Personalization of Pediatric Imaging in Terms of Needed <u>Indication-Based</u> Quality Per Dose

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MEDPHYS 3.0

Acknowledgments

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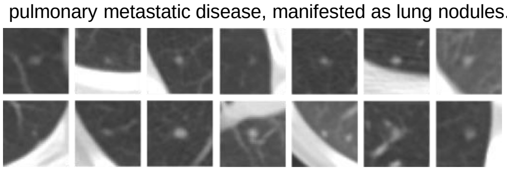
Ehsan Samei, PhD
Donald Frush, MD

A Specific Diagnostic Task:
<u>Lung Nodule Detection</u>

Children with (extra-thoracic) solid tumors are at risk for pulmonary metastatic disease, manifested as lung nodules.



- Small size (3-5 mm)
- low contrast (200-500 HU)

A Specific Diagnostic Task:
<u>Lung Nodule Detection</u>

- Presence of a single nodule affects treatment plan and prognosis
- Chest CT to screen for <u>lung nodules</u> at
  - > initial evaluation
  - > throughout treatment
  - > during routine follow-up
- Many CT scans!
- Curable cancers → long life expectancy

} require low dose

- Small size (3-5 mm)
- low contrast (200-500 HU)
- Easily missed under high-noise conditions

} require high dose

Chest CT Protocols

GE LightSpeed VCT scanner

Protocol	Mean Age (year)	kVp	Scan FOV	Slice Thickness (mm)	Collimation (mm)	Pitch	Noise Index	Max mA
pink	0.2	100	Ped Body	2.5	20	0.969	9.5	70
red	0.7	100	Ped Body	3.75	20	0.969	10	80
purple	1.4	100	Small Body	3.75	20	0.969	10.5	90
yellow	2.5	120	Small Body	5	20	1.375	11	70
white	4.1	120	Small Body	5	20	1.375	12	75
blue	6.2	120	Medium Body	5	20	1.375	13	80
orange	8.2	120	Medium Body	5	20	1.375	14	90
green	11.3	120	Medium Body	5	40	1.375	15	95
black	14.7	120	Large Body	5	40	1.375	16	110

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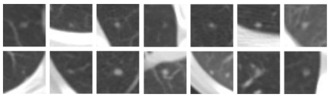
intended for general diagnostic purposes,
but not tailored to a specific task

Task



Protocols

Protocol	Mean Age (year)	kVp	Scan FOV	Slice Thickness (mm)	Collimation (mm)	Pitch	Noise Index	Max mA
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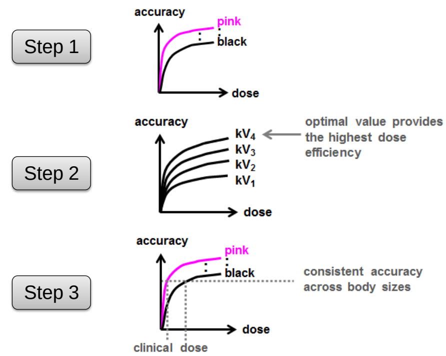
consistent diagnostic accuracy?

How to optimize for a specific task?

Protocol Optimization Framework



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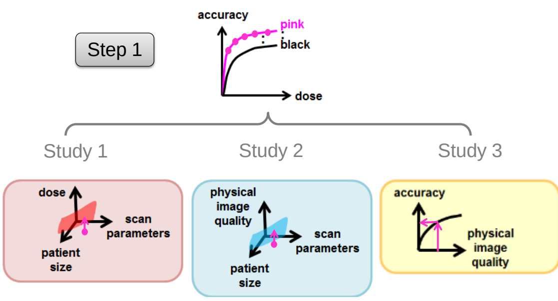
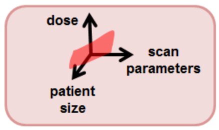




How can we obtain this relationship quicker?

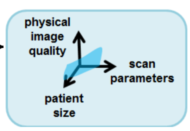
$CTDI_{vol}$ or SSDE

Monte Carlo study

$$E / DLP = \exp(\alpha_k d_{chest} + \beta_k)$$

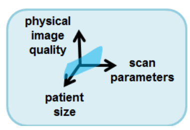
Li et al., Med Phys, 38(1), 397-407 (2011)
Li et al., Radiology, 259, 862-874 (2011)

lung nodule detection:
(1) nodule contrast
(2) nodule size
(3) noise in the lung



$\sigma = \sigma(\text{diameter, scan parameters})$ $\sigma = f(\text{noise index})$

Li X et al., Med Phys. 38(5):2609-18 (2011).
Solomon JB et al., AJR Am J Roentgenol. 200(3):592–600 (2013).



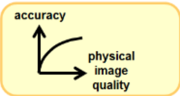
How can we obtain this relationship quicker?

Data from CT manufacturers?

AAPM TG 233:

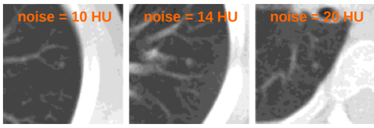
Image Quality = *f* (Diameter, Scan Parameters)

Wilson et al., Medical physics 40 (3): 031908, 2013



ROC observer study

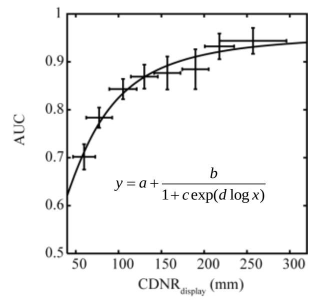
real images + simulated nodules + simulated noise

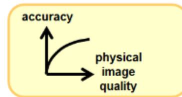


Li et al. Br J Radiol. 82(977):401-11 (2009)
Li et al. Med Phys 38(5), 2609-2618 (2011)

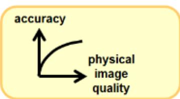
diagnostic accuracy: area under ROC curve (AUC)

image quality: $\mathrm{CDNR}_{\mathrm{display}} = \frac{\mathrm{Contrast} \times \mathrm{Displayed\ Diameter}}{\mathrm{Noise}}$





Li et al. Med Phys 38(5), 2609-2618 (2011)



How can we obtain this relationship quicker?

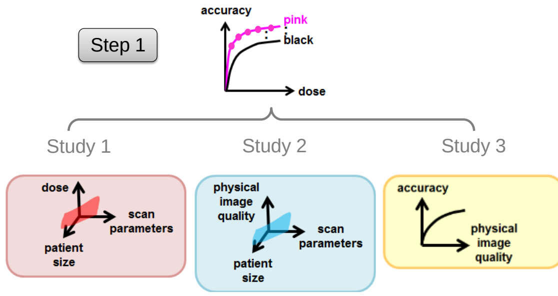
model observers

$$d'^{2}_{NPWE} = \frac{\left[\iint |W(u,v)|^2 \cdot TTF^2(u,v) \cdot E^2(u,v)\,du\,dv\right]^2}{\iint |W(u,v)|^2 \cdot TTF^2(u,v) \cdot NPS(u,v) \cdot E^4(u,v)\,du\,dv}$$

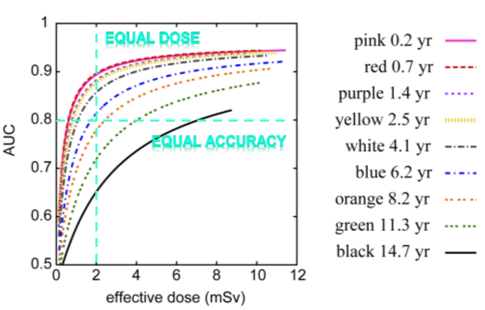
$$\lambda_{CHO} = \boldsymbol{\omega}^t_{CHO}\,\boldsymbol{g}_c$$

Yu et al., Med. Phys. 2017. doi:10.1002/mp.12380
Barrett et al. Physics in medicine and biology 60.2 (2015): R1.
Solomon et al., Proc. SPIE. Vol. 9416. 2015

Protocol Optimization Framework



Diagnostic Accuracy VS Effective Dose



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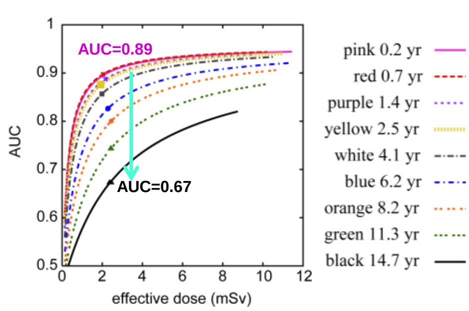

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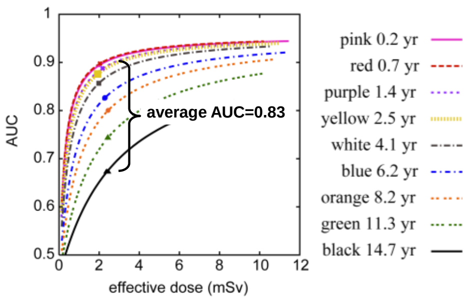

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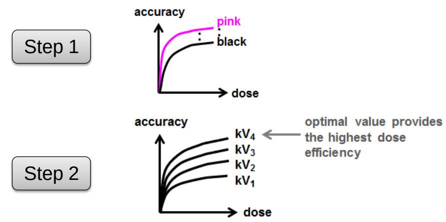
Protocol Optimization Framework



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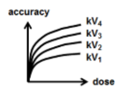
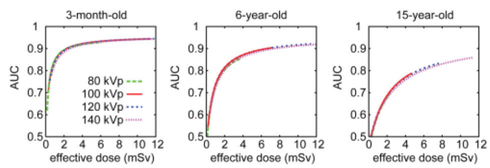
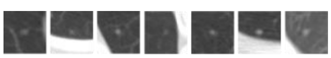
Optimize kVp







- no iodinated contrast used
- low incidence of calcification

Nodules → low-density soft tissue

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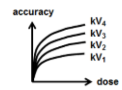
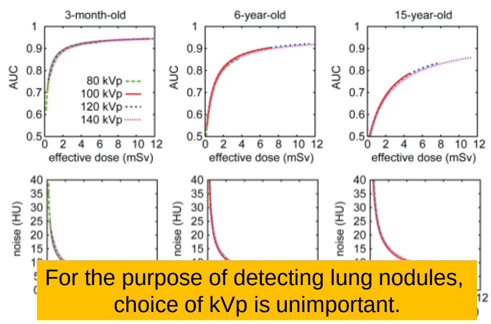
Optimize kVp





For the purpose of detecting lung nodules, choice of kVp is unimportant.

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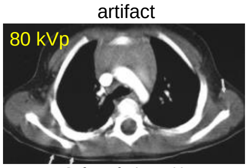
Optimize kVp

- Soft-tissue contrast is superior at a lower kVp
- How about using 80 kVp for all pediatric patients?

limitations of low kVp

require higher mA
↓ exceed system limit
increase rotation time
decrease pitch
↓
prolong scan time
↓
more motion artifact

more beam-hardening artifact



Cody et al., AJR, 2004

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Optimize kVp

category	weight (kg)	tube voltage (kVp) Singh et al.	Yu et al.	our choice
pink	5.5-7.4	80	80	80
red	7.5-9.4	80	80	80
purple	9.5-11.4	100	100	100
yellow	11.5-14.4	100	100	100
white	14.5-18.4	100	100	100
blue	18.5-23.4	100	100/120	100
orange	23.5-29.4	100/120	120	100
green	29.5-36.4	120	120	120
black	36.5-55	120	120	120

Singh et al. Radiology 2009;252(1):200-208
Yu et al. RadioGraphics 2011; 31:835–848

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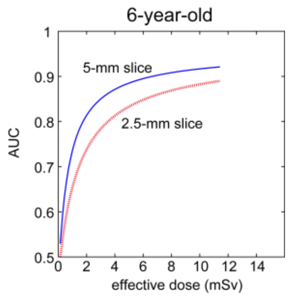
Optimize Slice Thickness

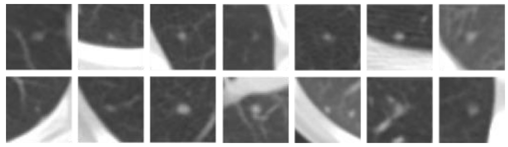
Protocol	Mean Age (year)	Slice Thickness (mm)
pink	0.2	2.5
red	0.7	3.75
purple	1.4	3.75
yellow	2.5	5
white	4.1	5
blue	6.2	5
orange	8.2	5
green	11.3	5
black	14.7	5

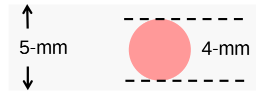
$$\sigma \propto \frac{1}{\sqrt{t}}$$



Optimize Slice Thickness

Small Size (3-5 mm)





partial volume averaging

Optimize Slice Thickness

	current		optimized
Protocol	Mean Age (year)	Slice Thickness (mm)	Slice Thickness (mm)
pink	0.2	2.5	2.5
red	0.7	3.75	3.75
purple	1.4	3.75	3.75
yellow	2.5	5	3.75
	4.1	5	3.75
blue	6.2	5	3.75
orange	8.2	5	3.75
green	11.3	5	3.75
black	14.7	5	3.75

Protocol	Mean Age (year)	kVp	Scan FOV (bowtie filter)	Slice Thickness (mm)	Collimation (mm)	Pitch
pink	0.2	80	Ped Body (s)	2.5	20	1.375
red	0.7	80	Ped Body (s)	3.75	20	1.375
purple	1.4	100	Small Body (s)	3.75	20	1.375
yellow	2.5	100	Medium Body (m)	3.75	20	1.375
	4.1	100	Medium Body (m)	3.75	20	1.375
blue	6.2	100	Medium Body (m)	3.75	20	1.375
orange	8.2	100	Medium Body (m)	3.75	20	1.375
green	11.3	120	Medium Body (m)	3.75	40	1.375
black	14.7	120	Medium Body (m)	3.75	40	1.375

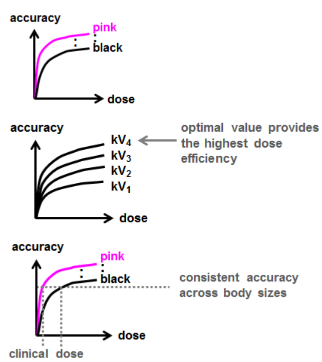
- Maximize dose efficiency
- Achieve desired spatial resolution
- Respect system limit and scanning speed requirement

Protocol Optimization Framework

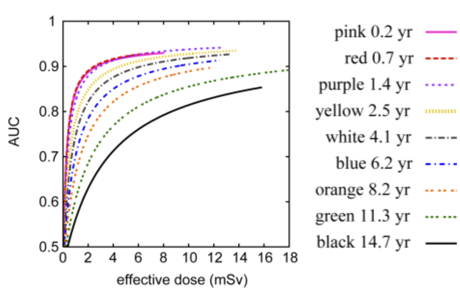
Step 1

Step 2

Step 3

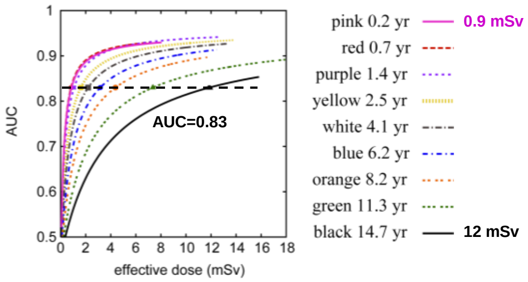


Diagnostic Accuracy VS Effective Dose



Samei et al., J. Med. Imag. (2017)

Diagnostic Accuracy VS Effective Dose



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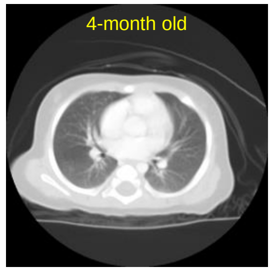
Breathing Artifact



Not factored into image quality metric:

$$CDNR_{display} = \frac{Contrast \times Displayed\ Diameter}{Noise}$$

- Slightly blurred blood vessels
- Higher lung density (less air in lung due to shallow breathing)

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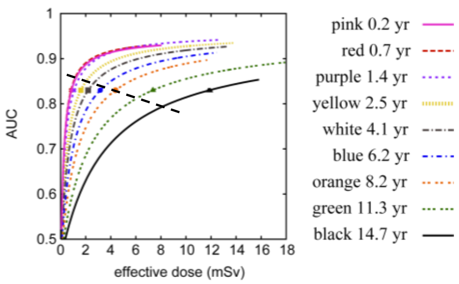
Diagnostic Accuracy VS Effective Dose



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Conclusions

- A framework for formulating size-specific pediatric protocols for a given diagnostic task
- Diagnostic Accuracy = ***f*** (Radiation Dose)
- To achieve the same diagnostic accuracy, more dose is needed to scan a larger/older patient
- Optimize individual scan parameters
- Achieve consistent diagnostic accuracy across pediatric sizes

Thank you!

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