Automated CT Protocol Design

Advantages and Pitfalls of Algorithm-Based Technique Selection in Pediatrics

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Boston Children's Hospital

Disclosures

Learning Objectives

1. Justification and Basics of Automatic Exposure Control (AEC)
2. Review of Two Commercial Products
3. Building Pediatric Protocols with AEC
4. The Boston Children's Hospital Experience

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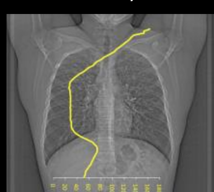
1. Justification and Basics

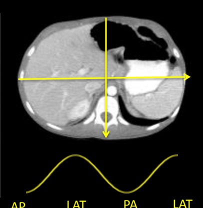
Dose Adaption to Patient:

Size

Anatomy



Shape



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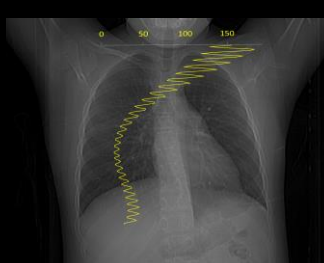
1. Justification and Basics



If all patients were perfect cylinders, this would be easy!

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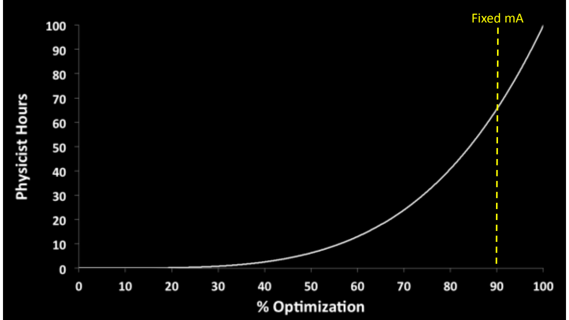
1. Justification and Basics



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Learning Objectives

1. Justification and Basics of Automatic Tube Current Modulation (AEC)
2. Review of Two Commercial Products
3. Building Pediatric Protocols with AEC
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Learning Objectives

2. Review of Two Commercial Products
   a) GE Auto mA
   b) Siemens CareDose 4D and Care kV

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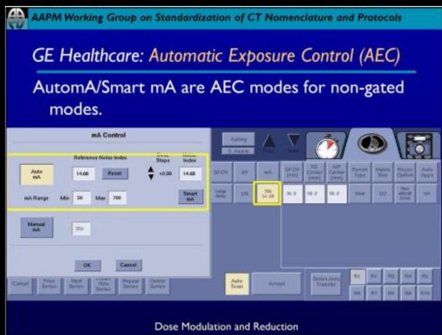
2a. GE Auto mA



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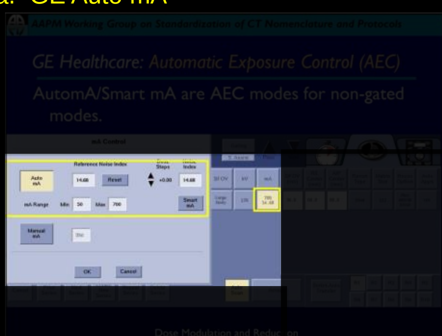

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2a. GE Auto mA

- Noise Index: Image Noise (SD) in uniform water phantom with same attenuation (D_w) as patient*

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2a. GE Auto mA

- Noise Index: Image Noise (SD) in uniform water phantom with same attenuation (D_w) as patient*

** NOT reference patient*

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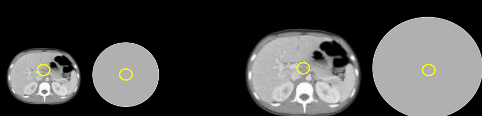
2a. GE Auto mA

Noise Index = 5	Noise Index = 5



SD = 5 HU	SD = 5 HU
CTDI = 3 mGy	CTDI = 12 mGy

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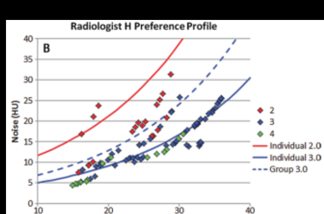
2a. GE Auto mA

- Noise Tolerance is size dependent !



Larson DB, Wang LL, Podberesky DJ, Goske MJ. System for Verifiable CT Radiation Dose Optimization Based on Image Quality. Part I. Optimization Model. Radiology. 2013 Oct 1;269(1):167–76.

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2a. GE Auto mA:

- GE FeatherLight Protocols

	Weight	Noise Index	Minimum mA	Maximum mA	kV	
Routine/ initial procedures	0-20 lbs = 0-9 kg	5	65	130	80	Pink Zone
	21-60 lbs = 9.1-27.2 kg	7	80	160	100	
	61-100 lbs = 27.3-45.4 kg	10	95	190	120	
	101-200 lbs = 45.5-90.7kg	12	110	220	120	
	>200 lbs = >90.8 kg	15	125	300	120	

http://www.gehealthcare.com/usen/ct/docs/GEHC_CT_Procedure-Based-Protocols.pdf

$$RxNoiseIndex_{thin} = RxNoiseIndex_{thick} \times \sqrt{\frac{ViewingSliceThickness}{FirstRxSliceThickness}}$$

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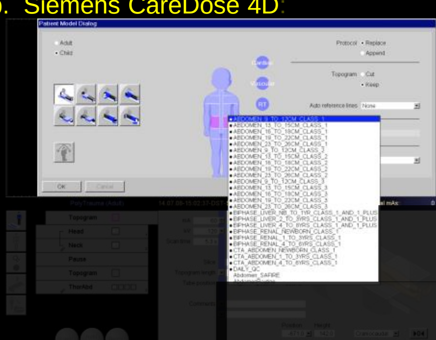
2b. Siemens CareDose 4D:



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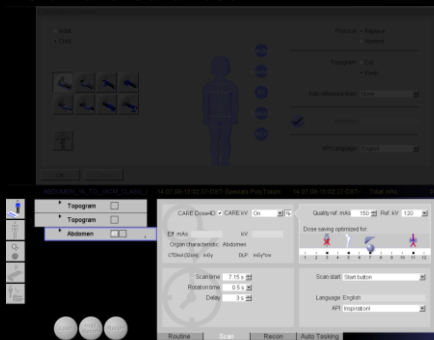

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2b. Siemens CareDose 4D:

Ref. kV and Quality ref. mAs:

Define desired noise level for standard adult patient (70 – 80 kg, D_W ~ 33 cm)

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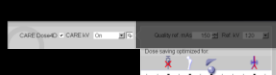
2b. Siemens CareDose 4D:

Dose Saving Optimizer:

Selects level of subject contrast in order to optimize kVp according to image quality metric



Yu L, Fletcher JG, Grant KL, Carter RE, Hough DM, Barlow JM, et al. Automatic Selection of Tube Potential for Radiation Dose Reduction in Vascular and Contrast-Enhanced Abdominopelvic CT. American Journal of Roentgenology. 2013 Aug;201(2):W297–W306.

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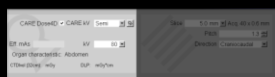
2b. Siemens CareDose 4D:

Semi Mode:

Set kVp, Effective mAs optimized based on Dose Optimizer



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2b. Siemens CareDose 4D:

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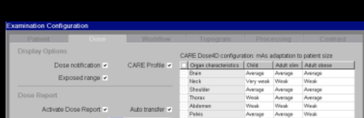
2b. Siemens CareDose 4D:

CareDose "Strength":

Determines mA-Modulation Strength for large and small patients



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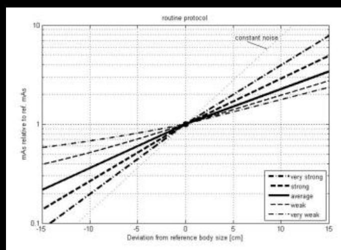

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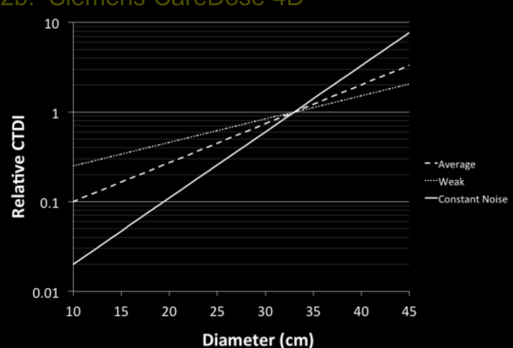

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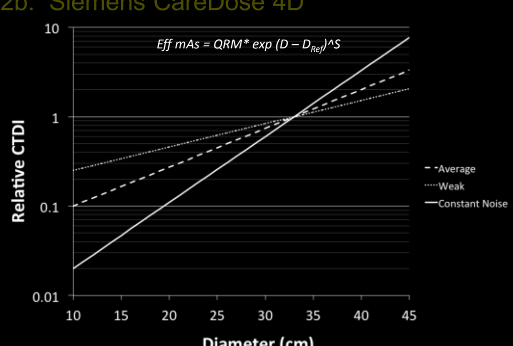

2b. Siemens CareDose 4D:

- Image Quality Metrics defined for *REFERENCE PATIENT*
- i.e. We are dependent on CareDose 4D algorithm to optimize IQ/Dose for all patient sizes
- Still need size based protocols if we want to customize IQ/Dose curve

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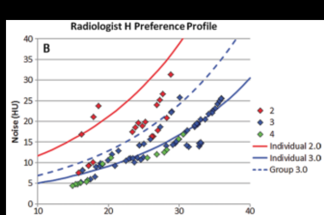
3a. Building Pediatric Protocols with GE Auto mA



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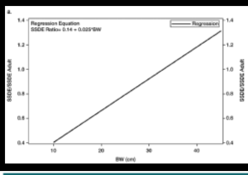

Table 3

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 MJ, Strauss KJ, Coombs LP, Mandel KE, Towbin AJ, Larson DB, et al. Diagnostic Reference Ranges for Pediatric Abdominal CT. Radiology 2013 Mar 19

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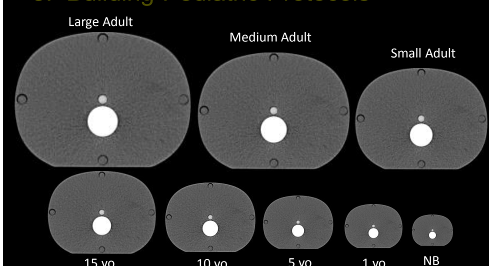
3. Building Pediatric Protocols



www.cirsinc.com/products/modality/17/tissue-equivalent-ct-dose-phantoms/

- 80 kVp
- 100 kVp
- 120 kVp

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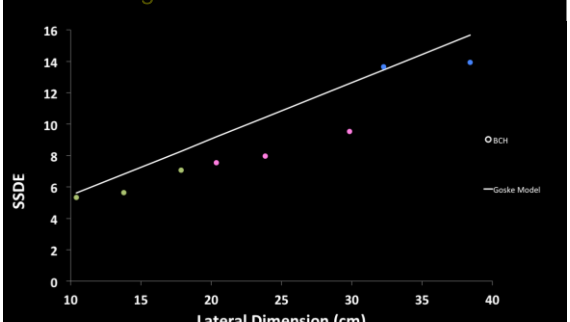
3. Building Pediatric Protocols with AEC



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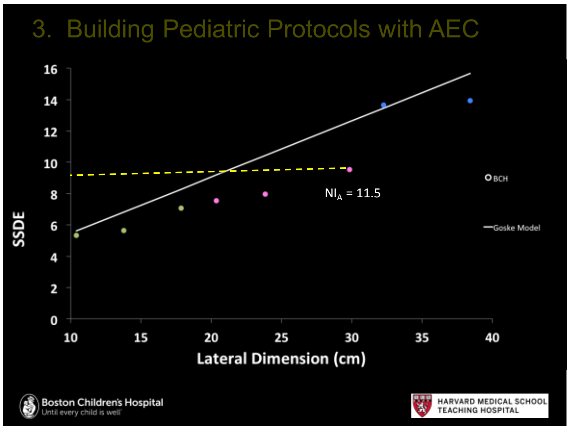
3. Building Pediatric Protocols with AEC
SSDE
16
14
12
10
8
6
4
2
0
10
15
20
25
30
35
40
Lateral Dimension (cm)
NI_A = 11.5
BCH
Goske Model
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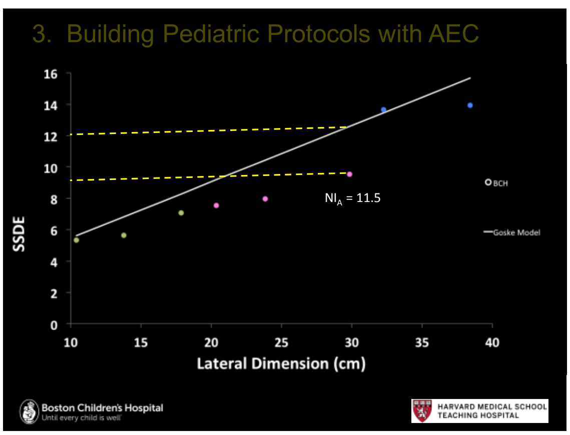
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SSDE
16
14
12
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6
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20
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35
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Lateral Dimension (cm)
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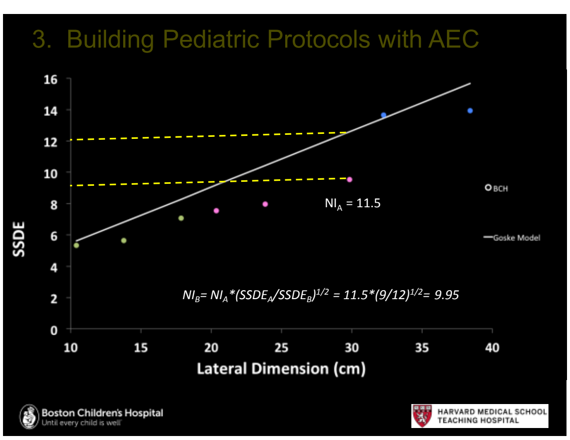
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SSDE
16
14
12
10
8
6
4
2
0
10
15
20
25
30
35
40
Lateral Dimension (cm)
NI_A = 11.5
$NI_B = NI_A*(SSDE_A/SSDE_B)^{1/2} = 11.5*(9/12)^{1/2} = 9.95$
BCH
Goske Model
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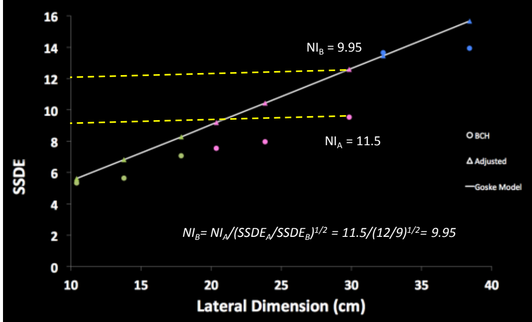
3. Building Pediatric Protocols with AEC



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3. Building Pediatric Protocols with AEC

Age (years)	AP (cm)	LAT (cm)	Dw (cm)	kVp	NI
NB	8.9	10.4	9.6	80	5.5
1	11.3	13.8	12.5	80	5.6
5	13.8	17.9	15.7	80	6.1
10	15.8	20.4	17.9	100	6.1
15	18.3	23.8	20.9	100	6.1
SA	21.8	29.8	25.5	100	10.1
MA	24.7	32.3	28.2	120	12.7
LA	30.7	38.4	34.3	120	20.7

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3. Building Pediatric Protocols with AEC

- GE Auto mA: Straight-forward to customize Dose Curve with size based protocols by modifying Noise Index
- kVp is fixed based on patient size and tube mA limits

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Learning Objectives

3. Building Pediatric Protocols with AEC
    a) GE Auto mA
    b) Siemens CareDose 4D

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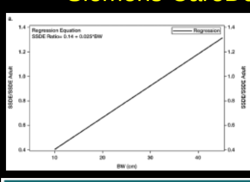
3b. Building Pediatric Protocols with Siemens CareDose 4D



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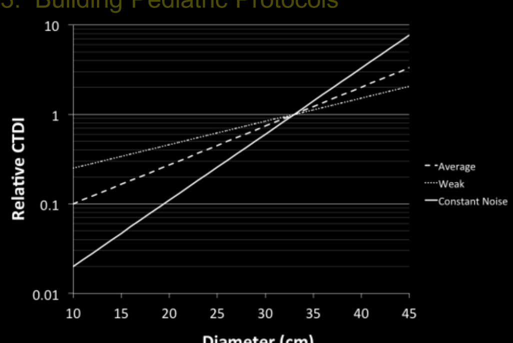
3. Building Pediatric Protocols



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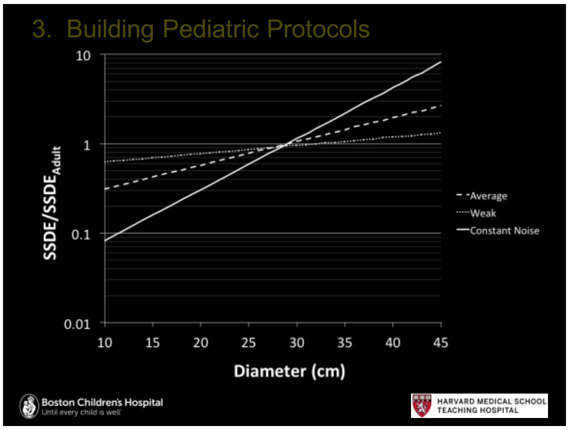

3. Building Pediatric Protocols
SSDE/SSDE$_{Adult}$
10
1
0.1
0.01
10 15 20 25 30 35 40 45
Diameter (cm)
Average
Weak
Constant Noise
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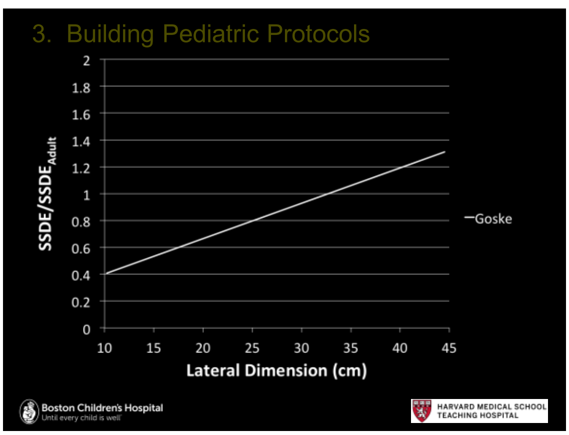

3. Building Pediatric Protocols
SSDE/SSDE$_{Adult}$
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10 15 20 25 30 35 40 45
Lateral Dimension (cm)
Goske
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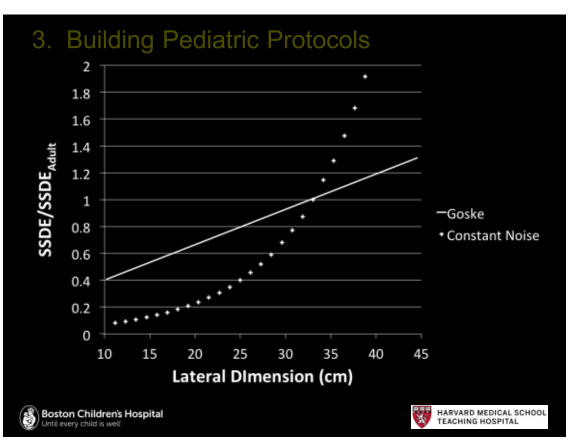

3. Building Pediatric Protocols
SSDE/SSDE$_{Adult}$
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10 15 20 25 30 35 40 45
Lateral DImension (cm)
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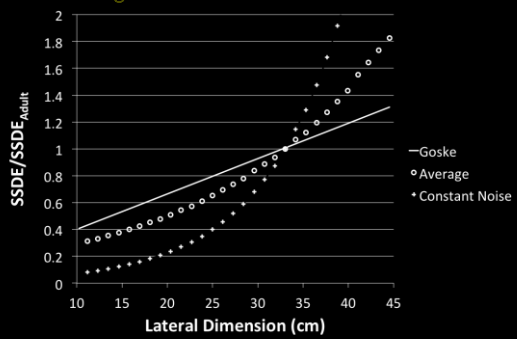

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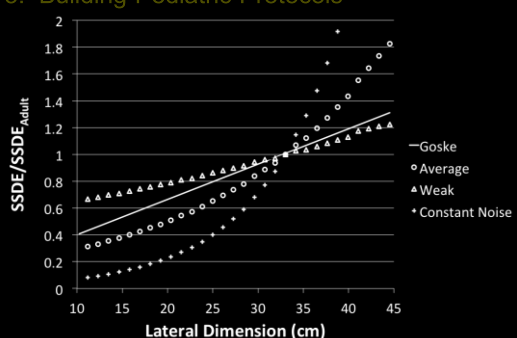

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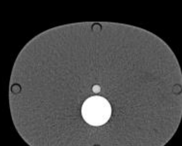
3c. Modeling CareDose 4D

The effect of following parameters on SSDE and CNR were modeled:

1. Patient Size
2. CareDose Strength
3. Quality Reference mAs
4. Dose Saving Optimizer Position
5. Semi Mode



80 kVp
100 kVp
120 kVp

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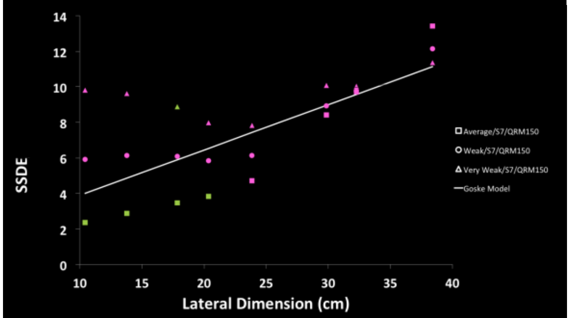
3c. Modeling CareDose 4D



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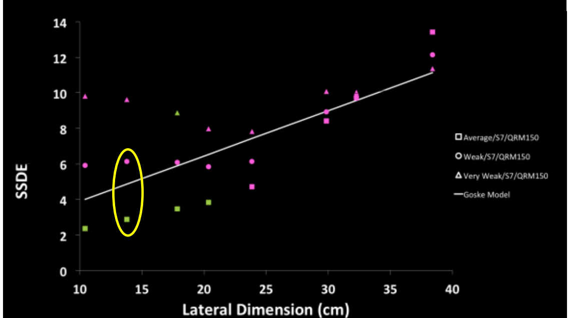

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3c. Modeling CareDose 4D

- CD4D Strength affects kVp selection.

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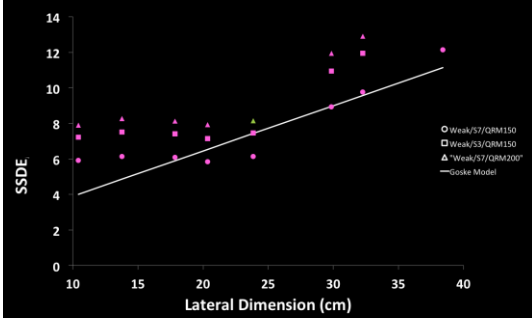
3c. Modeling CareDose 4D



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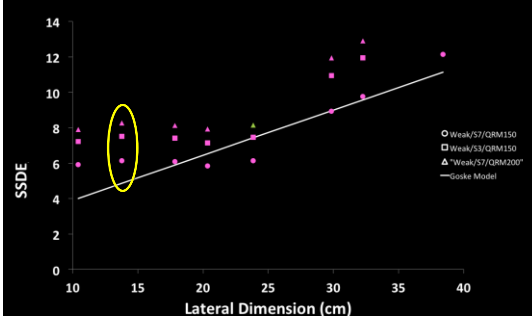
3c. Modeling CareDose 4D



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3c. Modeling CareDose 4D

- CD4D Strength affects kVp selection.
- Effect of Dose Optimizer is a fixed ratio across all patient size when same kV is used
  e.g. S7/S3 = 1.22
- Effect of QRM is fixed across all patient sizes
  e.g. 200/150 = 1.33

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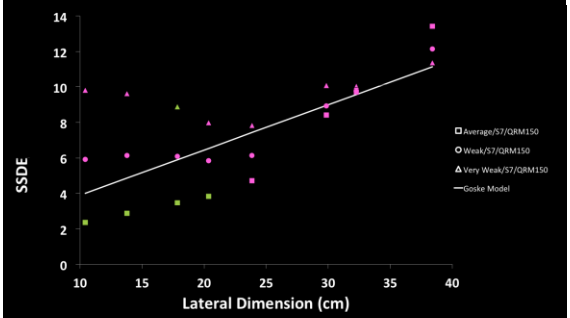
3c. Modeling CareDose 4D



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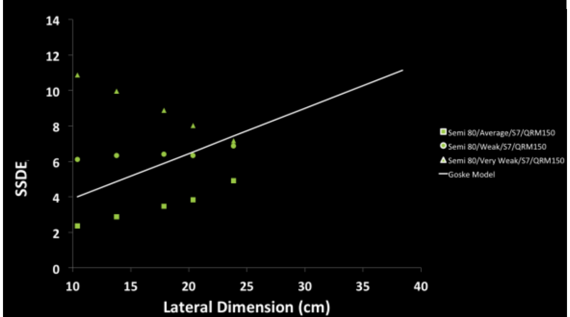
3c. Modeling CareDose 4D



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3c. Modeling CareDose 4D

- CD4D Strength affects kVp selection.
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  e.g. S7/S3 = 1.22
- Effect of QRM is fixed across all patient sizes
  e.g. 200/150 = 1.33
- Semi Mode has no effect on curve shape

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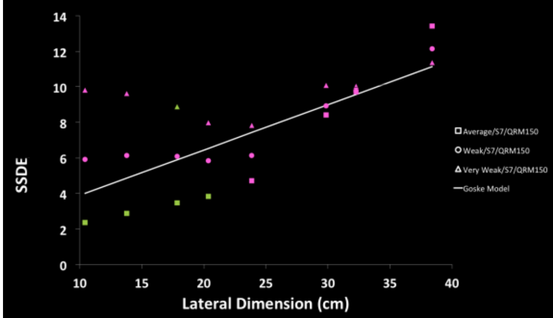
3c. Modeling CareDose 4D



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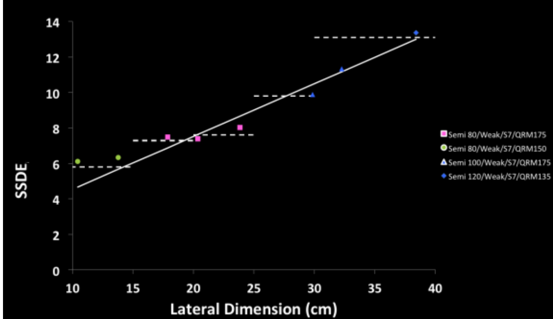
3c. Modeling CareDose 4D



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3a. Based on Diagnostic Reference Ranges

Age (years)	AP (cm)	LAT (cm)	Dw (cm)	kVp	CD4D Strength	Dose Optimzer	QRM
NB	8.9	10.4	9.6	80	Weak	7	150
1	11.3	13.8	12.5	80	Weak	7	150
5	13.8	17.9	15.7	100	Weak	7	175
10	15.8	20.4	17.9	100	Weak	7	175
15	18.3	23.8	20.9	100	Weak	7	175
SA	21.8	29.8	25.5	120	Weak	7	175
MA	24.7	32.3	28.2	120	Weak	7	175
LA	30.7	38.4	34.3	120	Weak	7	135

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Learning Objectives

1. Justification and Basics of Automatic Tube Current Modulation (ATCM)
2. Review of Two Commercial Products
3. Building Pediatric Protocols with ATCM
4. The Boston Children's Hospital Experience

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4. The BCH Experience

-Size based AEC Techniques operated with Fixed kV (Semi Mode with CD4D)

-Patient Size measured on PA localizer

-Size-Based Protocol Selected

-Three Image Quality "Classes"

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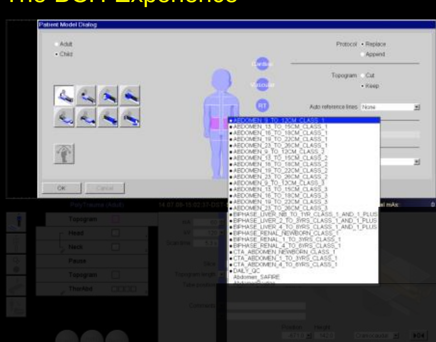
4. The BCH Experience



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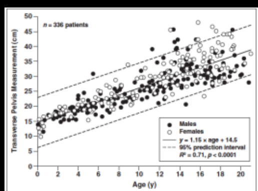
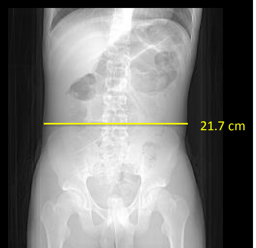
4. The BCH Experience



Kleinman PL, Strauss KJ, Zurakowski D, Buckley KS, Taylor GA. Patient Size Measured on CT Images as a Function of Age at a Tertiary Care Children's Hospital. AJR. 2010 Jun 1;194(6):1611–9.



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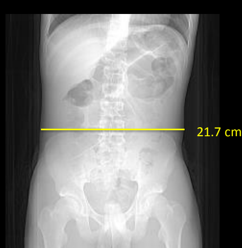
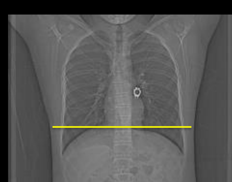
4. The BCH Experience

Abdomen/Pelvis: Measure at Iliac Crest



Chest: Measure at Xyphoid Tip



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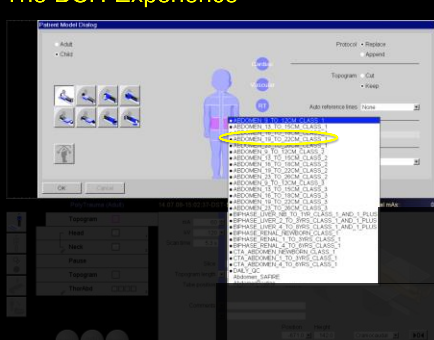
4. The BCH Experience



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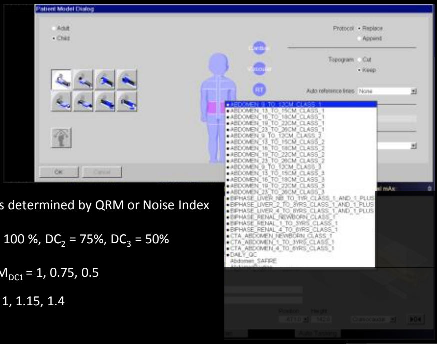
4. The BCH Experience



Dose Class determined by QRM or Noise Index

e.g. DC_1 = 100 %, DC_2 = 75%, DC_3 = 50%

QRM/QRM_{DC1} = 1, 0.75, 0.5

NI/NI_{DC1} = 1, 1.15, 1.4

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To achieve an acceptable level of image noise across all patient sizes using GE auto mA and constant image thickness, Noise Index (NI) should:

17%	1. Increase with increasing patient size
30%	2. Decrease with increasing patient size
23%	3. Remain fixed for increasing patient size
7%	4. Be disabled and a fixed mA used
23%	5. Be disabled and a fixed kV used

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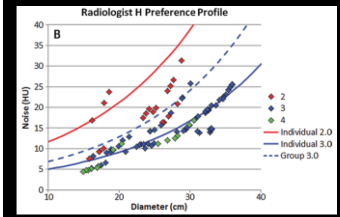
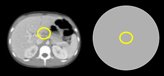
Noise Index (NI) should increase with patient size:

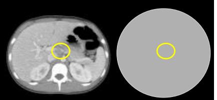


Larson DB, Wang LL, Podberesky DJ, Goske MJ. System for Verifiable CT Radiation Dose Optimization Based on Image Quality. Part I. Optimization Model. Radiology. 2013 Oct 1;269(1):167–76.

Ref: GE HD750 User Manual



NI = 5, SD = 5 HU



NI = 8, SD = 8 HU

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The following is the most reliable metric to estimate patient attenuation and selection of a size-based CT protocol:

23%	1. Patient Weight (kg)
13%	2. Patient Age (years)
23%	3. Body Mass Index (BMI)
23%	4. Patient Girth (Calipers or e-Calipers)
17%	5. Technologist best guess

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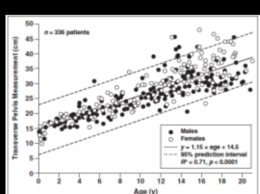
4. Patient Girth Measured with Calipers or e-Calipers



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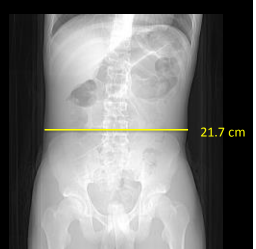

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3c. Advantages of AEC protocols

- Adapts to changing anatomy (Lung/Pelvis)
- Adapts to patient geometry (AP/LAT)
- CareDose 4D: Less Risk of Error adapting to patient size (-10% to + 15 %)

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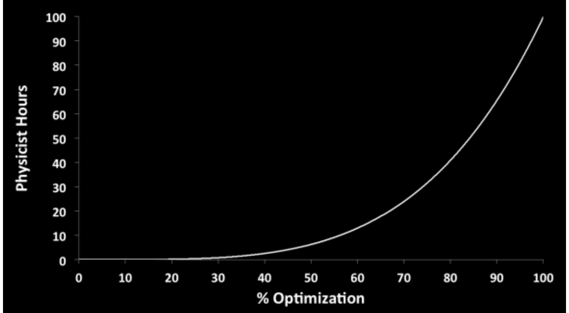
3c. Disadvantages of AEC protocols



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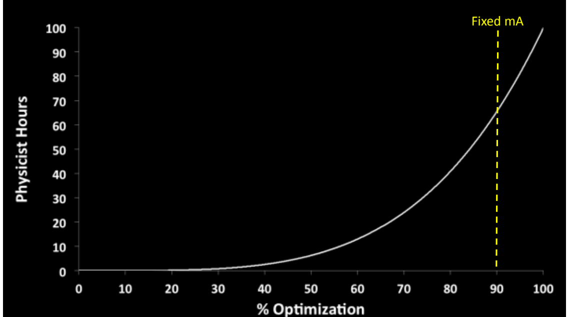
3c. Disadvantages of AEC protocols



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3c. Disadvantages of AEC protocols (1)

- Takes *extensive* testing to optimize protocols
- Without phantoms, process is iterative and time consuming
- Dependent on localizer position

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3c. Disadvantages of AEC protocols (2)

- Diminishing returns on very small patients
- Still need size based protocols

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Thank You!

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