3rd CT Dose Summit:
Strategies for CT Scan Parameter Optimization
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CURRENT CT DOSE METRICS: MAKING CTDI SIZE-SPECIFIC

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Acknowledgments

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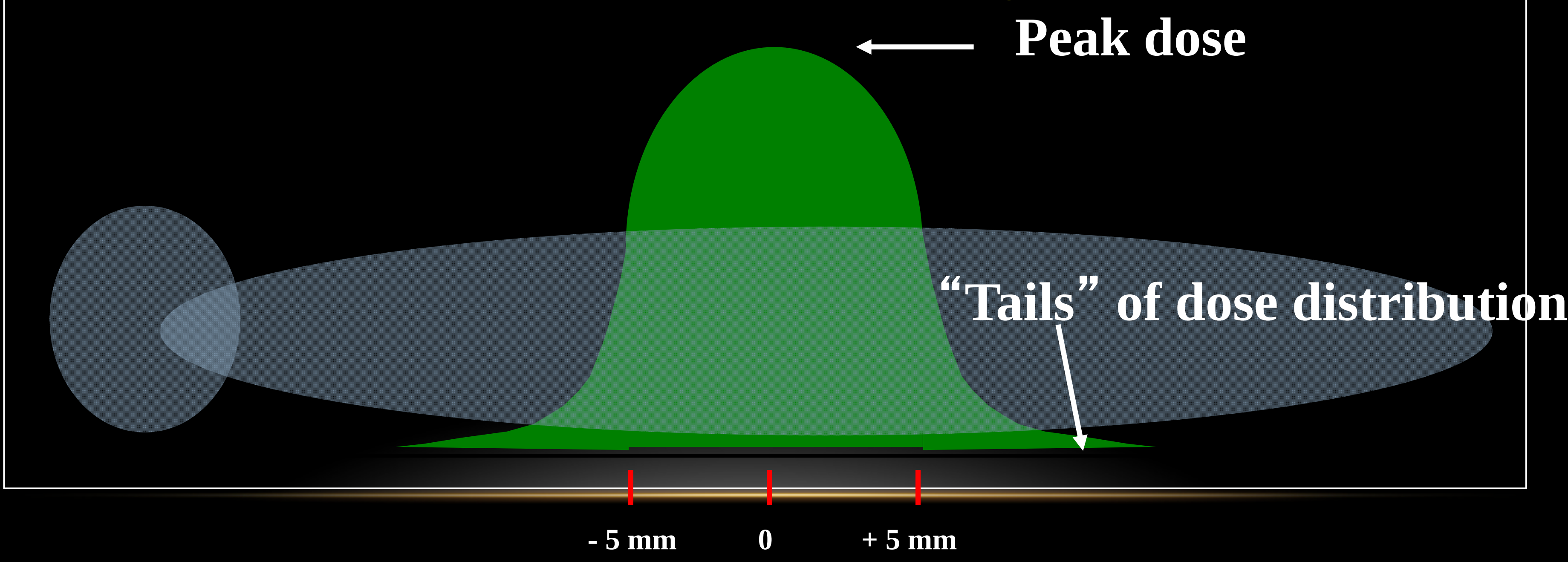
INTRODUCTION

- CT Dose Indices
  - CTDI
  - $CTDI_{100}$, $CTDI_{w}$, $CTDI_{vol}$
  - Displayed vs Measured $CTDI_{vol}$
  - DLP
- Clinical Dilemma
- SSDE
- E Dose Limitations
- Simple Application of SSDE in the Clinic
- Estimating Organ Doses from SSDE

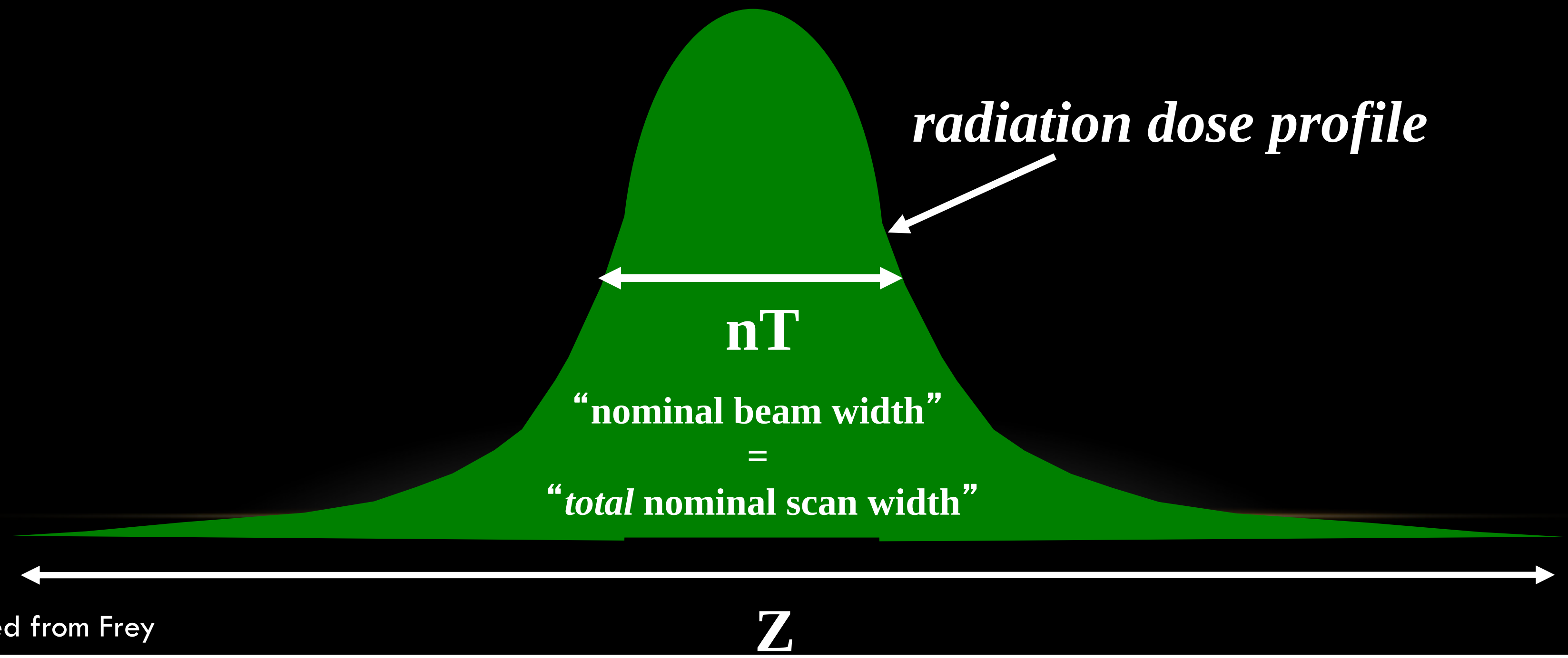
REAL WORLD ….

Radiation distribution *crosses* the imaged volume



Adapted from Frey

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

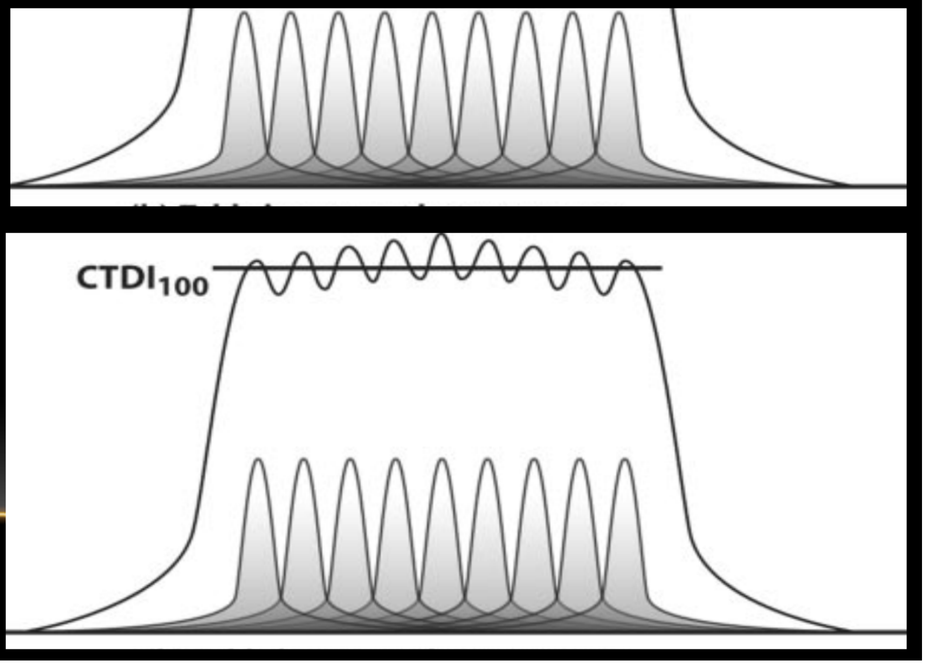


Adapted from Frey

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.

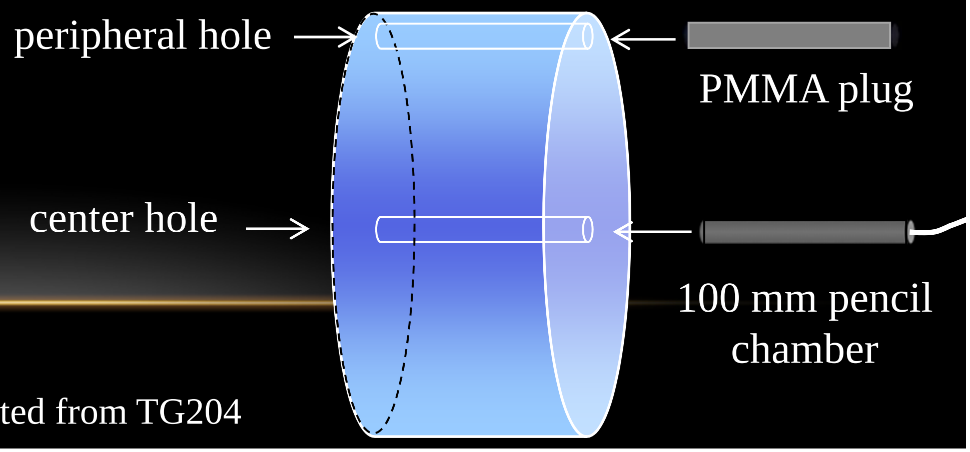
CT SCANNER DOSE INDICES

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



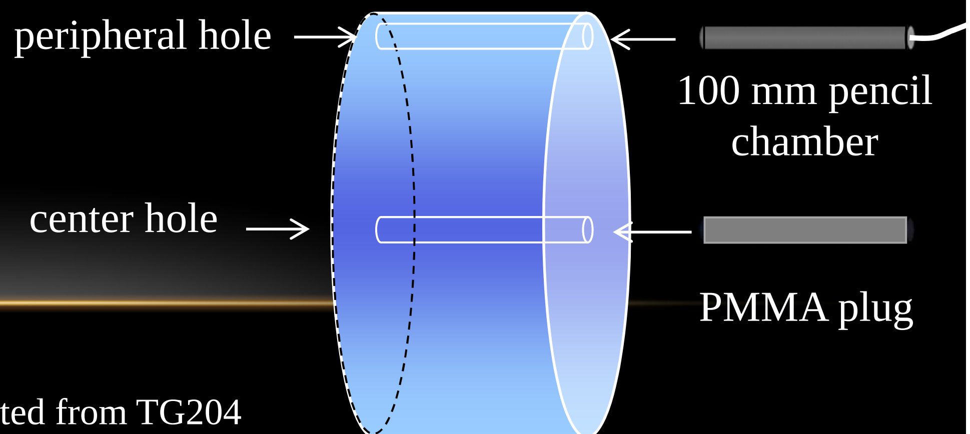
Adapted from TG204

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
  - Surface of phantom
  - Non measured holes plugged



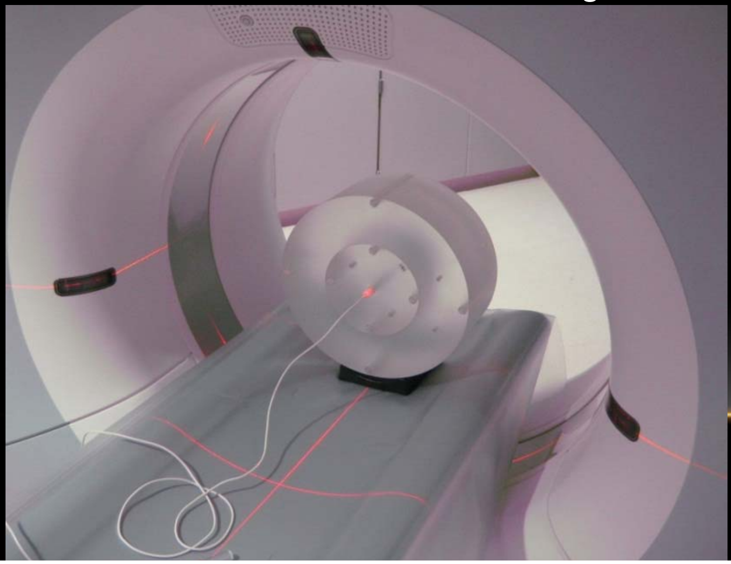
Adapted from TG204

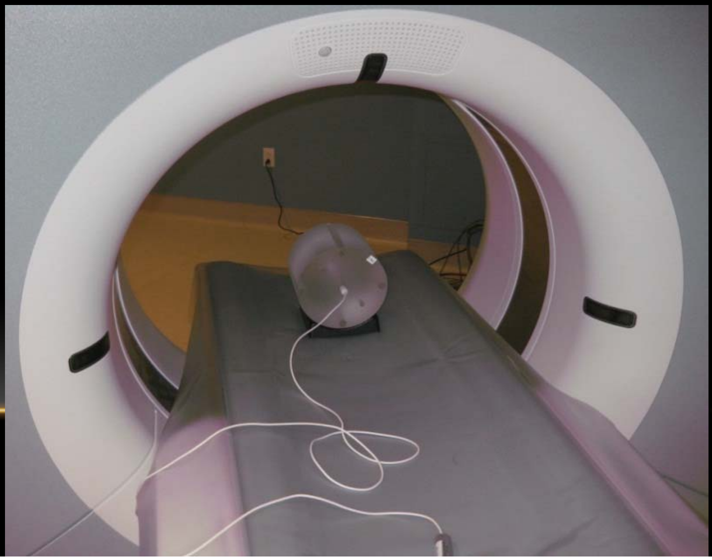
CT SCANNER DOSE INDICES

Measurement of CT Radiation Dose

- 32 and 16 cm CTDI standard phantoms positioned to measure CT doses.

Images Courtesy of John Boone

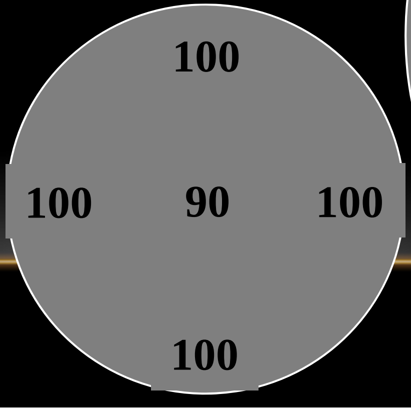


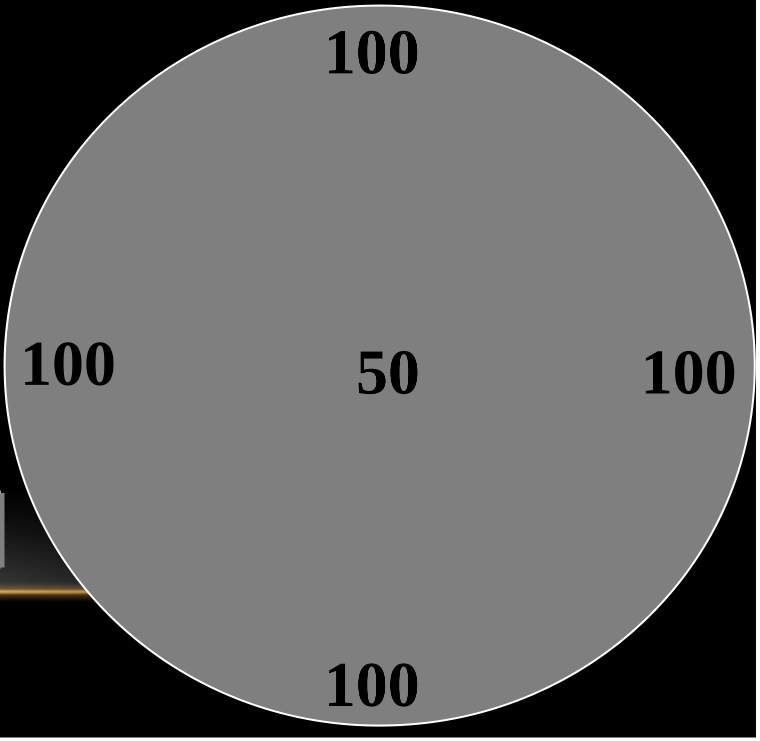


CT SCANNER DOSE INDICES

Measurement of CT Radiation Dose

- Dose readings at two points in phantom
  - 1 cm below surface
  - Center
- Dose distribution depends on phantom diameter



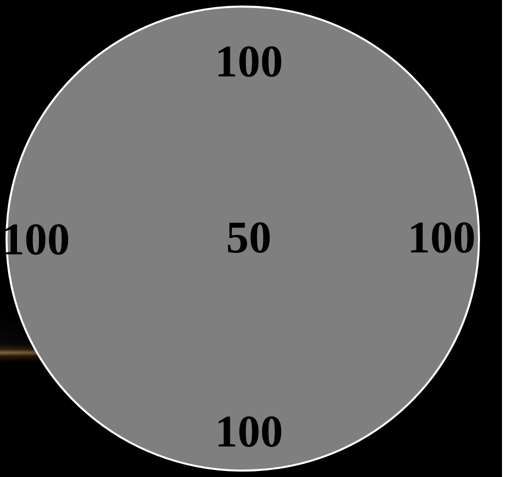


CT SCANNER DOSE INDICES

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

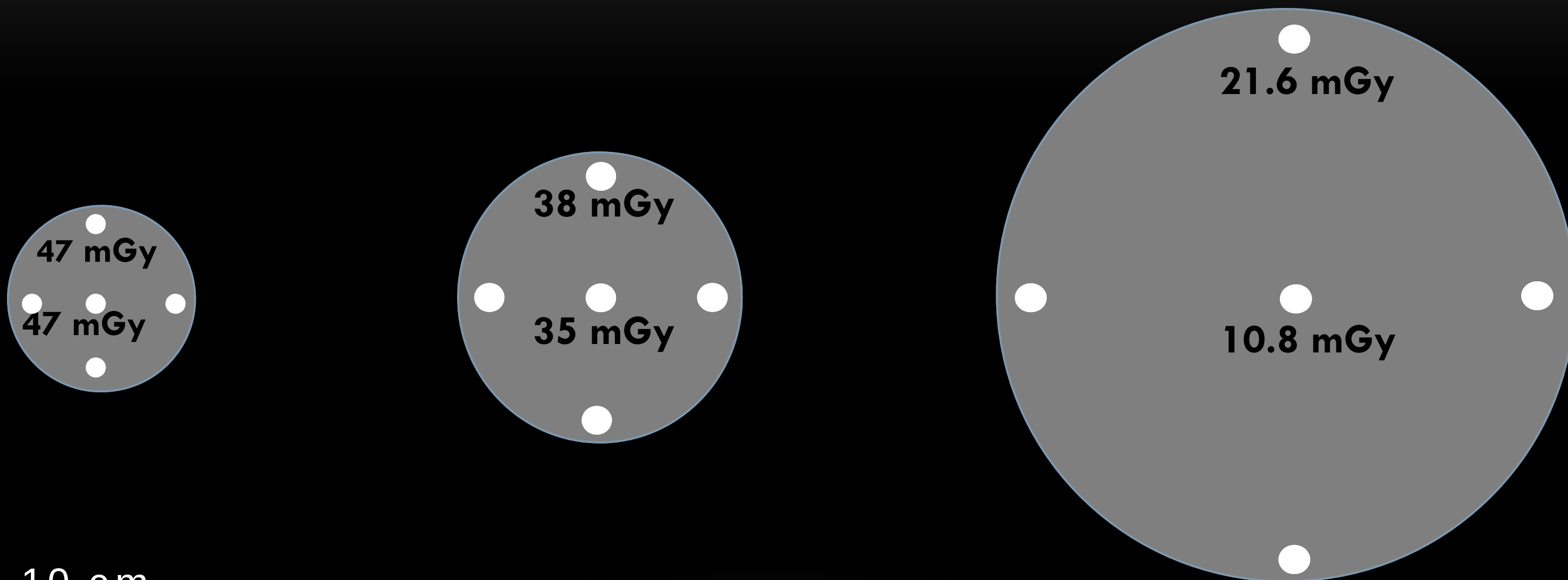
CT SCANNER DOSE INDICES

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

Measured $CTDI_{vol}$ = 47

Measured $CTDI_{vol}$ = 37

Measured $CTDI_{vol}$ = 18



10 cm Diameter

16 cm Diameter

32 cm Diameter

Measured $CTDI_{vol}$ increases 2.6 times as phantom size decreases!

CT SCANNER DOSE INDICES

Displayed $CTDI_{vol}$

- Dose that represents distribution of dose given to cross-sectional area of a slab of the CTDI phantom (16 or 32 cm diameter)
- Reflects changes in:
  - High voltage to x-ray tube (kV)
  - X-ray tube current (mA)
  - Rotation time (sec)
  - Pitch
  - Bow tie filter shape, thickness, material
  - Source to detector distance

CT SCANNER DOSE INDICES

Displayed $CTDI_{vol}$

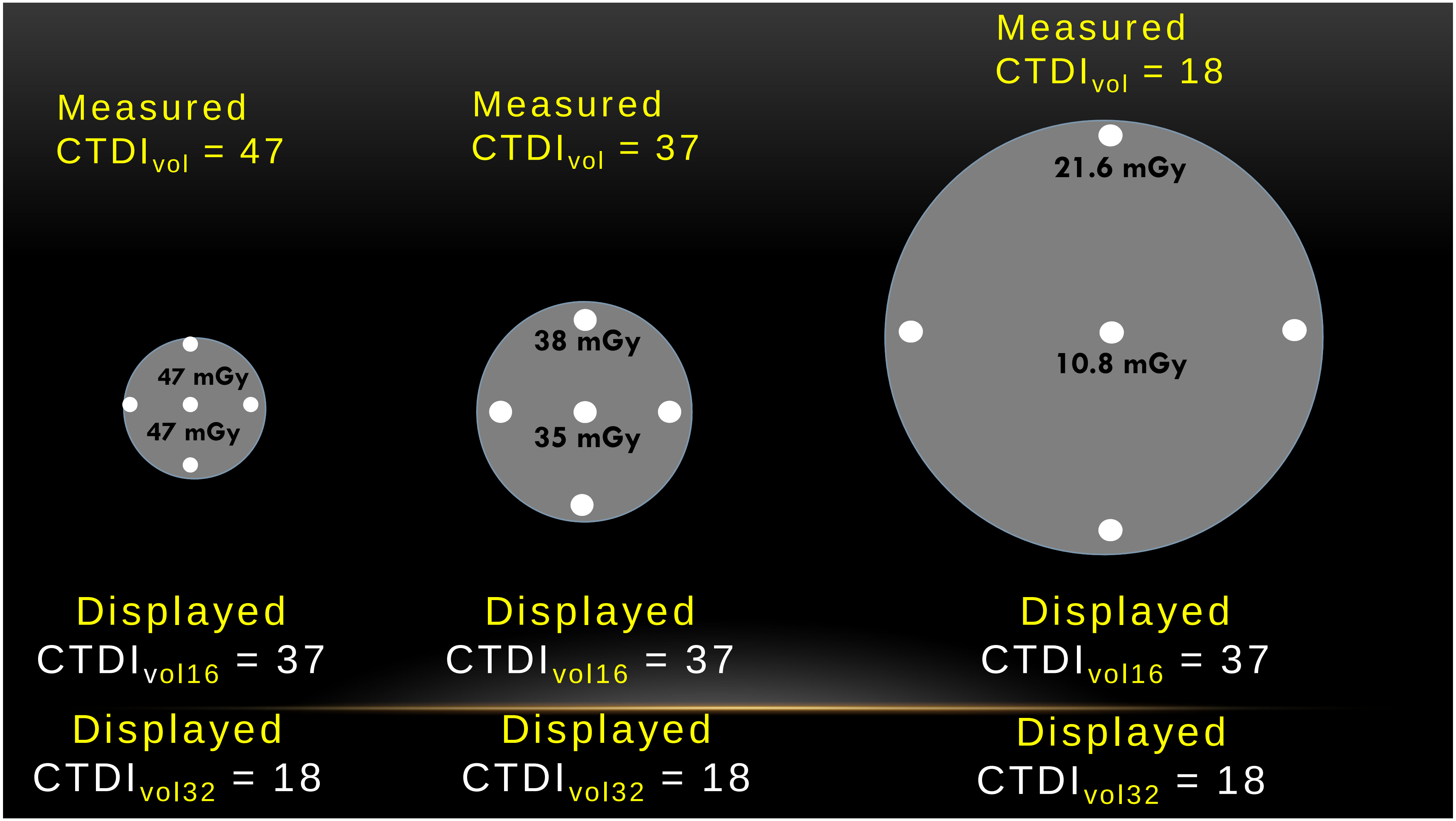
- Standardized method to estimate and compare the radiation output of two different CT scanners to same phantom.
- Dose index of CT scanners if the fan beam width in z direction of the patient is small (< 1 cm)
- If fan beam width (> 1 cm), dose index addressed by AAPM TG111

CT SCANNER DOSE INDICES

Displayed $CTDI_{vol}$

- does not represent . . .

Patient dose!!

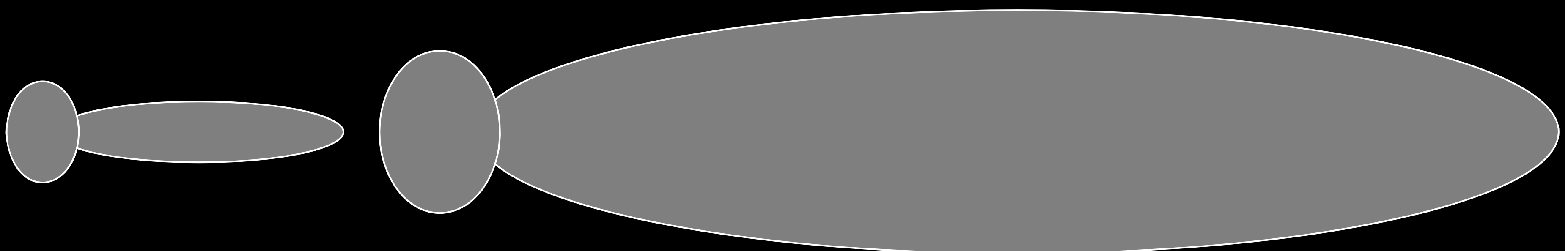


Measured
CTDIvol = 47
47 mGy
47 mGy
Measured
CTDIvol = 37
38 mGy
35 mGy
Measured
CTDIvol = 18
21.6 mGy
10.8 mGy
Displayed
CTDIvol16 = 37
Displayed
CTDIvol32 = 18
Displayed
CTDIvol16 = 37
Displayed
CTDIvol32 = 18
Displayed
CTDIvol16 = 37
Displayed
CTDIvol32 = 18

CTDI SHORTCOMING

Same radiographic technique

- 32 cm CTDI Phantom



- Displayed $CTDI_{vol}$ = 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

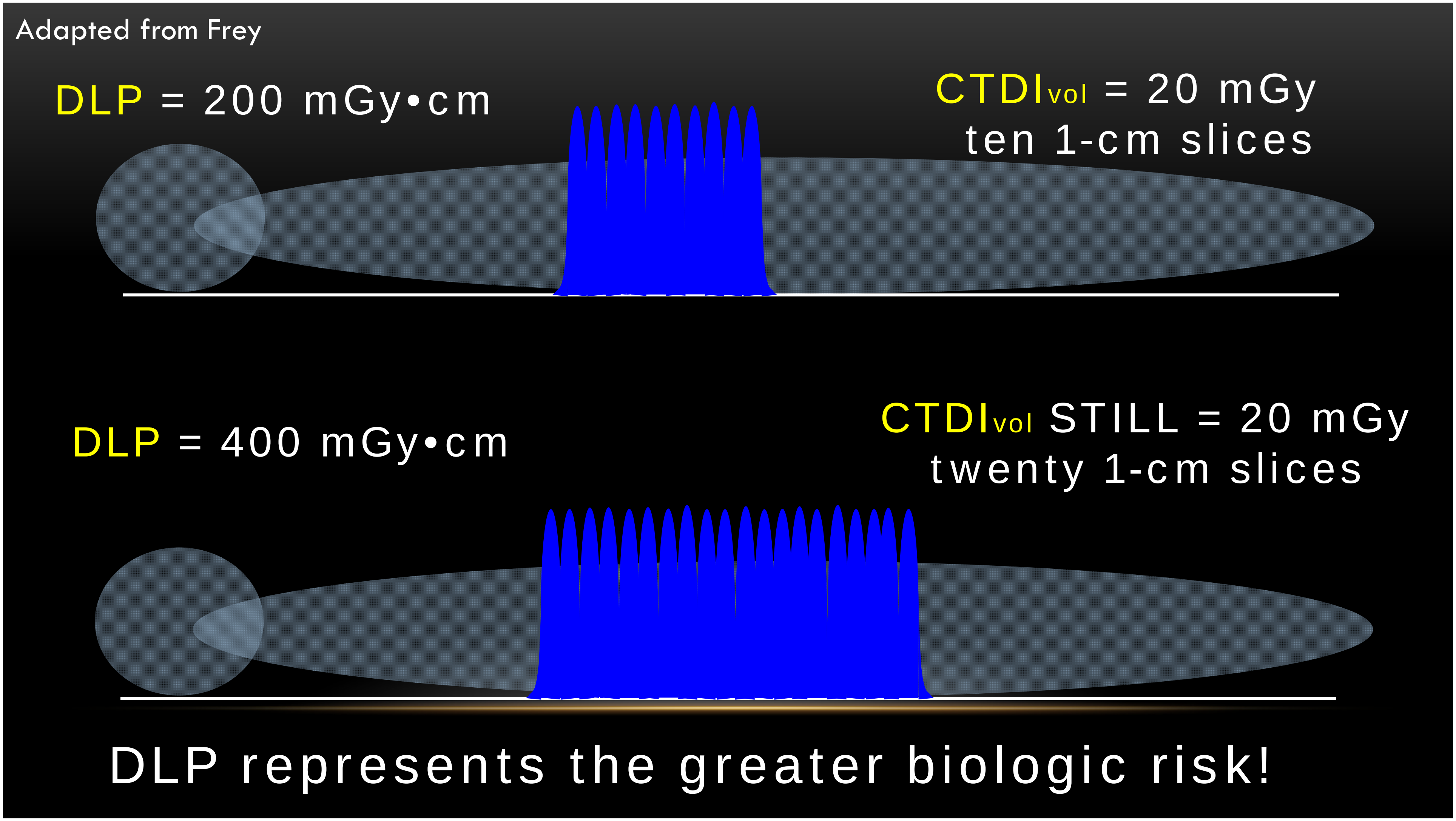
- Anthropomorphic Phantoms only approximate the human body

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.

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



Adapted from Frey
DLP = 200 mGy•cm
CTDIvol = 20 mGy
ten 1-cm slices
DLP = 400 mGy•cm
CTDIvol STILL = 20 mGy
twenty 1-cm slices
DLP represents the greater biologic risk!

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.

ICRU

image gently℠

TG 204

Report does not:

- Address correction factors for heads
- Correct small (< 1%) doses from scanned projection images.
- Correct for variation (~ 5%) in attenuation of thorax vs abdomen
- Correct small variation in pre and post contrast scans

TG 204

So what is SSDE?:

- Estimate of the average patient dose within the entire scan volume of patient.
  - Adjusts for patient size and varying attenuation from overlying tissue thickness.
  - Uses average scanner radiation output during CT scan: $CTDI_{vol}$
    - Output varies along z axis
    - Output varies as beam rotates
    - Output varies based on bow tie filter

TG 204

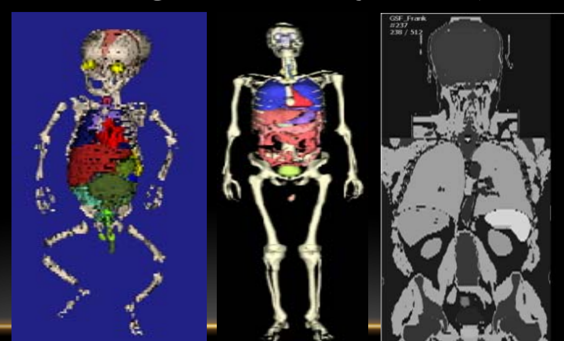
Data from four independent investigators studying patient size correction factors.

Adapted from TG 204

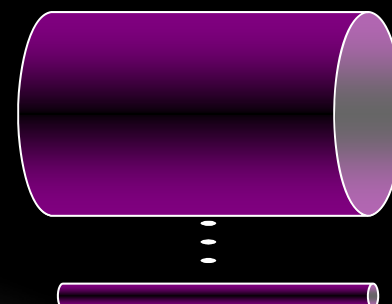
- Physical measurements on phantoms
- Monte Carlo computer modeling

. Anthropomorphic Phantoms
(McCollough Laboratory "Mc")

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

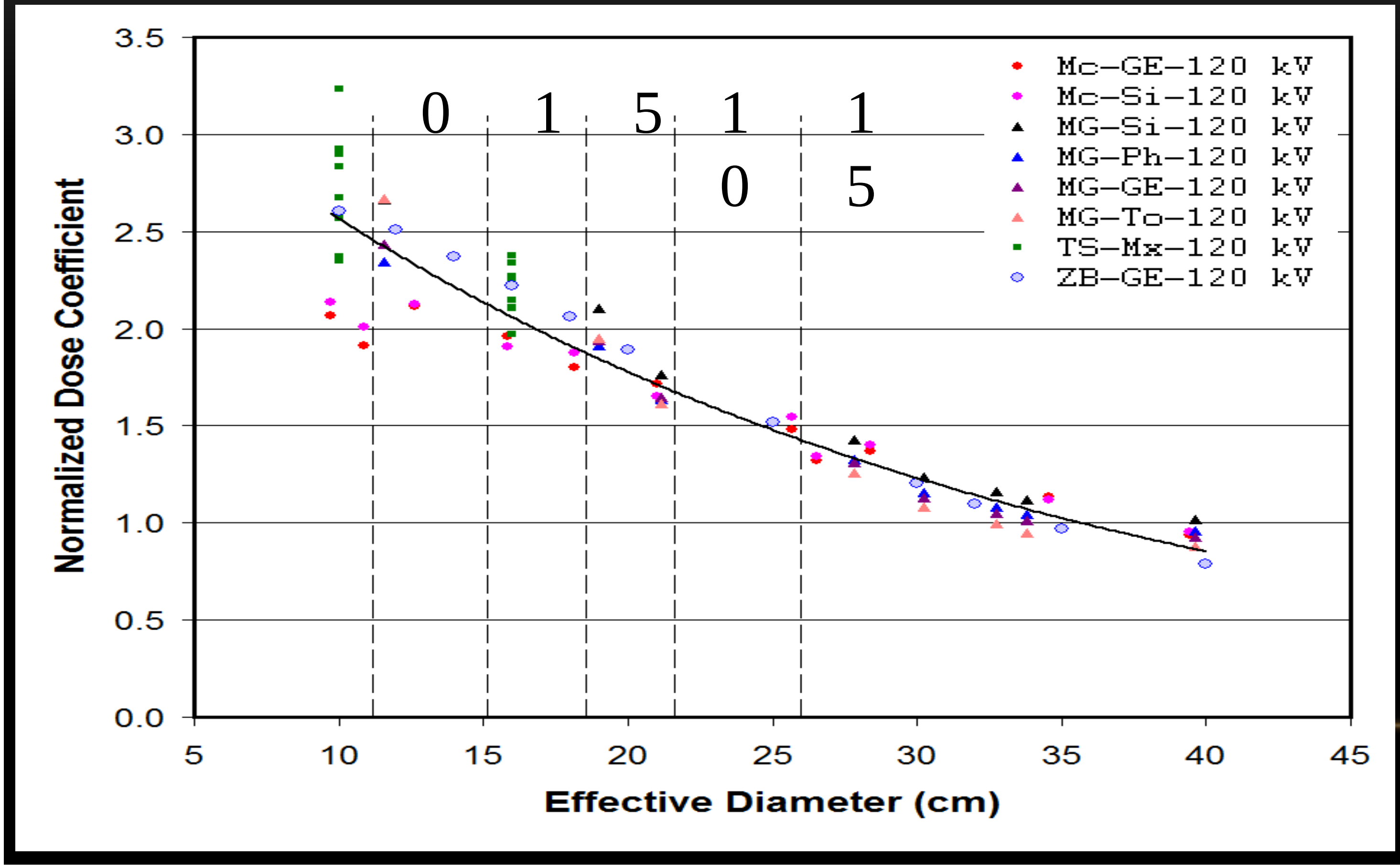


. Monte Carlo Voxelized Phantoms
(McNitt-Gray Laboratory "MG")



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

TG 204



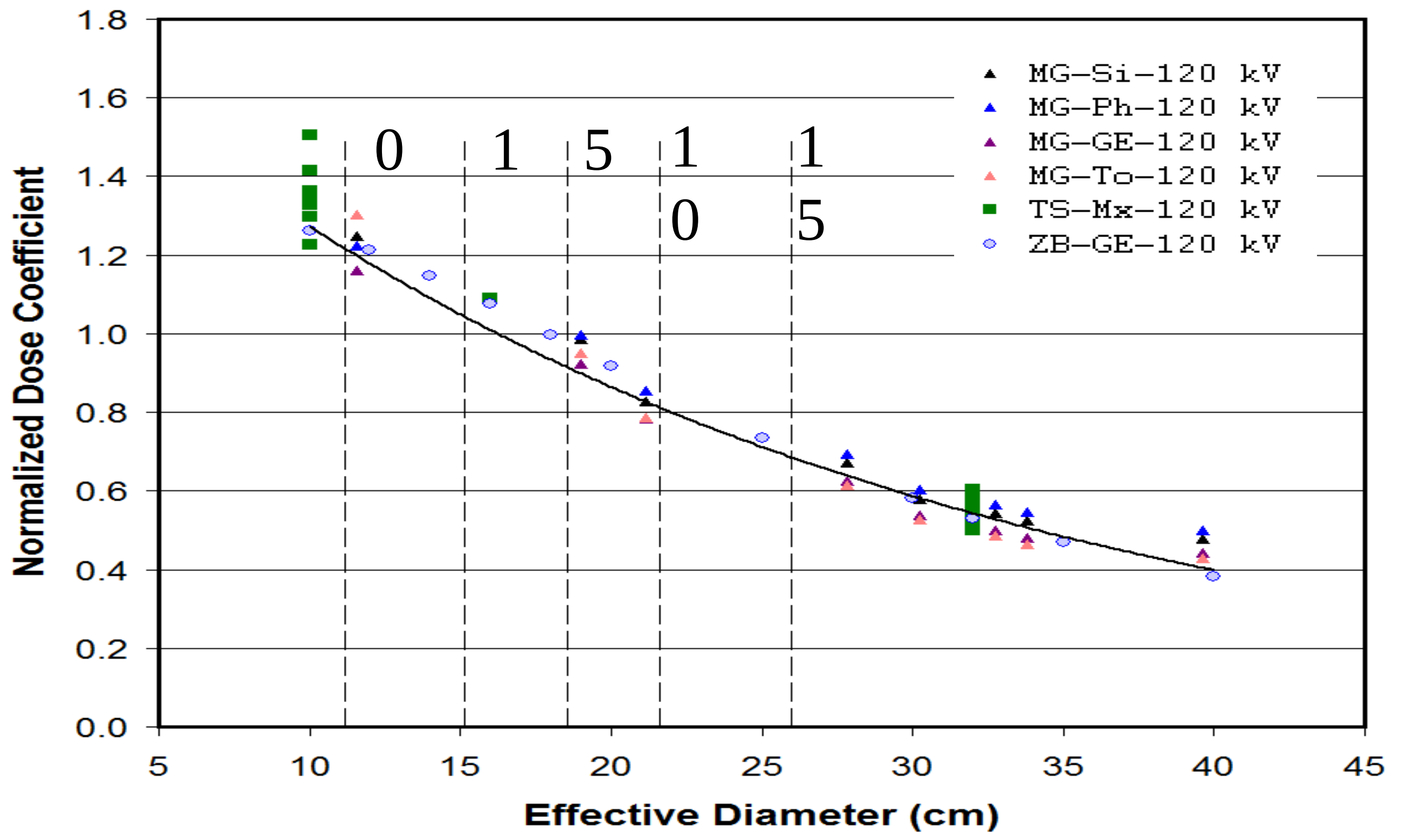
32 cm 120 kV

Adapted from TG 204

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

$R^2 = 0.9429$

TG 204



16 cm 120 kV

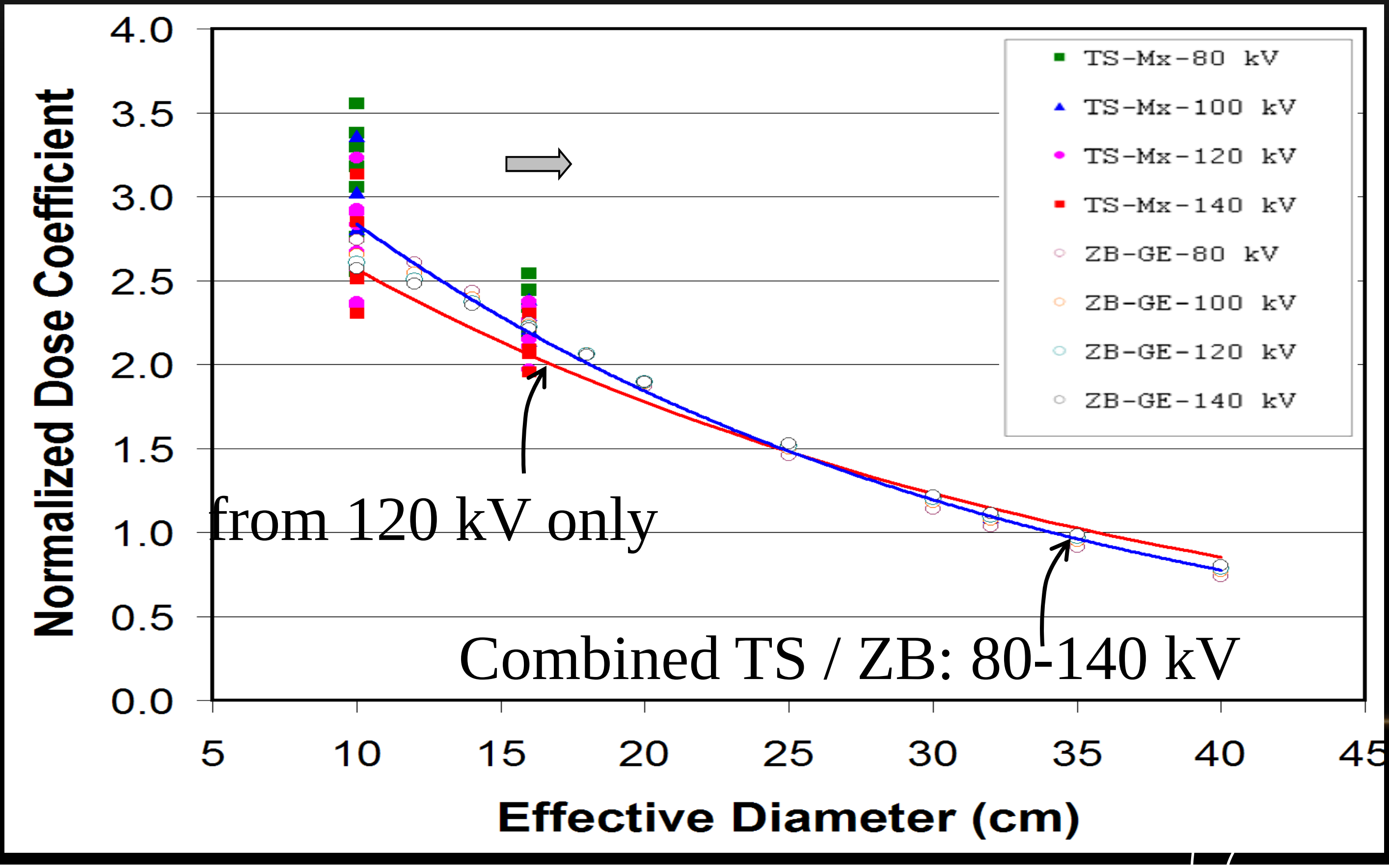
Adapted from TG 204

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

$R^2 = 0.9673$

TG 204

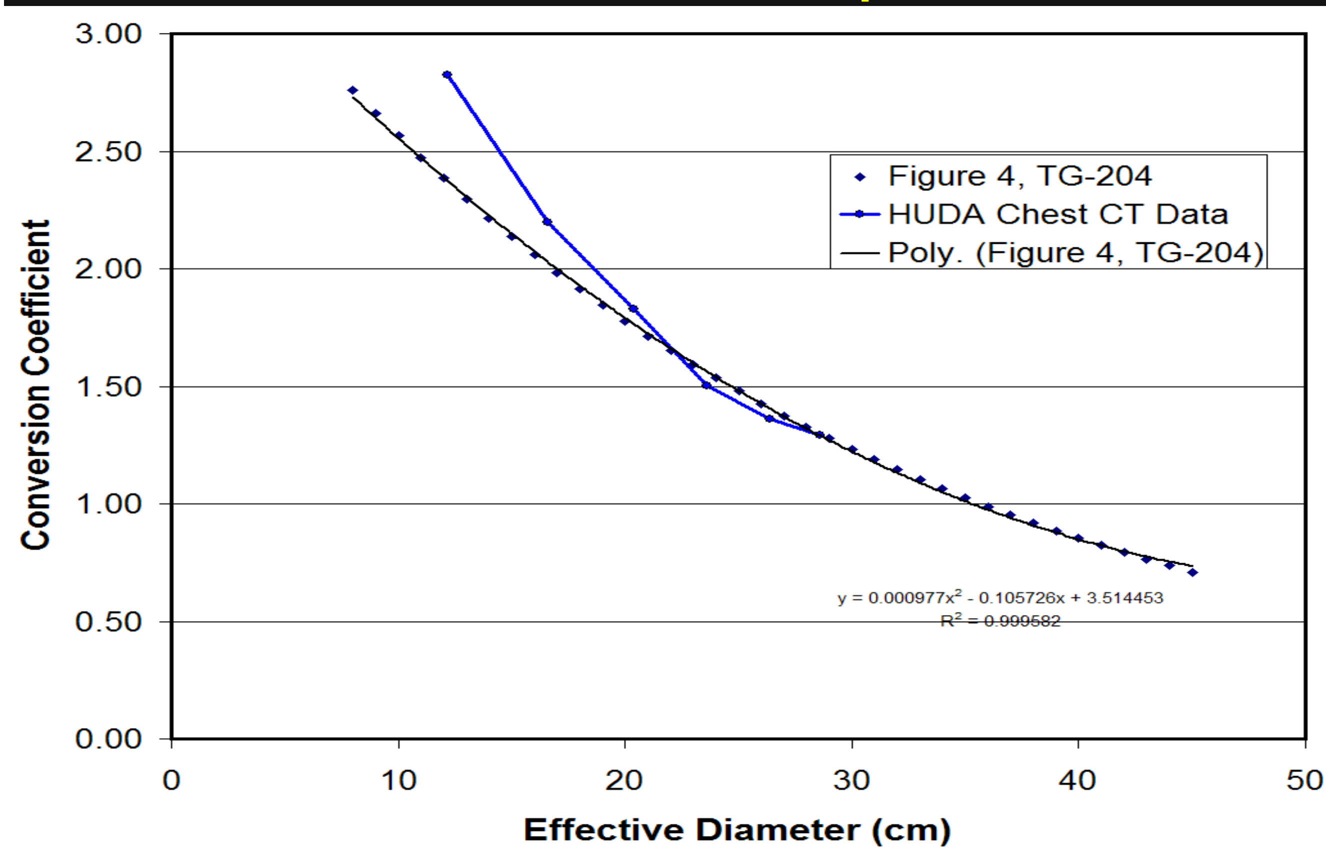
What about scans performed at 80, 100, or 140 kV?



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

TG 204

What about scans performed in the



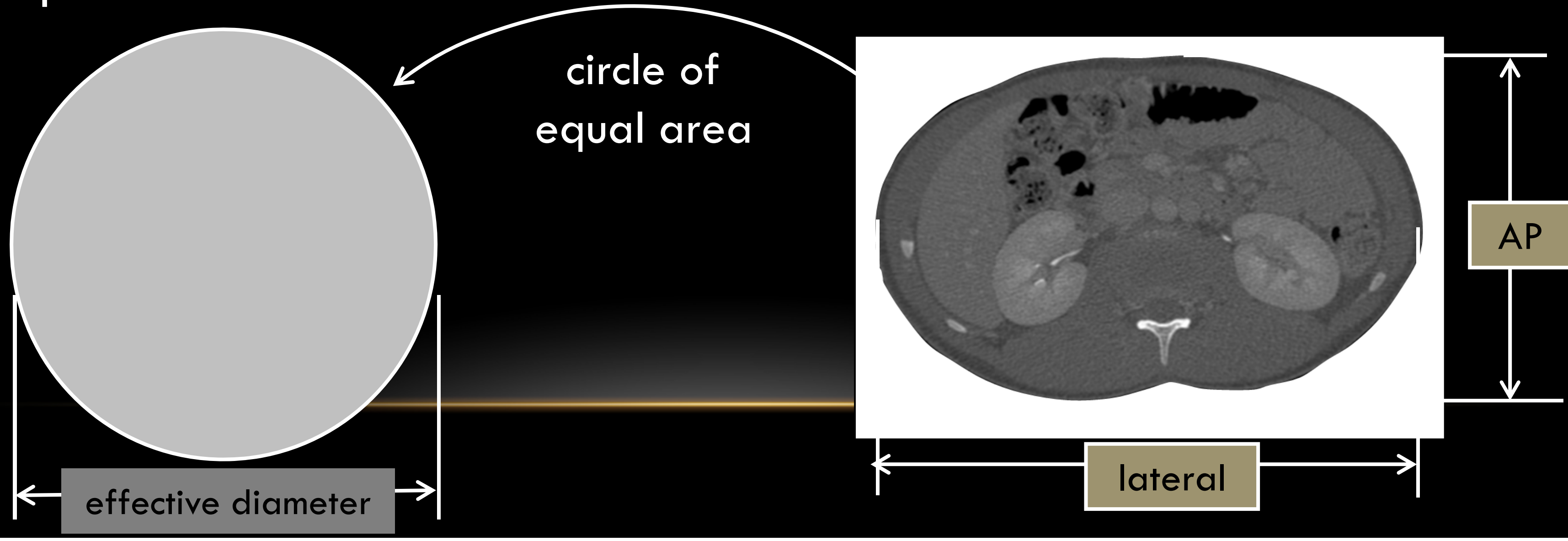
1. Thorax data from Huda et al.
2. 16% dif @ 12 cm
3. 7% dif @ 17 cm
4. < 3% dif > 17 cm

Adapted from Boone

TG 204

What is an effective diameter?

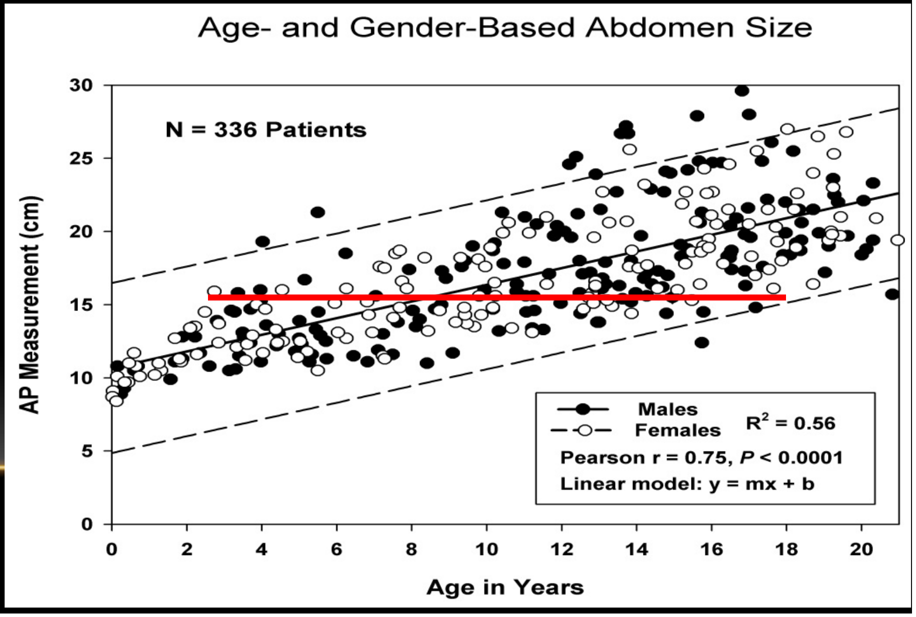
- Circle with area of patient’s cross section
- Effective diameter can be estimated if the patient’s AP or lateral dimension is known.



AGE vs PATENT SIZE

Same age patients vary dramatically in size.

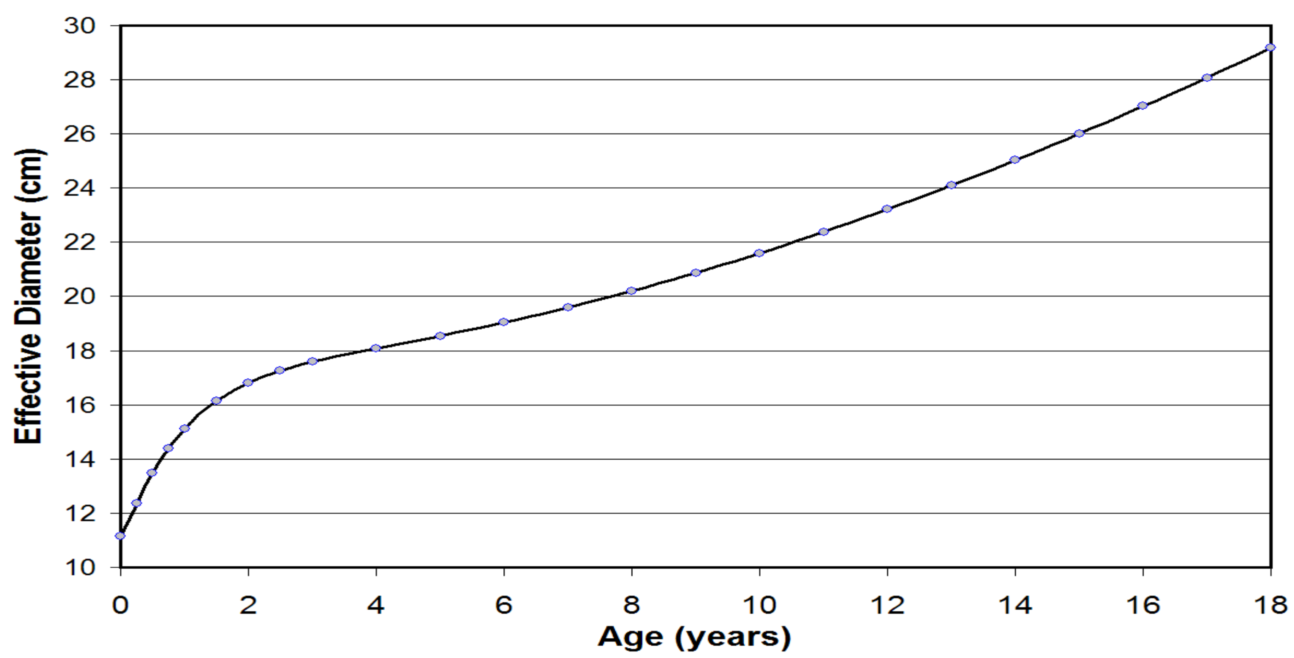
- Abdomens of:
  - Largest 3 year olds and
  - Smallest adults are the same size.



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.



Adapted from TG 204

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

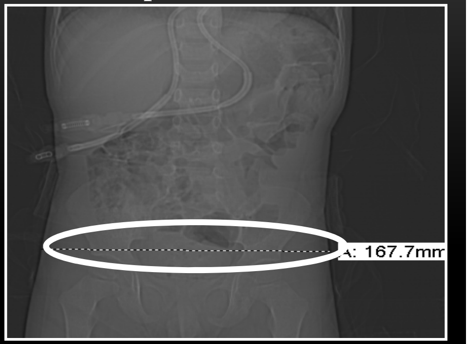
Effective Diameter as a function of age per ICRU 74

TG 204

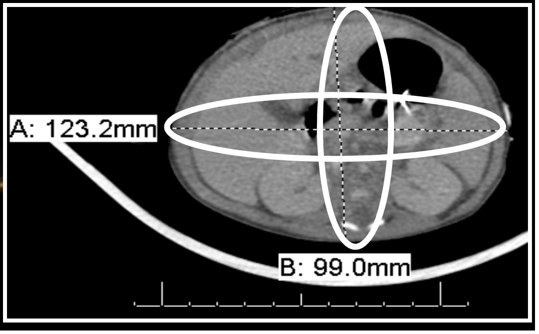
Determining patient size

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

AP or PA Projection Scan
Adapted from TG204



AP or PA Projection Scan
Adapted from TG204



TG 204

Determining size of CTDI phantom your CT scanner used to estimate $CTDI_{vol}$

- Failure to identify correct phantom, 16 or 32 cm leads to a systematic error of up to 100%.
- No standard exists. Choice may depend on:
  - Selected protocol: adult or pediatric
  - Selected scan field of view
  - Year of manufacture
  - Software level
- Make no assumptions: contact manufacturer of your unit through their service organization.

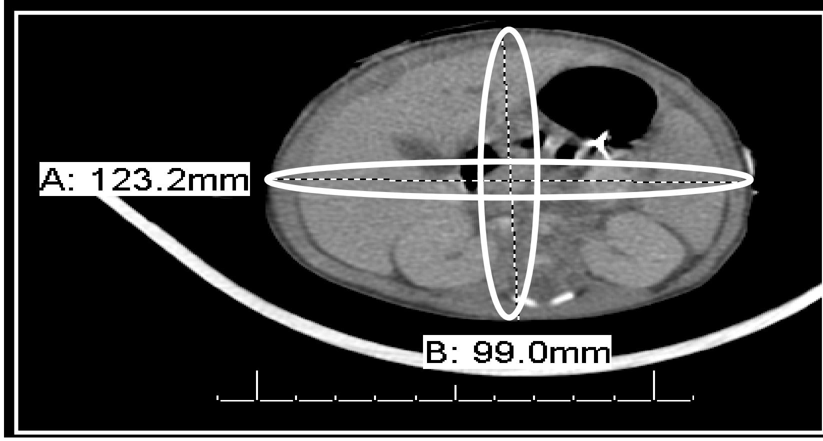
TG 204

SSDE Accuracy

- 20%
- Product is an *estimate* of patient dose
- Report doses with proper number of significant digits
  - SSDE $\geq$ 5 mGy: integers only, e.g. 7 or 23 mGy
  - SSDE < 5 mGy: one decimal point, e.g. 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

Effective Dose Limitations

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.

CLINICAL APPLICATIONS OF SSDE

Phantom		16 CTDI	32 CTDI	16/32 CTDI
	$CTDI_{vol}$	SSDE	SSDE	SSDE
Abdomen	(mGy)	(mGy)	(mGy)	(mGy)
Newborn	8			
Sm Adult	12			
Lg Adult	16			

Setting up reference values for all size patients based on $CTDI_{vol}$ results in odd patient doses.

CLINICAL APPLICATIONS OF SSDE

Phantom		16 CTDI	32 CTDI	16/32 CTDI
	$CTDI_{vol}$	SSDE	SSDE	SSDE
Abdomen	(mGy)	(mGy)	(mGy)	(mGy)
Newborn	8	9		
Sm Adult	12	10		
Lg Adult	16	7		

Setting up reference values for all size patients based on $CTDI_{vol}$ results in odd patient doses.

CLINICAL APPLICATIONS OF SSDE

Phantom		16 CTDI	32 CTDI	16/32 CTDI
	$CTDI_{vol}$	SSDE	SSDE	SSDE
Abdomen	(mGy)	(mGy)	(mGy)	(mGy)
Newborn	8	9	19	
Sm Adult	12	10	20	
Lg Adult	16	7	15	

Setting up reference values for all size patients based on $CTDI_{vol}$ results in odd patient doses.

CLINICAL APPLICATIONS OF SSDE

Phantom		16 CTDI	32 CTDI	16/32 CTDI
	$CTDI_{vol}$	SSDE	SSDE	SSDE
Abdomen	(mGy)	(mGy)	(mGy)	(mGy)
Newborn	8	9	19	9
Sm Adult	12	10	20	10
Lg Adult	16	7	15	15

Setting up reference values for all size patients based on $CTDI_{vol}$ results in odd patient doses.

CLINICAL APPLICATIONS OF SSDE

Abdomen	SSDE (mGy)	$CTDI_{v16}$ (mGy)	$CTDI_{v32}$ (mGy)	$CTDI_{v16/32}$ (mGy)
Newborn	9			
Sm Adult	12			
Lg Adult	15			

Setting up reference values for all size patients based on SSDE is more straight forward.

CLINICAL APPLICATIONS OF SSDE

Abdomen	SSDE (mGy)	$CTDI_{v16}$ (mGy)	$CTDI_{v32}$ (mGy)	$CTDI_{v16/32}$ (mGy)
Newborn	9	8		
Sm Adult	12	15		
Lg Adult	15	35		

Setting up reference values for all size patients based on SSDE is more straight forward.

CLINICAL APPLICATIONS OF SSDE

Abdomen	SSDE (mGy)	$CTDI_{v16}$ (mGy)	$CTDI_{v32}$ (mGy)	$CTDI_{v16/32}$ (mGy)
Newborn	9	8	4	
Sm Adult	12	15	7	
Lg Adult	15	35	16	

Setting up reference values for all size patients based on SSDE is more straight forward.

CLINICAL APPLICATIONS OF SSDE

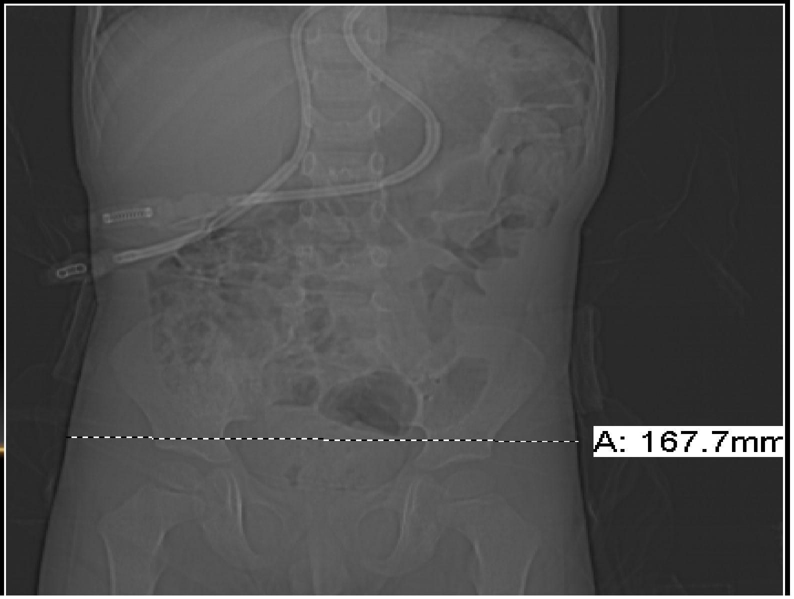
Abdomen	SSDE (mGy)	$CTDI_{v16}$ (mGy)	$CTDI_{v32}$ (mGy)	$CTDI_{v16/32}$ (mGy)
Newborn	9	8	4	8
Sm Adult	12	15	7	15
Lg Adult	15	35	16	16

Setting up reference values for all size patients based on SSDE is more straight forward.

CLINICAL APPLICATIONS OF SSDE

SSDE estimates patient dose for both adult and pediatric patients.

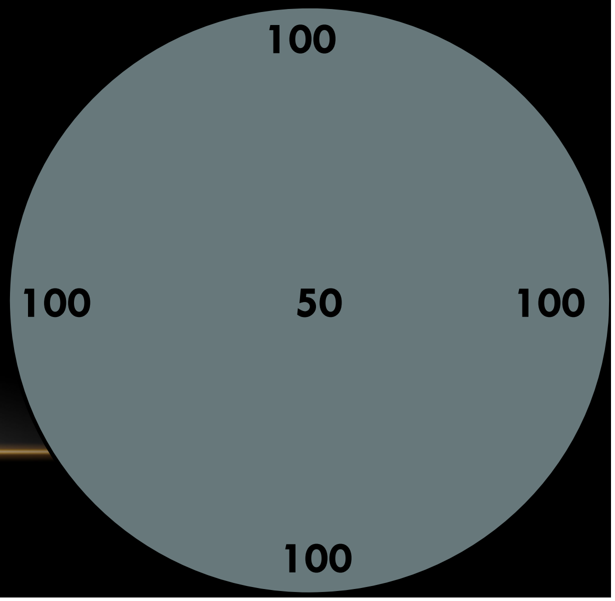
- can be first approximation of some organ doses
  - Soft tissues only
  - Organ completely in scan volume in z direction.



CLINICAL APPLICATIONS OF SSDE

SSDE

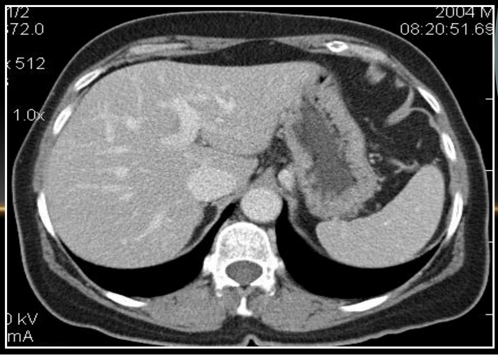
- Can be first approximation of some organ doses:
  - Radial dose profiles
  - Range dependent on patient diameter
    - Pediatric vs Adult?
  - $CTDI_{vol}$ (83)



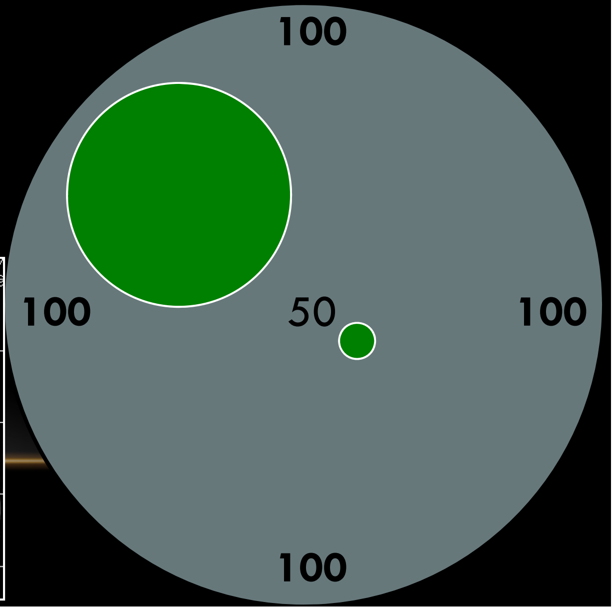
CLINICAL APPLICATIONS OF SSDE

SSDE

- Can be first approximation of some organ doses:
  - Increased error for small organs depending on location.
    - Less effect for pediatrics



Adapted from McCollough



CONCLUSIONS

Estimating and managing a patient's CT dose as a function of their size is facilitated by the use of SSDE provided:

- $CTDI_{vol}$,
- CTDI phantom size assumed by the CT scanner, and
- Patient size

are known.