ESTABLISHING DRLs in PEDIATRIC CT

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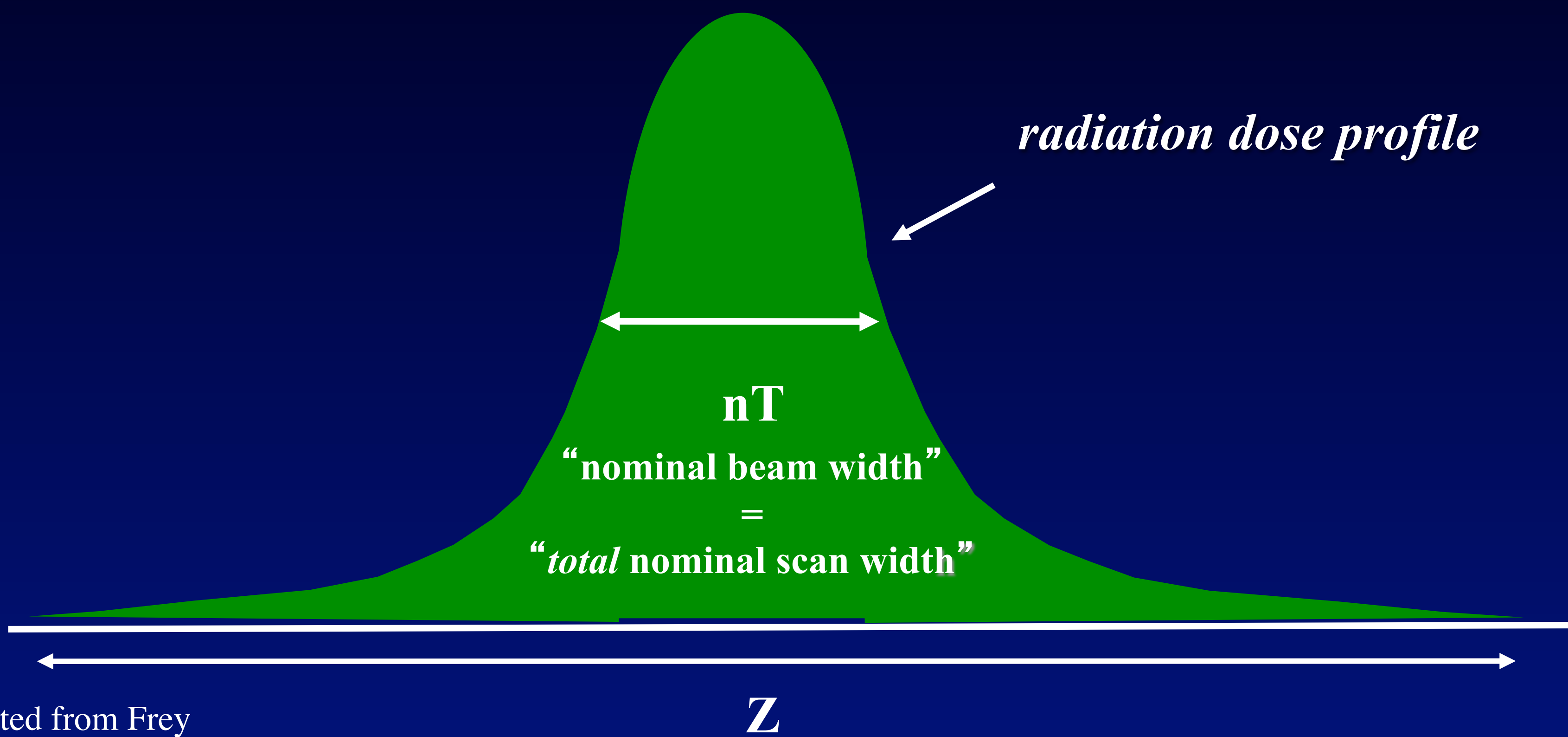
INTRODUCTION

- CT Dose Indices
  - CTDI
  - $CTDI_{100}$, $CTDI_w$, $CTDI_{vol}$
  - Displayed vs Measured $CTDI_{vol}$
  - DLP
  - E Dose and its limitations
- SSDE
- Applications of SSDE in the Clinic

Clinical Application

- 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.

CTDI = Integral under the *radiation dose profile* along the z-axis from a <u>single *axial* scan</u> of width nT.

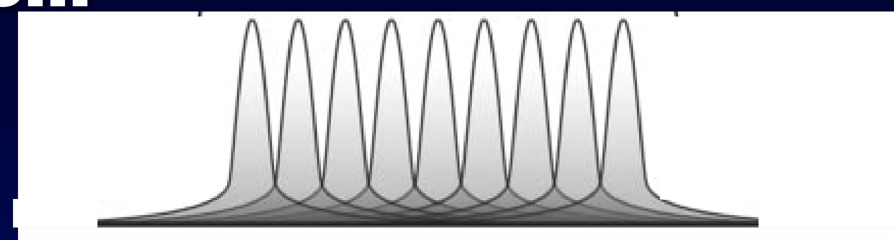


Adapted from Frey

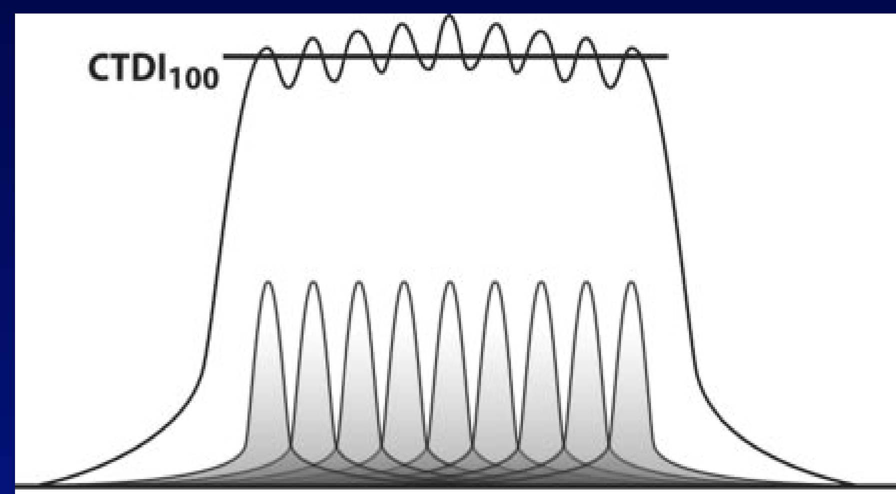
CT SCANNER DOSE INDICES

Computed Tomography Dose Index (CTDI)

- Represents the average integrated absorbed dose along the z axis from a series of contiguous irradiations.



- $CTDI_{100}$ represents accumulated multiple scan dose at center of 100 mm scan.

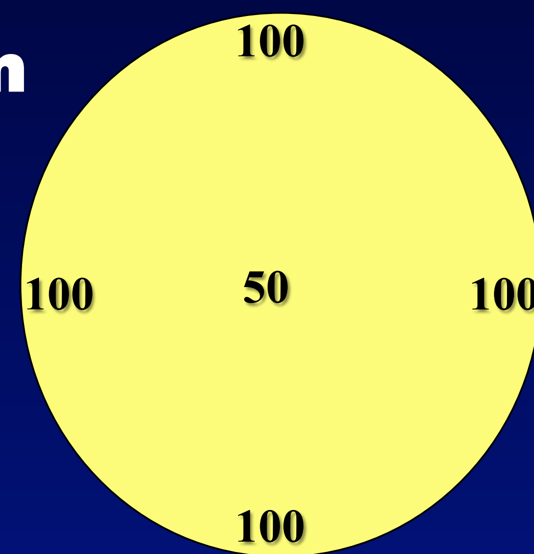


CT SCANNER DOSE INDICES

Calculation of CTDI Values

- Weighted CTDI: $CTDI_w$
  - Average CTDI across the FoV
- $CTDI_w = 1/3\ CTDI_{100,center} + 2/3\ CTDI_{100,edge}$
- $CTDI_w = 17 + 66 = 83$ mGy

  for 32 cm CTDI phantom



- Ave Dose over x & y direction

CT SCANNER DOSE INDICES

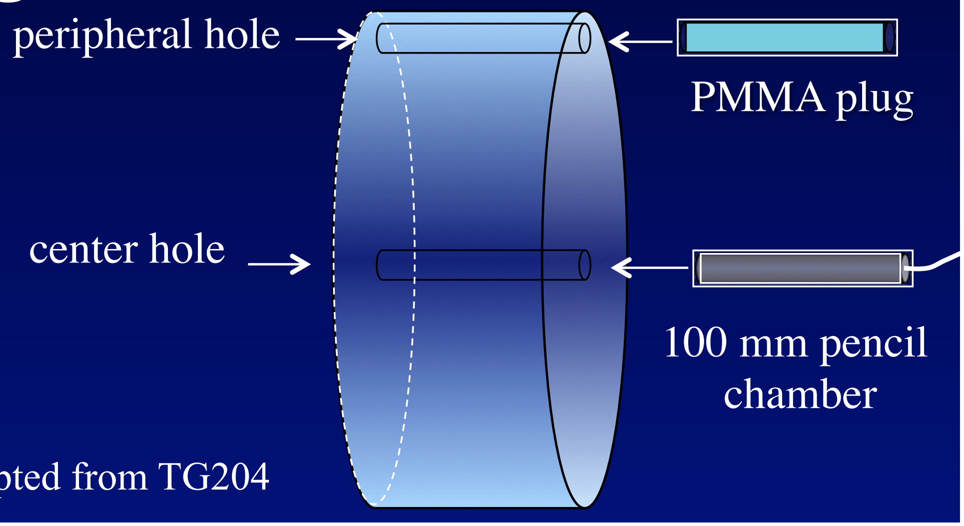
Calculation of CTDI Values

- Volume CTDI: $CTDI_{vol}$
- $CTDI_{vol}$ = $CTDI_{w}$ / pitch
- Addresses dose when table motion occurs

CT SCANNER DOSE INDICES

Measurement of CT Radiation Dose

- Plastic cylindrical phantoms: CTDI Phantoms
  - (PMMA)
  - 16 & 32 cm diameter
- Pencil chamber moved into provided holes to measure radiation dose
  - Center of phantom
  - Non measured holes plugged



Adapted from TG204

CURRENT ADULT PATIENT MODEL

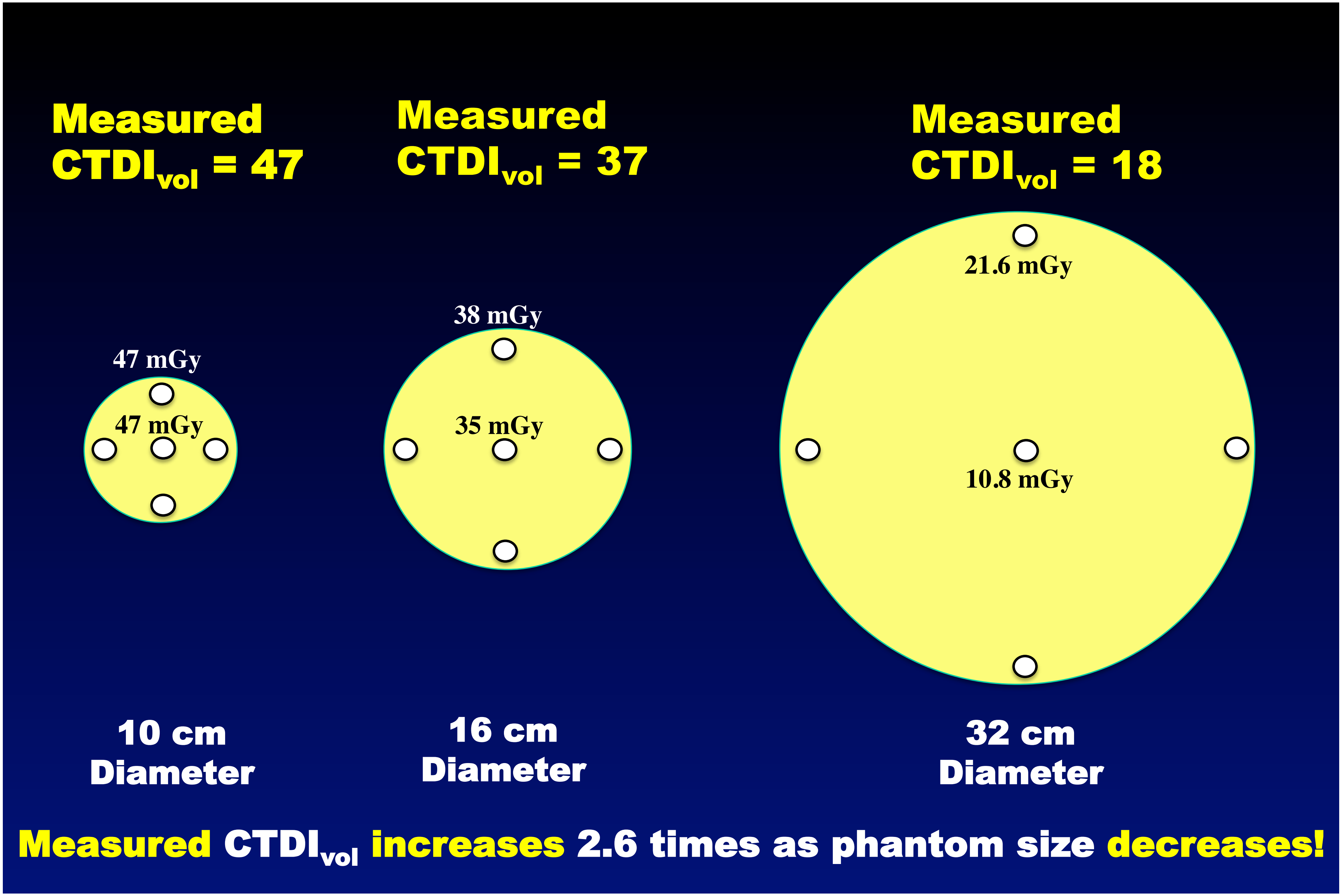
B. CTDI_{100} measured with 100 mm pencil chamber in two standard phantoms

1. Sample 100 mm along the z-axis of patient

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



Measured
CTDIvol = 47
Measured
CTDIvol = 37
Measured
CTDIvol = 18
47 mGy
47 mGy
38 mGy
35 mGy
21.6 mGy
10.8 mGy
10 cm
Diameter
16 cm
Diameter
32 cm
Diameter
Measured CTDIvol increases 2.6 times as phantom size decreases!

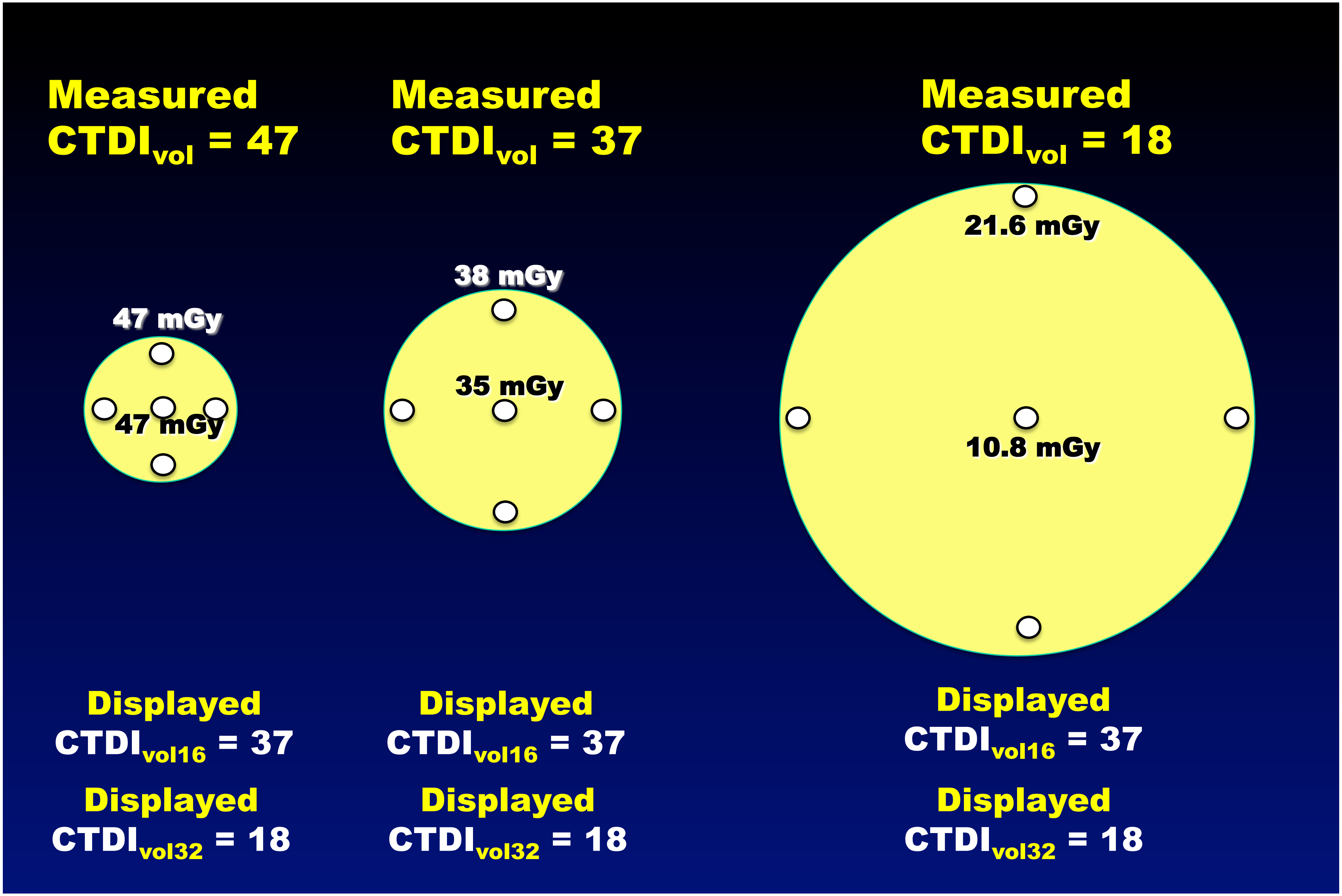
CT SCANNER DOSE INDICES

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!!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Displayed
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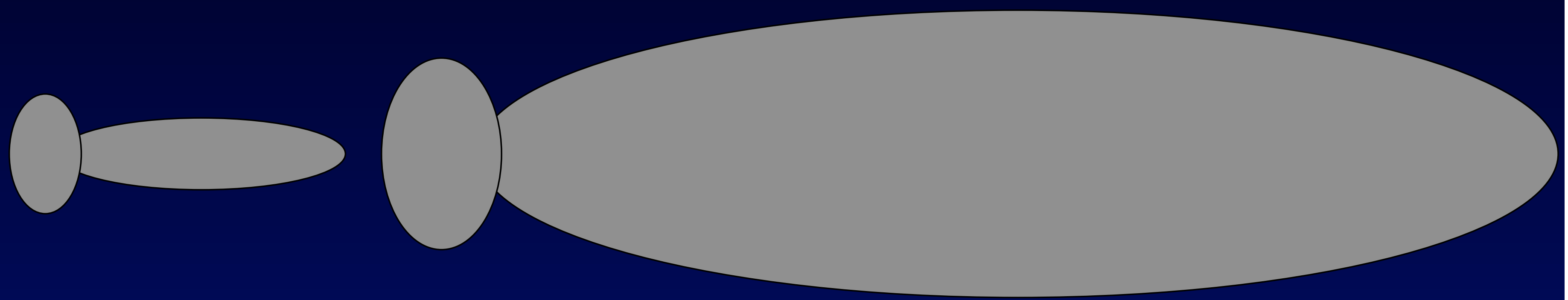
Displayed
$CTDI_{vol32}$ = 18
Displayed
$CTDI_{vol16}$ = 37
Displayed
$CTDI_{vol32}$ = 18

DISPLAYED CTDI SHORTCOMING

Same radiographic technique

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



18 mGy for both patients!

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 Reports and CT scanner dose reports.

CLINICAL DILEMMA

- **CTDI Phantoms are not clinical models**

CLINICAL DILEMMA

- Anthropomorphic Phantoms only approximate the human body

$CTDI_{vol}$:

20%	1. Is measured with a point, small volume ionization chamber.
20%	2. Represents the radiationdose to the patient.
20%	3. Estimates and compares the radiation output of two different CT scanners to the same phantom.
20%	4. Can be determined with a single measurement.
20%	5. Is measured with a pencil ionization chamber with a length of 90 mm.

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4. Can be measured with a single measurement.
5. Is measured with a pencil ionization chamber with a length of 90 mm

Ref: "The Measurement, Reporting, and Management of Radiation Dose in CT", AAPM Report No. 96 (2008), p. 10.

CT SCANNER DOSE INDICES

Displayed Dose Length Product (DLP)

- DLP (mGycm) = $CTDI_{vol}$ * Scan Length
  - Scan length is the length of phantom irradiated.
  - 'Represents' energy transferred.
- DLP is not a patient dose index because $CTDI_{vol}$ does not represent patient dose.

CT SCANNER DOSE INDICES

Effective Dose (E)

- Whole body uniform radiation dose that reflects the same risk to the patient as the larger radiation dose delivered to a fraction of the patient's body during a CT scan.

$$E\ (\text{mSv}) = k * \text{DLP}$$

Units of k: mSv / mGy-cm

- k values depend on:
  - Patient size
  - Body region
  - CTDI phantom assumed by vendor (16 or 32)

Effective Dose Limitations

- ‘SSDELP’ = SSDE * Scan Length
- **Better** estimate of energy transferred.

Caution:

- SSDE can **NOT** be substituted in place of $CTDI_{vol}$ when using k-factors to estimate Effective Doses from CT exam.

Effective Dose Limitations

- Can Effective Dose be used to estimate:
  - An individual patient's radiation dose?
  - Organ doses?

- ABSOLUTELY NOT, despite the fact that one can find numerous published papers that make this error!!

Effective Dose Limitations

- Effective Dose was originally defined to address radiation protection concerns of occupationally exposed workers.

- Effective dose can be used to facilitate a comparison of biological effects between diagnostic exams of different types.

Effective Dose Limitations

Effective Dose Recommended Reading

- ICRP 103 Executive Summary
- AD Nixon, "New ICRP recommendations", J Radiol Prot 2008.
- CJ Martin, "Effective dose: How should it be applied to medical exposures?", BJR 2007
- "Rational approach to the clinical use of effective dose estimates", AJR 2011.

Christner JA, Sturchio G, McCollough CH, et al. Use of Effective Dose in Medical Imaging. Mayo Clinic Rochester, MN

Effective Dose:

20%

20%

20%

20%

20%

1. **Compares biological effects between diagnostic exams of different types.**
2. **Accuracy is improved when SSDE is multiplied times the appropriate k-factor instead of $CTDI_{vol}$.**
3. **Can be used to estimate an individual patient's radiation dose.**
4. **Can be used to estimate organ doses.**
5. **Is defined to address radiation protection concerns of medically exposed patients.**

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Effective Dose:

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Ref: "The Measurement, Reporting, and Management of Radiation Dose in CT", AAPM Report No. 96 (2008), p. 11.

AAPM Report No. 204

Size Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations

Report of AAPM Task Group 204, in collaboration with the International Commission on Radiological Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging.

Clinical Applications of SSDE

So what is SSDE?:

- Estimates the peak soft tissue dose of the patient at the center of the scan length.
  - Adjusts for patient size and varying attenuation from overlying tissue thickness.
  - Uses **average** scan radiation output: $CTDI_{vol}$
  - Useful first approximation of organ dose?

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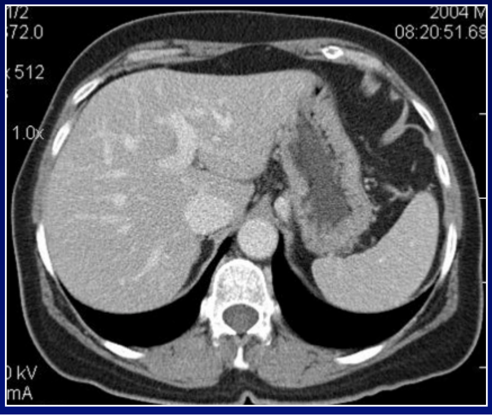
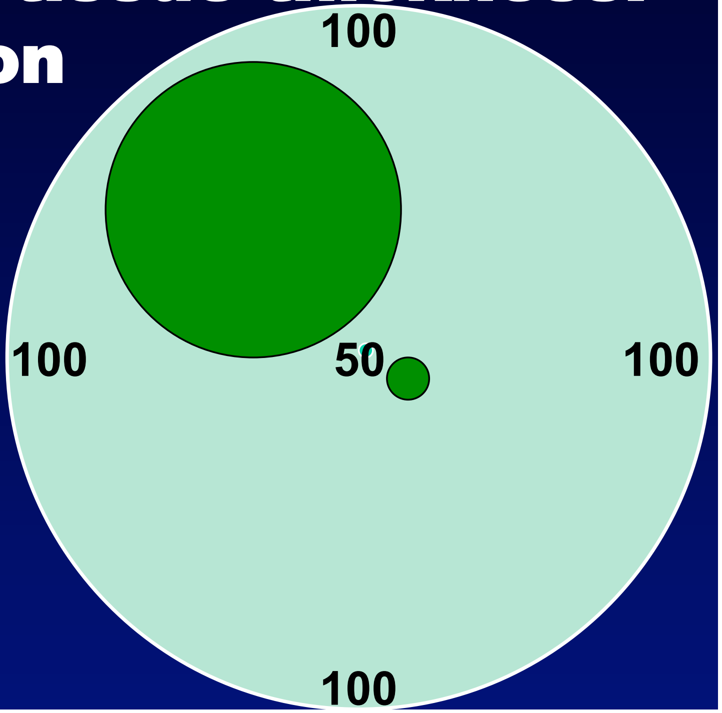
Adapted from McCollough





TG 204

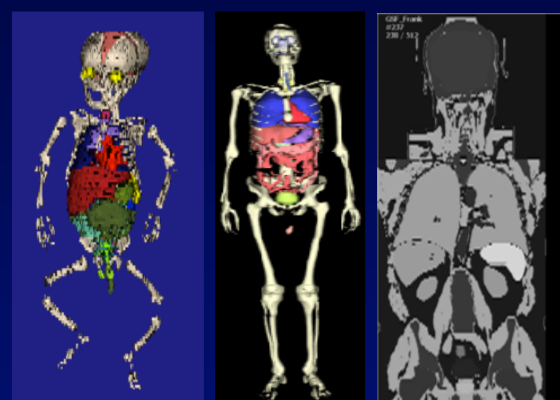
Data from four independent investigators studying patient size correction factors.

- **Physical measurements on phantoms**
- **Monte Carlo computer modeling**

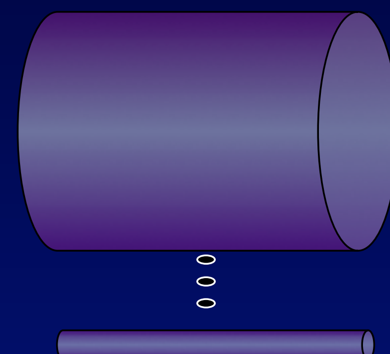
Adapted from TG 204

A. Anthropomorphic Phantoms
(McCollough Laboratory "Mc")

B. Cylindrical PMMA phantoms
(Toth / Strauss Collaboration "T-S")

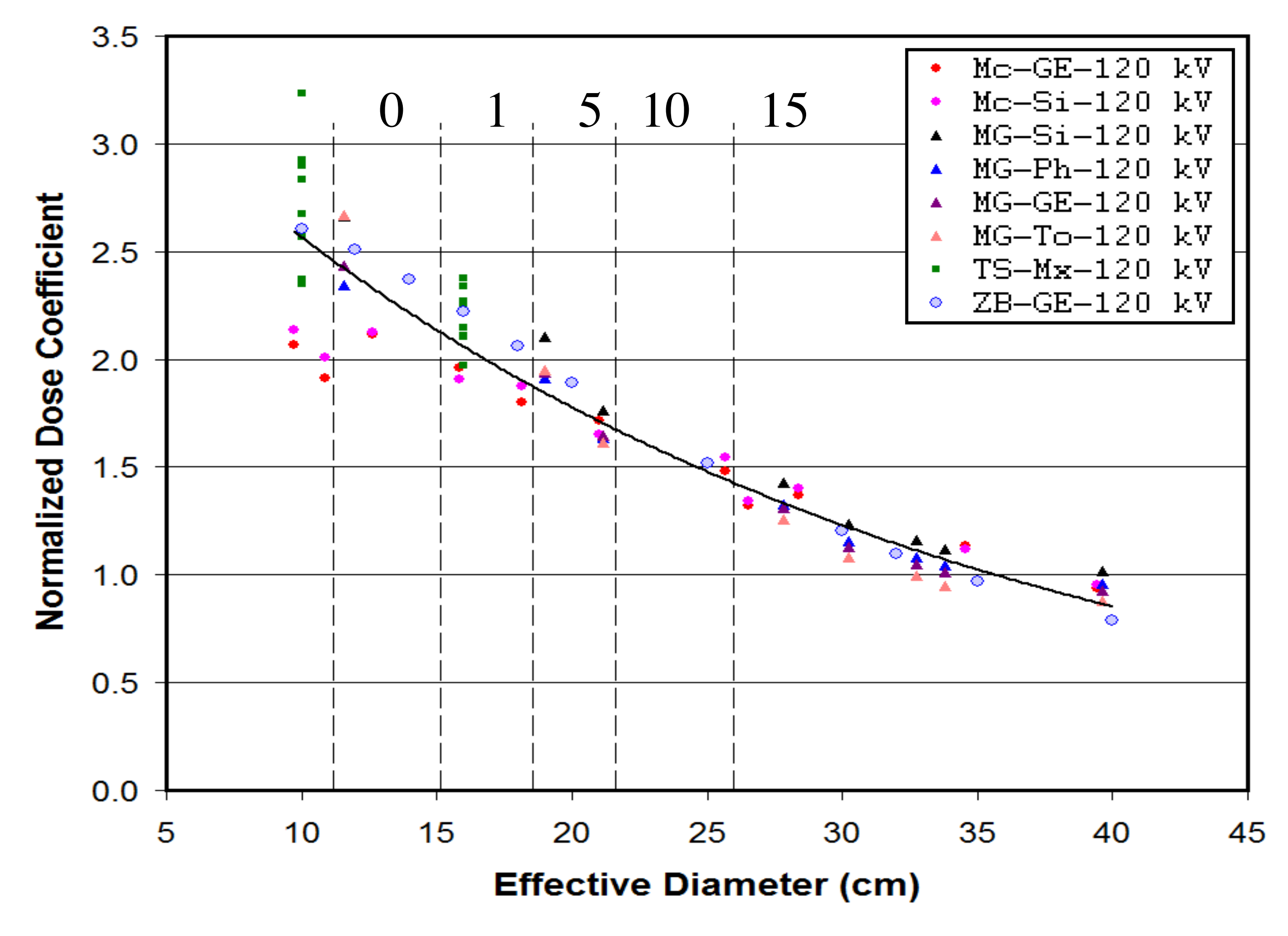


C. Monte Carlo Voxelized Phantoms
(McNitt-Gray Laboratory "MG")



D. Monte Carlo Mathematical Cylinders
(Boone Laboratory "Z-B")

TG 204



32 cm 120 kV

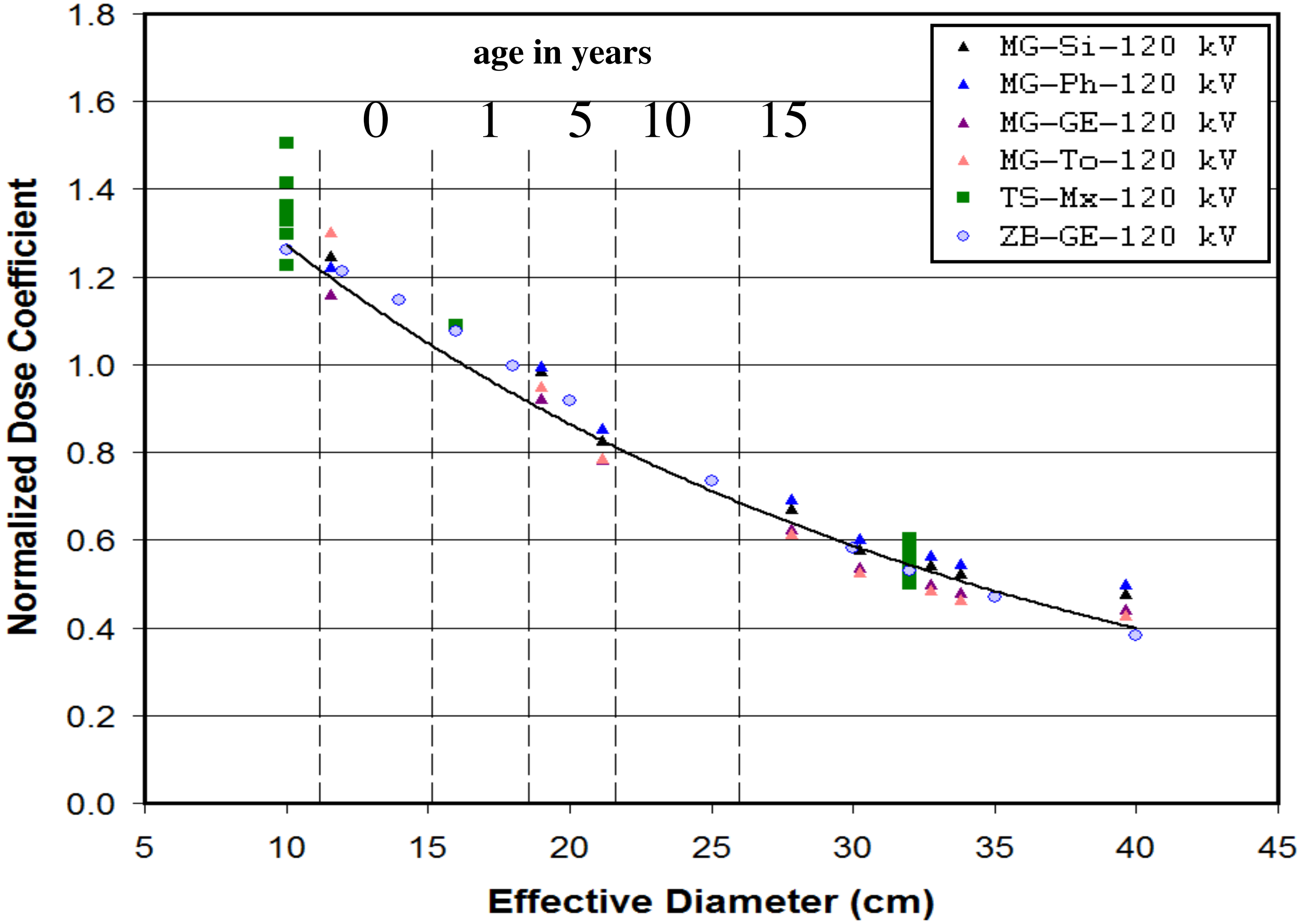
Adapted from TG 204

Patient trunk dose > $CTDI_{vol}$ by 2.5 x for smallest patients

$y = 3.7044e^{-0.0367x}$

$R^2 = 0.9429$

TG 204



16 cm 120 kVp

Adapted from TG 204

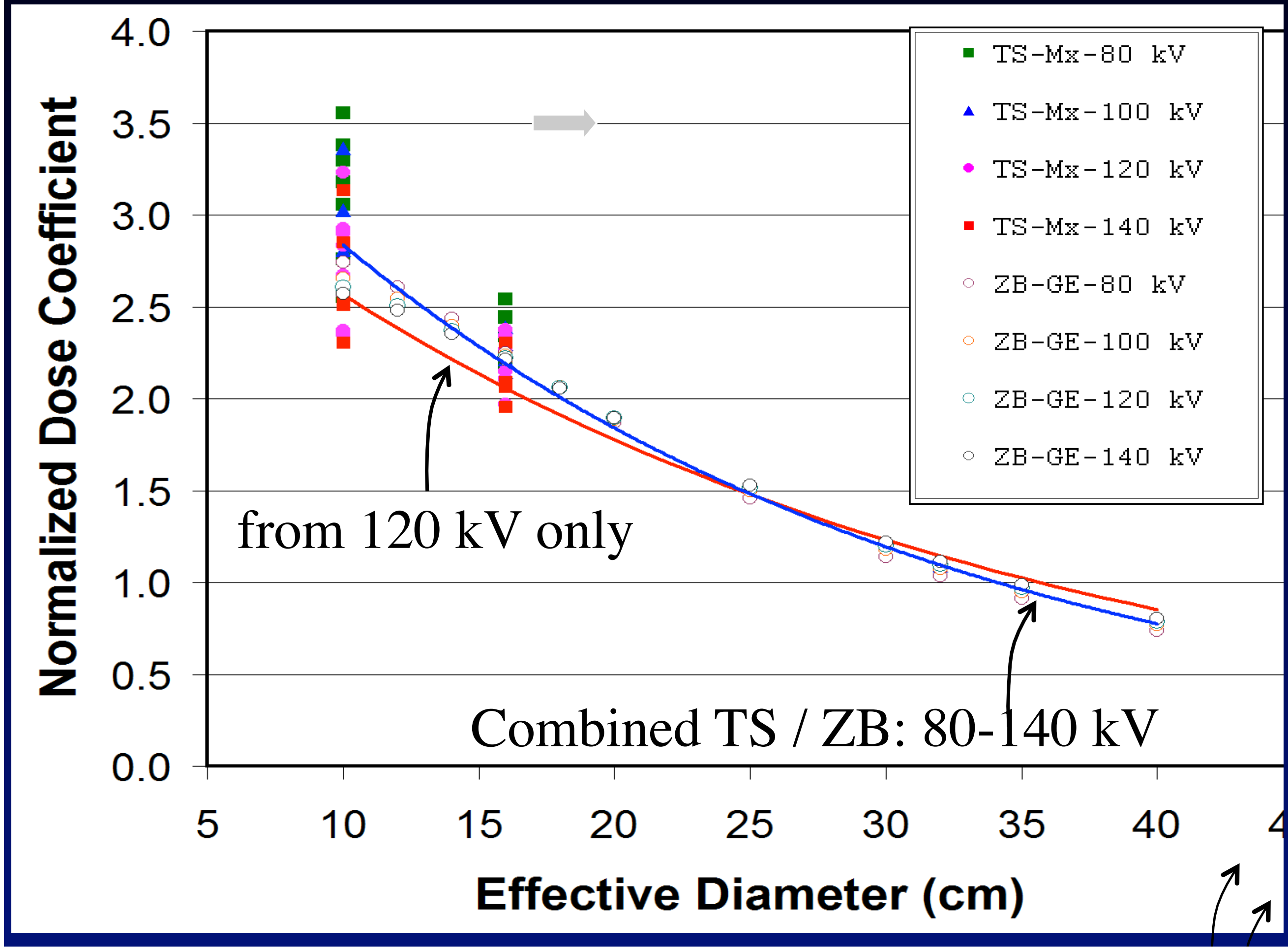
Patient head dose $\geq$ CTDI$_{vol}$ for smallest patients by only 20%

$$y = 1.8748e^{-0.0387x}$$

$$R^2 = 0.9673$$

TG 204

What about scans performed at 80, 100, or 140 kV?

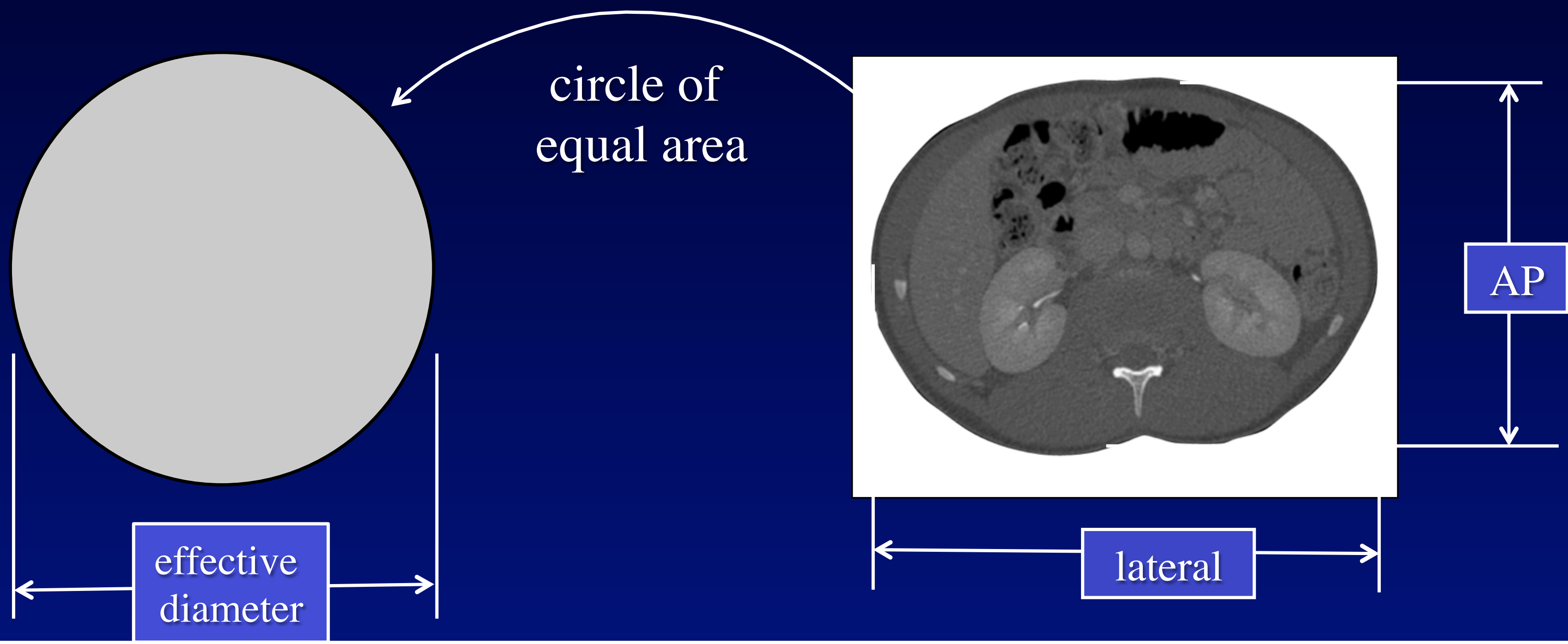


1. 5% difference overall
2. 3% difference between 1 yr old (15 cm) & adult (32cm)

TG 204

What is an effective diameter?

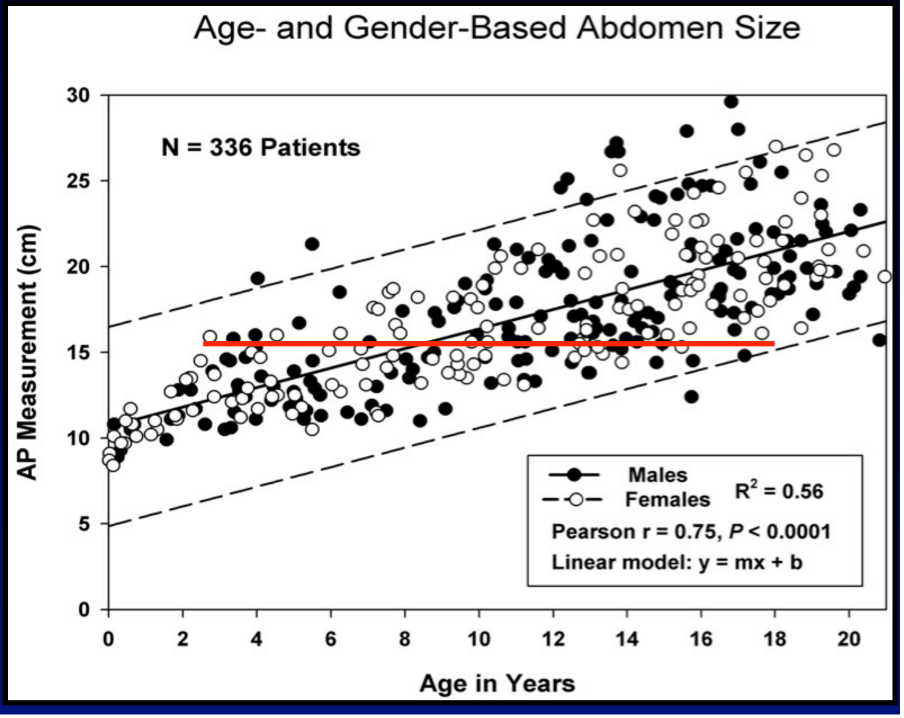
- **Circle with area of patient's cross section**
- **Effective diameter can be estimated if the patient's AP or lateral dimension is known.**



AGE vs PATENT SIZE

Same age patients vary dramatically in size.

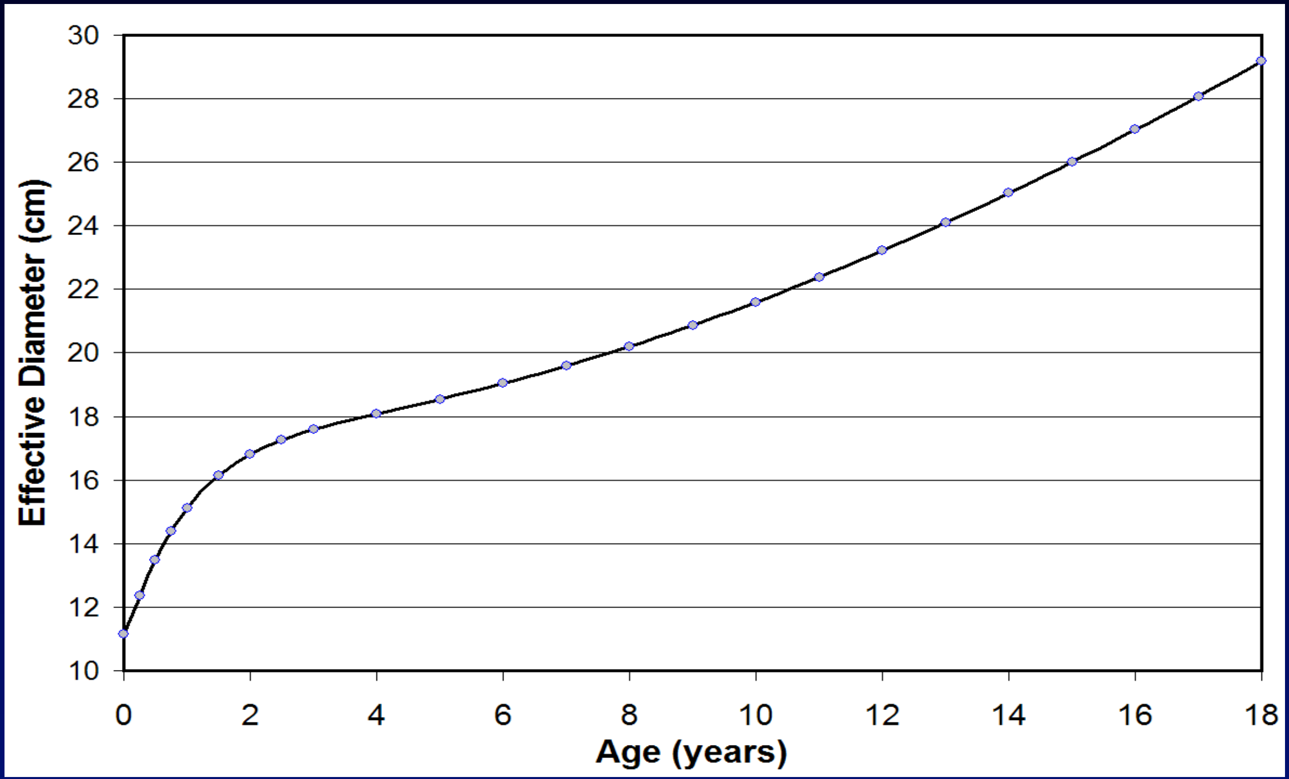
- **Abdomens of:**
  - **Largest 3 year olds and**
  - **Smallest adults are the same size.**



- **Patient cross section size, not age, should be used.**

What if I am doing retrospective dose analysis and I only know age of patient?

- **Corrections based on patient size are more accurate.**



Age (years)	Effective Diameter (cm)
0.00	11.2
0.25	12.3
0.50	13.5
0.75	14.4
1.00	15.1
1.50	16.1
2.00	16.8
2.50	17.3
3	17.6
4	18.1
5	18.5
6	19.0
7	19.6
8	20.2
9	20.9
10	21.6
11	22.4
12	23.2
13	24.1
14	25.0
15	26.0
16	27.0
17	28.1
18	29.2

Adapted from TG 204

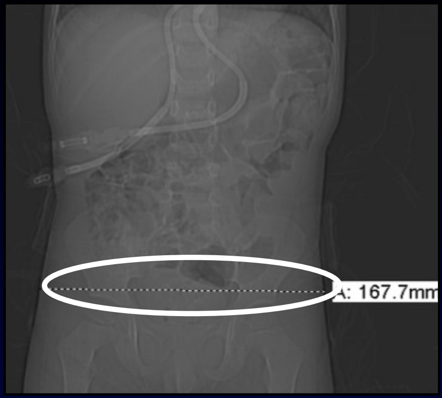
Effective Diameter as a function of age per ICRU 74

TG 204

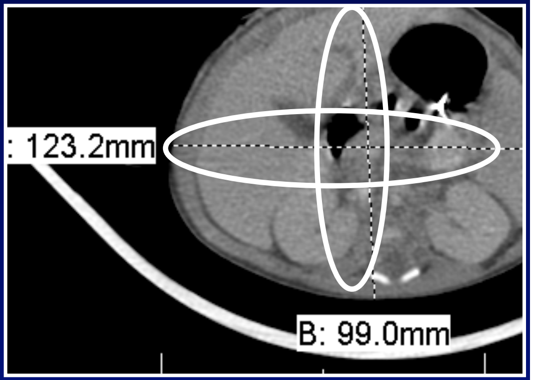
Determining patient size

- **Measure Lateral dimension with mechanical calipers.**
- **Measure Lateral or AP dimension from AP or Lateral projection scan.**
  - **Magnification Error**
- **Measure AP or LAT dimen-sion from axial scan view.**

AP or PA Projection Scan
Adapted from TG204



AP or PA Projection Scan
Adapted from TG204



TG 204

SSDE Calculations

- Failure to identify correct CTDI phantom, 16 or 32 cm: systematic error of up to 100%.
- No standard exists: depends on:
  - Selected protocol: adult or pediatric
  - Selected scan field of view
  - Year of manufacture
  - Software rev
- Make no assumptions: contact manufacturer

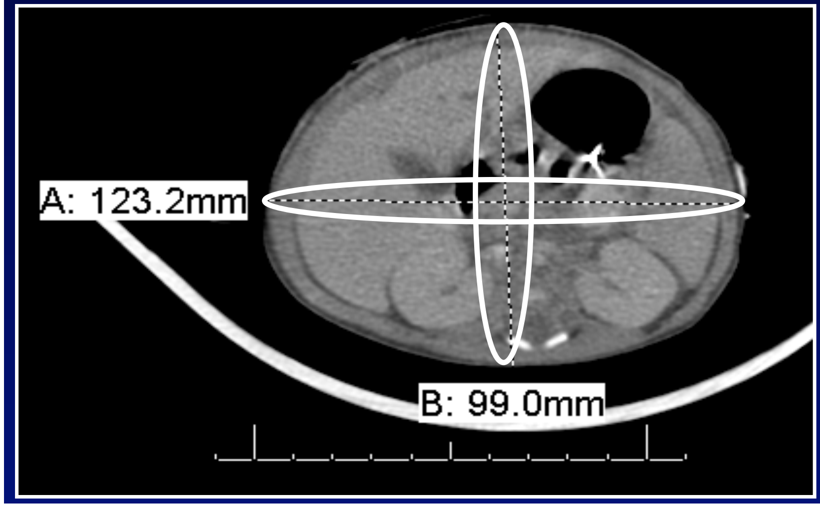
TG 204

SSDE Accuracy

- 20%
- Product is an ***estimate*** of patient dose
- Significant digits?
  - SSDE $\geq$ 5 mGy: integers only, 7 or 23 mGy
  - SSDE < 5 mGy: one decimal point, 2.7 or 4.5 mGy

SAMPLE CALCULATION: POST SCAN

- **Determine size of patient**
  - **AP = 9.9 cm; LAT = 12.3 cm**
  - **AP + LAT = 22.2 cm**
- **32 cm CTDI phantom assumed**
- **Displayed $CTDI_{vol}$ = 5.4 mGy**
- **5.4 mGy x 2.5 = 13 mGy SSDE**



Adapted from TG 204

Lat + AP Dim (cm)	Effective Dia (cm)	Correction Factor
16	7.7	2.79
17	8.2	2.74
18	8.7	2.69
19	9.2	2.64
20	9.7	2.59
21	10.2	2.55
22	10.7	2.50
23	11.2	2.46
24	11.7	2.41
25	12.2	2.37
26	12.7	2.32
27	13.2	2.28
28	13.7	2.24
29	14.2	2.20
30	14.7	2.16
31	15.2	2.12
32	15.7	2.08
33	16.2	2.05
34	16.7	2.01
35	17.2	1.97
36	17.6	1.94
37	18.1	1.90
38	18.6	1.87
39	19.1	1.83
40	19.6	1.80

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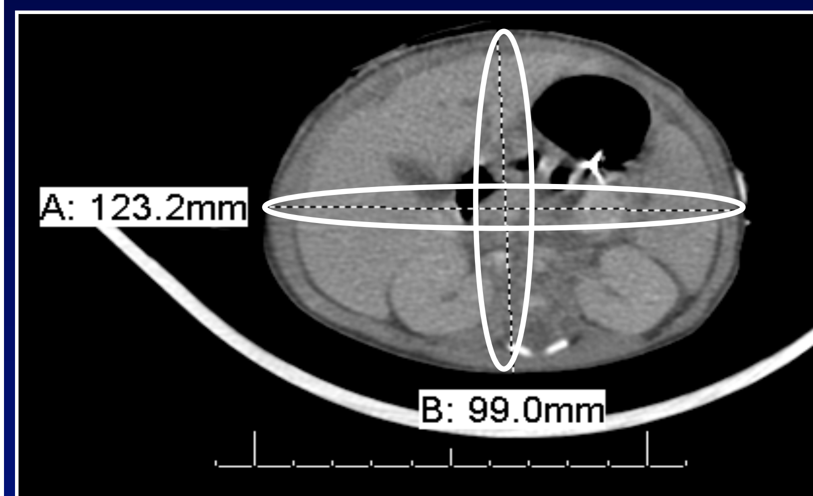

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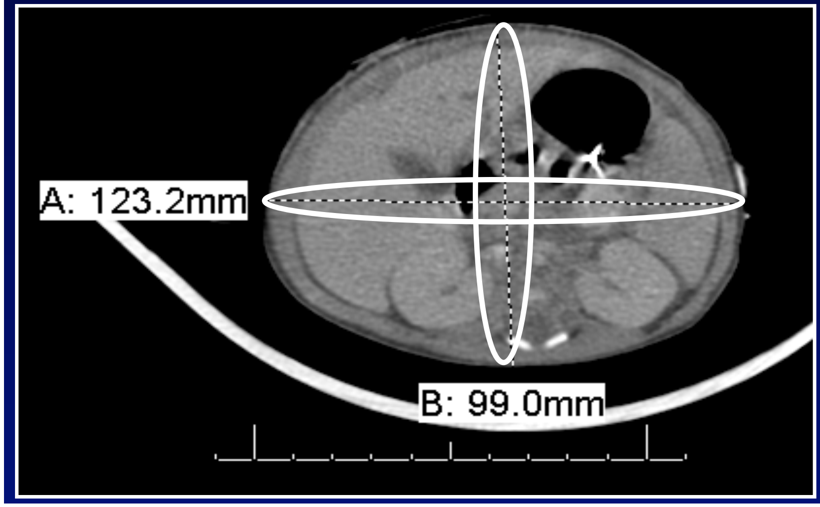

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SSDE:

20%

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20%

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1. Calculation has an estimated error of 10%.
2. Accounts for both the radiation output of the scanner and patient size.
3. Cannot be estimated until after the CT examination is completed.
4. Is more accurate if patient size is estimated based on the patient's age.
5. Should not be used for CT examinations of the thorax.

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Ref: "Size Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations", AAPM Report No. 204 (2011), p. 2.

Clinical Application

- 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 $CTDI_{vol}$

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					
			120	200	1	1.0	1.0	23			Scanner #1: 23 mGy Adult SSDE		
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)	*Aggres-sive* 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
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.

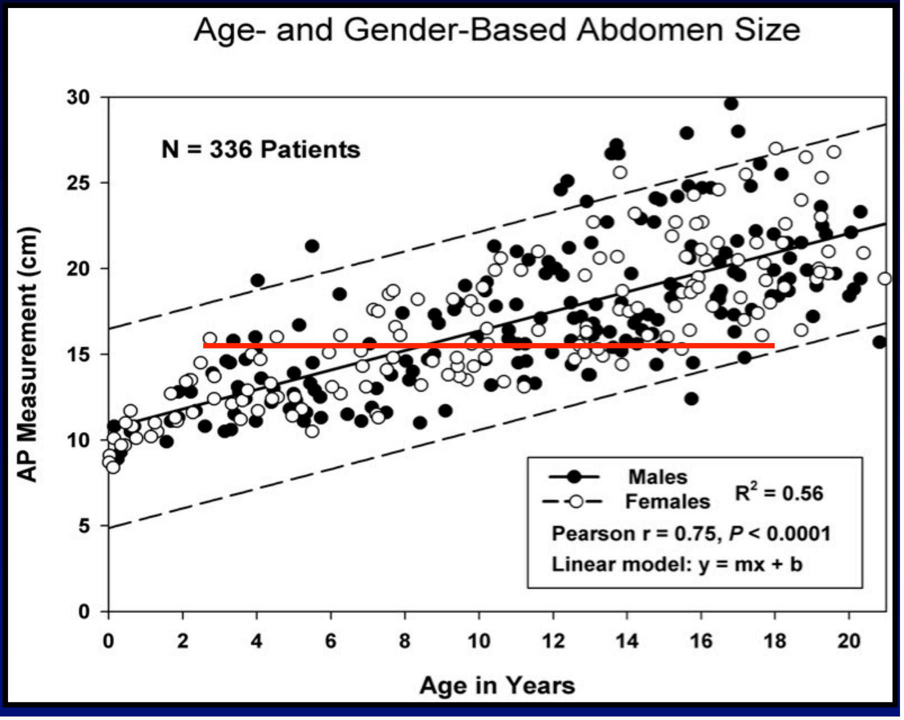
Abdomen/ Pelvis:	Abdomen/ Pelvis:	Abdomen/ Pelvis:	kVp	mA
			120	200
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age
10	14	11.8	4	newborn
11	16	13.3	10	1 yr
14	20	16.7	18	5 yr
16	25	20.0	33	10 yr
19	29	23.5	54	15 yr
22	32	26.5	65	20 yr
25	35	29.6	75	md adult
31	41	35.7	110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

[redacted]

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

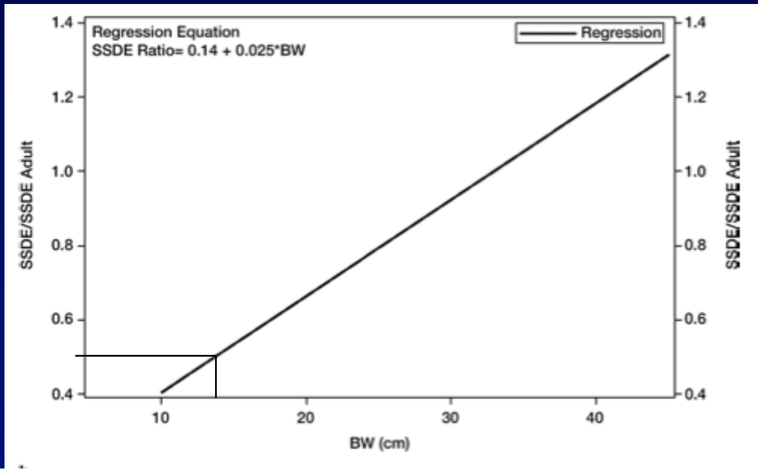
D. QuIRCC published research?

- 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)**	***Aggres-sive* 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	26.5	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 <u>Abdominal</u> DRL (without iterative reconstruction) Required mAs**

mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE
200	1	1.0	1.0	23

							Scanner #1: 23 mGy Adult SSDE			Scanner #2: 23 mGy Adult SSDE		
Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor	*Limited* mAs SSDE (mGy)	*Moderate* mAs SSDE (mGy)	*Aggres-sive* 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

Reduction of mAs for abdominal CT for a newborn patient:

20%	1. Newborn (NB) dose = adult dose (AD) if adult mAs is unchanged.
20%	2. NB dose = half of AD if adult mAs cut in half.
20%	3. NB dose = AD if adult mAs divided by 3.
20%	4. NB dose = half of AD if adult mAs divided by 4.
20%	5. NB dose = half of AD does not provide clinically useful images.

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Reduction of mAs for abdominal CT 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 2014 Oct;44 Suppl 3:479-488.

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 aseline:	Head Baseline:	Head Baseline:	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Scan #1
			120	370	1.00	1.0	1.0	
AP hickness (cm)	**LAT Thickness (cm)**	**Effective Diameter (cm)**	**Mass (kg)**	**Age**	***Limited* mAs Reduction Factor**	***Moderate* mAs Reduction Factor**	**Limited Estimated mAs**	**Mode Estima mA**
14	12	13	4	newborn	0.74	0.38	274	14
16	13	14.5	10	1 yr	0.80	0.47	296	17
17	14	15.5	13	2 yr	0.86	0.62	318	22
19	15	17	21	6 yr	0.93	0.79	344	29

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 aseline:	Head Baseline:	Head Baseline:	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Scan #1
			120	370	1.00	1.0	1.0	
AP hickness (cm)	**LAT Thickness (cm)**	**Effective Diameter (cm)**	**Mass (kg)**	**Age**	***Limited* mAs Reduction Factor**	***Moderate* mAs Reduction Factor**	**Limited Estimated mAs**	**Mode Estima mA**
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

Managing Pediatric Head CT Doses:

20% 1. Calculate 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%

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

20%

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.

10

Managing Pediatric Head CT Doses:

1. Calculate SSDE to estimate patient dose.
2. Cut 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 2014 Oct;44 Suppl 3:479-488.

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

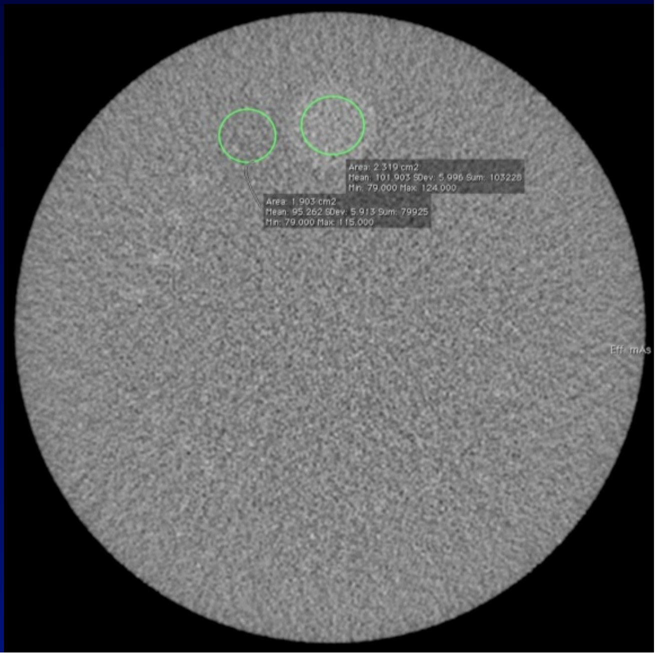
Establish Department DRLs

- **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 to improve image quality and reduce radiation dose for pediatric patients, one can ignore the effect on:

20%	1. Contrast.
20%	2. Noise.
20%	3. Sharpness
20%	4. Artifacts
20%	5. Scanning speed

10

When reducing the high voltage to improve image quality and reduce radiation dose for pediatric patients, 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

Automatic Mode

- Adjust provided parameters to result in desired SSDE based on voltage choice
  - Image quality index is not constant for all sized patients
    - Radiologists demand greater CNR in images of smaller patients
      - GE: Noise Index
        - Maintain constant noise in all images
        - Doubling Noise index quarters dose and doubles noise in images

Automatic Mode

- Adjust provided parameters to result in desired SSDE based on voltage choice
  - Image quality index typically is not constant for all sized patients
    - Toshiba: Standard Deviation
      - Doubling Std Dev quarters dose and doubles noise in images
    - Siemens: Quality Reference Effective mAs for ~ 80 kg standard patient
    - Philips: Automatic Current Setting (ACS)

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!