Tomo Topics – Focus on the Clinical Plane

CT SSDE – Body, Head, and Beyond

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Disclosures

- UCLA Department of Radiology has a Master Research Agreement (MRA) with Siemens Healthineers
- I currently receive grant support from MRA with Siemens Healthineers
- I am a Member of the Advisory Board, Hura Imaging, Inc.

CT Dosimetry - Background

- Current clinical CT dosimetry metrics typically used are $CTDI_{vol}$ and DLP.
- These have substantial limitations, which motivated the development of Size Specific Dose Estimates (SSDEs) that account for patient size.

- This presentation will describe several key elements related to SSDE including:

(a) Water Equivalent Diameter, as described in AAPM Report 220

(b) SSDE for body originally described in AAPM Report 204 and updated with AAPM report 220 and

(c) SSDE for head described in AAPM Report 293.

- This presentation will focus on how these metrics were developed, how they are expected to be calculated and how they might be used clinically in the future.

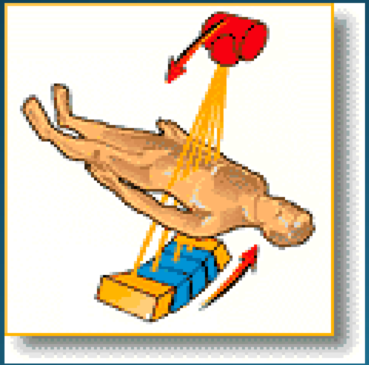
CT Dosimetry

Learning Objectives

- Review current radiation dose index metrics used in CT Dosimetry and their limitations
- Explain how the Size Specific Dose Estimates (SSDEs) for Body and Head overcome some of these limitations and how they can be used in clinical practice

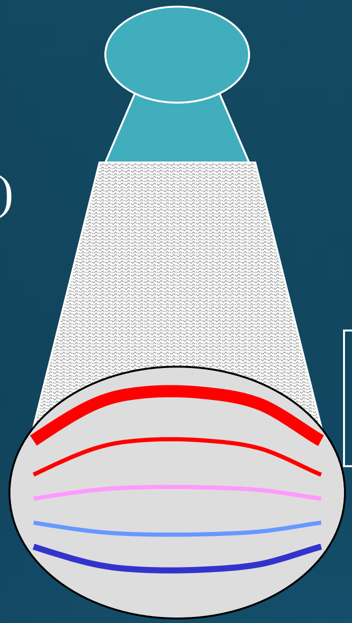
CT –Specific definitions

- What is unique about CT?
  - Geometry and usage
  - Exposure is at multiple points around patient
  - Typically thin - ish (1 - 160 mm) beam widths
  - Multiple Scans (Series of Scans)



RADIOGRAPHIC EXPOSURE
(single tube position)

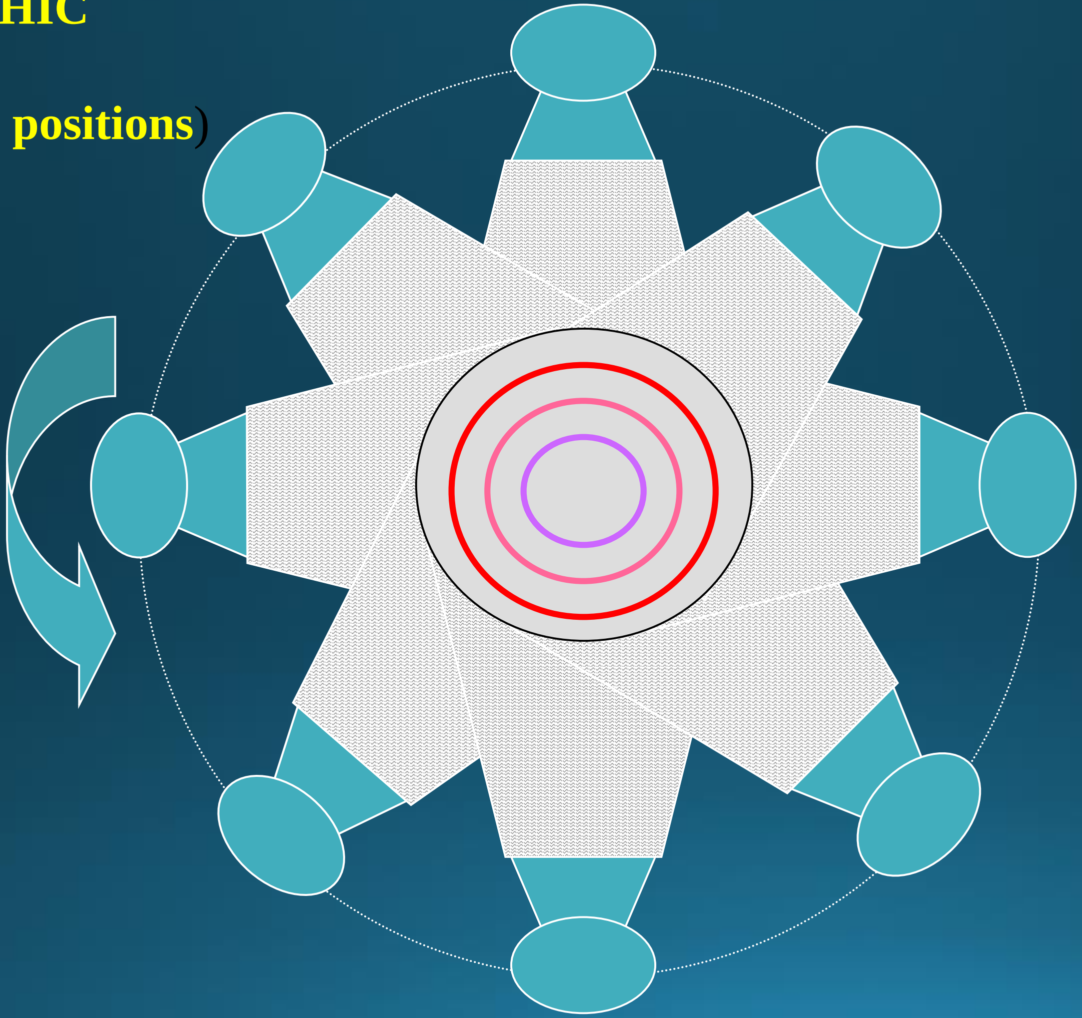
Dose Gradient



Entrance Skin Exposure (ESE)

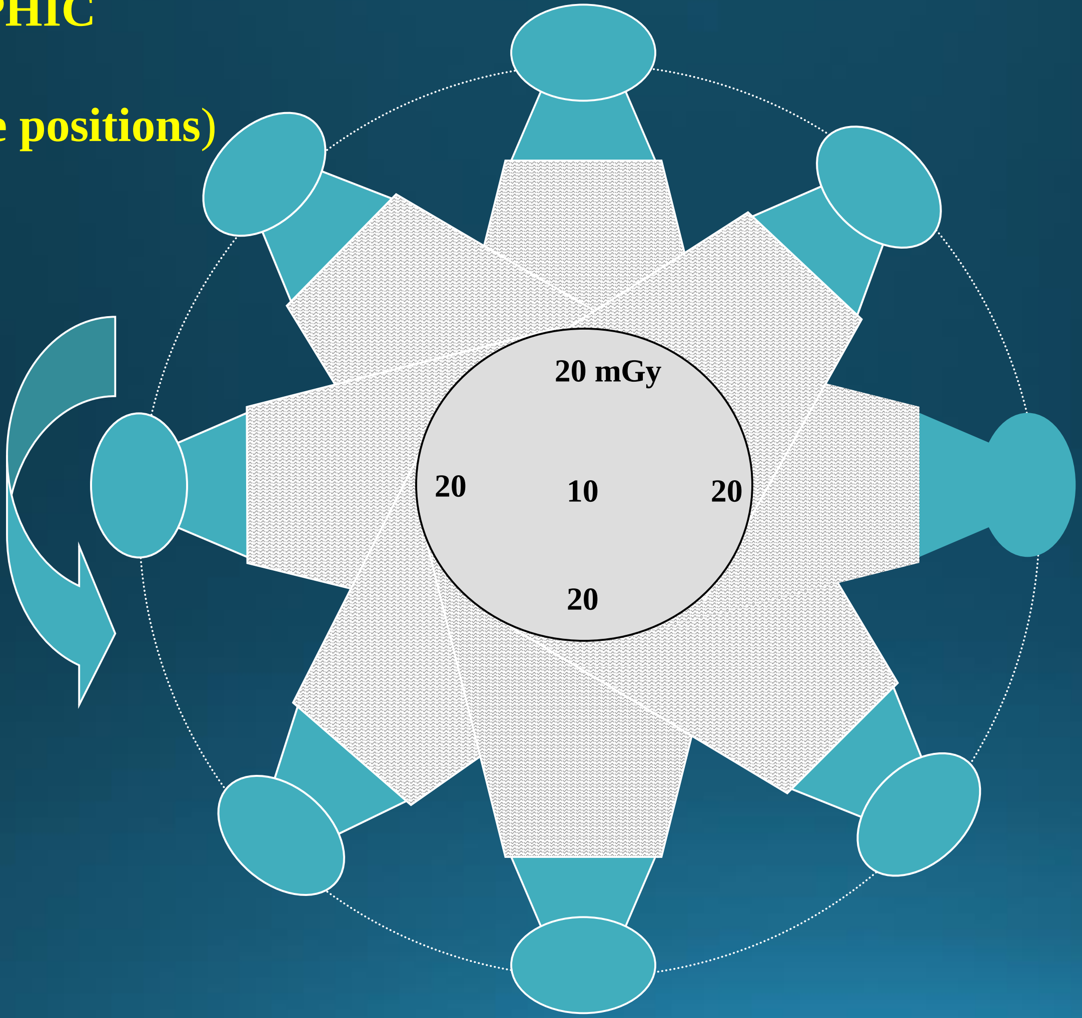
Exit Skin Exposure

TOMOGRAPHIC EXPOSURE (multiple tube positions)



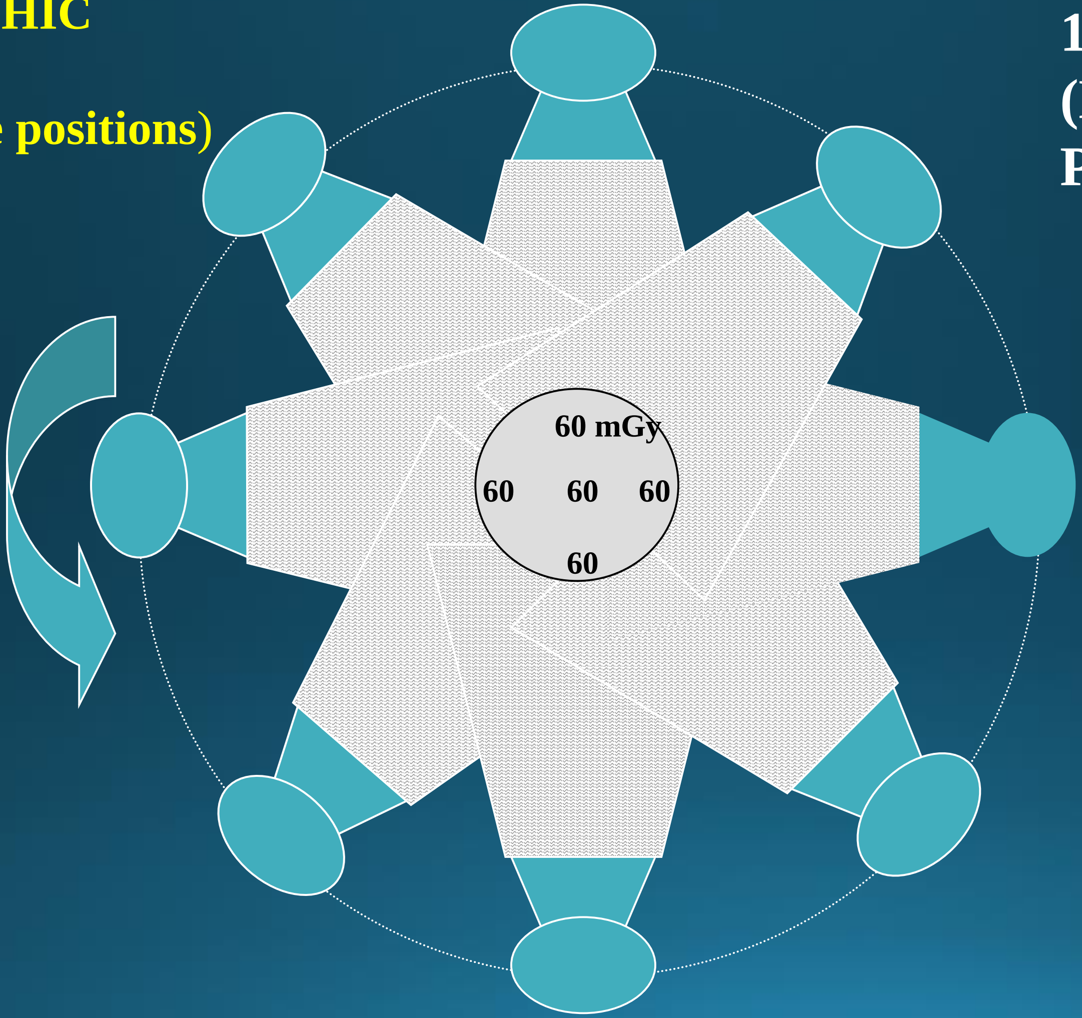
TOMOGRAPHIC EXPOSURE
(multiple tube positions)

32 cm Diameter (Body) Acrylic Phantom



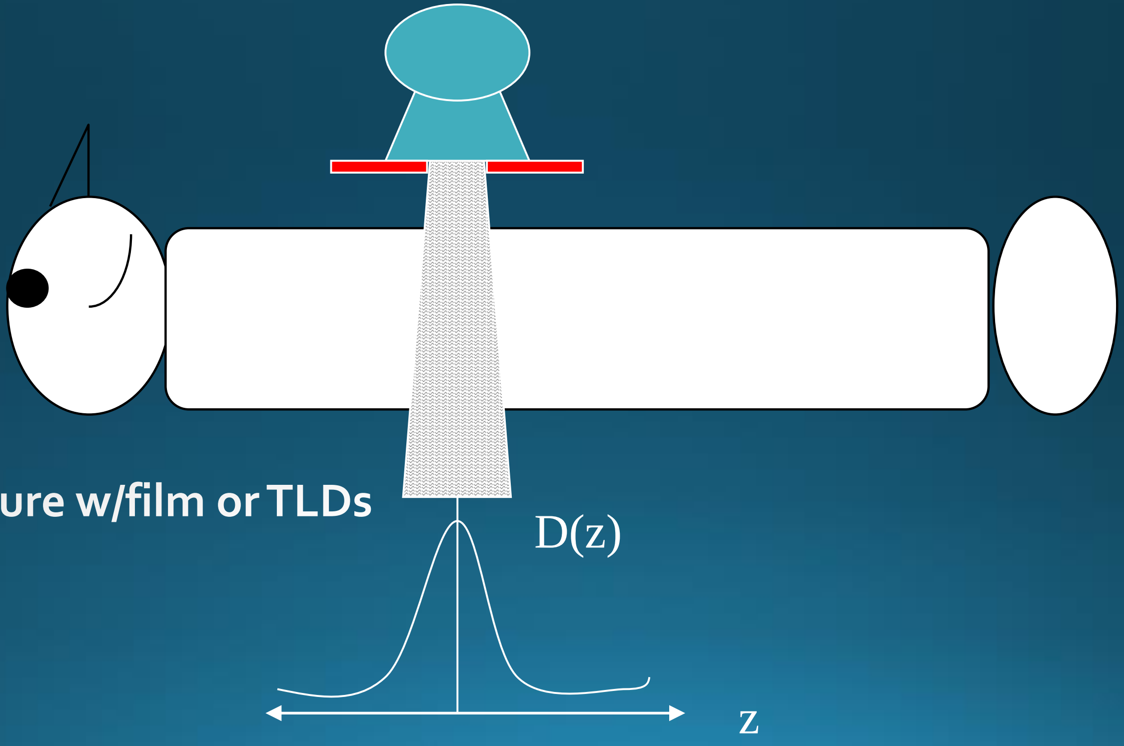
TOMOGRAPHIC
EXPOSURE
(multiple tube positions)

16 cm Diameter
(Head) Acrylic
Phantom



CT Dose Distributions

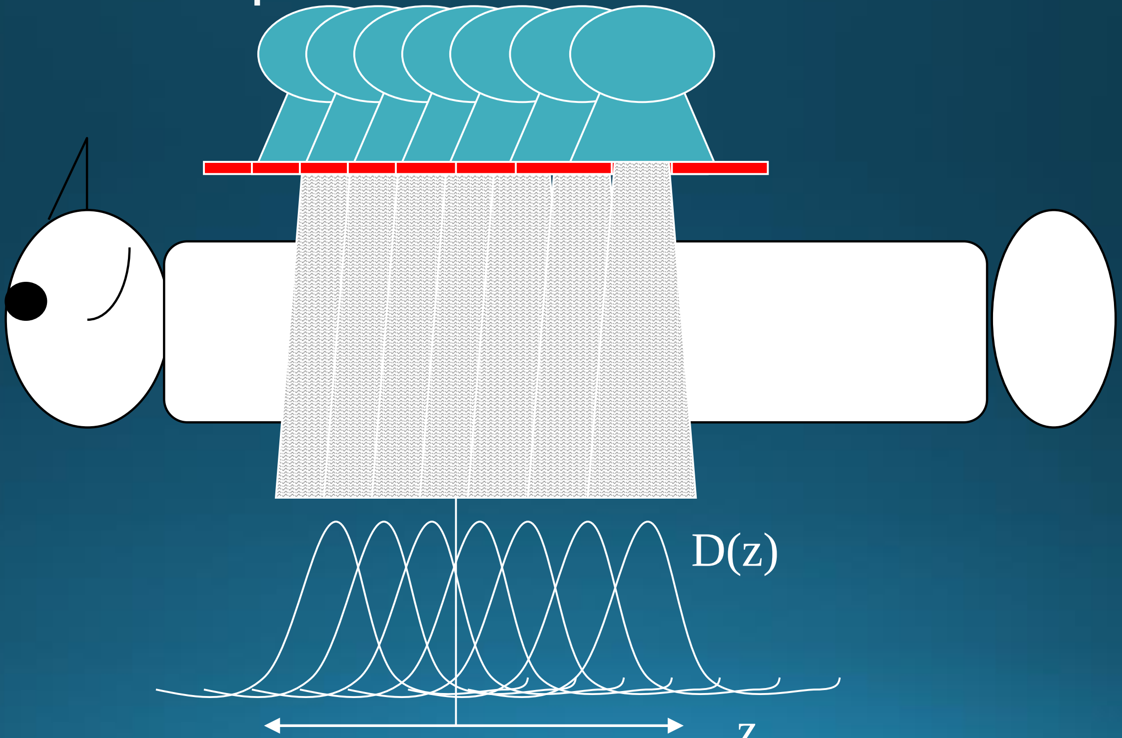
- D(z) = dose profile along z-axis from a single acquisition



- Measure w/film or TLDs

CT Dose Distributions

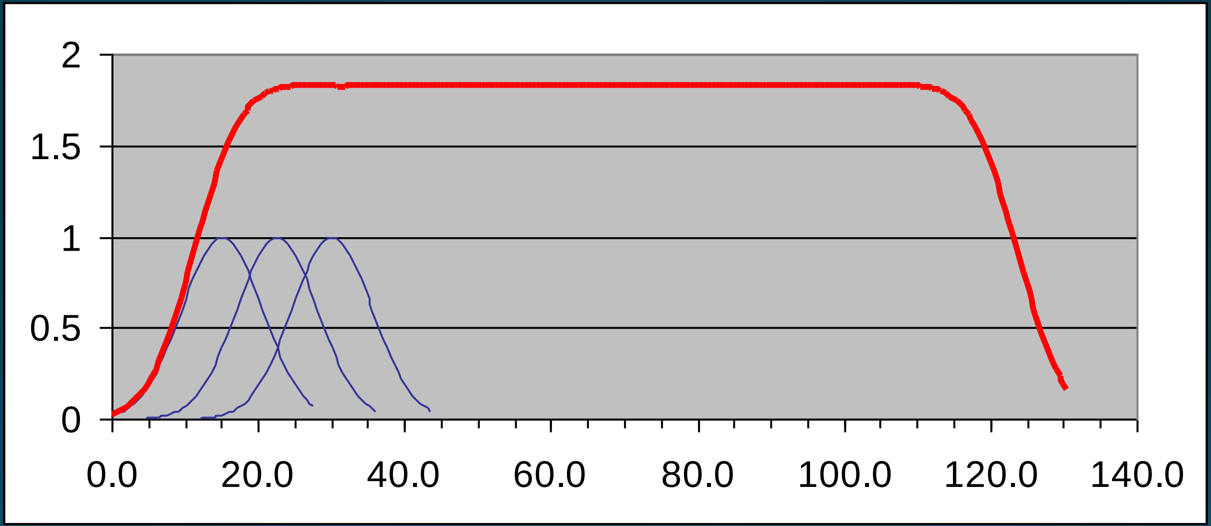
- **What about Multiple Scans?**



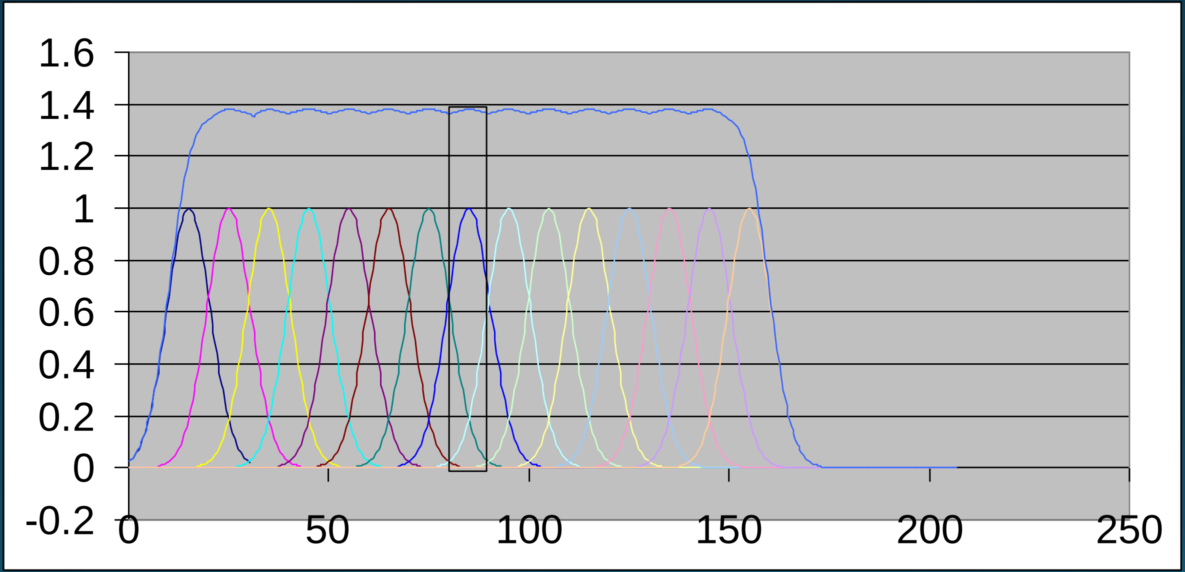
CT Dose Distributions

- What about Multiple Scans?
  - They can overlap and create higher dose profiles

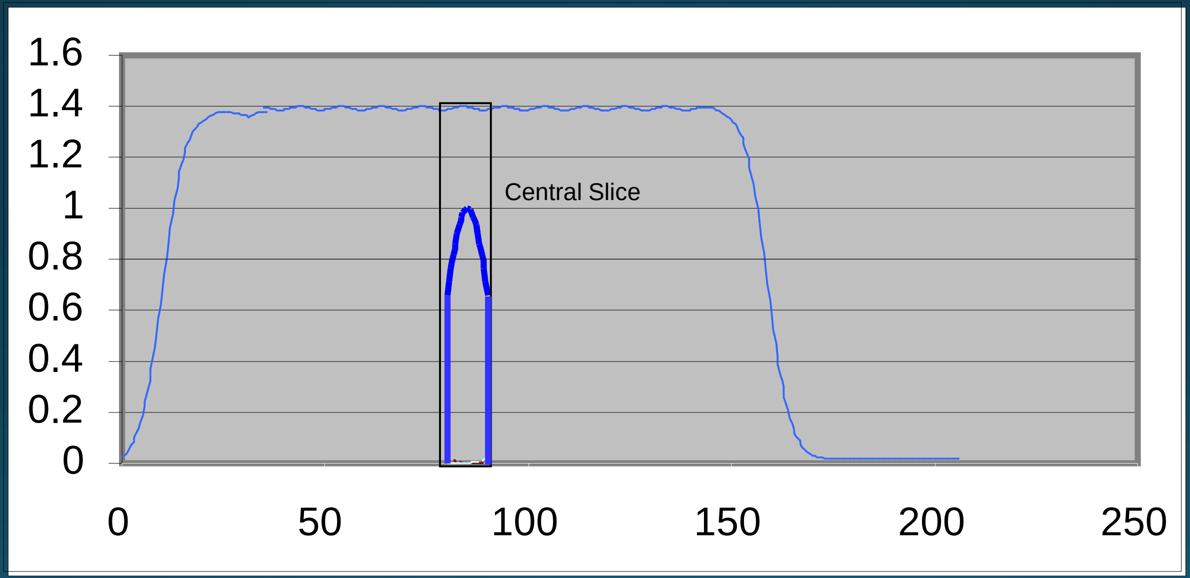
CT Dose Distributions



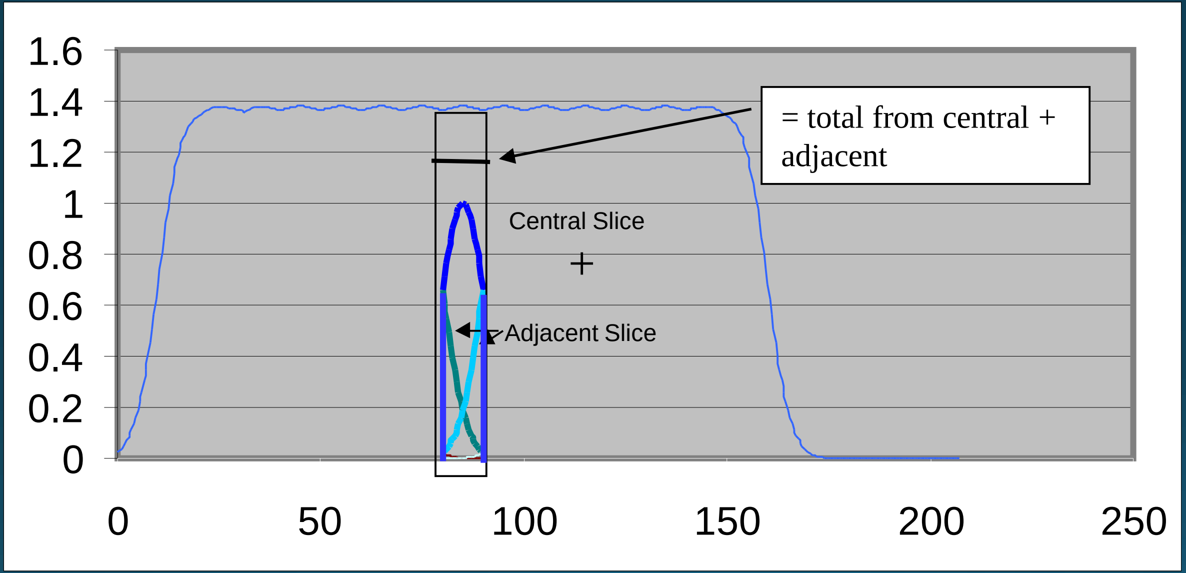
CT Dose Distributions



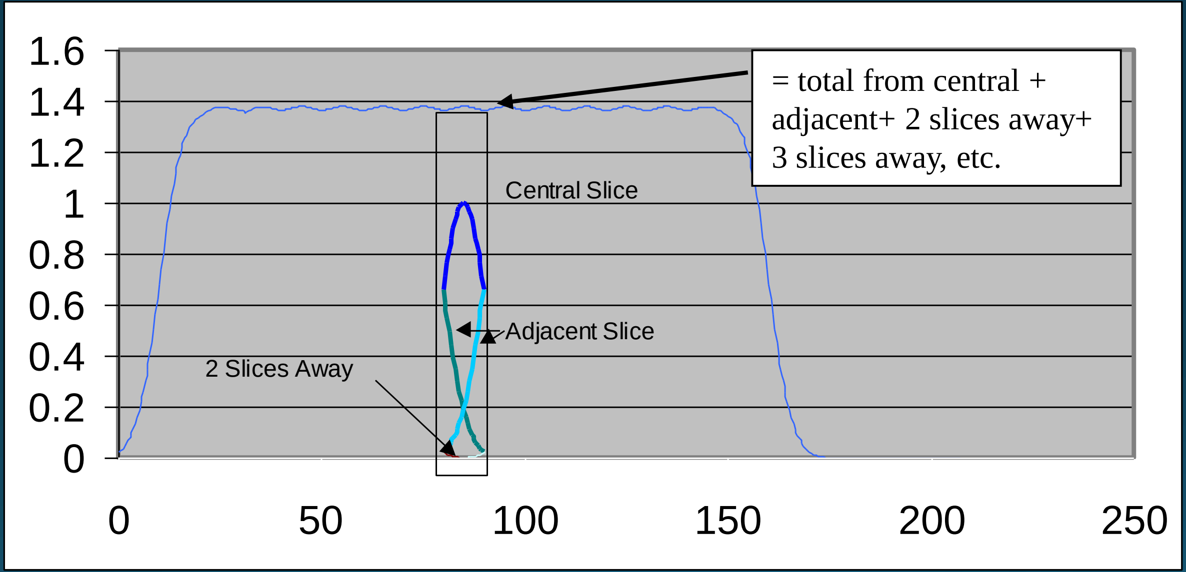
CT Dose Distributions



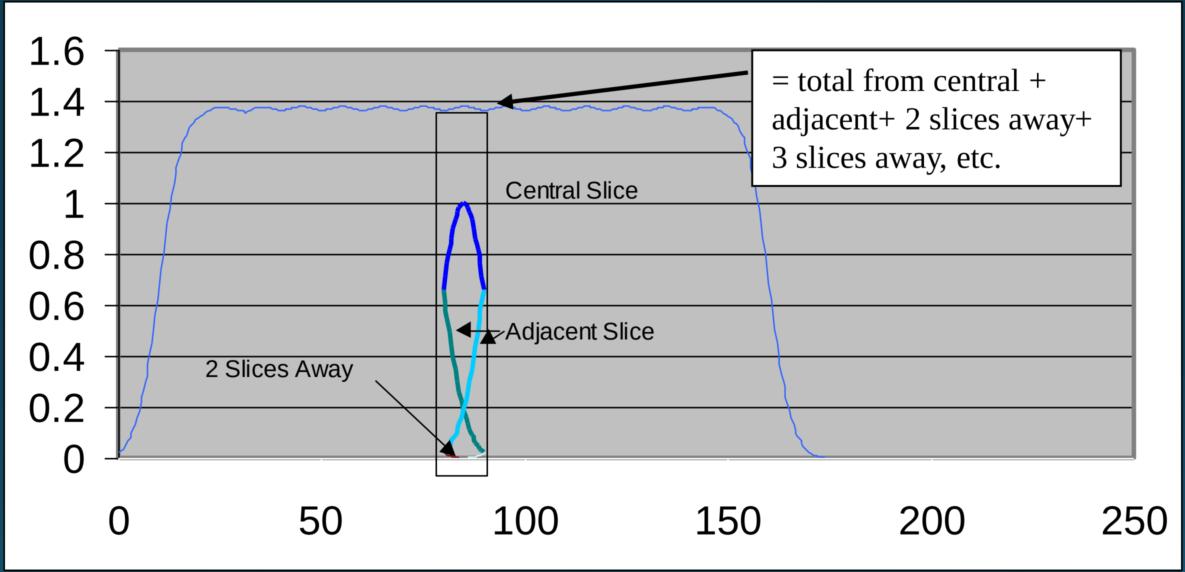
CT Dose Distributions



CT Dose Distributions

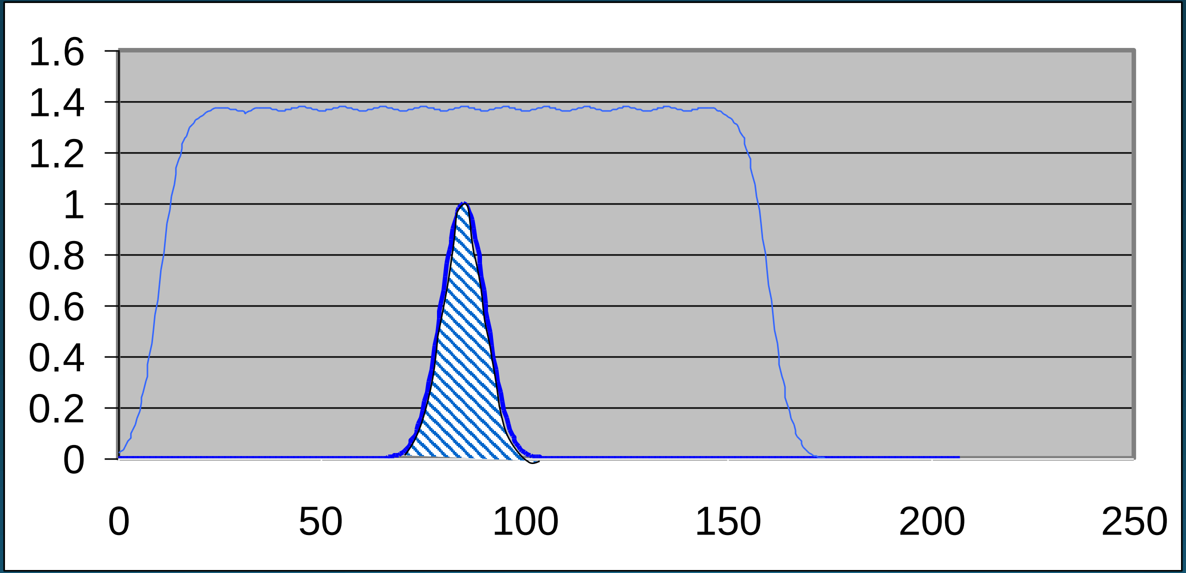


CT Dose Distributions



The average dose in central slice is the sum of contributions from all slices to that small width; if one rearranges the contributions from each slice, they are just different portions of the single scan dose profile.

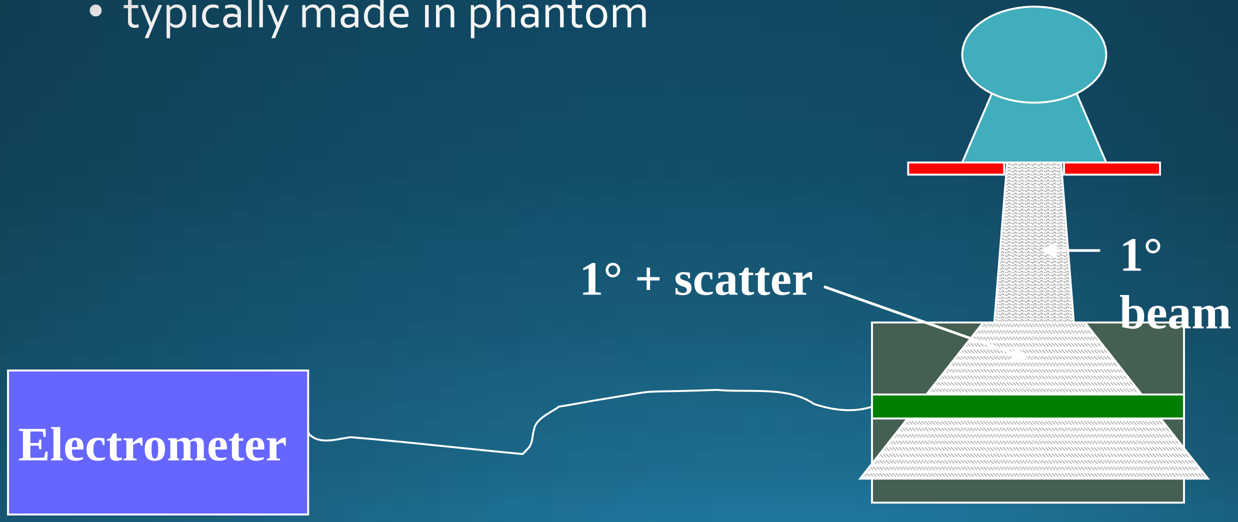
CT Dose Distributions



To sum their contributions, just take the area under the curve of that single slice dose profile

(CTDI) – defined

- How to get area under single scan dose profile?
  - Using a pencil ion chamber
  - one measurement of an <u>axial scan (no table motion)</u>
  - typically made in phantom



(CTDI) – defined

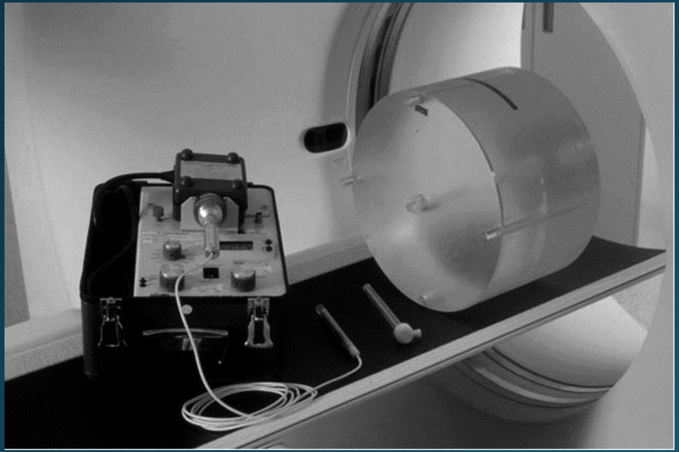


Figure 3 from Bauhs, RadioGraphics, 2008

(CTDI) – defined

- CTDI **Represents**
  - **Average dose** along the z direction
  - at a given **point (x,y)** in the scan plane
  - over the **central scan of a series of scans**
  - when the series consists of a **large number of scans**
  - **separated by the slice thickness** (contiguous scanning)

CTDI Phantoms

- Body (32 cm diam), Head (16 cm diam)
- Holes in center and at 1 cm below surface

$CTDI_{100}$

- Measurement is made w/100 mm chamber:
- $CTDI_{100} = \mathbf{(1/NT) \int_{-5cm}^{5cm} D(z)\, dz}$

$$= \mathbf{(f*C*E*L)/(NT)}$$

f = conversion factor from exposure to dose in air, use 0.87 rad/R

C = calibration factor for electrometer (typical= 1.0 or close to this)

E = measured value of exposure in R

L = active length of pencil ion chamber (typical= 100 mm)

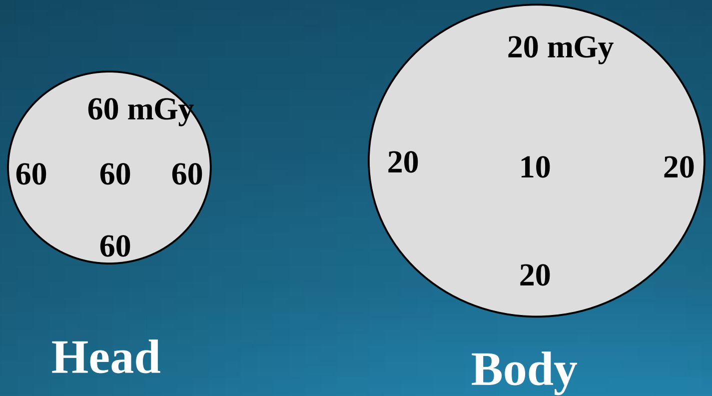
N = *actual* number of data channels used during one axial scan

T = nominal slice width of one data channel

NT = nominal total beam collimation width (e.g. 32 x 0.6 mm)

$CTDI_{100}$

- $CTDI_{100}$ Measurements are done:
  - In Both Head and Body Phantoms
  - Using ONLY AXIAL scan techniques
    (CTDI = Area under the single scan dose profile)
  - At isocenter and at least one peripheral position in each phantom



$CTDI_w$

- $CTDI_w$ is a **weighted average** of center and peripheral $CTDI_{100}$ to arrive at a single descriptor

- **$CTDI_w = (1/3)CTDI_{100,center} + (2/3)CTDI_{100,peripheral}$**

$CTDI_{vol}$ – accounts for table motion

- Based on $CTDI_w$
- Hence measured from an axial acquisition; EVEN THOUGH a pitch value is used.
  - Think of this as the pitch that you would have used if you were performing a helical scan.

$CTDI_{vol}$ - EXAM-related performance

- Exam parameters such as thickness, spacing between slices (axial) or table speed (helical)
- $CTDI_{vol} = CTDI_w$ *NT/I
- where N= number of data channels used,
  T= thickness of each data channel
  I = spacing or tablefeed/rotation for helical

Note: NT = total collimated width of beam
Also pitch= I/NT, so

$CTDI_{vol} = CTDI_w$/pitch

Dose Length Product (DLP) – defined

- Dose Length Product is:
  - $CTDI_{vol}$* length of scan (in mGy*cm)

CT Dosimetry – $CTDI_{vol}$ and DLP

- $CTDI_{vol}$ and DLP are reported on all scanners
- Used for Dose Notifications and Dose Alerts (XR-29)
- Used for ACR accreditation (and ACR's Dose Index Registry)

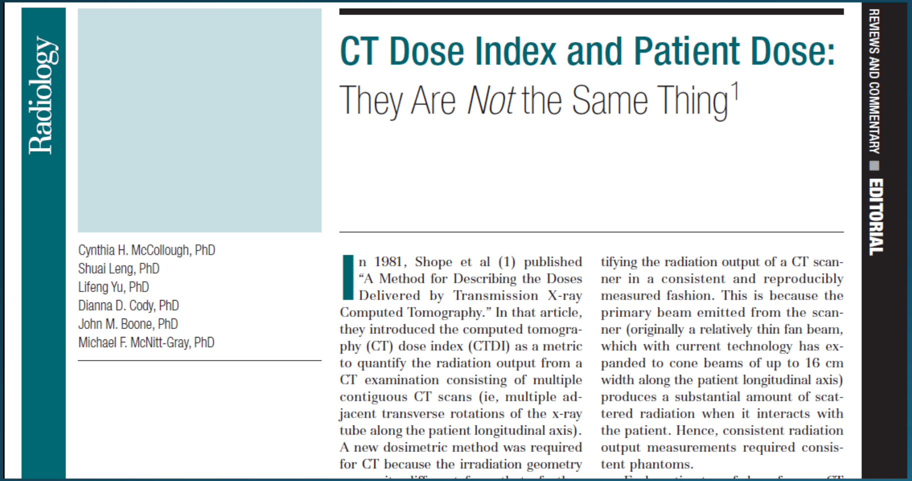
CT Dosimetry: Are $CTDI_{vol}$ and DLP enough?

- What do $CTDI_{vol}$ and DLP tell us?
- And what do they **not** tell us?

- Do they tell us about scanner output? (Yes)
- Can they be used to tell us about CT system performance? (Yes)
- Can they be used for acceptance testing? (Yes) Ongoing QC? (Yes)
- Can they be used for ACR accreditation (and ACR's Dose Index Registry)? (Yes)
- Can they tell us about Patient Dose? ...well.....

CT Dosimetry: Are $CTDI_{vol}$ and DLP enough?

- Can they tell us about Patient Dose? …well…..



Radiology

REVIEWS AND COMMENTARY ■ EDITORIAL

CT Dose Index and Patient Dose:
They Are *Not* the Same Thing[1]

Cynthia H. McCollough, PhD
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Michael F. McNitt-Gray, PhD

In 1981, Shope et al (1) published "A Method for Describing the Doses Delivered by Transmission X-ray Computed Tomography." In that article, they introduced the computed tomography (CT) dose index (CTDI) as a metric to quantify the radiation output from a CT examination consisting of multiple contiguous CT scans (ie, multiple adjacent transverse rotations of the x-ray tube along the patient longitudinal axis). A new dosimetric method was required for CT because the irradiation geometry

tifying the radiation output of a CT scanner in a consistent and reproducibly measured fashion. This is because the primary beam emitted from the scanner (originally a relatively thin fan beam, which with current technology has expanded to cone beams of up to 16 cm width along the patient longitudinal axis) produces a substantial amount of scattered radiation when it interacts with the patient. Hence, consistent radiation output measurements required consistent phantoms.

"The CTDI values are included in … a screen-captured 'patient dose report'…which reinforces the ***incorrect*** belief that CTDI is a measure of patient dose."

"The $CTDI_{vol}$ is a **standardized measure of the radiation output of a CT system…**"

McCollough et al, Radiology, 2011

CT Dosimetry: Are $CTDI_{vol}$ and DLP enough?

- Can they tell us about the effects of Patient Size? Like for Peds Patients? (well…kind of…)
  - If a scanner is adjusting for patient size, we can see lower $CTDI_{vol}$ values for smaller patients and higher $CTDI_{vol}$ values for larger patients.

- However, we found that different scanner manufacturers were using different schemes for reporting $CTDI_{vol}$ values:
  - One manufacturer reports $CTDI_{vol}$ for 32 cm for all body scans regardless of patient size (even for pediatrics and neonates)
  - Another manufacturer reports $CTDI_{vol}$ for 16 cm phantom for small body sizes and used 32 cm phantom for larger body sizes (Depends on Scan Field of View).
- So if a peds patient underwent a scan on a CT from manufacturer A for one scan and then had a scan on a CT from manufacturer B, it could be difficult to compare relative dose levels.

Size Specific Dose Estimates (SSDE) from AAPM Report 204

AAPM Report No. 204

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

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

I C R U

image gently℠

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https://www.aapm.org/pubs/reports/rpt_204.pdf (it's free!!)

Size Specific Dose Estimates (SSDE) from AAPM Report 204

"The dose received by a patient from a CT scan is dependent on both the patient zie and scanner radiation output. $CTDI_{vol}$ provides information regarding *only* the scanner output. "

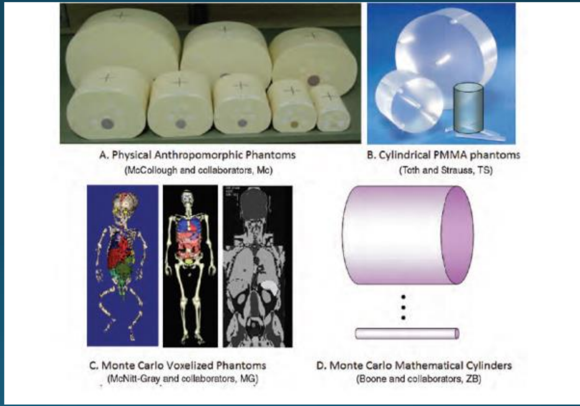
"This task group was charged with developing conversion factors that can be applied to the displayed $CTDI_{vol}$ dose index to allow practitioners to be able to estimate patient dose. **These factors take into account patient size, and hence are especially important for pediatric CT or when small adults are scanned"**

(BTW, "…Other differences between the current scanner radiation output indictes and patient dose estimes due to the use of "short" phantoms …are not addressed by this task group"…in other words, this does not address issues of "approach to equilibrium" or TG 111 or TG 200 related issues).

https://www.aapm.org/pubs/reports/rpt_204.pdf (it's free!!)

Size Specific Dose Estimates (SSDE) from AAPM Report 204

- Methodology
  - 2 Groups did measurements on various sized phantoms
  - 2 Groups performed simulations



  - John Boone overlaid the results (Amazing consistency!)

https://www.aapm.org/pubs/reports/rpt_204.pdf (it's free!!)

Size Specific Dose Estimates (SSDE) from AAPM Report 204

- Our group's contribution (Adam Turner's paper)
  - Organ Dose normalized by $CTDI_{vol}$ vs. Patient Size (we used perimeter)

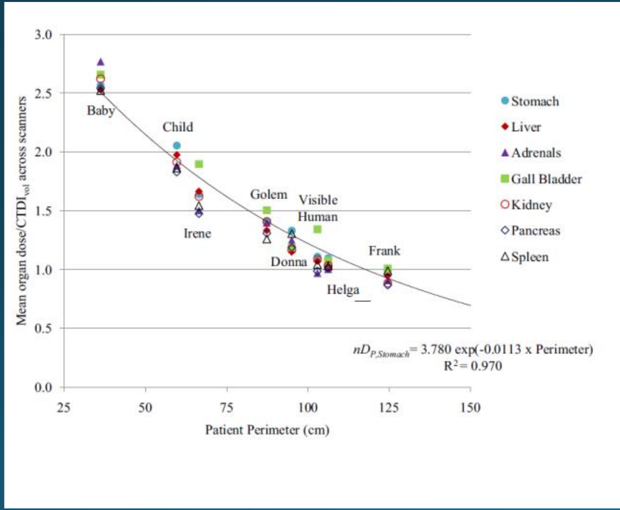


Figure 2 from Turner et al, Medical Physics, 38(2), 2011.

Size Specific Dose Estimates (SSDE) from AAPM Report 204

Size Metric for Report 204 - Effective Diameter (AP and Lateral dimensions)

Definitions: Size related parameters

Figure 2. The anterior posterior (AP) and lateral dimension, along with effective diameter are illustrated in this figure. The lateral dimension can be determined from a PA or AP CT radiograph, and the AP dimension can be determined by a lateral CT radiograph. The effective diameter corresponds to a circle having an area equal to that of the patient's cross section on a CT image. Some investigators have also used patient perimeter (circumference) as a metric of patient size.

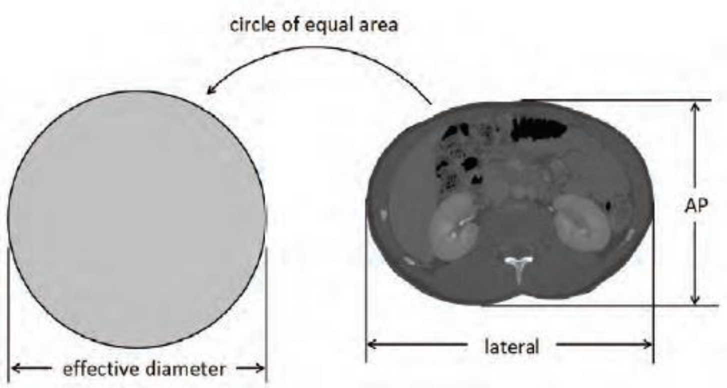


Figure 2 of AAPM Report 204 (page 3)

https://www.aapm.org/pubs/reports/rpt_204.pdf (it's free!!)

Size Specific Dose Estimates (SSDE) from AAPM Report 204

- "f" factors
  - Normalized Dose Coefficient vs. patient size (effective diameter)

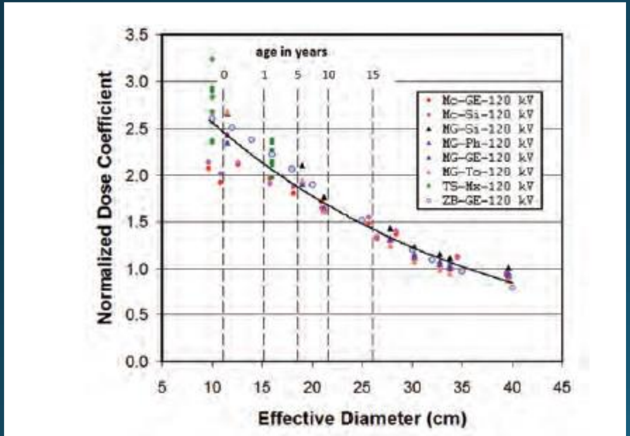


Figure 4 of AAPM Report 204 (page 8)
Conversion factors for 32 cm phantom

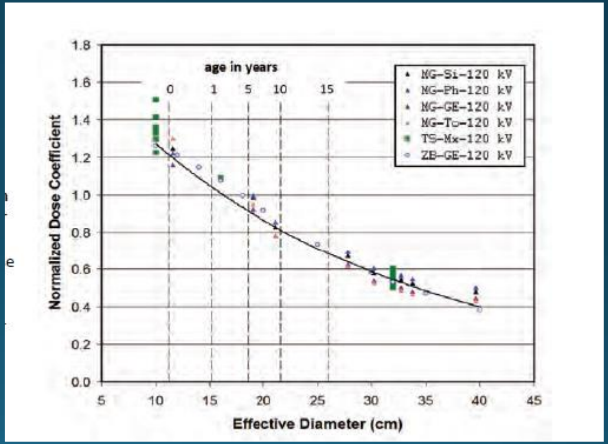


Figure 6 of AAPM Report 204 (page 12)
Conversion factors for 16 cm phantom

Size Specific Dose Estimates (SSDE) from AAPM Report 204

- Calculating SSDE

  - SSDE = $f_{sie}^{32X}\ x\ CTDI_{vol}^{32}$ equation 8a

  for 32 cm diameter CTDI phantom

  - SSDE = $f_{sie}^{16X}\ x\ CTDI_{vol}^{16}$ equation 8b

  for 16 cm diameter CTDI phantom

  In each case, the superscript X refers to the S (sum of Lat+AP), L(Lat only), A (AP only) and D (effective diameter) and identifies which Table is to be used for conversion factors

Size Specific Dose Estimates (SSDE) from AAPM Report 204

Table 1A

Lat + AP Dim (cm)	Effective Dia (cm)	Conversion Factor
16	7.7	2.79
18	8.7	2.69
20	9.7	2.59
22	10.7	2.50
24	11.7	2.41
26	12.7	2.32
28	13.7	2.24
30	14.7	2.16
32	15.7	2.08
34	16.7	2.01
36	17.6	1.94
38	18.6	1.87
40	19.6	1.80
42	20.6	1.74
44	21.6	1.67
46	22.6	1.62
48	23.6	1.56
50	24.6	1.50
52	25.6	1.45
54	26.6	1.40
56	27.6	1.35
58	28.6	1.30
60	29.6	1.25
62	30.5	1.21
64	31.5	1.16
66	32.5	1.12
68	33.5	1.08
70	34.5	1.04
72	35.5	1.01
74	36.5	0.97
76	37.5	0.94
78	38.5	0.90
80	39.5	0.87
82	40.5	0.84
84	41.5	0.81
86	42.4	0.78
88	43.4	0.75
90	44.4	0.72

Table 1B

Lateral Dim (cm)	Effective Dia (cm)	Conversion Factor
8	9.2	2.65
9	9.7	2.60
10	10.2	2.55
11	10.7	2.50
12	11.3	2.45
13	11.8	2.40
14	12.4	2.35
15	13.1	2.29
16	13.7	2.24
17	14.3	2.19
18	15.0	2.13
19	15.7	2.08
20	16.4	2.03
21	17.2	1.97
22	17.9	1.92
23	18.7	1.86
24	19.5	1.81
25	20.3	1.76
26	21.1	1.70
27	22.0	1.65
28	22.9	1.60
29	23.8	1.55
30	24.7	1.50
31	25.6	1.45
32	26.6	1.40
33	27.6	1.35
34	28.6	1.30
35	29.6	1.25
36	30.6	1.20
37	31.7	1.16
38	32.7	1.11
39	33.8	1.07
40	34.9	1.03
41	36.1	0.98
42	37.2	0.94
43	38.4	0.90
44	39.6	0.87
45	40.8	0.83

Table 1C

AP Dim (cm)	Effective Dia (cm)	Conversion Factor
8	8.8	2.68
9	10.2	2.55
10	11.6	2.42
11	13.0	2.30
12	14.4	2.18
13	15.7	2.08
14	17.0	1.98
15	18.3	1.89
16	19.6	1.81
17	20.8	1.73
18	22.0	1.65
19	23.2	1.58
20	24.3	1.52
21	25.5	1.45
22	26.6	1.40
23	27.6	1.34
24	28.7	1.29
25	29.7	1.25
26	30.7	1.20
27	31.6	1.16
28	32.6	1.12
29	33.5	1.08
30	34.4	1.05
31	35.2	1.02
32	36.0	0.99
33	36.8	0.96
34	37.6	0.93
35	38.4	0.91
36	39.1	0.88
37	39.8	0.86
38	40.4	0.84
39	41.1	0.82
40	41.7	0.80
41	42.3	0.78
42	42.8	0.77
43	43.4	0.75
44	43.9	0.74
45	44.4	0.73

Table 1D

Effective Dia (cm)	Conversion Factor
8	2.76
9	2.66
10	2.57
11	2.47
12	2.38
13	2.30
14	2.22
15	2.14
16	2.06
17	1.98
18	1.91
19	1.84
20	1.78
21	1.71
22	1.65
23	1.59
24	1.53
25	1.48
26	1.43
27	1.37
28	1.32
29	1.28
30	1.23
31	1.19
32	1.14
33	1.10
34	1.06
35	1.02
36	0.99
37	0.95
38	0.92
39	0.88
40	0.85
41	0.82
42	0.79
43	0.76
44	0.74
45	0.71

Table 1 (A, B, C, D) for 32 cm phantom

Table 2A

Lat + AP Dim (cm)	Effective Dia (cm)	Conversion Factor
12	5.7	1.50
13	6.2	1.47
14	6.7	1.44
15	7.2	1.42
16	7.7	1.39
17	8.2	1.36
18	8.7	1.34
19	9.2	1.31
20	9.7	1.29
21	10.2	1.26
22	10.7	1.24
23	11.2	1.22
24	11.7	1.19
25	12.2	1.17
26	12.7	1.15
27	13.2	1.13
28	13.7	1.10
29	14.2	1.08
30	14.7	1.06
31	15.2	1.04
32	15.7	1.02
33	16.2	1.00
34	16.7	0.98
35	17.2	0.97
36	17.6	0.95
37	18.1	0.93
38	18.6	0.91
39	19.1	0.89
40	19.6	0.88
42	20.6	0.84
44	21.6	0.81
46	22.6	0.78
48	23.6	0.75
50	24.6	0.72
52	25.6	0.70
54	26.6	0.67
56	27.6	0.64
58	28.6	0.62
60	29.6	0.60
62	30.5	0.57
64	31.5	0.55
66	32.5	0.53
68	33.5	0.51
70	34.5	0.49
72	35.5	0.47
74	36.5	0.46
76	37.5	0.44
78	38.5	0.42
80	39.5	0.41
82	40.5	0.39

Table 2B

Lateral Dim (cm)	Effective Dia (cm)	Conversion Factor
6	8.2	1.36
7	8.7	1.34
8	9.2	1.32
9	9.7	1.29
10	10.2	1.26
11	10.7	1.24
12	11.3	1.21
13	11.8	1.19
14	12.4	1.16
15	13.1	1.13
16	13.7	1.10
17	14.3	1.08
18	15.0	1.05
19	15.7	1.02
20	16.4	0.99
21	17.2	0.96
22	17.9	0.94
23	18.7	0.91
24	19.5	0.88
25	20.3	0.85
26	21.1	0.83
27	22.0	0.80
28	22.9	0.77
29	23.8	0.75
30	24.7	0.72
31	25.6	0.70
32	26.6	0.67
33	27.6	0.65
34	28.6	0.62
35	29.6	0.60
36	30.6	0.57
37	31.7	0.55
38	32.7	0.53
39	33.8	0.51
40	34.9	0.48
41	36.1	0.46
42	37.2	0.44
43	38.4	0.42
44	39.6	0.40
45	40.8	0.39
46	42.1	0.37
47	43.3	0.35
48	44.6	0.33
49	45.9	0.32
50	47.2	0.30
51	48.5	0.29
52	49.9	0.27
53	51.3	0.26
54	52.7	0.24
55	54.1	0.23

Table 2C

AP Dim (cm)	Effective Dia (cm)	Conversion Factor
6	5.8	1.50
7	7.3	1.41
8	8.8	1.33
9	10.2	1.26
10	11.6	1.19
11	13.0	1.13
12	14.4	1.07
13	15.7	1.02
14	17.0	0.97
15	18.3	0.92
16	19.6	0.88
17	20.8	0.84
18	22.0	0.80
19	23.2	0.76
20	24.3	0.73
21	25.5	0.70
22	26.6	0.67
23	27.6	0.64
24	28.7	0.62
25	29.7	0.59
26	30.7	0.57
27	31.6	0.55
28	32.6	0.53
29	33.5	0.51
30	34.4	0.50
31	35.2	0.48
32	36.0	0.46
33	36.8	0.45
34	37.6	0.44
35	38.4	0.42
36	39.1	0.41
37	39.8	0.40
38	40.4	0.39
39	41.1	0.38
40	41.7	0.37
41	42.3	0.36
42	42.8	0.36
43	43.4	0.35
44	43.9	0.34
45	44.4	0.34
46	44.8	0.33
47	45.2	0.33
48	45.6	0.32
49	46.0	0.32
50	46.4	0.31
51	46.7	0.31
52	47.0	0.30
53	47.2	0.30
54	47.5	0.30
55	47.7	0.30

Table 2D

Effective Dia (cm)	Converion Factor
6	1.49
7	1.43
8	1.38
9	1.32
10	1.27
11	1.22
12	1.18
13	1.13
14	1.09
15	1.05
16	1.01
17	0.97
18	0.93
19	0.90
20	0.86
21	0.83
22	0.80
23	0.77
24	0.74
25	0.71
26	0.69
27	0.66
28	0.63
29	0.61
30	0.59
31	0.56
32	0.54
33	0.52
34	0.50
35	0.48
36	0.47
37	0.45
38	0.43
39	0.41
40	0.40
41	0.38
42	0.37
43	0.35
44	0.34
45	0.33
46	0.32
47	0.30
48	0.29
49	0.28
50	0.27
51	0.26
52	0.25
53	0.24
54	0.23
55	0.22

Table 2 (A,B,C,D) for 16 cm phantom

Size Specific Dose Estimates (SSDE) from AAPM Report 204

- Appendix A (formulae to represent data in figures and tables)

  - y = a x e^{-bx} (x = patient size) equation A-1

Figure Number	X parameter	Y parameter	a	b
4	Eff. Diameter (cm)	Conversion Factor	3.704369	0.03671937
5	Eff. Diameter (cm)	Conversion Factor	4.378094	0.04331124
6	Eff. Diameter (cm)	Conversion Factor	1.874799	0.03871313

Size Specific Dose Estimates (SSDE) from AAPM Report 204

- Summary of AAPM Report 204 in one line:

$$\text{SSDE} = (\text{a x } e^{-bx}) \text{ x CTDI}_{\text{vol}}$$

- Scanner reports CTDIvol
- a and b are known (depends on phantom)
- Estimate patient size

Patient Size (v2) – Water Equivalent Diameter

AAPM REPORT NO. 220

Use of Water Equivalent Diameter for Calculating Patient Size and Size-Specific Dose Estimates (SSDE) in CT

The Report of AAPM Task Group 220

September 2014

Use of Water Equivalent Diameter for Calculating Patient Size and Size-Specific Dose Estimates (SSDE) in CT

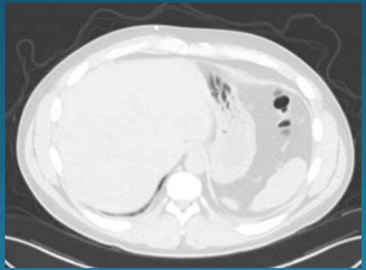
The Report of AAPM Task Group 220

Cynthia McCollough, Ph.D., FAAPM, Chairperson[1], Donovan M. Bakalyar, Ph.D.[2], Maryam Bostani, Ph.D.[3], Samuel Brady, Ph.D.[4], Kristen Boedeker, Ph.D.[5], John M. Boone, Ph.D., FAAPM[6], H. Heather Chen-Mayer, Ph.D.[7], Olav I. Christianson, Ph.D.[8], Shuai Leng, Ph.D.[1], Baojun Li, Ph.D.[9], Michael F. McNitt-Gray, Ph.D., FAAPM[3], Roy A. Nilsen, B.S.[10], Mark P. Supanich, Ph.D.[11], and Jia Wang, Ph.D.[12]

https://www.aapm.org/pubs/reports/rpt_220.pdf (it's free!!)

Water Equivalent Diameter - Motivation

- For the task of calculating SSDE, geometric size was used as a surrogate for a patient's x-ray attenuation.
- However, x-ray attenuation is the fundamental physical parameter affecting the absorption of x-rays and is thus more relevant than geometric patient size in determining patient dose.
- For example, the thorax and abdomen could have the same external physical dimensions, but have different composition and hence different attenuation (and absorption) properties.



Water Equivalent Diameter - Motivation

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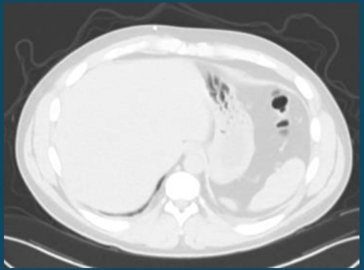

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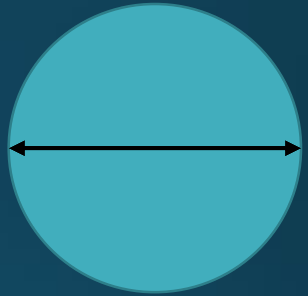


Effective Diameter

Circle of equal area

- So, this thorax and abdomen have approximately the same area and effective diameter
- But they have different attenuation properties (due to air in lung)

https://www.aapm.org/pubs/reports/rpt_220.pdf (it's free!!)

Water Equivalent Diameter - Motivation

- The charge of AAPM Task Group 220 was to develop a …metric for automatically estimating patient size in CT that would account for patient attenuation and allow routine determination of SSDE for all patients, with little or no user intervention.
- TG had a specific goal of developing a practical, standardized approach to estimating patient size that could be implemented by CT scanner manufacturers and others using CT localizer radiographs, axial CT images, or other data derived from the scanning process (e.g., projection data).

Water Equivalent Diameter - Motivation

- While CT operators can measure a patient's AP or lateral width, they currently have no practical way to measure attenuation. Both a CT localizer radiograph and CT projection data are measurements of the integrated x-ray attenuation along a ray path, and a CT image is a cross-sectional map of the linear attenuation coefficients of the materials in the image.
- Therefore, the CT localizer radiograph, the CT projection data, and the CT image all contain information that can be used to estimate patient attenuation.

https://www.aapm.org/pubs/reports/rpt_220.pdf (it's free!!)

Water Equivalent Diameter

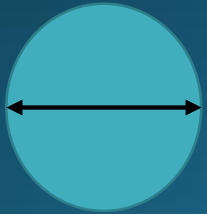
- **Water Equivalent Diameter (*Dw*)**
- Express the x-ray attenuation of a patient in terms of a water cylinder having the same x-ray absorption.
- The area and diameter of such a cylinder of water are referred to as the water equivalent area (*Aw*) and water equivalent diameter (*Dw*), respectively.
- This can be done:
  - From CT image data (after scan is performed)
  - From CT localizer radiograph (scout, topogram, planning scan) – after localizer is performed, but before CT scan is performed.

https://www.aapm.org/pubs/reports/rpt_220.pdf (it's free!!)

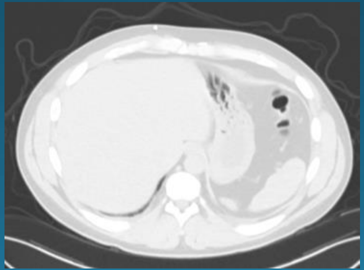
Water Equivalent Diameter (D_w) From CT image

- $A_w = \left(\frac{1}{1000}\overline{CT(x,y)_{ROI}} * A_{ROI}\right) + A_{ROI}$ Equation 3d (Page 8)
  - Where $\overline{CT(x,y)_{ROI}}$ = the mean CT number in the ROI (Region of Interest) and A_{ROI} is the total Area of that ROI (which encompasses the body).
- $D_w = 2\sqrt{\frac{A_w}{\pi}} = 2\sqrt{\left[\frac{1}{1000}\overline{CT(x,y)_{ROI}} + 1\right]\frac{A_{ROI}}{\pi}}$ Equation 4b (Page 8)

=



(D_w)



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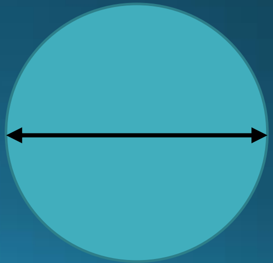

(D_w)

Water Equivalent Diameter (D_w) From CT Localizer Radiograph (Scout, Topogram, Pilot)

- $A_w = \sum L_w * S$ Equation 6 (Page 9)
  - Where L_w = the water equivalent length and S = detector spacing at isocenter and the sum is taken over a horizontal line of a CT localizer radiograph
- Note: Siemens estimates the (water equivalent) attenuation for both AP and Lat directions and stores it in a private field w/in DICOM header of topogram.
- From McMillan et al, Medical Physics, 2017

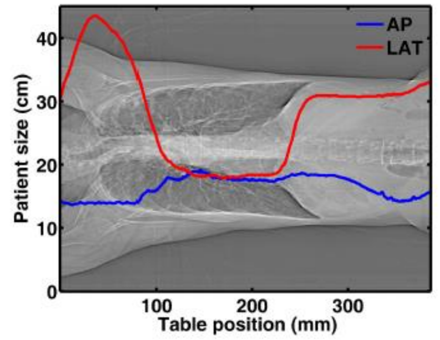

Figure 1.
AP and LAT water-equivalent estimates of patient size extracted from the DICOM header of a topogram.

Use of Water Equivalent Diameter for Calculating Patient Size and SSDE in CT AAPM Report 220

- Summary of AAPM Report 220 :
  - Water Equivalent Diameter accounts for patient attenuation in patient size metric
  - Can be estimated from either CT Image Data or CT localizer radiograph
  - Can be used to estimate SSDE
  - "No additional corrections are required when substituting D_w for effective diameter" from AAPM report 204.
  - Can use the same equations and figures shown previously

$$SSDE = (a \times e^{-bx}) \times CTDI_{vol}$$

- Scanner reports CTDIvol
- a and b are known (depends on phantom)
- Patient size (x) uses D_w

Size Specific Dose Estimate (SSDE) for Head CT - AAPM Report 293

AAPM REPORT NO. 293

Size-Specific Dose Estimate (SSDE) for Head CT

Size-Specific Dose Estimate (SSDE) for Head CT

The Report of AAPM Task Group 293

John M. Boone[1], Chair; Keith J. Strauss[2], Vice Chair; Andrew M. Hernandez[1]; Anthony Hardy[3]; Kimberly E. Applegate[4]; Nathan S. Artz[5]; Samual L. Brady[2]; Dianna D. Cody[6]; Nima Kasraie[7]; Cynthia H. McCollough[8]; Michael McNitt-Gray[3]

https://www.aapm.org/pubs/reports/RPT_293.pdf (it's free!!)

SSDE for Head - Motivation

- The size-dependent conversion factors provided in Report 204 were developed specifically for CT imaging of the abd/ pel
  - although use in thorax was acceptable since the errors were expected to be below 20%.
- Purpose of Report 293 was to extend the development of SSDE concepts to the head
- Particular interest was variation of head size and scan length across age (and specifically for pediatric patients)
- TG sought to develop conversion factors for 1 y/o to adult (though variation is small after 7 y/o)

SSDE for Head - Motivation

- SSDE represents the *absorbed dose* to the center section along the z-axis of a typical clinical CT scan.
- For head scans, the absorbed dose in this thin center section includes dose from scattered radiation from the tissues above (superior to) and below (inferior to) the center section.
- It is recognized that the dose to the center section (along z) of the CT scan represents a near-maximum absorbed dose to the tissues within the scan volume and, consequently, the average absorbed dose to the entire scan volume will be lower in virtually all cases.
- The principal outcome of this report is a set of $CTDI_{vol,16}$-to-SSDE conversion factors for CT examinations of the head as a function of water-equivalent diameter (D_w) and will use same form of conversion equation.

SSDE for Head - Methods

- Similar to TG 204
- 2 groups made measurements
- 2 groups performed Monte Carlo simulations
- Compiled results of Dose in center of scan volume vs. D_w

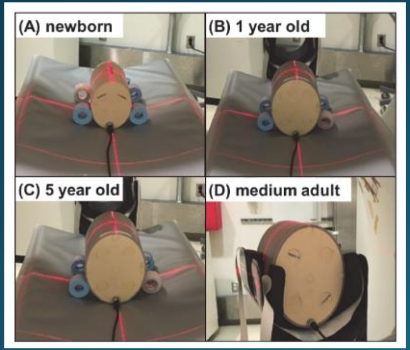

Figure 2 from page 7 – different sized tissue equivalent head phantoms

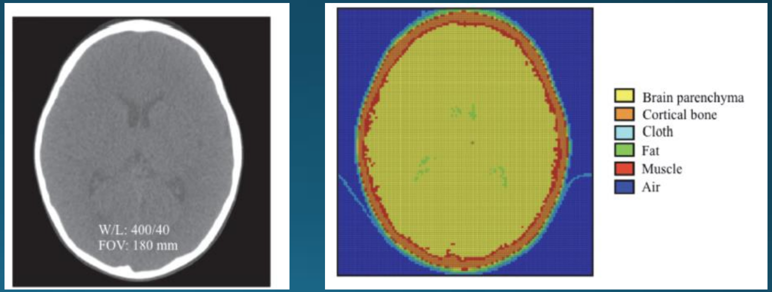

Figure 5 from page 11 – CT image and voxelized patient model for simulations

SSDE for Head - Results

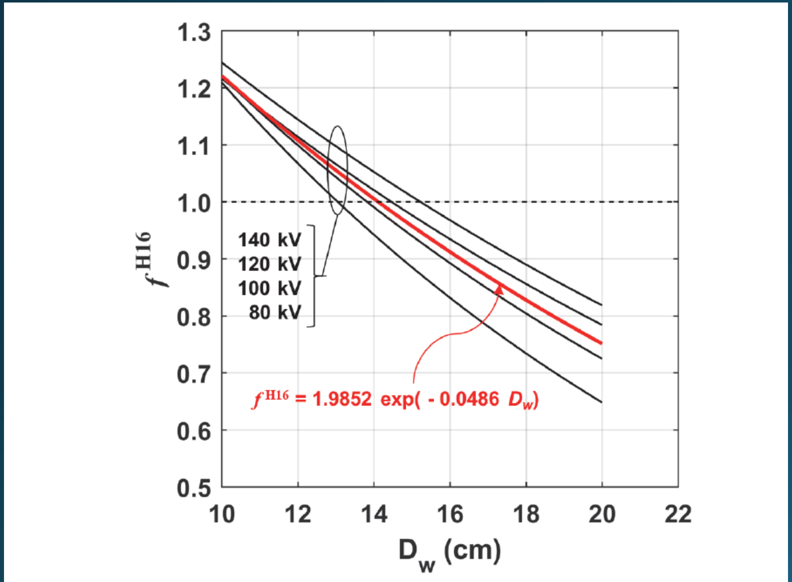

Figure 11 from page 16 – Conversion factors (for various kV and overall)

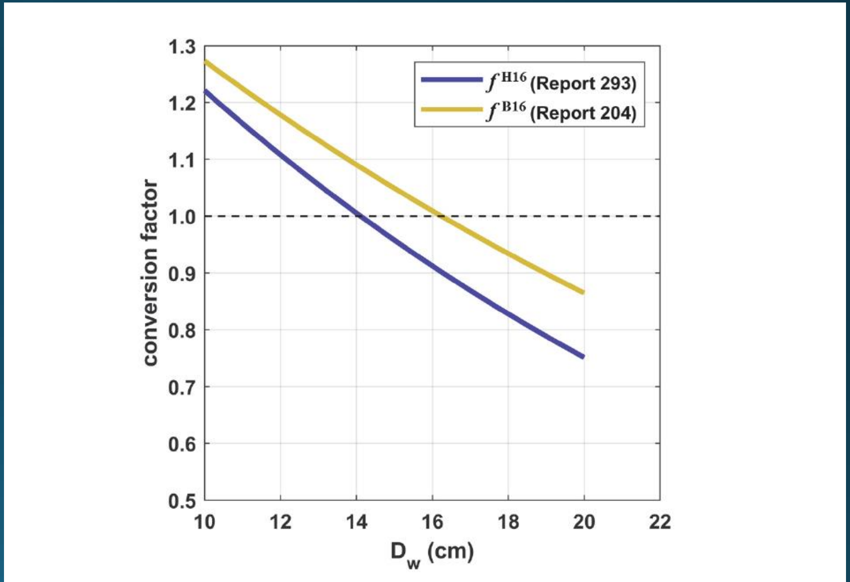

Figure 12 from page 18 – Comparison of conversion factors between 204 and 293

Report 293 SSDE for Head - Summary

- SSDE for Head that is consistent with SSDE for Body (but different coefficients)

  SSDE = (a x e^{-bx}) x $CTDI_{vol}$

  - Scanner reported $CTDI_{vol}$
  - a and b are known (for head, limited to 16 cm phantom)
  - Patient size (x) uses D_w

- Even for the same Dw, the spatial distribution of absorbed dose deposition to the brain is considerably different than the absorbed dose deposition to the body
- Primarily due to the fact that the head is encased in a shell of relatively dense bone.
- Comparing the f16 conversion factors between the body (AAPM Report 204, fB16) and those of the head (this report, fH16), it is seen
  - the shapes of the curves are quite similar
  - SSDE conversion factors for head CT are consistently lower
  - likely due to the attenuation of the skull and the more aggressive beam shaping (i.e., bow tie) filters used in head CT scans

Where is SSDE today?

- Calculated on ACR Phantom Submissions (Just Abdomen for now)
  - Automatically from CTDIvol values
  - Assumes a patient size for adult and peds (5 y/o)
- Some Dose Management software systems report this
  - Though not always clear how this is done
- There is an IEC Standard (PT 62985 Ed.1.0) that has been approved ("published")
  - Hope is that manufacturers will include reporting SSDE in future software releases (DICOM RDSR?)
- ACR DIR also calculates SSDE but only for body

Clinical Use of SSDE

- SSDE overcomes some of the limitations of $CTDI_{vol}$ by accounting for patient size
- Provides an estimate of patient dose (not organ dose and not risk)
- Eventually may be able to replace (supplement?) metrics of scanner output.
- Soon captured by scanner; May eventually be displayed on scanner (not a current requirement), but at least available in RDSR
- ACR DIR already includes an estimate of SSDE
- Future investigations – can SSDE be used as an estimate of radiation dose to organs? If so, where? (and where not?) Will this be a better input to risk models than $CTDI_{vol}$ and DLP?

Summary

- AAPM Report 204 Introduced the concept of SSDE
  - For body scanning
  - Used "Effective Diameter"
- AAPM report 220 introduced the concept of Water Equivalent Diameter (D_w)
  - Patient size metric that accounts for attenuation and not just morphology
  - Could be used in calculations developed in Report 204
- AAPM Report 293 extended these concepts to Head CT scans
  - Used D_w as size metric
  - Coefficients are slightly different from those in 204
  - Combination of attenuation environment (bony skull) and bowtie filters tailored towards head
- Together, these provide a comprehensive methodology to estimate SSDE
  - For Head, Chest and Body
  - Using a standardized methodology that can be implemented automatically and widely
- IEC Standard for manufacturers to implement
- Inclusion in ACR DIR; other uses in future?

Thank you!