Establishing a Managed Radiation Dose for any Pediatric Exam on any CT Scanner

Keith J. Strauss, MSc, FAAPM, FACR
Clinical Imaging Physicist
Cincinnati Children's Hospital
University of Cincinnati College of Medicine

Introduction

- Adult hospitals perform 80% of pediatric CT exams.
- Pediatric radiation doses and image quality should be managed.
- Both tube voltage and mAs should be altered for pediatric imaging.
- Minimalist approach (change mAs only) is preferred over doing nothing.

The Challenge

- Ideally, unique scan parameters should be established for each individual patient accounting for:
  - Patient size
  - Type of CT examination
  - Design of actual CT scanner
- This can be done in academic centers with diligent effort.

The Challenge

- Is this a practical solution for a community hospital that performs an occasional pediatric CT scan?
- Yet, majority of pediatric CT imaging in the US OCCURS in non-dedicated pediatric hospitals

A Solution: Patient Specific Technique on any CT Scanner

- Establish Diagnostic Reference Levels (DRL) for an examination for a given size patient
- Compare SSDE after the projection scan to department's DRL
- Adjust the clinical technique to match the desired DRL
  - Manual mode
  - Automated tube current mode
  - Enlist the help of your qualified medical physicist (QMP)

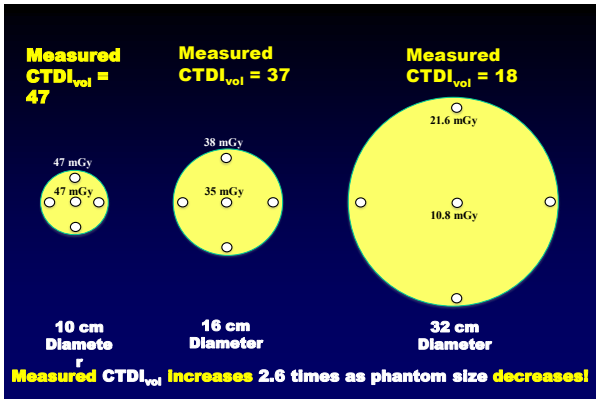
Establish Department DRLs

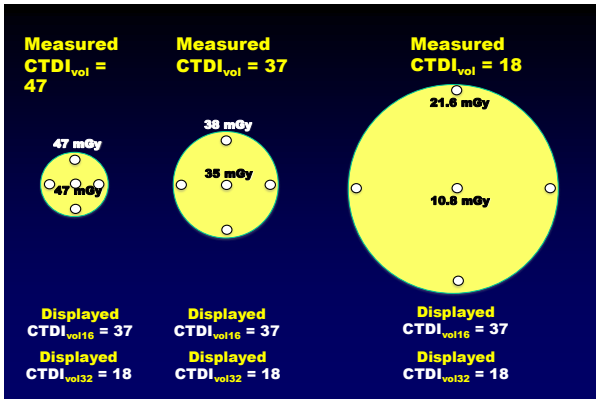
- Adult Patient for Scanner #1
  - Use your measured dose data
  - Measured $CTDI_{vol}$ data
    - Head
    - Body
    - Associated technique factors which created measured $CTDI_{vol}$

CT SCANNER DOSE INDICES

Measured $CTDI_{vol}$

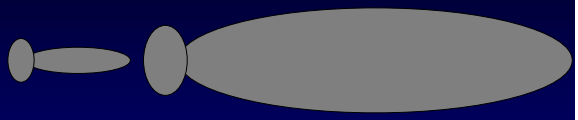
- Measure $CTDI_{vol}$ with **identical** scan parameters
  - kVp
  - mA
  - Rotation time
  - **Bow Tie Filter**
- Use phantom 10, 16, and 32 cm diameter





DISPLAYED CTDI SHORTCOMING

Same radiographic technique
Displayed $CTDI_{vol}$ based on 32 cm CTDI Phantom



18 mGy for both patients!

CT SCANNER DOSE INDICES

Displayed $CTDI_{vol}$

- Standardized method to estimate and compare the radiation output of two different CT scanners to same phantom.

does not represent . . .

Patient dose!!

CLINICAL DILEMMA

- Displayed $CTDI_{vol}$ on scanner is independent of patient size
  - 16 cm CTDI phantom: adult dose over while pediatric dose under estimated.
  - 32 cm CTDI phantom: adult and pediatric dose under estimated ~ 2.5 times!
  - Propagated by DICOM Structured Dose Reports and CT scanner dose reports.

Establish Department DRLs

- Adult Patient for Scanner #1
  - Do your measured $CTDI_{vol}$ results agree with published (national DRLs)?
  - ACR Accreditation submitted values without Iterative reconstruction
  - Routine head $CTDI_{vol16}$ < 75 mGy
  - Routine body $CTDI_{vol32}$ < 25 mGy
  - Discuss with your site's QMP

Establish Department DRLs

- Adult Patient for Scanner #1
  - Scale the mAs value if necessary to adjust $CTDI_{vol}$ to desired level.
    - Calculate SSDE for routine abdomen
      - (28 & 38 cm AP & LAT dimensions)
    - DRL for Scanner #1

Establish Department DRLs

- Adult Patient DRL, Scanners #1, #2, #3, etc.
  - Scanner #1 (28 x 38 cm adult abdomen):
    - 120 kV, 250 mAs, pitch = 1, 25 mGy $CTDI_{vol}$
  - Site elects to reduce dose 20%
    - 120 kV, 200 mAs, pitch = 1, 20 mGy $CTDI_{vol}$
    - 120 kV, 250 mAs, pitch = 1.2, 20 mGy $CTDI_{vol}$
    - 20 mGy * 1.14 = 23 mGy SSDE

Establish Department DRLs

- Adult Patient DRL for Scanners #2, #3, etc.
  - Goal: similar image quality on all of site's CT scanners
  - First step: match the patient's radiation dose to the on all site's scanners.
  - Similar image quality is not guaranteed.
  - Evaluate image quality any time patient doses are altered
  - Cooperative task between radiologists, technologists, and QMP

Establish Department DRLs

- Adult Patient DRL, Scanners #1, #2, #3, etc.
  - 'Same' adult DRL for each scanner
  - SSDEs are equal
  - $CTDI_{vol}$ values are equal
  - Unique technique for each scanner
  - mAs alone cannot be used to compare patient dose between two CT scanners

Establish Department DRLs

- Adult Patient DRL, Scanners #1, #2, #3, etc.
  - Scanner #1 (28 x 38 cm adult abdomen):
    - 120 kV, 200 mAs, pitch = 1, 20 mGy $CTDI_{vol}$
  - Scanner #2 (28 x 38 cm adult abdomen):
    - 120 kV, 250 mAs, pitch = 1, 13 mGy $CTDI_{vol}$
    - 120 kV, 385 mAs, pitch = 1, 20 mGy $CTDI_{vol}$
    - 120 kV, 250 mAs, pitch = 0.65, 20 mGy $CTDI_{vol}$
  - 23 mGy SSDE for both scanners

Establish Department DRLs

- Select **Pediatric** Patient DRL (without iterative reconstruction)

Abdomen/ Pelvis:	Abdomen/ Pelvis:	Abdomen/ Pelvis:	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE			Scanner #1: 23 mGy		Adult SSDE
			120	200	1	1.0	1.0	23			*Limited*	*Moderate*	
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor	*Limited* mAs SSDE (mGy)	*Moderate* mAs SSDE (mGy)	*Aggressive* mAs SSDE (mGy)	NB = Adult SSDE Estimated mAs	NB = 0.75 * Adult SSDE Estimated mAs	*Aggressive* NB = 0.5 * Adult SSDE Estimated mAs
10	14	11.8	4	newborn	0.52	0.39	0.25	23	17	11	104	77	50
11	16	13.3	10	1 yr	0.55	0.42	0.29	23	18	12	110	84	59
14	20	16.7	18	5 yr	0.62	0.50	0.39	23	19	15	123	100	78
16	25	20.0	33	10 yr	0.70	0.62	0.53	23	20	18	140	123	106
19	29	23.5	54	15 yr	0.80	0.74	0.68	23	21	20	160	148	137
22	32	26.5	65	20 yr	0.89	0.86	0.83	23	22	22	179	172	165
25	35	29.6	75	md adult	1.00	1.00	1.00	23	23	23	200	200	200
31	41	35.7	110	lg adult	1.25	1.31	1.43	23	25	27	250	262	287

Establish Department DRLs

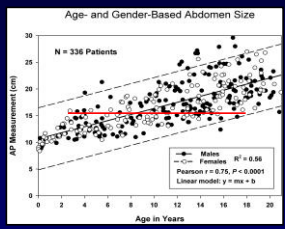
- AP & LAT thicknesses are average values from study of 360 random patients
- Kleinman PL et al. AJR June 2010, pp. 1611 – 19.

Abdomen/ Pelvis:	Abdomen/ Pelvis:	Abdomen/ Pelvis:	kVp	mA
			120	200
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age
10	14	11.8	4	newborn
11	16	13.3	10	1 yr
14	20	16.7	18	5 yr
16	25	20.0	33	10 yr
19	29	23.5	54	15 yr
22	32	26.5	65	20 yr
25	35	29.6	75	md adult
31	41	35.7	110	lg adult

AGE vs PATENT SIZE

Same age patients vary dramatically in size.

- **Abdomens of:**
  - **Largest 3 year olds and smallest adults are the same size.**
- **Patient cross section size, not age, should be used.**



Establish Department DRLs

- AP & LAT thicknesses are average values from study of 360 random patients
- Kleinman PL et al. AJR June 2010, pp. 1611 – 19.
- Effective Diameter = (AP Thk * LAT Thk)$^{0.5}$
  - Boone JM et al. TG204, AAPM website
  - Average mass of boys & girls
  - National Center for Health Statistics 2000

Abdomen/ Pelvis:	Abdomen/ Pelvis:	Abdomen/ Pelvis:	kVp	mA
			120	200
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age
10	14	11.8	4	newborn
11	16	13.3	10	1 yr
14	20	16.7	18	5 yr
16	25	20.0	33	10 yr
19	29	23.5	54	15 yr
22	32	26.5	65	20 yr
25	35	29.6	75	md adult
31	41	35.7	110	lg adult

Establish Department DRLs

- Select Pediatric Patient DRL (without iterative reconstruction)

A. Use adult techniques
  - Newborn (10 x 14 cm) dose = 2.4 * adult dose
  - Common practice prior to 2001

B. Limited reduced pediatric techniques
  - Newborn SSDE = adult SSDE
  - Basis of CT protocols on Image Gently Website posted in 2008

Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor
newborn	0.52	0.39	0.25
1 yr	0.55	0.42	0.29
5 yr	0.62	0.50	0.39
10 yr	0.70	0.62	0.53
15 yr	0.80	0.74	0.68
20 yr	0.89	0.86	0.83
md adult	1.00	1.00	1.00
lg adult	1.25	1.31	1.43

Establish Department DRLs

- Select Pediatric Patient DRL (without iterative reconstruction)

D. Aggressive pediatric techniques
  - Newborn SSDE = 0.5 * adult SSDE
  - Results of QuIRCC published research

Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor
newborn	0.52	0.39	0.25
1 yr	0.55	0.42	0.29
5 yr	0.62	0.50	0.39
10 yr	0.70	0.62	0.53
15 yr	0.80	0.74	0.68
20 yr	0.89	0.86	0.83
md adult	1.00	1.00	1.00
lg adult	1.25	1.31	1.43

Establish Department DRLs

- **Select Pediatric Patient DRL (without iterative reconstruction)**
  - **C. Moderate pediatric techniques**
    - Newborn SSDE = 0.75 * adult SSDE
  - **D. Aggressive pediatric techniques**
    - Newborn SSDE = 0.5 adult SSDE
    - Results of QuIRCC published research

Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor
newborn	0.52	0.39	0.25
1 yr	0.55	0.42	0.29
5 yr	0.62	0.50	0.39
10 yr	0.70	0.62	0.53
15 yr	0.80	0.74	0.68
20 yr	0.89	0.86	0.83
md adult	1.00	1.00	1.00
lg adult	1.25	1.31	1.43

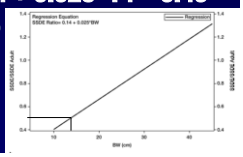
Establish Department DRLs

D. QuIRCC published research?

- Six pediatric hospitals submitted CT patient $CTDI_{vol}$ dose data from late 2009; prior to iterative reconstruction reductions
- Image quality was evaluated
- $SSDE/SSDE_{adult}$ = 0.14 + 0.025*LAT size
  = 0.14 + 0.025*14 = 0.49

Goske MJ, et al. Radiology (2013) 268(1), 208-18.

- NB dose is half of adult dose in Aggressive model



Establish Department DRLs

- **Pediatric Patient DRL (without iterative reconstruction) SSDE**

Abdomen/ Pelvis:	Abdomen/ Pelvis:	Abdomen/ Pelvis:	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE			
			120	200	1	1.0	1.0	23			
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor	*Limited* mAs SSDE (mGy)	*Moderate* mAs SSDE (mGy)	*Aggressive* mAs SSDE (mGy)	
10	14	11.8	4	newborn	0.52	0.39	0.25	23	17	11	
11	16	13.3	10	1 yr	0.55	0.42	0.29	23	18	12	
14	20	16.7	18	5 yr	0.62	0.50	0.39	23	19	15	
16	25	20.0	33	10 yr	0.70	0.62	0.53	23	20	18	
19	29	23.5	54	15 yr	0.80	0.74	0.68	23	21	20	
22	32	26.6	65	20 yr	0.89	0.86	0.83	23	22	22	
25	35	29.6	75	md adult	1.00	1.00	1.00	23	23	23	
31	41	35.7	110	lg adult	1.25	1.31	1.43	23	25	27	

Establish Department DRLs

- **Pediatric Abdominal DRL (without iterative reconstruction) Required mAs**

mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE			Scanner #1: 23 mGy Adult SSDE			Scanner #2: 23 mGy Adult SSDE		
200	1	1.0	1.0	23								
Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor	*Limited* mAs SSDE (mGy)	*Moderate* mAs SSDE (mGy)	*Aggressive* mAs SSDE (mGy)	*Limited* NB = Adult SSDE Estimated mAs	*Moderate* NB = 0.75 * Adult SSDE Estimated mAs	*Aggressive* NB = 0.5 * Adult SSDE Estimated mAs	*Limited* NB = Adult SSDE Estimated mAs	*Moderate* NB = 0.75 * Adult SSDE Estimated mAs	*Aggressive* NB = 0.5 * Adult SSDE Estimated mAs
newborn	0.52	0.39	0.25	23	17	11	104	77	50	201	149	97
1 yr	0.55	0.42	0.29	23	18	12	110	84	59	212	162	113
5 yr	0.62	0.50	0.39	23	19	15	123	100	78	237	193	149
10 yr	0.70	0.62	0.53	23	20	18	140	123	106	270	237	204
15 yr	0.80	0.74	0.68	23	21	20	160	148	137	308	286	263
20 yr	0.89	0.86	0.83	23	22	22	179	172	165	344	331	318
md adult	1.00	1.00	1.00	23	23	23	200	200	200	385	385	385
lg adult	1.25	1.31	1.43	23	25	27	250	262	287	481	504	552

With respect to reduction of mAs when developing abdominal CT technique factors for a newborn patient:

17% 1. Newborn (NB) dose = adult dose (AD) if adult mAs is unchanged.

23% 2. NB dose = half of AD if adult mAs cut in half.

30% 3. NB dose = AD if adult mAs divided by 3.

13% 4. NB dose = half of AD if adult mAs divided by 4.

17% 5. NB dose = half of AD does not provide clinically useful images.

With respect to reduction of mAs when developing abdominal CT technique factors for a newborn patient:

1. Newborn (NB) dose = adult dose (AD) if adult mAs is unchanged.
2. NB dose = half of AD if adult mAs cut in half.
3. NB dose = AD if adult mAs divided by 3.
4. NB dose = half of AD if adult mAs divided by 4.
5. NB dose = half of AD does not provide clinically useful images.

Goske MJ, et al. Radiology 2013 Jul;268(1):208-18.
Strauss KJ. Pediatr Radiol Supplement 2014 (In press)

Establish Department DRLs

- **Pediatric Chest DRL (without iterative reconstruction) Required mAs**
  - **Scanner 1 (28 x 38 cm adult abdomen):**
    - **120 kV, 200 mAs, pitch = 1, 20 mGy $CTDI_{vol}$**
    - **20 mGy * 1.14 = 23 mGy SSDE**
    - **120 kV, 160 mAs, pitch = 1, 16 mGy $CTDI_{vol}$**
    - **16 mGy * 1.14 = 18 mGy SSDE**

kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE
fill in	fill in	fill in	fill in	fill in	fill in

Establish Department DRLs

- **Pediatric Chest DRL (without iterative reconstruction) Required mAs**
  - **BE CAREFUL:**
    - **Data has not been published to date for the chest where pediatric radiologists have evaluated image quality and dose.**
    - **Consider using Moderate as opposed to Aggressive mAs reduction until more data is published**

Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor
newborn	0.52	0.39	0.25
1 yr	0.55	0.42	0.29
5 yr	0.62	0.50	0.39
10 yr	0.70	0.62	0.53
15 yr	0.80	0.74	0.68
20 yr	0.89	0.86	0.83
md adult	1.00	1.00	1.00
lg adult	1.25	1.31	1.43

Establish Department DRLs

- **Pediatric Head Exams w/o iterative recon**
  - **Have validated adult head doses by ACR.**
  - **Limited: ped doses = adult dose (75 mGy max)**

Head Baseline:	Head Baseline:	Head Baseline:	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Scanner #1
			120	370	1.00	1.0	1.0	
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	Limited Estimated mAs	Moderate Estimated mAs
14	12	13	4	newborn	0.74	0.38	274	141
16	13	14.5	10	1 yr	0.80	0.47	296	174
17	14	15.5	13	2 yr	0.86	0.62	318	229
19	15	17	21	6 yr	0.93	0.79	344	292
20	16	18	75	md adult	1	1	370	370

Establish Department DRLs

- **Pediatric Head Exams w/o iterative recon**
  - **Have validated adult head doses by ACR.**
  - **Limited: ped doses = adult dose (75 mGy max)**
  - **Moderate: 16 vs 20 cm AP: 35 mGy vs 75 mGy**
    - **Maximum ACR reference values**

Head Baseline:	Head Baseline:	Head Baseline:	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Scanner #1
			120	370	1.00	1.0	1.0	
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	Limited Estimated mAs	Moderate Estimated mAs
14	12	13	4	newborn	0.74	0.38	274	141
16	13	14.5	10	1 yr	0.80	0.47	296	174
17	14	15.5	13	2 yr	0.86	0.62	318	229
19	15	17	21	6 yr	0.93	0.79	344	292
20	16	18	75	md adult	1	1	370	370

With respect to managing pediatric head CT doses:

20% 1. Calculate the SSDE to estimate patient dose.

20% 2. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 35 mGy $CTDI_{vol}$.

20% 3. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 75 mGy $CTDI_{vol}$.

13% 4. 35 mGy $CTDI_{vol}$ is recommended by Image Gently for 1 yr old patient head.

27% 5. 35 mGy $CTDI_{vol}$ is recommended by ACR for a newborn head.

With respect to managing pediatric head CT doses:

1. Calculate the SSDE to estimate patient dose.
2. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 35 mGy $CTDI_{vol}$.
3. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 75 mGy $CTDI_{vol}$.
4. 35 mGy $CTDI_{vol}$ is recommended by Image Gently for 1 yr old patient head.
5. 35 mGy $CTDI_{vol}$ is recommended by ACR for a newborn head.

Strauss KJ. Pediatr Radiol Supplement 2014 (in press)

Establish Department DRLs

- **Iterative Reconstruction** Required mAs
  - Scans **with iterative reconstruction** should deliver **significantly** less dose than DRL values of ACR
  - Degree of iterative reconstruction
  - Vendor recommendation?
  - Site's **radiologists and QMP** should evaluate degree of iterative reconstruction that provides desired image quality.

Establish Department DRLs

- **Iterative Reconstruction** Required mAs
  - **Scanner 1** (28 x 38 cm adult abdomen):
    - Scale adult patient mAs to reflect the reduction in adult patient SSDE
    - Plug technique and SSDE values into table.
    - Consider **moderate** as opposed to **aggressive** mAs reduction until more data is published

kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE
fill in	fill in	fill in	fill in	fill in	fill in

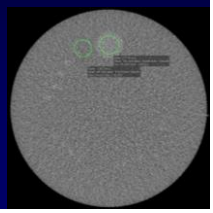
Establish Department DRLs

- **Tube Voltage < 120 kV:** Required mAs?
  - Any size patient: **Less** voltage, **same** dose
    - Set size dependent mAs at 120 kV
    - Note displayed $CTDI_{vol120}$
    - Reduce voltage to desired value on scanner
    - Increase mAs until $CTDI_{vol} = CTDI_{vol120}$
    - **Increased** Contrast at ~ **same** dose

kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE
fill in	fill in	fill in	fill in	fill in	fill in

Establish Department DRLs

- **Voltage < 120 kV:** Required mAs?
  - 10 yr patient: **Less** voltage, **same** image quality
  - Set size dependent mAs at 120 kV
  - Note displayed $CTDI_{vol120}$
  - Measure increased contrast at kV_{ref} compared to 120 kV.
  - Place 'roi' over 1 cm disk & background region



Establish Department DRLs

- **Voltage < 120 kV:** Required mAs?
  - 10 yr patient: Less voltage, same image quality
    - Noise increase: $CTDI_{vol120}$ vs $CTDI_{vol80}$
    - Assume contrast up 20% / Noise up 40%
    - **Increase mAs** at 80 kV until Noise increases only 20%
    - $CNR_{120kV} = CNR_{80kV}$
    - **Same** image quality; **Reduced** patient dose

kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE
fill in	fill in	fill in	fill in	fill in	fill in

Establish Department DRLs

Previous analysis: Reduced mAs @ 120 kV

- **Voltage < 120 kV:** Required mAs?
  - 120 vs 100, 90, 80, & 70 kV
  - Affect on:
    - Contrast
    - Noise
    - Artifacts
    - Scanning speed: Motion Unsharpness

When reducing the high voltage of the CT scanner in an effort to improve image quality and reduce the radiation dose to pediatric patients one can ignore the effect on:

13% 1. Contrast.
23% 2. Noise.
23% 3. Sharpness
17% 4. Artifacts
23% 5. Scanning speed

When reducing the high voltage of the CT scanner in an effort to improve image quality and reduce the radiation dose to pediatric patients, for each type of clinical examination one can ignore the effect on:

1. Contrast.
2. Noise.
3. Sharpness.
4. Artifacts.
5. Scanning Speed

Ref: Yu L, Bruesewitz MR, Thomas KB, Fletcher JG, Kofler JM, McCollough CH. Radiographics 2011 May-Jun;31(3):835-48, p 835.

Scan Progression

- Complete projection Scan
- Setup voltage and mAs as previously determined to achieve department DRLs

or

- Calculate SSDE
- Compare calculated SSDE to reference SSDE
- Adjust mAs or kV as necessary

Conclusions

Due to variations in:
- Patient size,
- Type of CT examinations, and
- Design of actual CT scanners,

Patient's CT dose should be appropriately
- Estimated and
- Managed during the examination,

regardless of patient size!