Estimating Patient Dose

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Learning Objectives:

- Limitations for estimating patient dose for CT
- Methods for estimating patient dose for CT
- Potential future options?

What is reported?

- Volume CT Dose Index (CTDIvol) and Dose Length Product (DLP)
- Both specific to cylindrical plastic phantom
- Both are metrics for CT scanner output

- NOT PATIENT DOSE METRICS

- McCollough et al. CT Dose Index and Patient Dose: They are *NOT* the same thing. Radiology 259:311-416, 2011.

NOT patient dose?

- Does not adjust for:
  - Patient SIZE
  - Organs partially irradiated
  - Presence of contrast enhancement
  - Tissue composition (instead of plastic)
  - Energy absorbed by patient (presence or absence of naturally occurring attenuator layer – FAT)

What do we mean by patient dose?

- Absorbed dose (energy) by individual subject
- What about effective dose? Is that dose to a patient?
- Maybe organ dose would be a better measure?

Convert to effective dose…

- k-factor approach (AAPM Report 96)
- ImPACT CT Dosimetry Tool
- CT-Expo
- Commercial dose database packages

- Research facilities (also organ dose)
  - UCLA [Michael McNitt-Gray]
  - University of Florida [Wes Bolch]
  - Rensselaer Polytechnic Institute [George Xu]
  - Duke [Ehsan Samei and Xiang Li]
  - Others…

Effective dose definition

- $E(Sv) = \sum [w_T \times H_T(Sv)]$
  - w_T = tissue weighting factors
  - H_T = organ dose
- Applies to population, NOT individual

Effective dose?

- Specific to standard man size or geometric model
- May be automatically calculated by database
- But useful in what context?
  - Population studies
  - Overall practice patterns
  - Protocol quality assurance (outliers)

Effective dose?

- NOT suitable for individual patient histories
  - Only when patient size exactly matches modeling approach used to calculate effective dose
    - "Standard Man"
  - Durand DJ et al. Utilization strategies for cumulative dose estimates. J Am Coll Radiol 9:480-5, 2012.

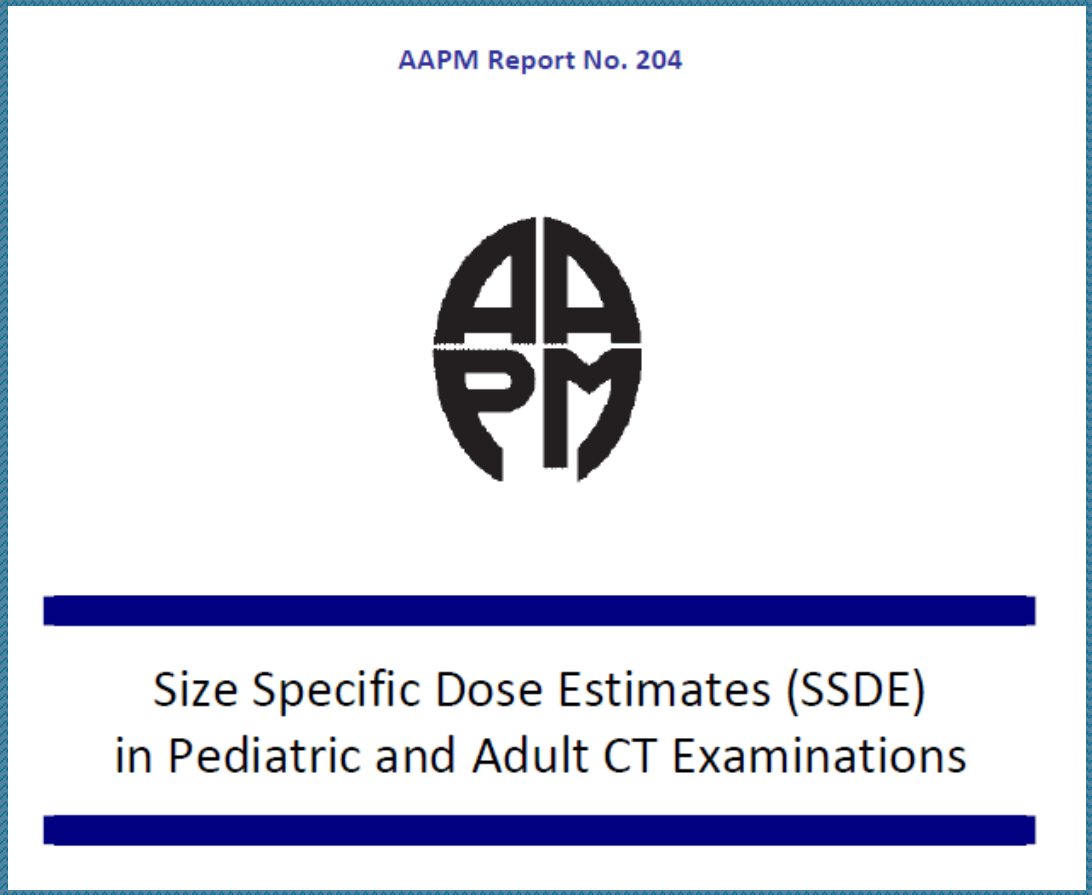
What would be most useful for our patients???

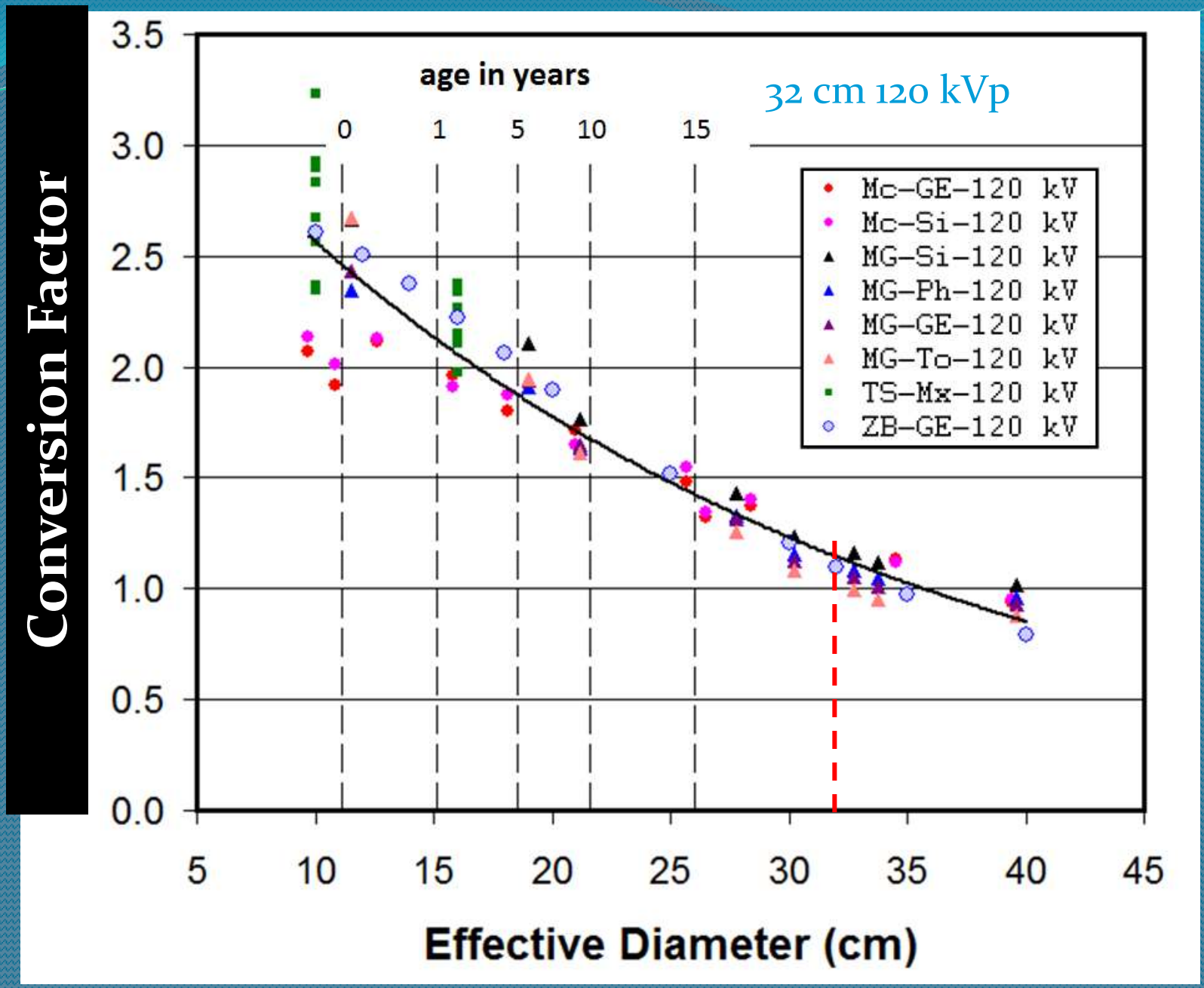
- ORGAN DOSE (relevant to size & scan details)
- Would help us understand risk to organ systems
- Would allow more useful cumulative analyses

- VERY complicated
- LOTS of values to track
- MUST be automated!!

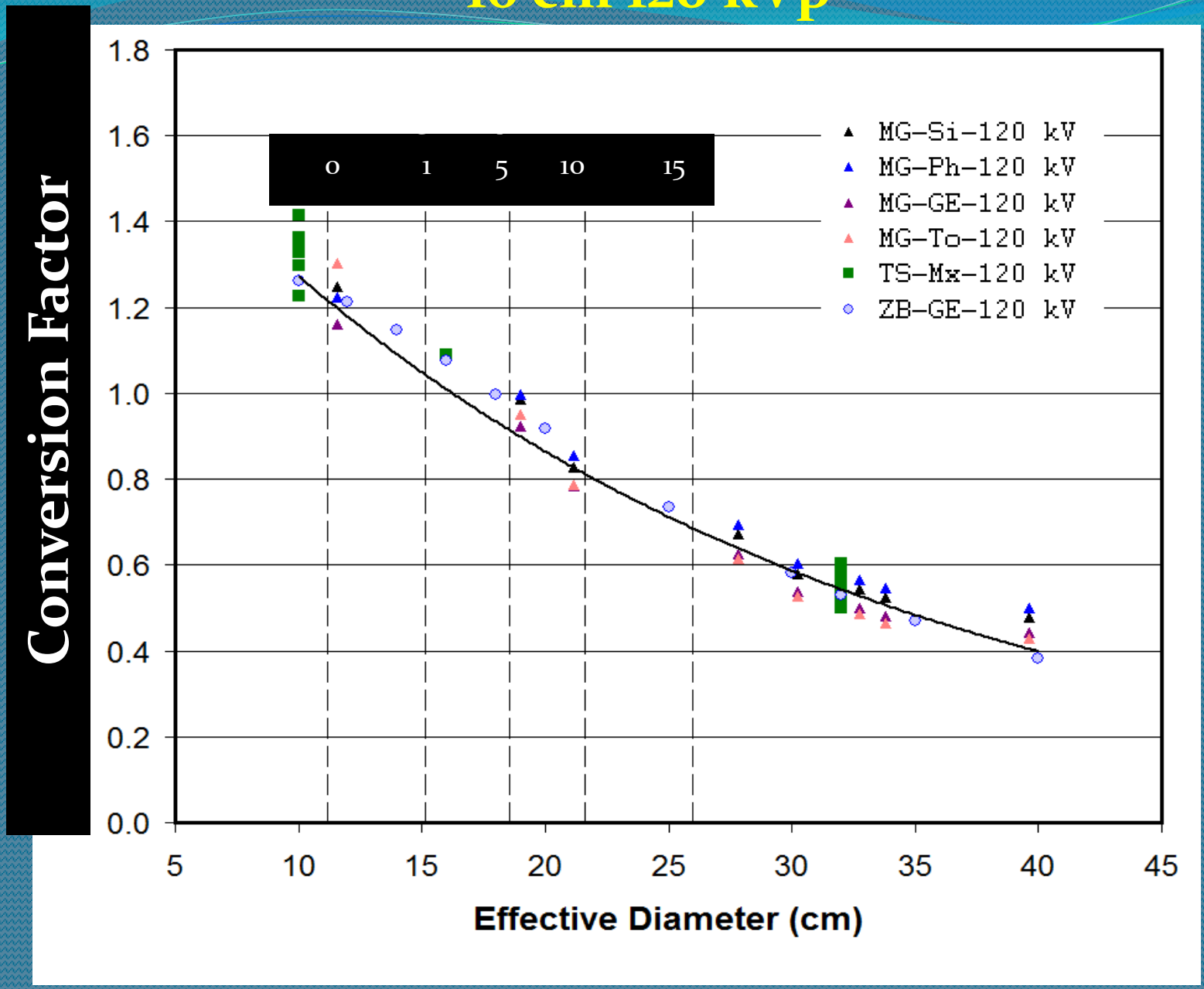
So what can we do???

- AAPM Report 204
- Chair: John Boone, Ph.D., FAAPM, FSBI, FACR
- Size Specific Dose Estimates

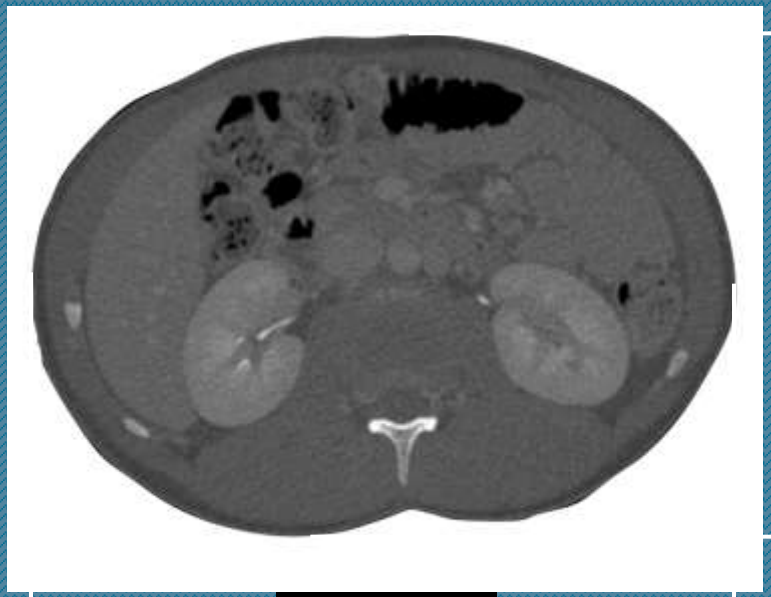



Conversion Factor
age in years
0
1
5
10
15
32 cm 120 kVp
Mc-GE-120 kV
Mc-Si-120 kV
MG-Si-120 kV
MG-Ph-120 kV
MG-GE-120 kV
MG-To-120 kV
TS-Mx-120 kV
ZB-GE-120 kV
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
15
20
25
30
35
40
45
Effective Diameter (cm)

16 cm 120 kVp


Conversion Factor
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
5
10
15
MG-Si-120 kV
MG-Ph-120 kV
MG-GE-120 kV
MG-To-120 kV
TS-Mx-120 kV
ZB-GE-120 kV
5
10
15
20
25
30
35
40
45
Effective Diameter (cm)

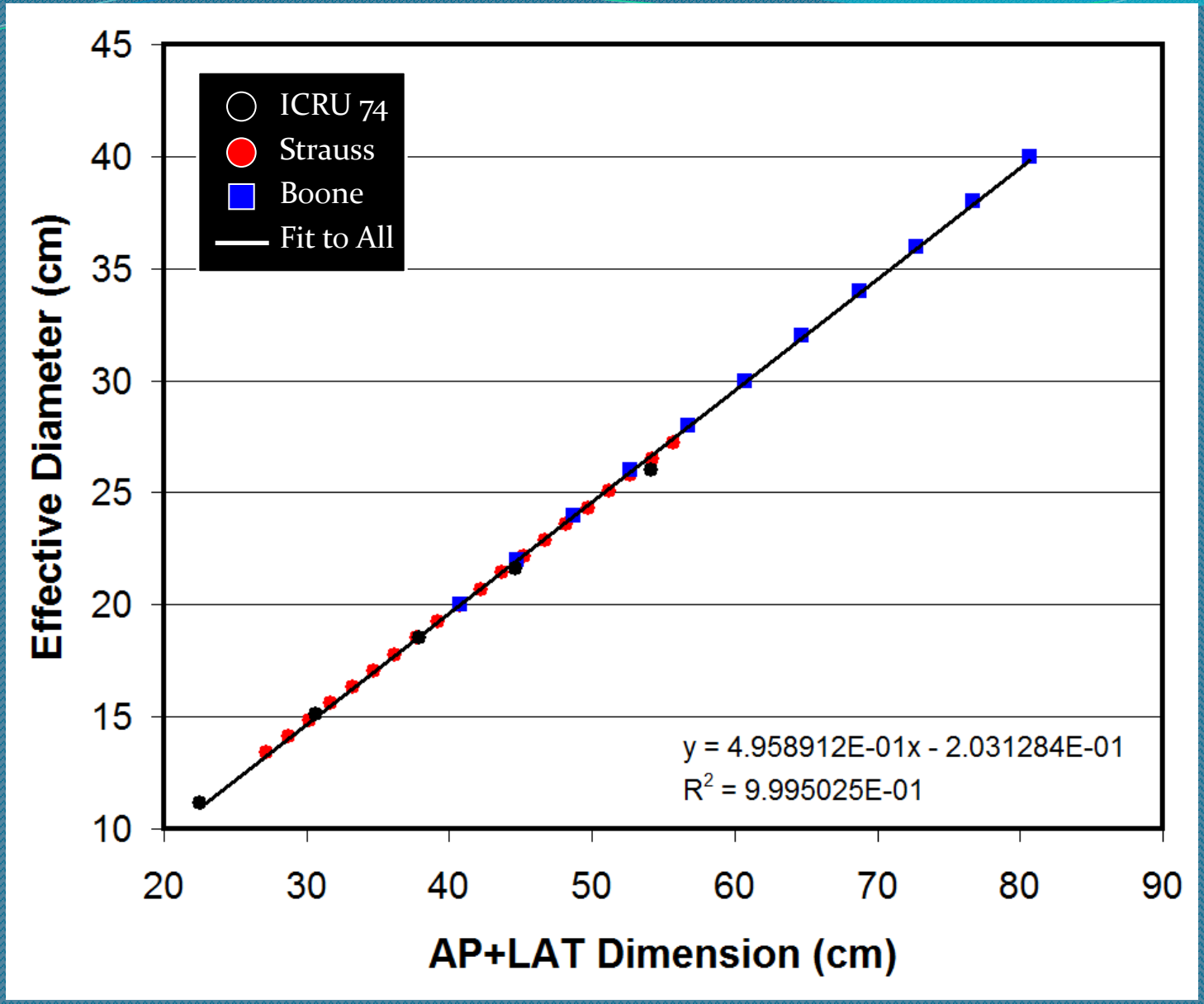
circle of equal area



AP

lateral

effective diameter


ICRU 74
Strauss
Boone
Fit to All
y = 4.958912E-01x - 2.031284E-01
R2 = 9.995025E-01
Effective Diameter (cm)
AP+LAT Dimension (cm)
10
15
20
25
30
35
40
45
20
30
40
50
60
70
80
90

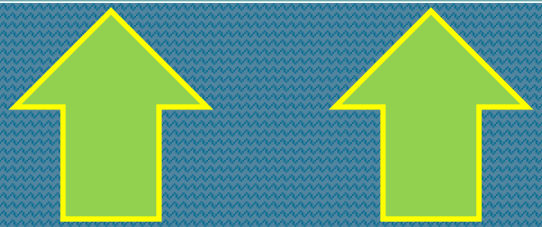
Real-Life Example

- Email from pediatric radiologist (July)
- Goske, et al… Diagnostic Reference Ranges for Pediatric Abdominal CT. Radiology 268:208-218, 2013.
- Dose ranges for pediatric CT exams
- How does the dose delivered in this particular case (5 year old abdomen/pelvis CT) compare to published range???

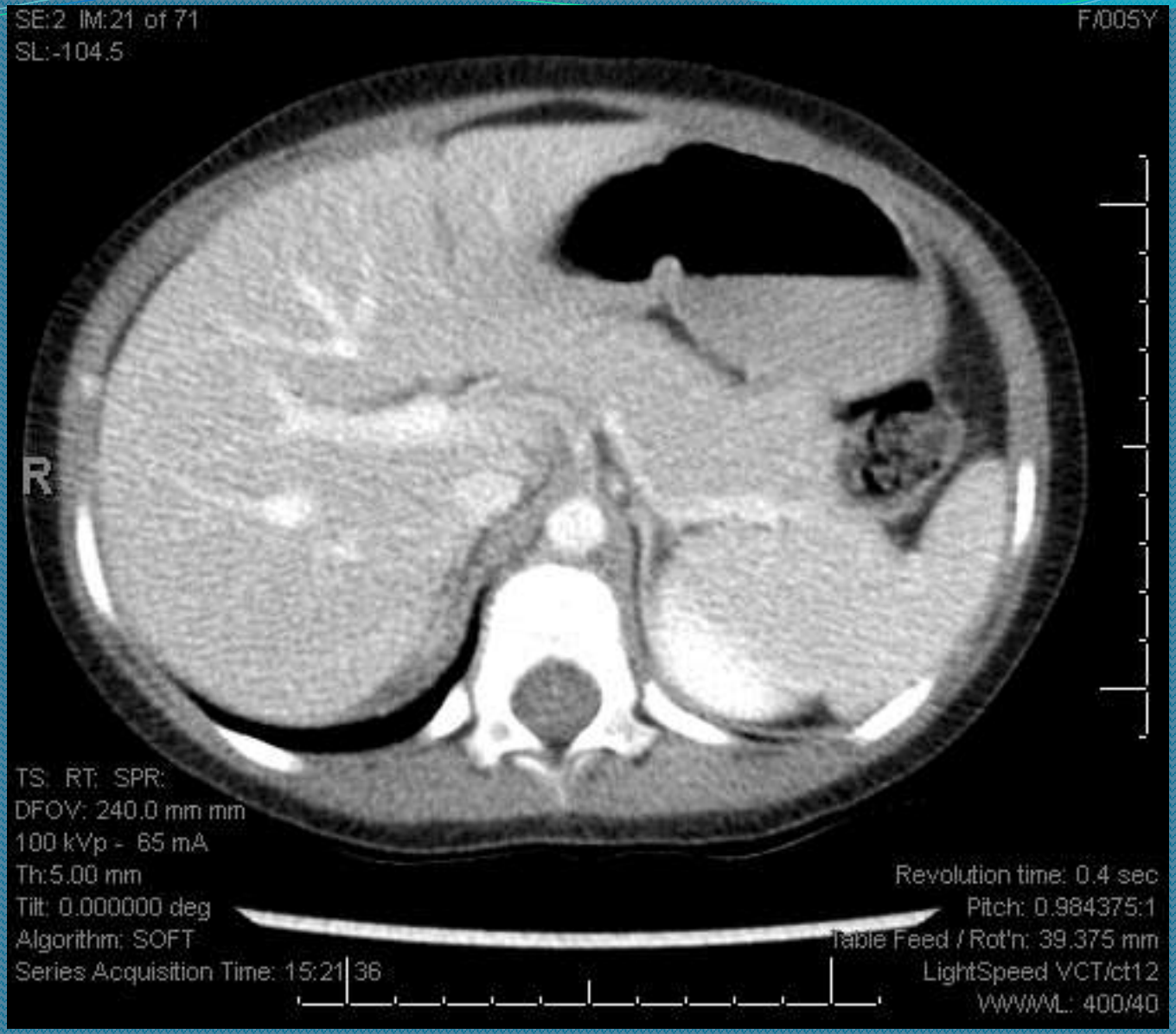
Table 3

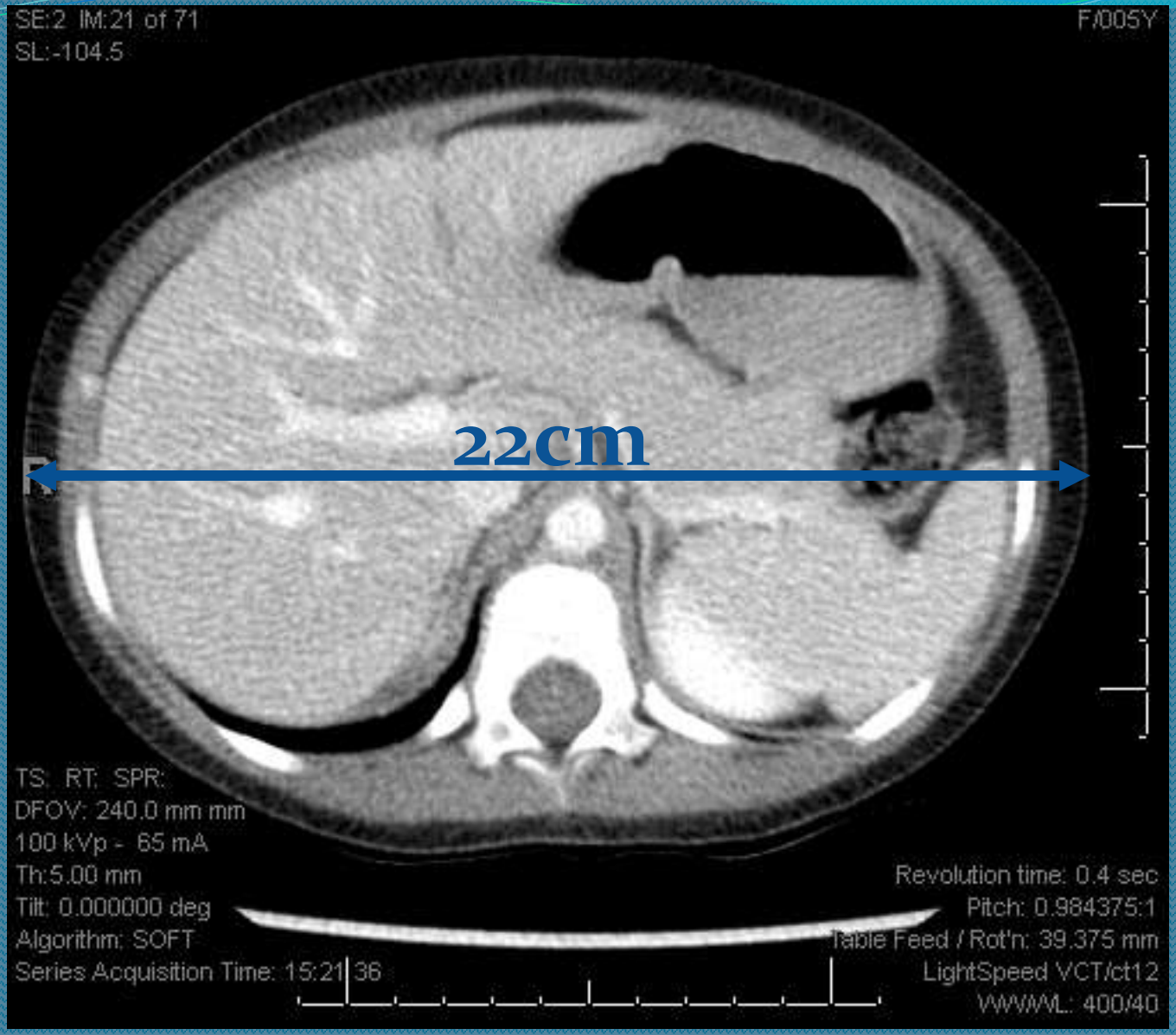
Distribution of SSDE

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



Body Width SSDE (mGy)


SE:2 IM:21 of 71
SL:-104.5
F/005Y
R
TS: RT: SPR:
DFOV: 240.0 mm mm
100 kVp - 65 mA
Th:5.00 mm
Tilt: 0.000000 deg
Algorithm: SOFT
Series Acquisition Time: 15:21:36
Revolution time: 0.4 sec
Pitch: 0.984375:1
Table Feed / Rot'n: 39.375 mm
LightSpeed VCT/ct12
WW/WL: 400/40


SE:2 IM:21 of 71
SL:-104.5
F/005Y
22cm
TS: RT: SPR:
DFOV: 240.0 mm mm
100 kVp - 65 mA
Th:5.00 mm
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Body Width

SSDE (mGy)

11.4 mGy average

7.6 to 13.4 mGy range

25^{th} - 75^{th} percentiles

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Helical	I4.500-I334.500	2.82		Head 16
2	Axial	I134.500-I139.500	2.91		Head 16
2	Axial	I269.000-I274.000	2.91	2.91	Head 16
			Total Exam DLP:	111.98	

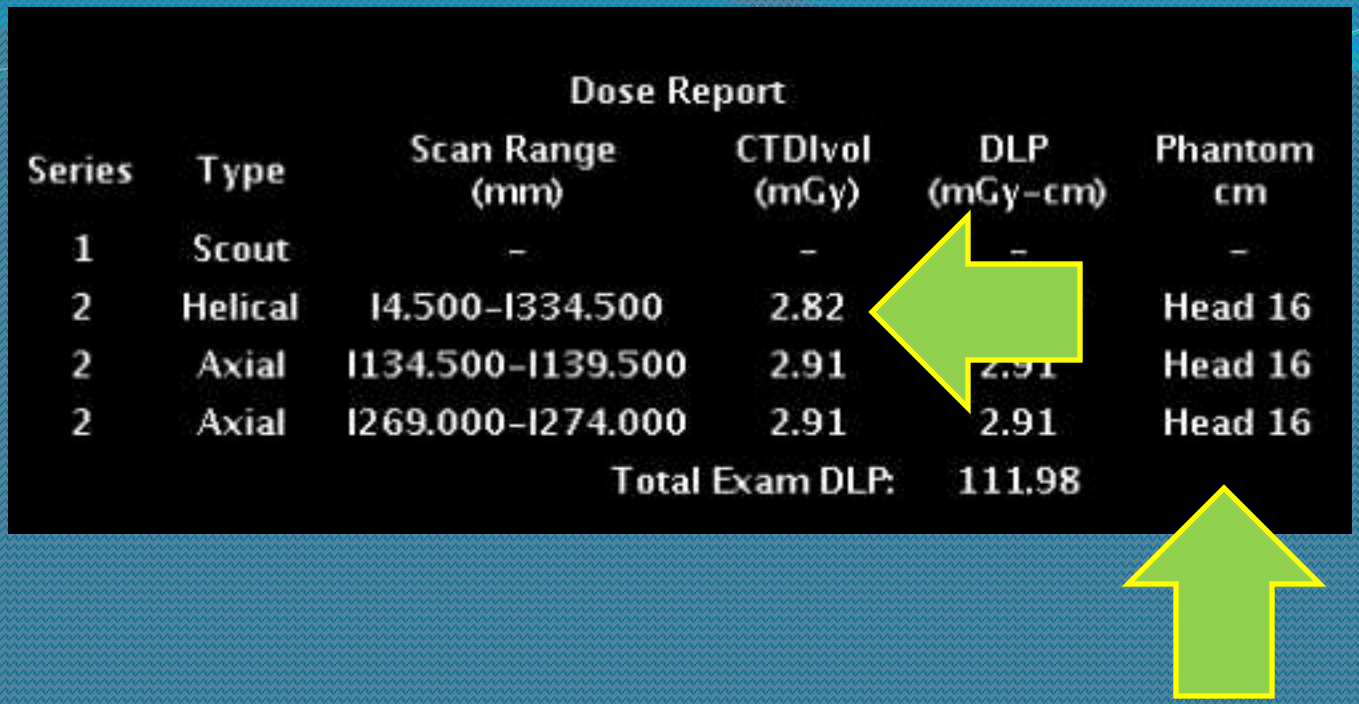

Table 2B

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

Report 204 – table for 16cm CTDI & Lateral dimension

SSDE = $CTDI_{vol}$ x conversion factor

SSDE = 2.82 mGy x 0.94

SSDE = 2.65 mGy, or 2.7 mGy

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Body Width

SSDE (mGy)

11.4 mGy average

7.6 to 13.4 mGy range

25th - 75th percentile

Our case SSDE = 2.7 mGy …

CLEARLY LOW COMPARED TO THIS RANGE

Reaction?

- Rationale to slowly systematically increase technique on our pediatric exam protocols
- Currently planning to increase $CTDI_{vol}$ in 25% steps

Take home message?

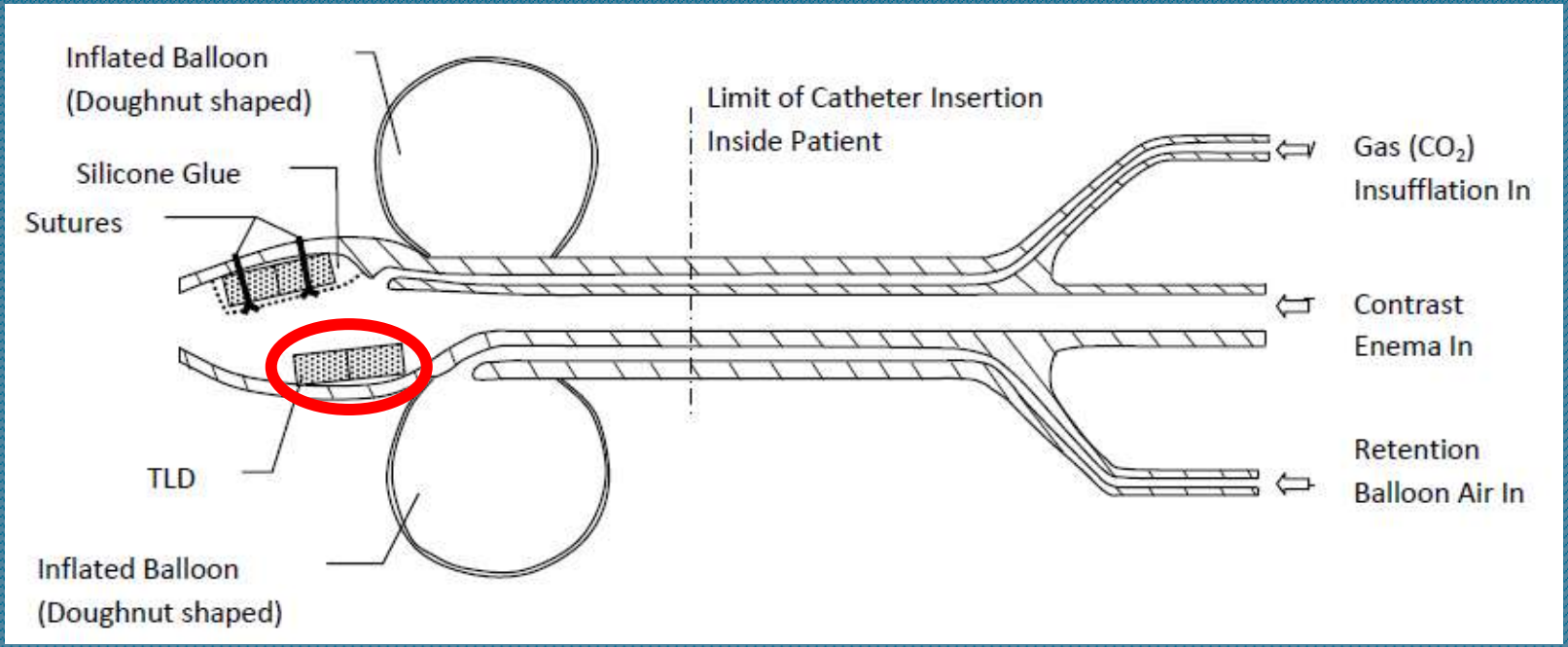
- SSDE can be hugely helpful in real clinical cases
- Individual patients can have **very** unique aspects
- Be wary of one-size-fits-all approach
- Think big-picture with dose data base analysis
- Think customized medicine for individual patient analysis

What does new metric mean? SSDE

- Size corrected CTDIvol
- DO NOT apply standard k-factors to this value
  - k-factors are based on standard man size
  - Will require some effort to sort out
- May be similar to average dose in cross-section
  - Organ dose???

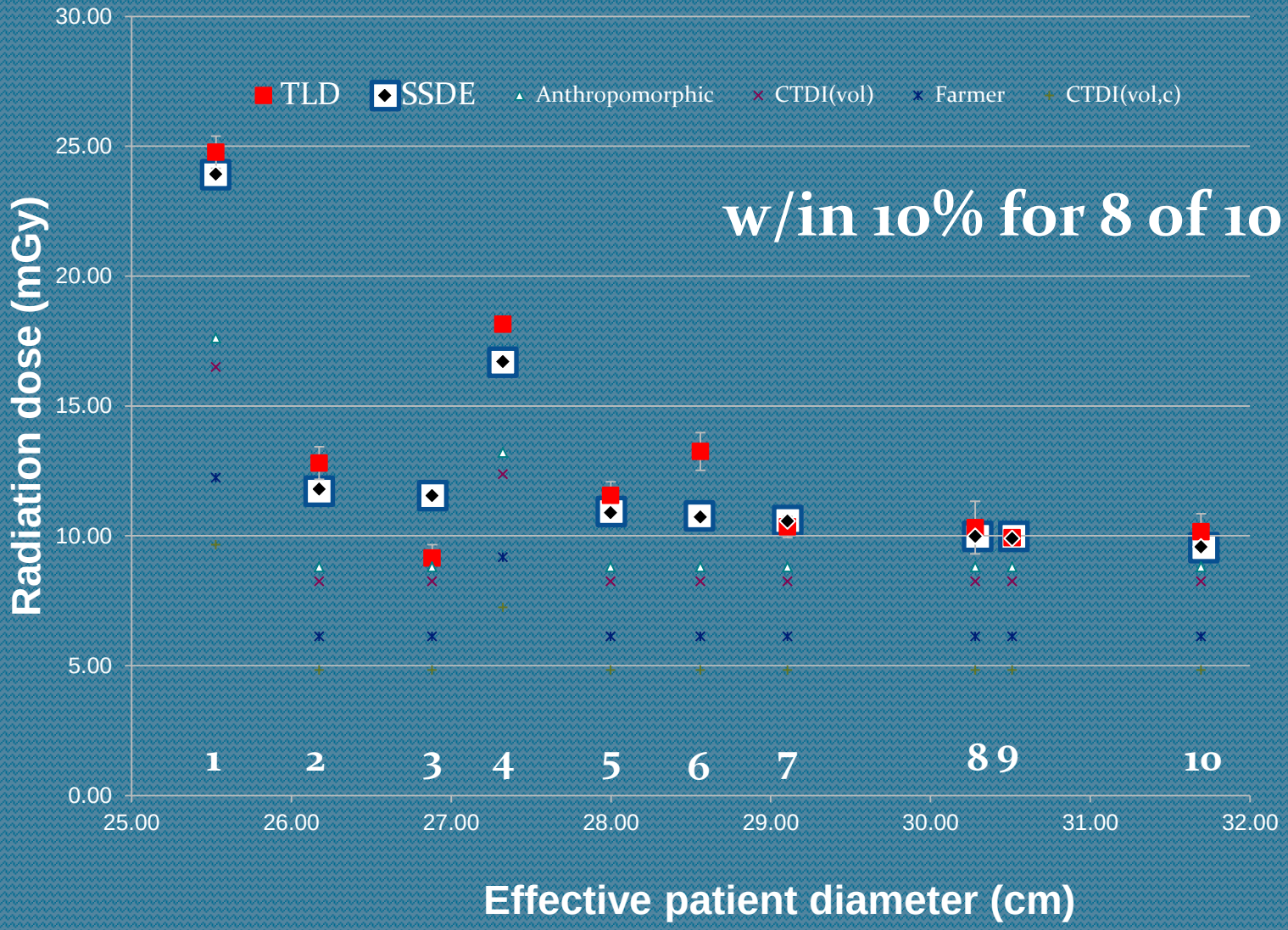
In Vivo dose comparison to SSDE

- TLDs attached to enema tip
- Virtual Colonoscopy CT Exam (no TCM)
- N=10 patients
- IRB approved



TLD vs SSDE

Under review, AJR



Future???

- CT Vendors –
  - Use information in localizer scan
    - Provide Water Equivalent Diameter (or surrogate)
  - With CTDIvol, provide *SSDE* automatically
  - For exams using tube current modulation (TCM):
    - Mean SSDE
    - Min & Max SSDE?
    - May need a method for scaling SSDE for specific organ locations (organ dose)

SSDE to Organ Dose?

- CTDIvol for average mA over scan extent
- Adjust for mA in section of interest
- Adjust for patient size (SSDE)
- Result – organ dose estimate for tissues in that section

- Potential for automated calculation of organ dose values

But…

- Just because we can, should we?
- Which patients would this benefit?
- Younger patients with chronic conditions or stable disease
- Small proportion of our patients?

- By the time organ data bases are ready, scanners may deliver tiny exposures
- Worth the effort and expense? Not sure…
- Over-zealous application of technology?

Summary

- Current metrics not intended for individual patients
- SSDE provides method for scaling $CTDI_{vol}$ for patient size
- SSDE may represent average dose at measured cross section
- May be useful in building organ dose databases
- Must be automatic and robust for routine clinical use