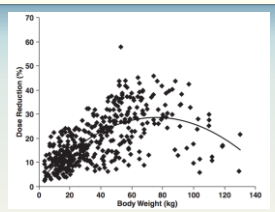
General Considerations: When to Use AEC & TCM

https://goo.gl/kyfUxf

Automatic Exposure Control (AEC) & Tube Current Modulation (TCM)

- Greater dose savings for mid-sized patients
- Greatest gains if AEC adapts 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.

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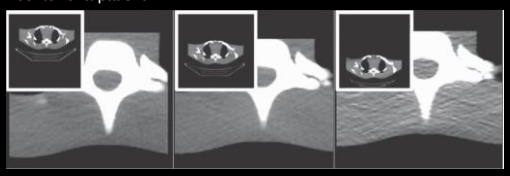
General Considerations: Appropriate Bow Tie Filter & Patient Positioning

- 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.

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General Considerations: Methods to Reduce Scan time & Maintain Image Quality

https://goo.gl/kyfUxf

Collimation	Rotation Time	Pitch	Tube Current
↑	↓	↑	↑

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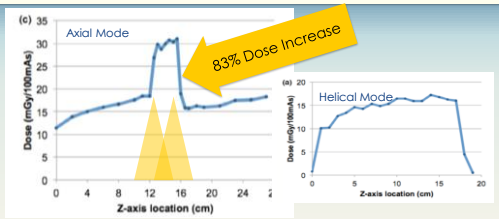
General Considerations: What About > 40 mm Beam Widths?

https://goo.gl/kyfUxf



Lambert, J. W., et al. "Axial or Helical? Considerations for Wide Collimation CT Scanners Capable of Volumetric Imaging in Both Modes." *Medical Physics* 44, no. 11 (2017): 5718–25. https://doi.org/10.1002/mp.12525.

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General Considerations: Iterative Reconstruction

https://goo.gl/kyfUxf

Table 2: Original and dose-reduced $CTDI_{vol}$ and noise values for all head protocols

Patient Age Category	Protocol	$CTDI_{vol}$ (mGy) Original	Dose-Reduced	Difference	Noise Difference
0–23 mo	Brain	15.0 ± 0.7	8.0 ± 0.4	−47%	−3%
2–5 yr	Brain	24.1 ± 0.9	14.6 ± 0.6	−39%	−3%
6–10 yr	Brain	26.3 ± 1.3	15.9 ± 0.4	−40%	4%
11–18 yr	Brain	29.1 ± 0.9	17.0 ± 0.5	−42%	3%
≥ 19 yr	Brain	36.6 ± 0.8	18.9 ± 0.5	−48%	3%
0–18 yr	Maxilla	19.4 ± 0.0	11.5 ± 0.1	−41%	3%
≥19 yr	Maxilla	22.8 ± 0.0	18.7 ± 0.2	−18%	−3%
0–18 yr	Orbits	26.9 ± 8.0	15.8 ± 0.5	−41%	−4%
0–18 yr	Sinus	13.1 ± 0.0	7.2 ± 0.3	−45%	5%
≥19 yr	Sinus	22.8 ± 0.0	13.7 ± 0.1	−40%	−1%
2–18 yr	Temporal	40.7 ± 0.0	22.8 ± 0.0	−44%	−2%
≥19 yr[a]	Temporal	49.9 ± 0.0	29.7 ± 0.0	−40%	

On average…

- 40% reduction in CTDI
- 0.2% reduction in phantom noise

Mirro, A. E., et al. "Full Dose-Reduction Potential of Statistical Iterative Reconstruction for Head CT Protocols in a Predominantly Pediatric Population." *American Journal of Neuroradiology* 37, no. 7 (July 1, 2016): 1199–1205. https://doi.org/10.3174/ajnr.A4754.

Seibert, James Anthony. "Iterative Reconstruction: How It Works, How to Apply It." *Pediatric Radiology* 44, no. 3 (October 1, 2014): 431–39. https://doi.org/10.1007/s00247-014-3102-1.

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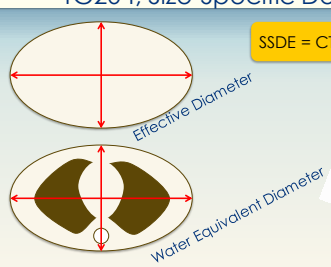
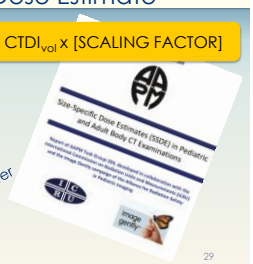
Scaling Radiation Output: TG204, Size-Specific Dose Estimate

https://goo.gl/kyfUxf



SSDE = $CTDI_{vol}$ x [SCALING FACTOR]



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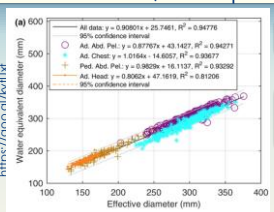
Scaling Radiation Output: TG204, Size-Specific Dose Estimate

https://goo.gl/kyfUxf



SSDE = $CTDI_{vol}$ x [SCALING FACTOR]

Effective diameter is highly correlated to water equivalent diameter

Burton, Christiane S., and Timothy P. Szczykutowicz. "Evaluation of AAPM Reports 204 and 220: Estimation of Effective Diameter, Water-Equivalent Diameter, and Ellipticity Ratios for Chest, Abdomen, Pelvis, and Head CT Scans." *Journal of Applied Clinical Medical Physics* 19, no. 1 (2017): 228–38. https://doi.org/10.1002/acm2.12223.

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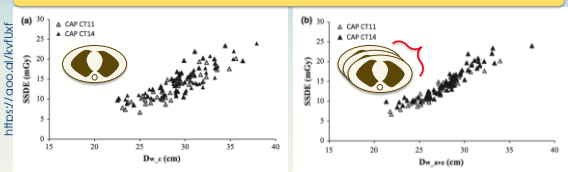
Scaling Radiation Output: TG204, Size-Specific Dose Estimate

Ave. water equivalent diameter is more strongly correlated to SSDE

https://goo.gl/kyfUxf



Sarmento, Sandra, Bruno Mendes, and Margarida Gouvêa. "Automatic Calculation of Patient Size Metrics in Computed Tomography: What Level of Computational Accuracy Do We Need?" *Journal of Applied Clinical Medical Physics* 19, no. 1 (n.d.): 218–27. https://doi.org/10.1002/acm2.12240.

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Binning Pediatric Protocols

https://goo.gl/kyfUxf

- Head: Age
  - 0 - 1 yr
  - 1 – 2 yr
  - 2 – 6 yr
  - 6 – 16 yr
  - 16 yr+
- Body: Effective Diameter
  - 7 – 13 cm
  - 14 – 16 cm
  - 17 – 22 cm
  - 23 – 27 cm
  - 28 – 32 cm

https://www.aapm.org/pubs/CTProtocols/

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

https://goo.gl/kyfUxf

Metric	Definition	How to use
Achievable Dose (AD)	Median Dose	Sanity check
Dose Reference Level (DRL)	75th Percentile	Review exams that are over-dosed
Dose Reference Ranges (DRR)	25th - 75th Percentile	Review exams that are over/under dosed

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Chest CT:
AD's, DRR's, & DRL's

https://goo.gl/kyfUxf

Distribution of SSDEs with 32-cm CTDI Phantom

Effective Diameter (cm)	No. of Examinations	AD (DRR) Median (mGy)*
<15	20	2.1 (1.8–3.9)
15–19	147	3.0 (2.2–4.5
20–24	165	3.4 (2.7–5.1)
25–29	134	4.7 (3.6–6.6)
≥30	52	6.3 (5.5–8.4)

* 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.

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Abdomen CT:
AD's, DRR's, & DRL's

Distribution of SSDE

BW Group	No. of Scans	Lower DRR, 25th Percentile	Median, 50th Percentile	Upper DRR, 75th Percentile
<15 cm	21	5.8	8.0	12.0
15–19 cm	153	7.3	8.7	12.2
20–24 cm	286	7.6	9.8	13.4
25–29 cm	326	9.8	13.0	16.4
≥30 cm	168	13.1	15.6	19.0

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.

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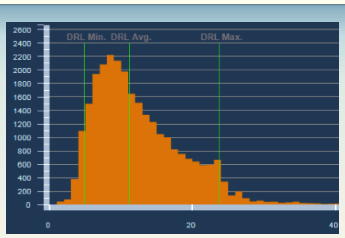
Building DRL's In-House

https://goo.gl/kyfUxf



For each binned demographic…

1. Collect patient data
2. Identify 95th percentile dose metric
3. Add a 10% buffer

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Pediatric considerations

https://goo.gl/kyfUxf

I. Challenges

II. Unique to pediatrics

III. Protocol Development & Optimization Tips

I. Resources
   I. AAPM CT Protocols
   II. Image Gently

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Baseline Pediatric Protocols

https://goo.gl/kyfUxf

Protocols for a spectrum of CT makes & models

http://www.aapm.org/pubs/CTProtocols/

- Head
- Chest
- Abdomen/Pelvis

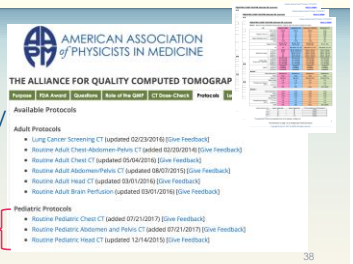

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Image Gently: Pediatric Protocol Generation Tools

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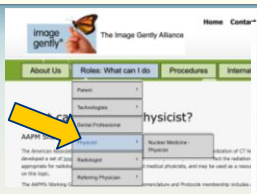

Abdomen:	kVp	mA	Time (sec)	Pitch Abdomen	Pitch Thorax
	fill in	fill in	fill in	fill in	fill in
		Abdomen		Thorax	
PA Thickness (cm)	Approx Age	mAs Reduction Factor (RF)	Estimated mAs = BL x RF	mAs Reduction Factor (RF)	Estimated mAs = BL x RF
9	newborn	0.43	#VALUE!	0.42	#VALUE!
12	1 yr	0.51	#VALUE!	0.49	#VALUE!
14	5 yr	0.59	#VALUE!	0.57	#VALUE!
16	10 yr	0.66	#VALUE!	0.64	#VALUE!
19	15 yr	0.76	#VALUE!	0.73	#VALUE!
22	small	0.90	#VALUE!	0.82	#VALUE!
25	med adult	1.0	fill in	0.91	#VALUE!
31	large	1.27	#VALUE!	1.16	#VALUE!

Strauss, Keith J. "Developing Patient-Specific Dose Protocols for a CT Scanner and Exam Using Diagnostic Reference Levels." *Pediatric Radiology* 44, no. 3 (October 1, 2014): 479–88. https://doi.org/10.1007/s00247-014-3088-8.

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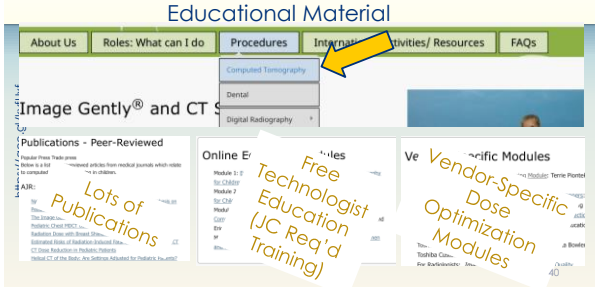
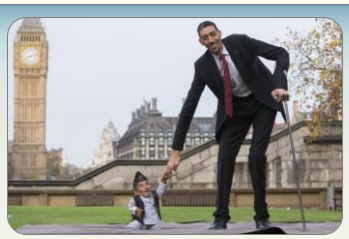
Image Gently: Educational Material



Thank You

https://goo.gl/kyfUxf



https://cdn.cnn.com/cnnnext/dam/assets/141113124808-01-shortest-tallest-man-horizontal-large-gallery.jpg

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