Optimization Strategies for Pediatric CT Imaging

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Educational Objectives

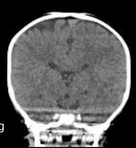
Pediatric CT Protocol Development

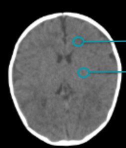
- Image Quality
- Radiation Dose
- Contrast Dose
- Sedation

Brain & Body CT

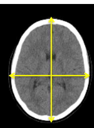
Brain CT

- Brain CT (*one of the more tricky protocols to optimize*)
  - Two biggest limitations
    - Skull (especially the posterior fossa)
    - Minimum inherent differentiation between structures in brain

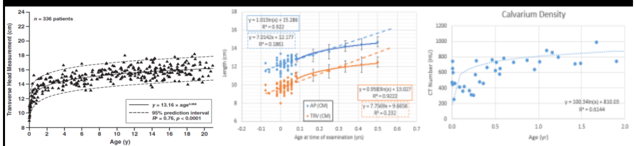




Brain CT



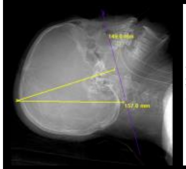
- The head grows logarithmically
  - In diameter & bone density

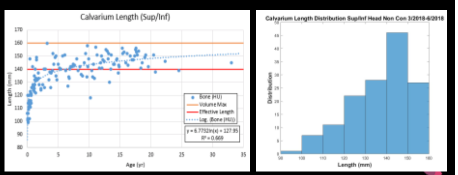


Kleinman, et al. AJR 2010; 194:1611–1619

Brain CT

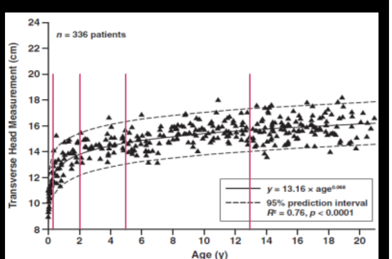
- The head grows logarithmically
  - In length (S/I)
  - Volumetric CT (160 mm) is limited by cone artifact (~140 mm)





Brain CT

- Established 5 protocols
  - 0-6 mon
  - 7-24 mon
  - 2-5 years
  - 6-13 years
  - > 13 years

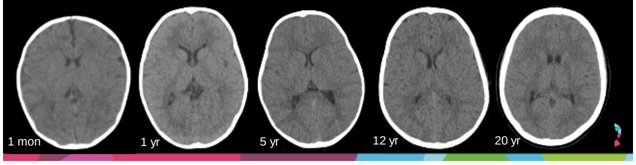


Kleinman, et al. AJR 2010; 194:1611–1619

Brain CT

- 100 kV: better gray/white differentiation
- CTDI: dose and noise balanced
- Fixed mA: not sensitive to misalignment issues with TCM
- Speed: volume mode < 2 yr old

Protocol	kV	mA	Rot (s)	Coll (mm)	CTDIvol (mGy)
0-6 m (V)	100	260	0.75	0.5x320	23.7
7-24 m (V)	100	280	0.75	0.5x320	27.6
24m-5y (H)	120	160	0.75	0.5x40	32.7
6-12y (H)	120	170	0.75	0.5x40	34.7
≥13y (H)	120	170	0.75	0.5x40	34.7



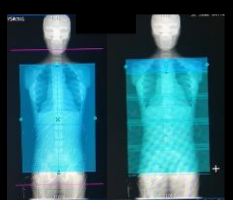
Body CT

- Proper protocol
- Organ dose modulation
- Iterative reconstruction
- Metal Artifact reduction software

- Keys to success:
  - Simplify protocol tree
    - Myth: you need lots of protocol variations for pediatrics
      - 5 will cover the range from 0 to > 100 kg

Acquisition Time

- Faster acquisition may lead to lower sedation rates
  - E.g. 5 yr; 30 cm scan length
  - Pitch 1.5 @ 0.28 sec rotation
  - Total exposure time = 0.7 sec
- Single acquisition
  - ~0.28 sec
  - Great for head, chest, cardiac, or limited FOV (e.g., kidneys)



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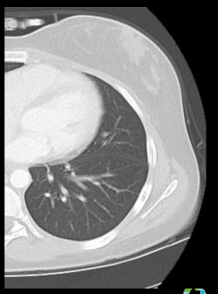
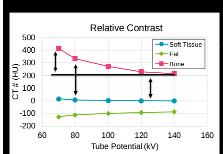
  - Can almost freeze even cardiac motion

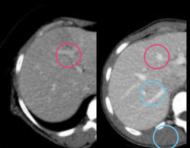


Body CT

- Proper protocol
- Organ dose modulation
- Iterative reconstruction
- Metal Artifact reduction software
- Weight/size based adjustments
  - kVp
- Develop good contrast timing schemes

Image Quality Optimization-kV

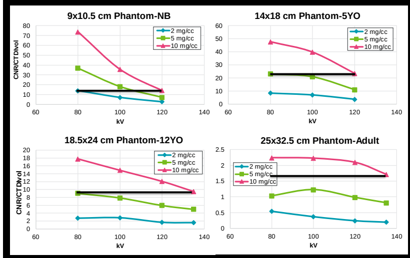




120 kV 100 kV

- Why decrease kV?
  - Enhance Iodine or bone contrast
    - 120 vs. 80 kV = 42% ↑ contrast
  - Soft tissue vs. bone
    - 120 vs. 80 kV ~ 100% ↑ contrast

Image Quality Optimization-kV



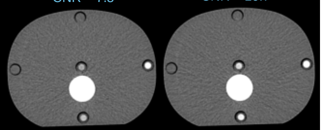
- Why decrease kV?
  - Lower IV/oral contrast dose
  - Compensate contrast intensity w/ lower kV
  - Only valid in small patients

Image Quality Optimization-kV

- How to decrease kV clinically?
- Don't match noise, match CNR!
- Calculate target CNR in phantom
  - $\frac{mAs_2}{mAs_1} = \left(\frac{kV_1}{kV_2}\right)^{\alpha}$
  - $\alpha = \frac{ln\left(\frac{mAs_2}{mAs_1}\right)}{ln\left(\frac{kV_1}{kV_2}\right)} = \frac{ln\left(\frac{116.5}{25}\right)}{ln\left(\frac{120}{80}\right)} = 3.8$

~5 yr old phantom

CNR = 7.5 | CNR = 10.7



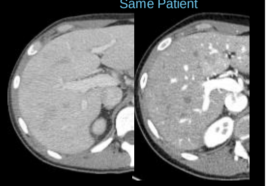
50 mA	230 mA
0.5 sec	0.5 sec
120 kV	80 kV
2 mGy	2 mGy

Bushberg et al, The essential physics of medical imaging 3rd Ed, LWW

Image Quality Optimization-kV

- Apply α value towards patient protocols
  - Use avg TCM mA value
  - $mAs_2 = mAs_1 * \left(\frac{kV_1}{kV_2}\right)^{\alpha}$
  - e.g., $\left(\frac{120}{100}\right)^4 * 40\ mAs \cong 85\ mAs$
  - CNR improves with lower kV even though noise increases
  - Noise can be higher at lower kV

Same Patient



120 kV | 100 kV

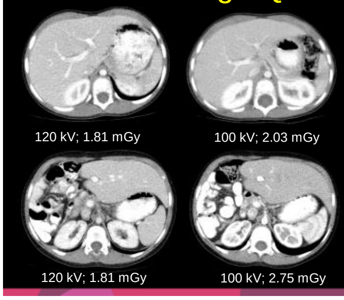
31% dose reduction

Fletcher, AAPM 2010

Yu et al. Med Phys 57(1) 2010; 234-243

Bushberg et al, The essential physics of medical imaging 3rd Ed, LWW

Dose and Image Quality Optimization-CT



- Why decrease kV?
  - Caveat: you can get good dose reduction at 120 kV
- Rule of thumb (trunk)
  - Routine imaging @ 80 kV
    - ≤ 15 cm d_w dia. (CCHMC, <15 kg)
    - ≤ 36 cm lat dim (Mayo)*
  - Routine imaging @ 100 kV
    - ≤ 25 cm dia./d_w (CCHMC, <71 kg)
    - ≤ 41 cm lat dim (*Mayo*)*

**Fletcher, AAPM 2010*
Yu et al. Med Phys 57(1) 2010; 234-243

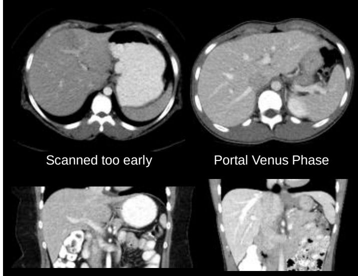
Image Quality Optimization-kV

- Why increase kV?
  - Penetration
    - Larger patients, *generally*, require higher kV (i.e., 120 kV)
    - Brain imaging ~> 4 yr old (use 120 kV)
- Focal spot consideration
  - For high resolution (small structure imaging) use smallest focal spot
  - Small focal spot (~0.6 mm) is available ~≤ 350 mA

Body CT

- Proper protocol
- Organ dose modulation
- Iterative reconstruction
- Metal Artifact reduction software
- Weight/size based adjustments
  - kVp
- Develop good contrast timing schemes

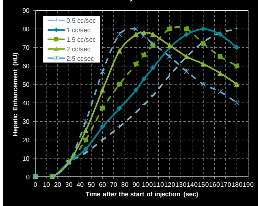
IV Contrast



- Develop good contrast timing schemes
  - Poor contrast management may mask pathology
- Popular approaches
  - Bolus tracking
  - Fixed time

IV Contrast

Constant injection duration



Bae; Radiology (2010) 256(1):32–61

- T_{delay} = ID+T_{ARR}-5- ½ $T_{ScanDuration}$ (Arterial phase)
- T_{delay} = ID+T_{ARR}+25- ½ $T_{ScanDuration}$ (PV phase)
- T_{ARR} for liver parenchyma is 2x Abd Aorta or ~15 sec

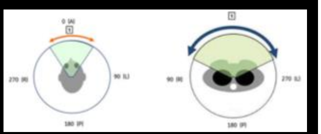
ID: injection delay

Only variable

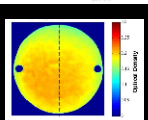
Protocol (kg)	ID_{Iodine} (sec)	Volume (cc);	Rate (cc/sec)	$T_{peak\ enhancement}$ (sec) (ID_{iodine} +10/30) (Arterial/PV)
0-14.9	20	<30	~0.7-1.5	30/50
15-31.4	30	30-62	1.0-2.0	40/60
31.5-55	40	62-110	1.5-2.7	50/70
>55-100	60	110-150	1.8-2.5	70/90
>100	60	150	2.5	70/90

Dose Dose and Image Quality Optimization-CT

- Proper protocol
- Proper set up
- Organ dose modulation
- Iterative reconstruction
- Metal Artifact reduction software



25-30% Anterior Reduction

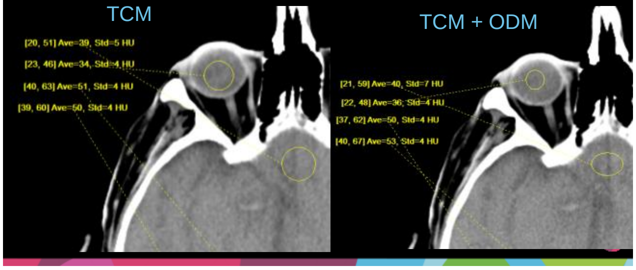


Lungren, et al, AJR (2012) 199:W65–W73

Dose and Image Quality Optimization-CT

TCM

TCM + ODM

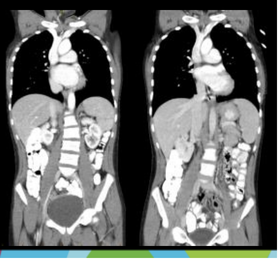


Dose and Image Quality Optimization-CT

- Proper protocol
- Proper set up
- Organ dose modulation
- Iterative reconstruction
- Metal Artifact reduction software

Dose Reduction **20-70%**

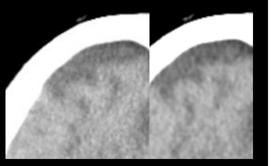
IR #1 IR # 2



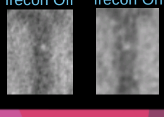
Dose and Image Quality Optimization-CT

- Iterative reconstruction limitations:
  - "Plastic" or "soft" look
  - *No matter* the level of iterative recon there will be losses in edge definition
    - Mostly affecting soft tissue kernels

Irecon Off Irecon On

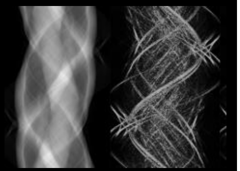


Irecon Off Irecon On



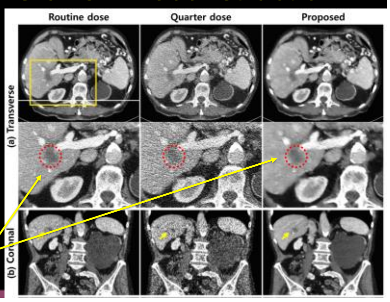
Future Directions of CT Reconstruction

- Deep learning models
  - 1000's of CT images used to train a reconstruction algorithm
  - Reconstruction will only be as good as the data used to train
    - Must include adults & peds
  - Performs well in sinogram space at "filling in" missing data
    - e.g., fixing metal artifact
    - e.g., cleaning up noisy data



Future Directions of CT Reconstruction

- Low dose reconstruction
  - Full dose ~230-430 mA
  - ¼ dose ~60-110 mA
  - Recon time 1.6 sec/slice
    - Total: 2-3 min (MATLAB)



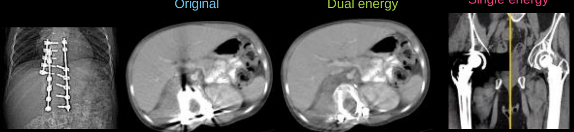
1 mm thin slices

Kang, et al. Med Phys 44 (10) 2017 e360-e375

Image Quality Optimization-kV

- Use metal artifact reduction software
  - Increasing kV and mAs does NOT improve metal artifacts!

Original | Dual energy | Single energy



Canon, SEMAR white paper

Thank you

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