UF UNIVERSITY of FLORIDA College of Medicine

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You Spin Me Right Round: Approaches to Measuring CT Dose in Helical Modes

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Disclosures

- None

Outline

1. Implications of measuring CTDI
   - Quantitative
   - Practical

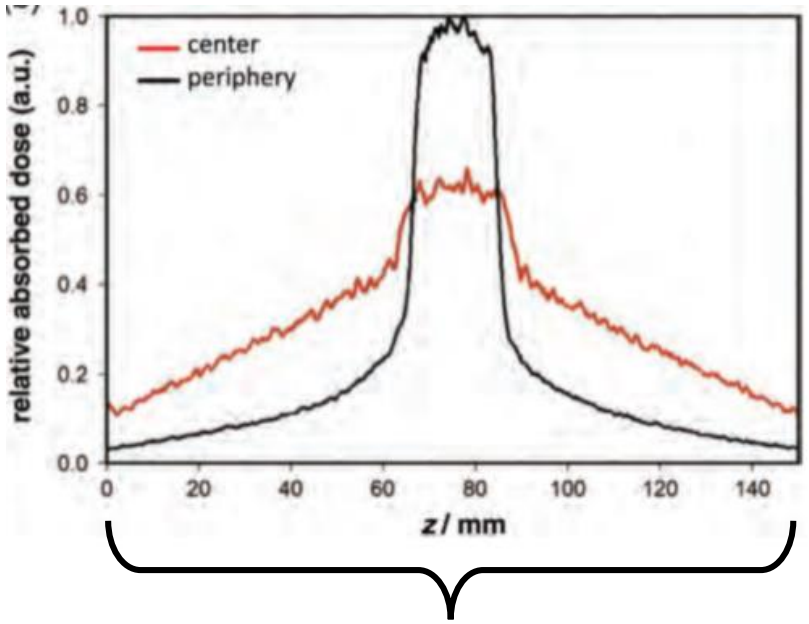
2. Measuring Rise to Equilibrium Curves

3. Estimating $CTDI_{vol}$ with a helical acquisition

Quantitative Limitations of the CTDI

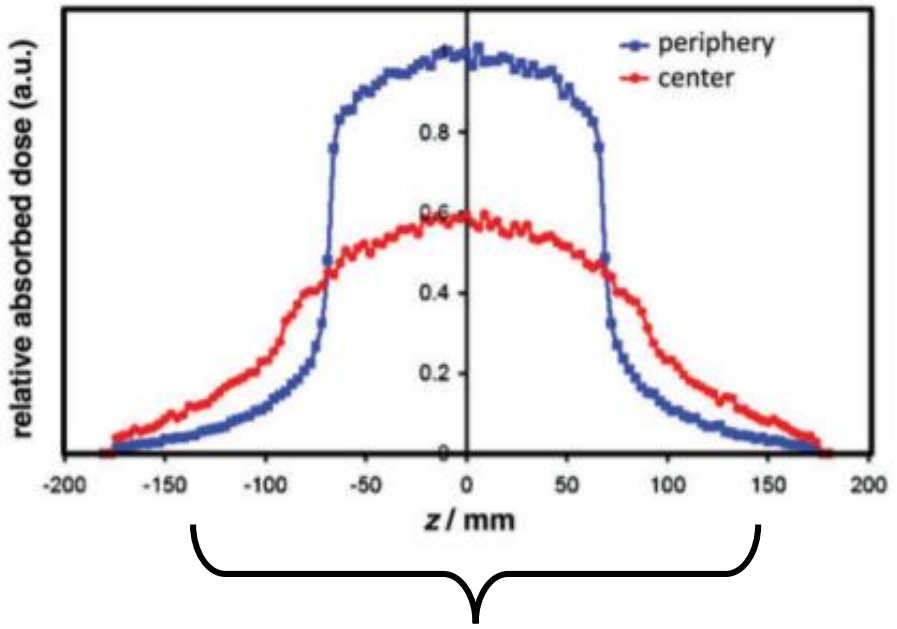
1. CTDI excludes dose that accumulates for long scans
2. CTDI excludes the primary beam for beams wider than 100 mm
3. CTDI is inappropriate for stationary table applications

Because of scatter tails, the dose profile extends beyond the nominal collimated beam width



Scatter tails (10% maximum) reach **150 mm** for a 19.2 mm nominal beam width

Figure 7.5b in ICRU 87, from McNitt-Gray et al., 2008



Scatter tails (10% maximum) reach **280 mm** for a 160 mm nominal beam width

Figure 7.8 in ICRU 87, from Geleijns et al., 2009

Dose profiles as a function of Scan Length

- Helical scans with various **different scan lengths**
- **Central cumulative dose** increases as scan length increases
  - Due to increased scatter contributions

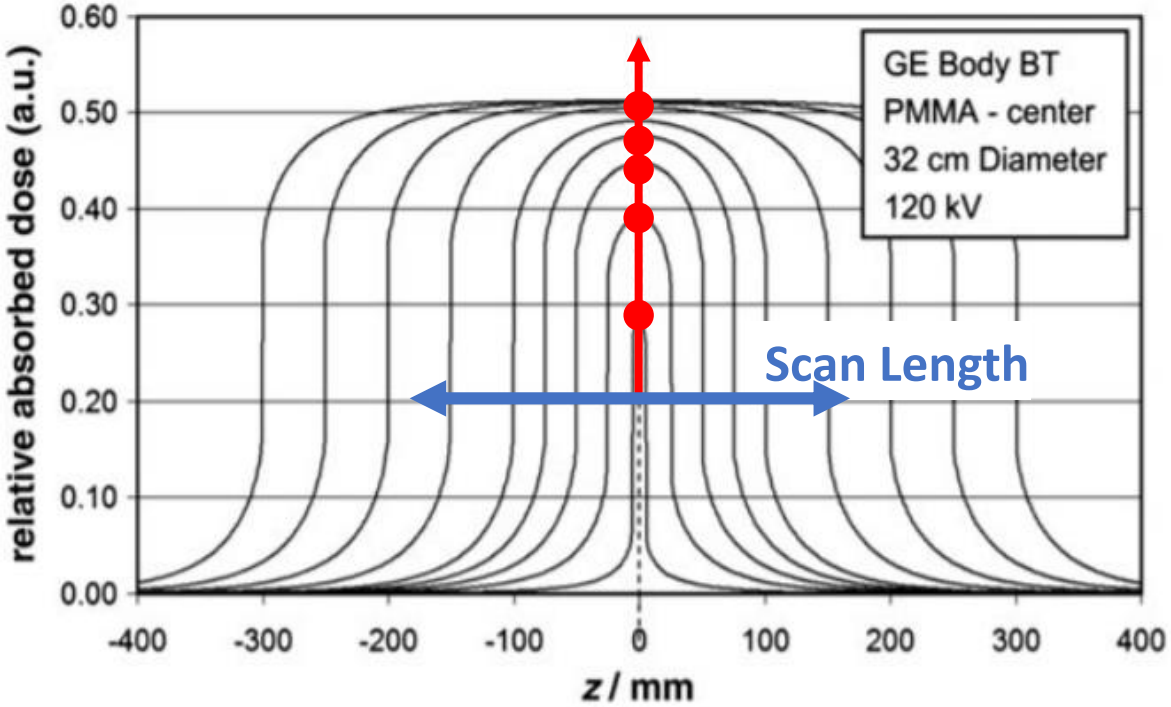
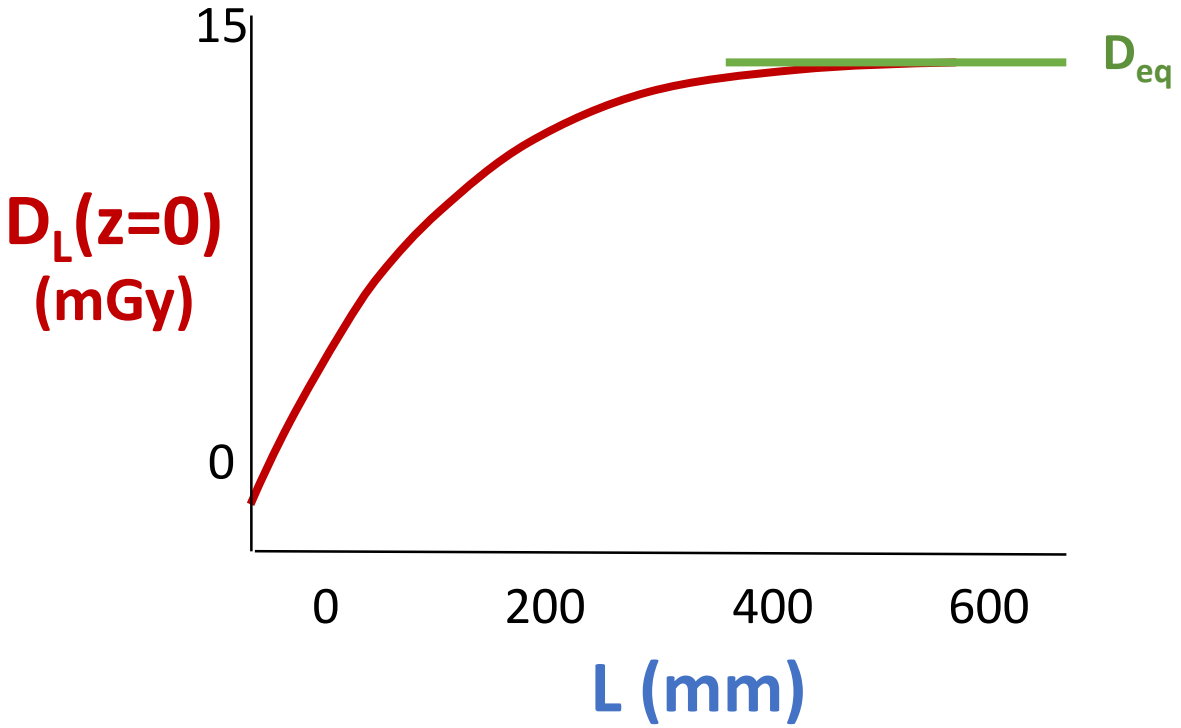


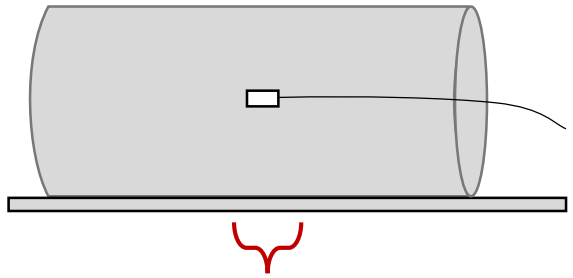
Figure 7.9 in ICRU 87, from Boone et al., 2009

Cumulative Dose as a function of Scan Length

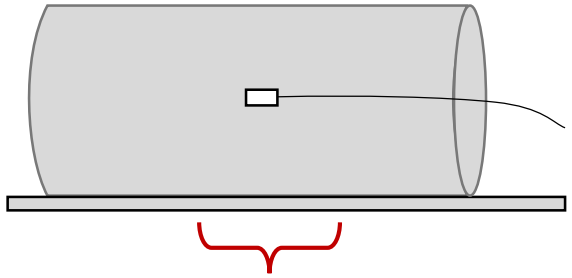
As **scan length** increases, the cumulative dose at the midpoint of the scan range increases, reaching an **equilibrium dose**



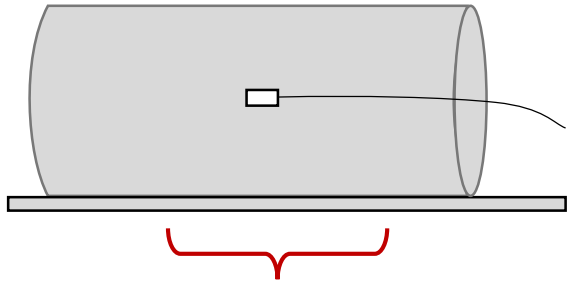
Measuring the *Approach-to-Equilibrium* Function (h(L) in TG111)



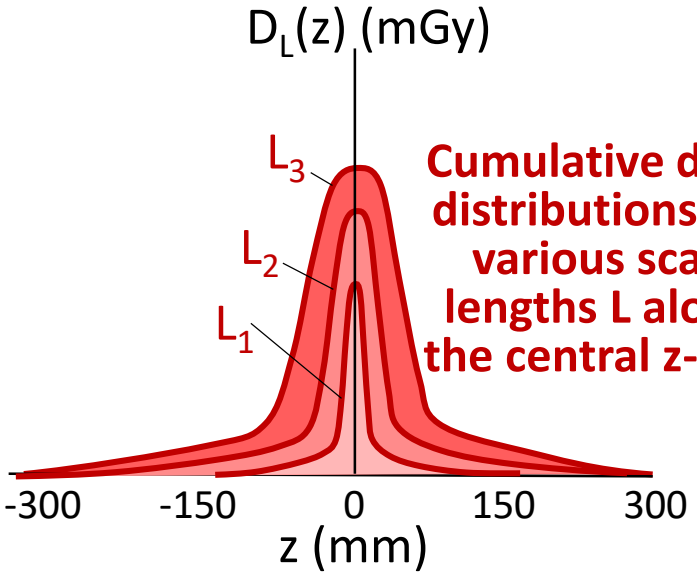
Scan Length L_1

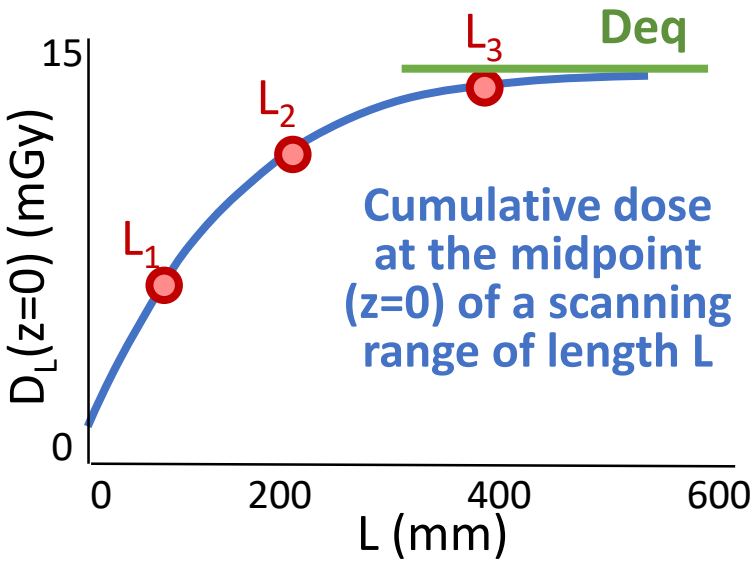


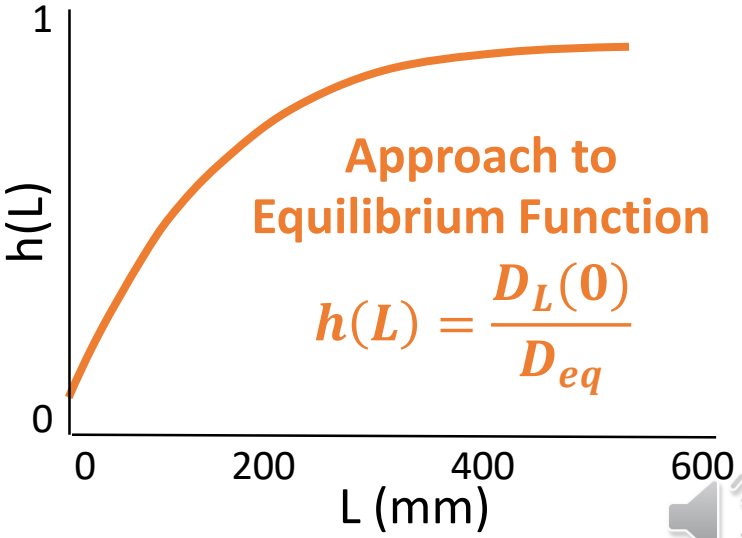
Scan Length L_2



Scan Length L_3







ICRU/AAPM Phantom

- AAPM TG200 & ICRU 87
  - Design of a new ICRU/AAPM phantom
    - 600 mm long, 91 lb
    - Divided into 3 sections
  - Measurement methodology that overcomes the limitations of CTDI

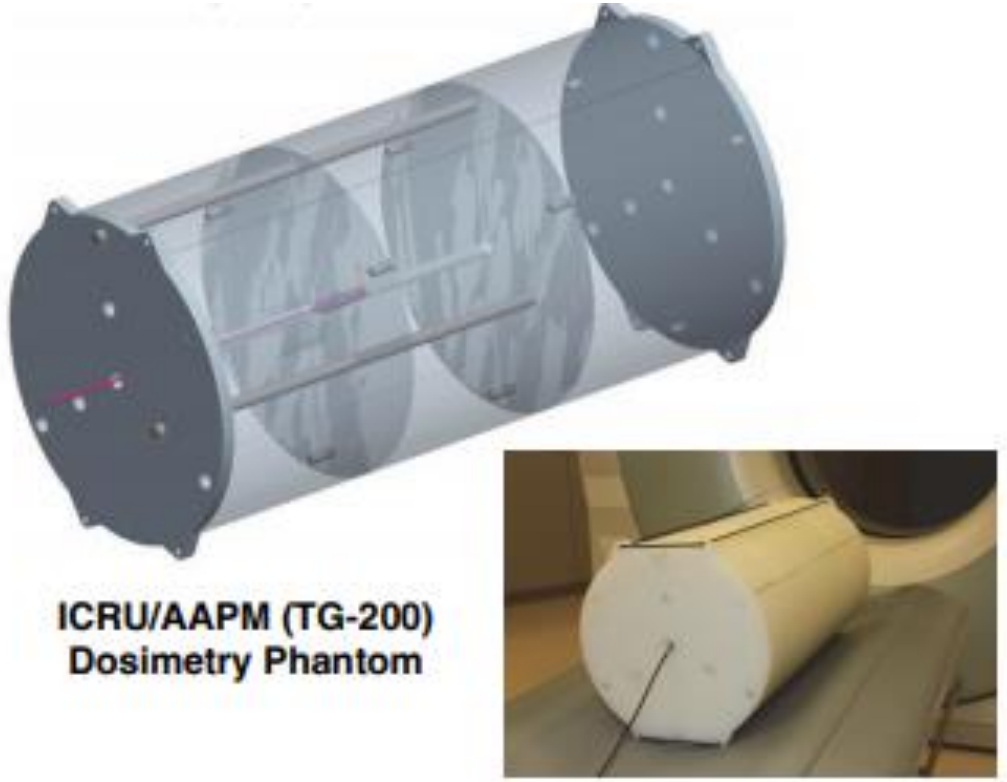
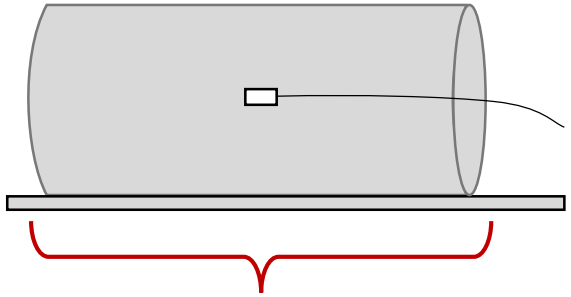
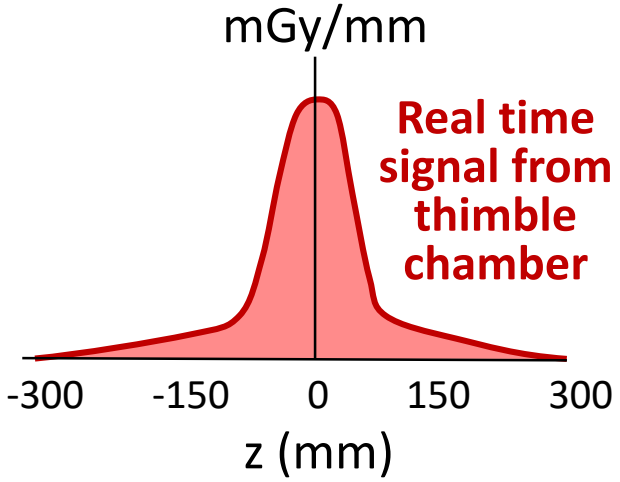
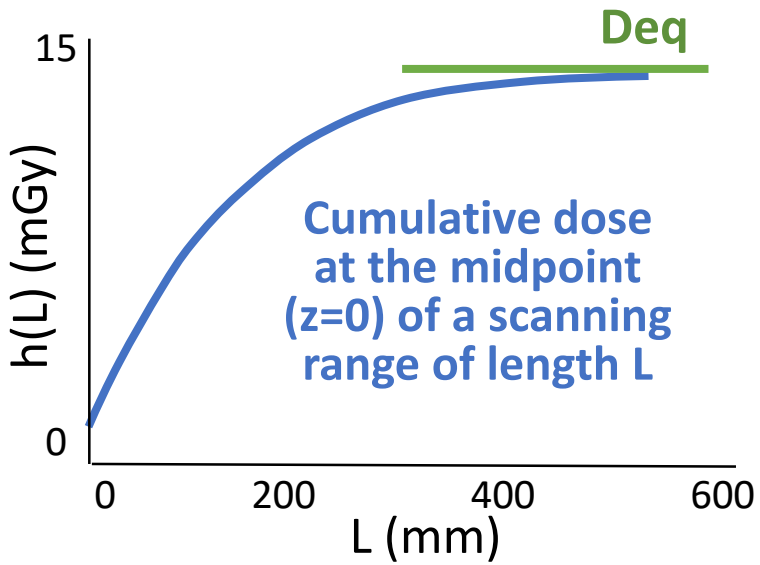


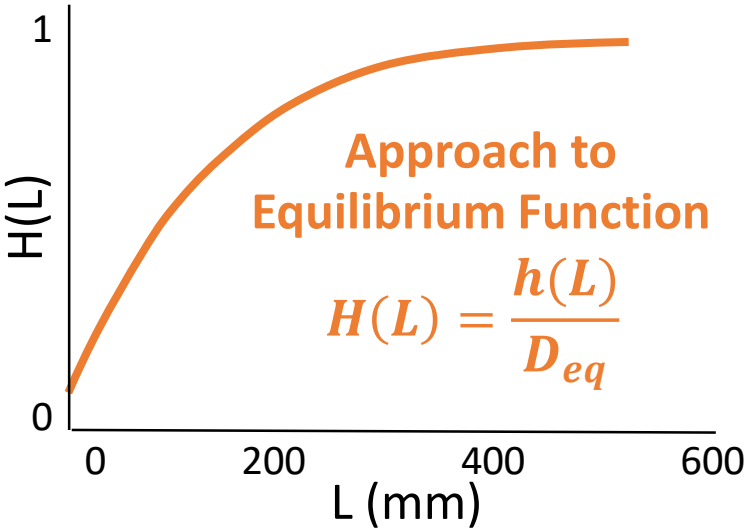
Figure 1 in AAPM TG200

Measuring the *Approach-to-Equilibrium* Function (H(L) in TG200)









Normalizing by $CTDI_{vol}$

- Normalization by $CTDI_{vol}$ corrects for differences in kVp, filtration, beam width, geometry, etc

$$G_x(L) = \frac{h_x(L)}{CTDI_{vol}}$$

x = center or periphery

- Very similar normalized **G(L)** curves for different kVp and scanners:

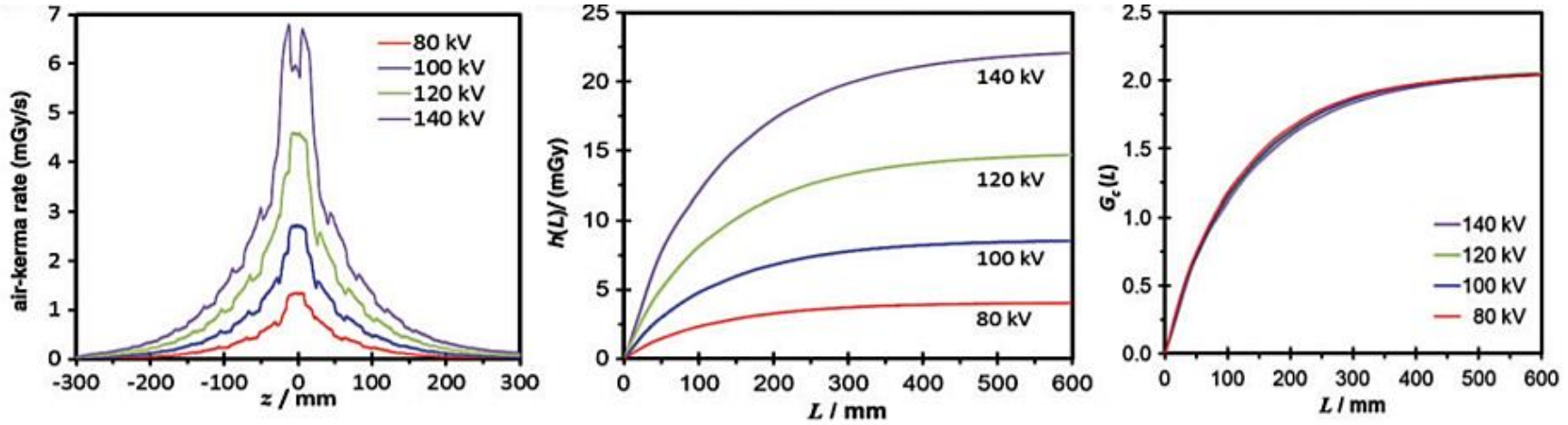


Figure 7.27 in ICRU 87

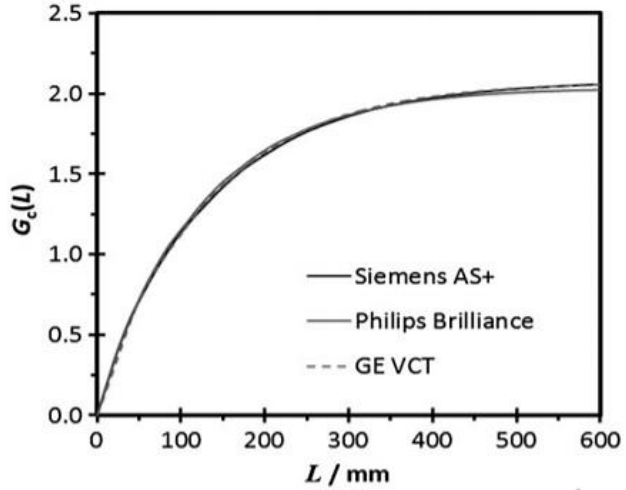


Figure 7.26 in ICRU 87

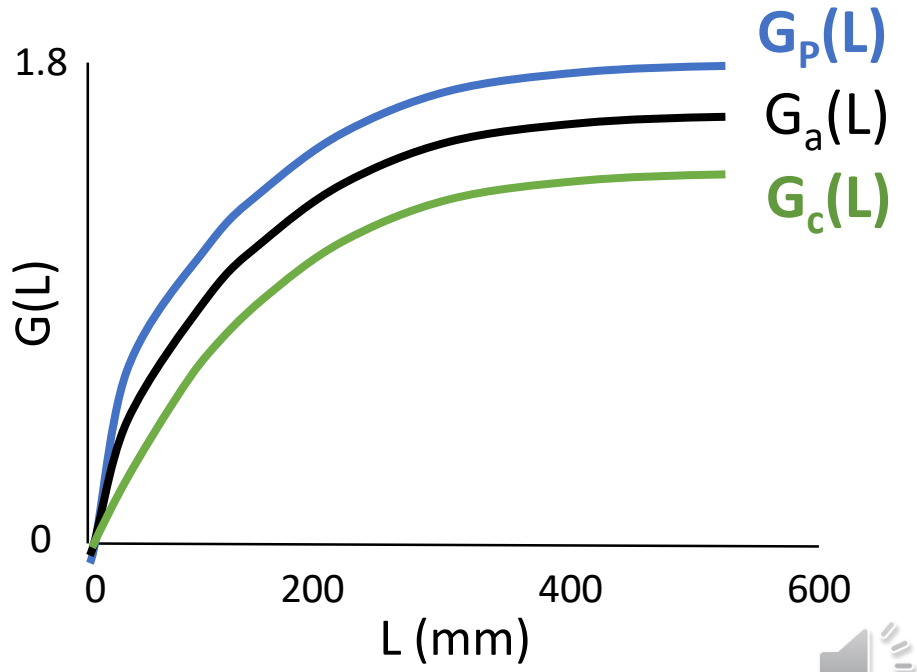
Measurement of h(L) in the Clinical Environment

- Combining the center and peripheral measurements:

$$\boldsymbol{CTDI_{vol}(L) = h_a(L) = \frac{1}{3}h_c(L) + \frac{2}{3}h_p(L)}$$

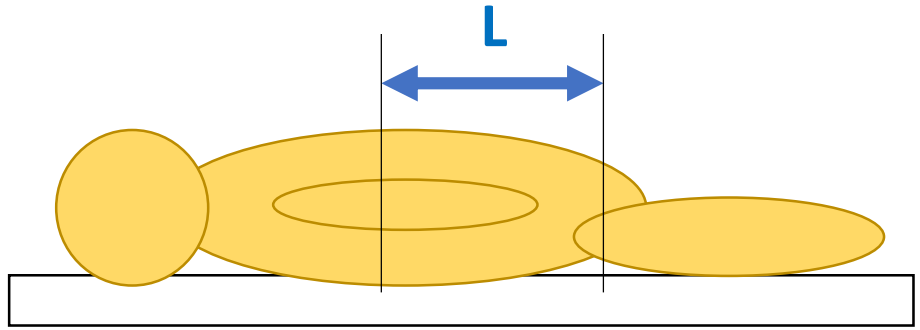
- Dividing by $CTDI_{vol}$ (100 mm) yields the average G(L):

$$\boldsymbol{G_a(L) = \frac{CTDI_{vol}(L)}{CTDI_{vol}(100\ mm)} = \frac{1}{3}G_c(L) + \frac{2}{3}G_p(L)}$$



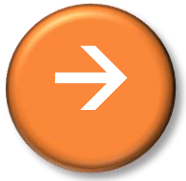
Clinical Assessment of Patient Dose

- The length-adjusted average dose can be estimated in the clinical setting if given:
  - G(L) function
  - Scanner-reported $CTDI_{vol}$
  - Scan length L



$$h_a(L) = CTDI_{vol}(L) = G_a(L) \times CTDI_{vol}(100\ \text{mm})$$

Practical Limitations of the CTDI



- CTDI is measured with a single axial scan with no table motion
  - Helical protocols must be converted to an axial scan

- Issues:
  - Unmatched collimation or bowtie filter settings
  - Manufacturer's CTDI Measurement Mode – Unavailable or Impractical
  - Some Dual Energy CT protocols can't be acquired in axial mode

- ACR: Use collimations matched as closely as possible
- These measurements may not accurately reflect the clinical protocol's CTDI

Converting a helical protocol to an axial scan

- Conversion is time consuming
  - Collimation, effective mAs
- Verification of appropriate parameters is time consuming
- Risk of failing ACR submission if performed incorrectly

Dosimetry	Minor	Major
Dosimetry images not submitted		X
Helical scans performed		X
Incorrect dosimetry phantom used		X
Parameters used on the dosimetry images do not match the protocols recorded in the phantom data form	X	
kV used on the dosimetry images does not match what is recorded on the phantom data form		X
Total beam width used is different than what is recorded in the phantom data form (exclusive of scanner limitations)		X
Non-chamber holes are not filled	X	
$CTDI_{vol}$ exceeds the pass-fail criteria		X
$CTDI_{vol}$ exceeds the reference level	X	
$CTDI_{vol}$ not calculated correctly but can be recalculated	X	

https://accreditationsupport.acr.org/

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MEDICAL IMAGING

WILEY

The helically-acquired $CTDI_{vol}$ as an alternative to traditional methodology

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Abstract

Purpose: Most clinical computed tomography (CT) protocols use helical scanning; however, the traditional method for $CTDI_{vol}$ measurement replaces the helical pro-

Assesses whether the traditional CTDI measurement methodology can be updated by measuring scanning the entire pencil ion chamber length helically

Evaluated

- 31 CT scanners

- 95 protocols

  - If used clinically and acquired helically
  - Collimation widths: 8 to 40 mm & Pitches: 0.298 to 1.728

- For each protocol, $CTDI_{vol}$ was
  - Measured with the **Traditional Axial Method**
  - Measured with the **Helical Method**
  - Recorded from the scanner display

Nomenclature

- **Traditional Axial Method** denoted **$CTDI_{vol}$ (A)**
- **Helical Method** denoted **$CTDI_{vol}$(H)**

  → $CTDI_{vol}$(H) is ***NOT*** a defined quantity by the IEC

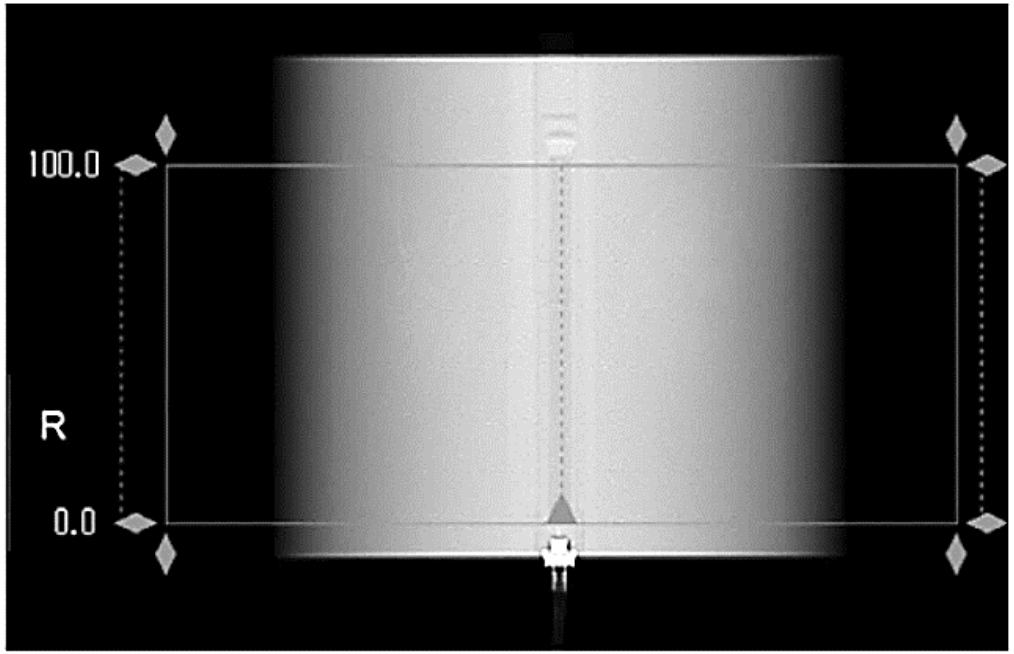
  - It is nomenclature adopted in this study to estimate what the $CTDI_{vol}$ would be for measurement with a helical acquisition

Measuring $CTDI_{vol}$(A)

- Using the methodology described by the ACR
  - Acquire a single axial slice at the center of the phantom
  - If the clinical protocol is normally scanned helically, change to an axial scan with the same (or closest) beam width

Measuring $CTDI_{vol}$(H)

1. Acquire a localizer image of the pencil chamber in the CTDI phantom
2. Select the helical clinical protocol
   - Use a fixed mA
3. Set the scan length to cover the entire visible chamber length (100 mm)
4. Scan the chamber with a helical acquisition
5. Perform 3 times in the central hole and 3 times in the 12:00 peripheral hole

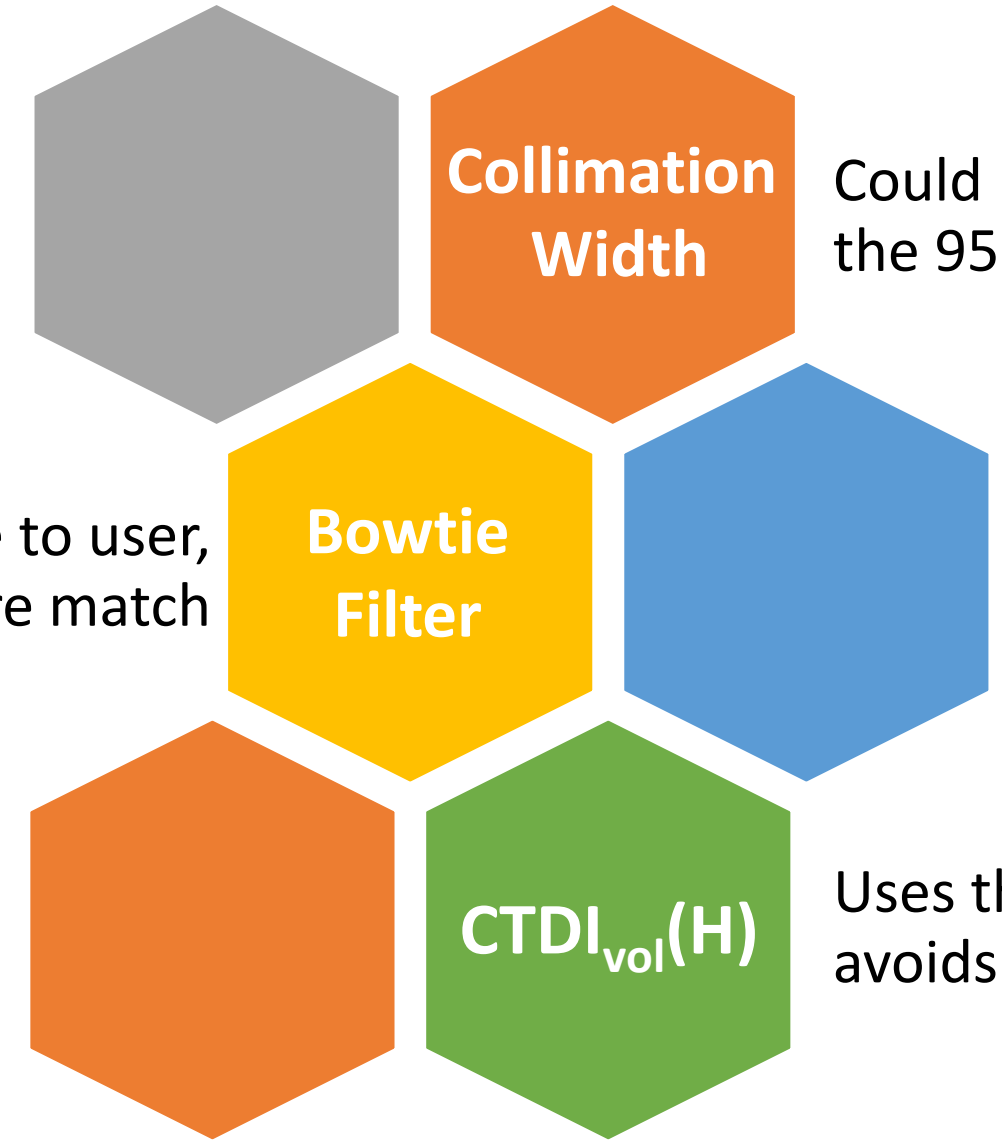


Calculating the $CTDI_{vol}$ (H)

$$CTDI_{vol}^{H}\,(mGy) = \left(1/3 \cdot M_{H}^{center} + 2/3 \cdot M_{H}^{peripheral}\right)$$

- M_H is the meter reading from the helical acquisition
- Don't correct for pitch
  - The meter reading was acquired with the clinical pitch applied

Results



Could not be matched for 12 of the 95 protocols tested (12.6%)

Not visible to user, difficult to ensure match

Uses the clinical protocol, avoids these complications

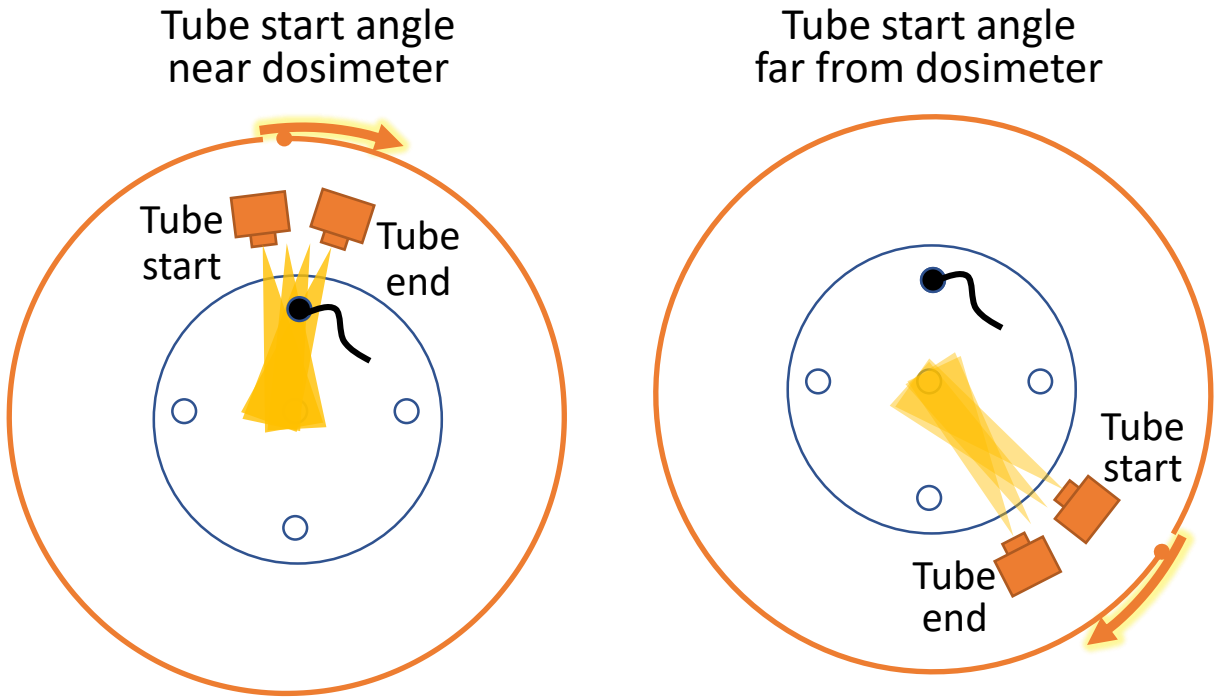
Reproducibility

- Scans were repeated 5 times for adult protocols on 3 scanners

Phantom	Manufacturer	Axial CTDI		Helical CTDI	
		Mean (mGy)	CV	Mean (mGy)	CV
Head	Canon	39.7	0.15%	37.0	0.17%
	GE	53.9	0.42%	55.0	0.30%
	Siemens	46.3	0.04%	43.4	0.09%
Body	Canon	14.2	1.31%	14.1	0.19%
	GE	15.0	2.55%	14.9	0.22%
	Siemens	8.9	4.17%	8.2	0.32%

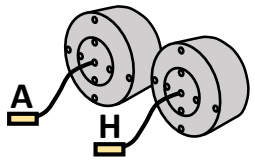
Peripheral Measurements

- Peripheral measurements from a single axial slice are prone to variation
  - Variability in tube start location and beam overlap

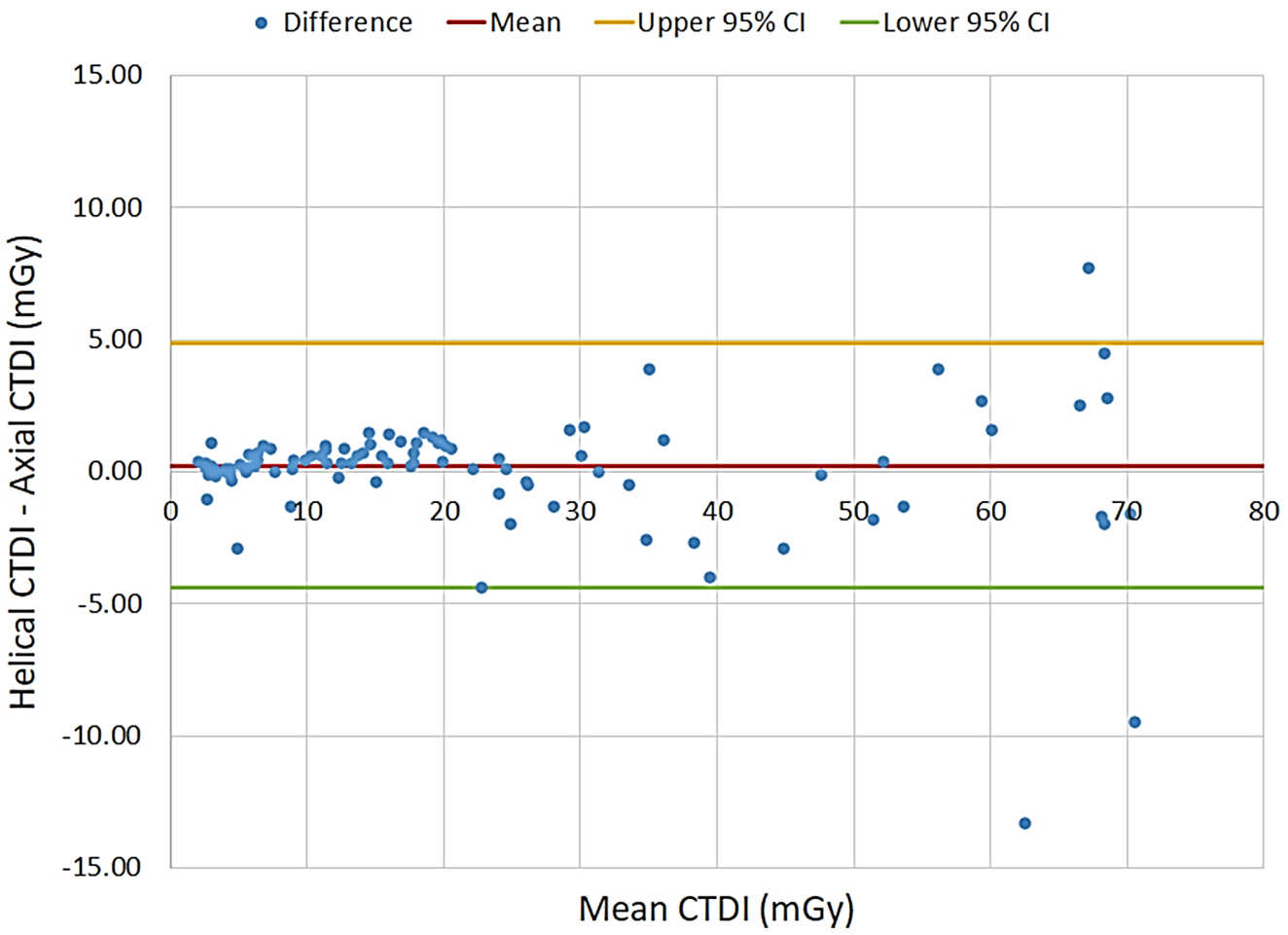


- $CTDI_{vol}(H)$ displayed less measurement variability than $CTDI_{vol}(A)$

Differences between Axial & Helical $CTDI_{vol}$

Protocol	Helical vs Axial (mGy)
	
 Adult Head	0.4
Adult Abdomen	0.6
 Pediatric Head	0.1
Pediatric Abdomen	0.0

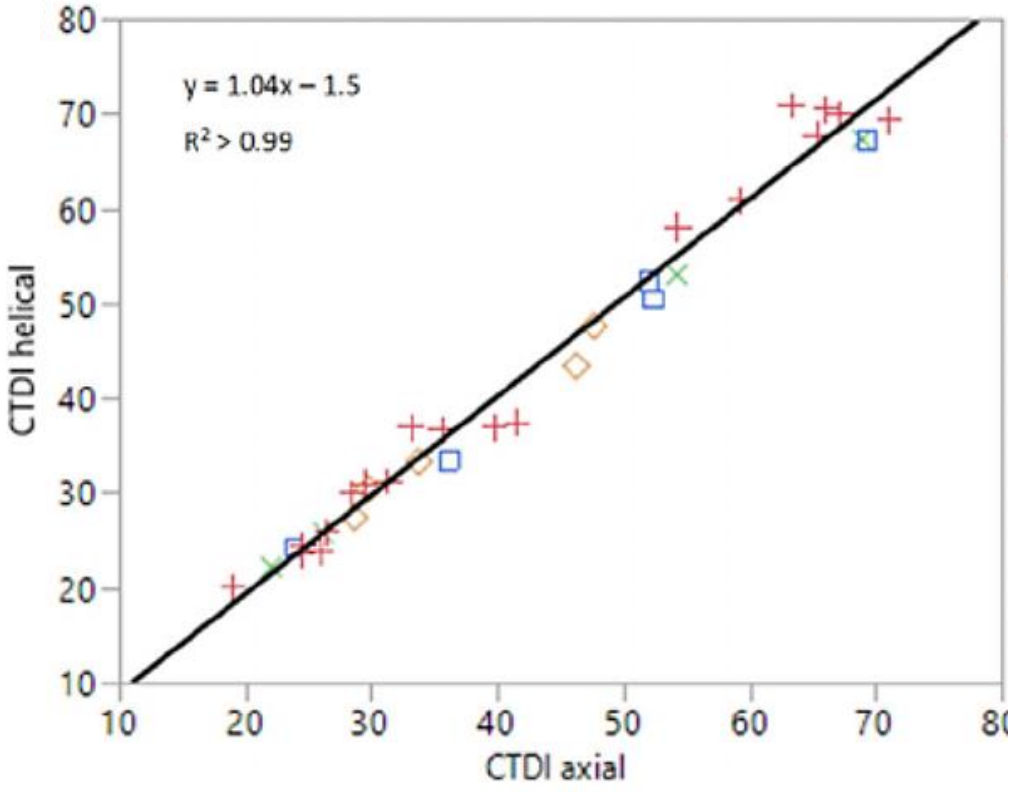
Differences between Axial & Helical $CTDI_{vol}$



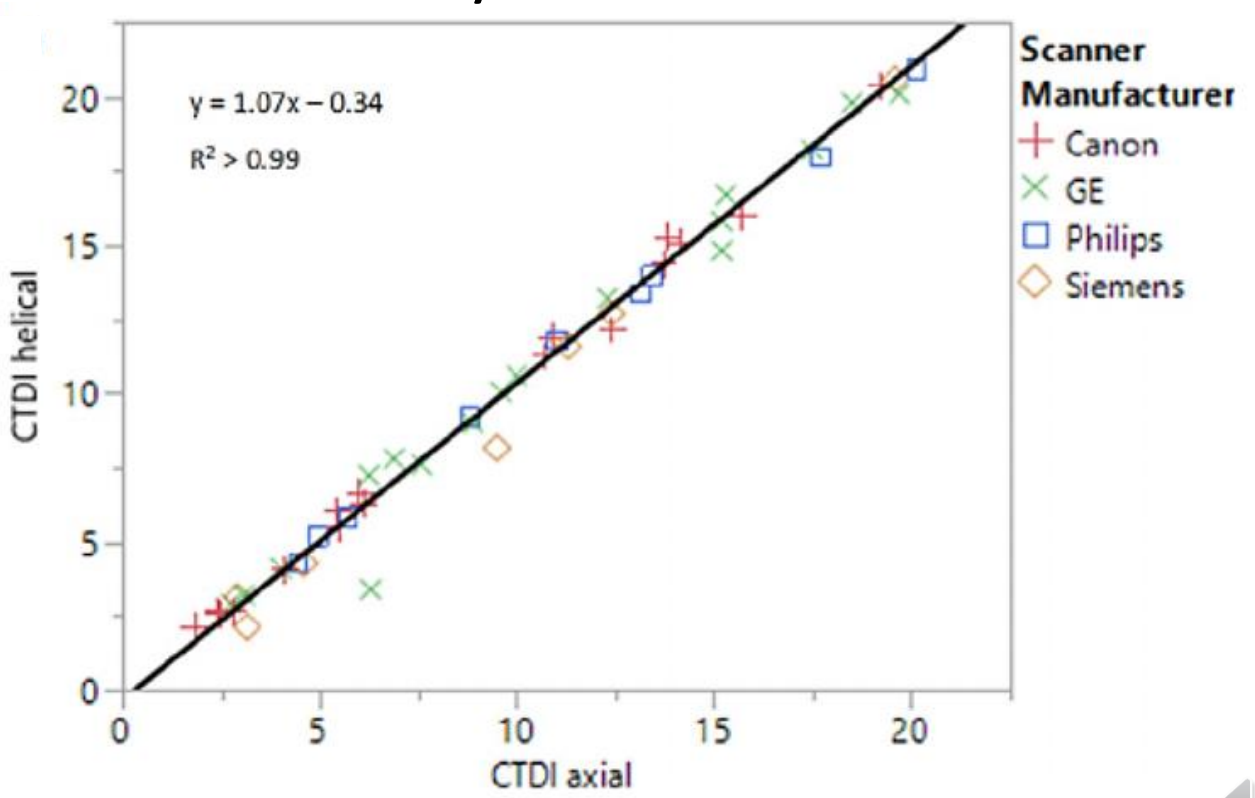
- Excellent agreement between $CTDI_{vol}$(A) and $CTDI_{vol}$(H)
- 95% CI = -4.4 mGy to 4.9 mGy
- No significant differences (*p-value* = 0.81)

Axial & Helical $CTDI_{vol}$ were strongly correlated

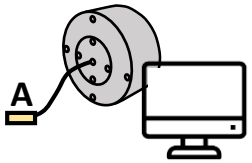
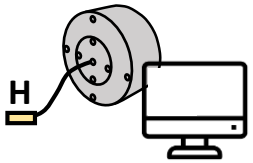
Head Phantom



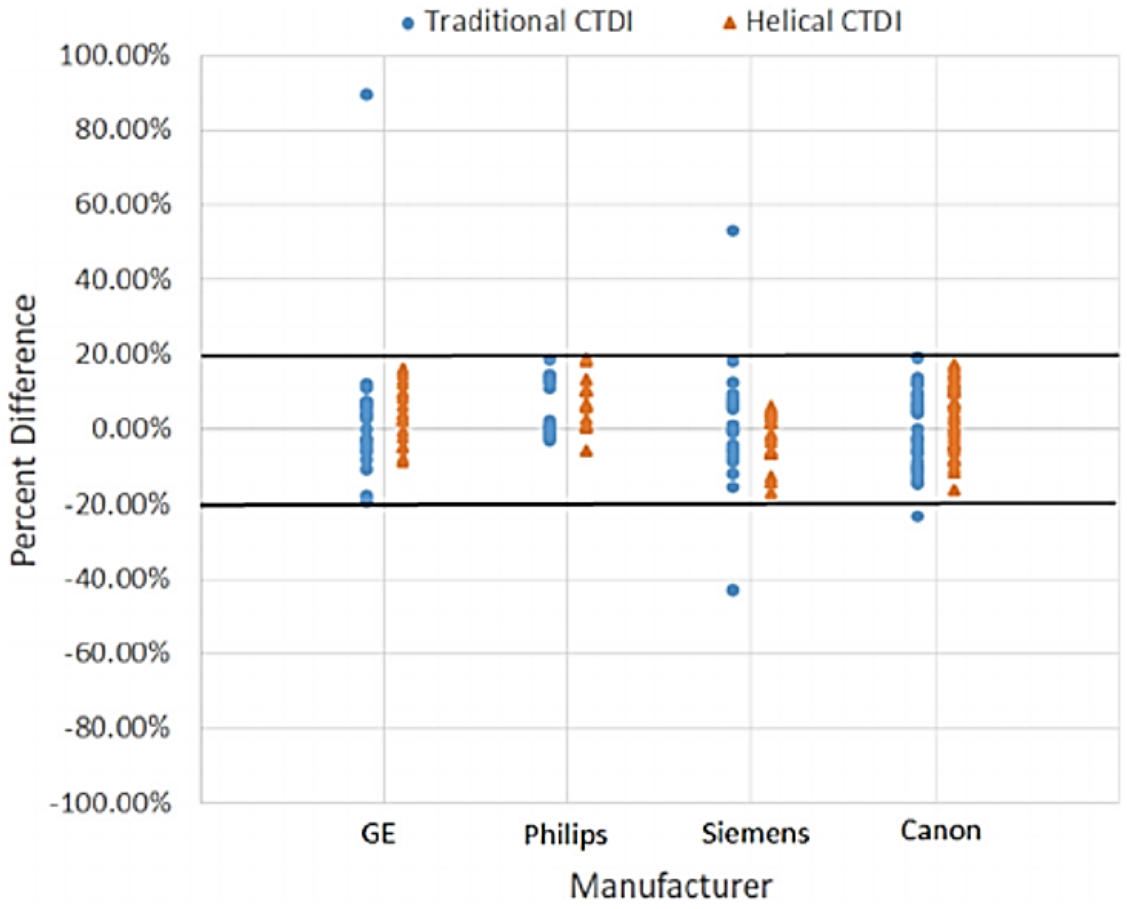
Body Phantom



Difference (mGy) between $CTDI_{vol}$ & Scanner Display

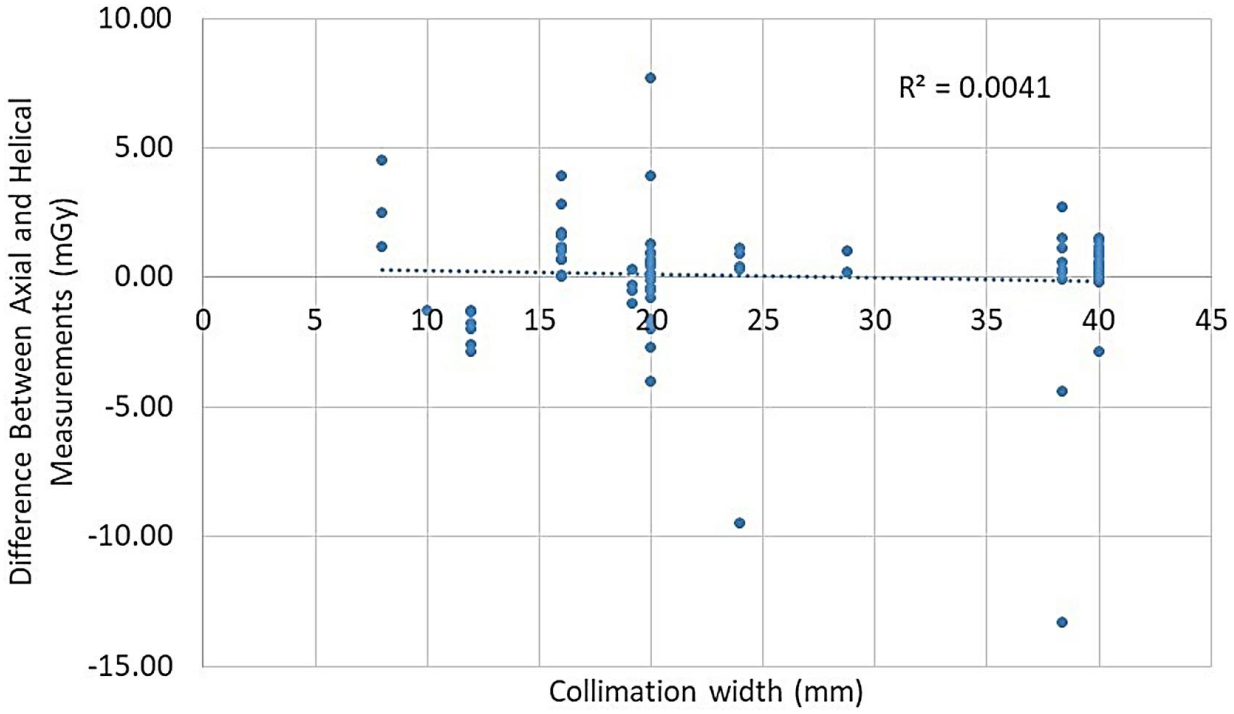
Protocol	Displayed $CTDI_{vol}$	Axial vs Displayed	Helical vs Displayed
			
Adult Head	57.4	-0.1	-0.6
Adult Abdomen	14.2	0.0	0.5
Pediatric Head	27.4	-0.1	-0.1
Pediatric Abdomen	4.6	0.1	0.1

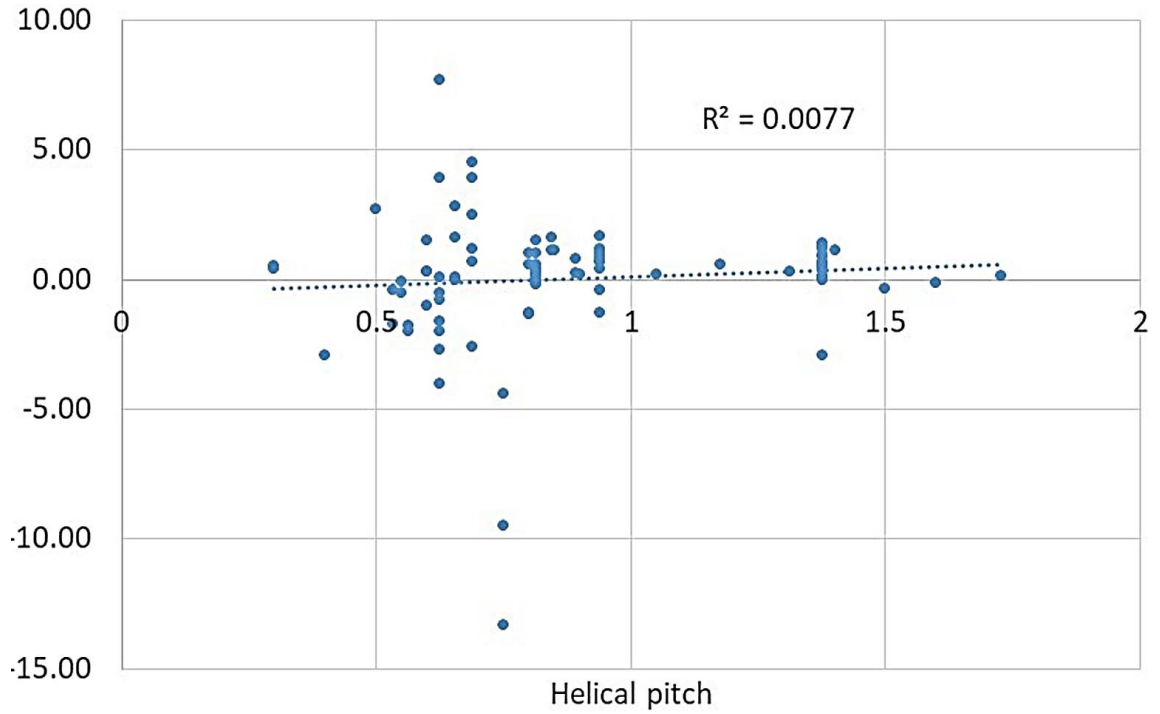
Difference (mGy) between $CTDI_{vol}$ & Scanner Display



- 4 protocols had discrepancies >20% from the display when measuring with $CTDI_{vol}$(A)
  - 1 had unmatched collimation
    - Siemens, 14.2 mGy
  - 3 had matched collimation
    - 2.07 to 3.32 mGy
- Discrepancies dropped <20% with $CTDI_{vol}$(H)

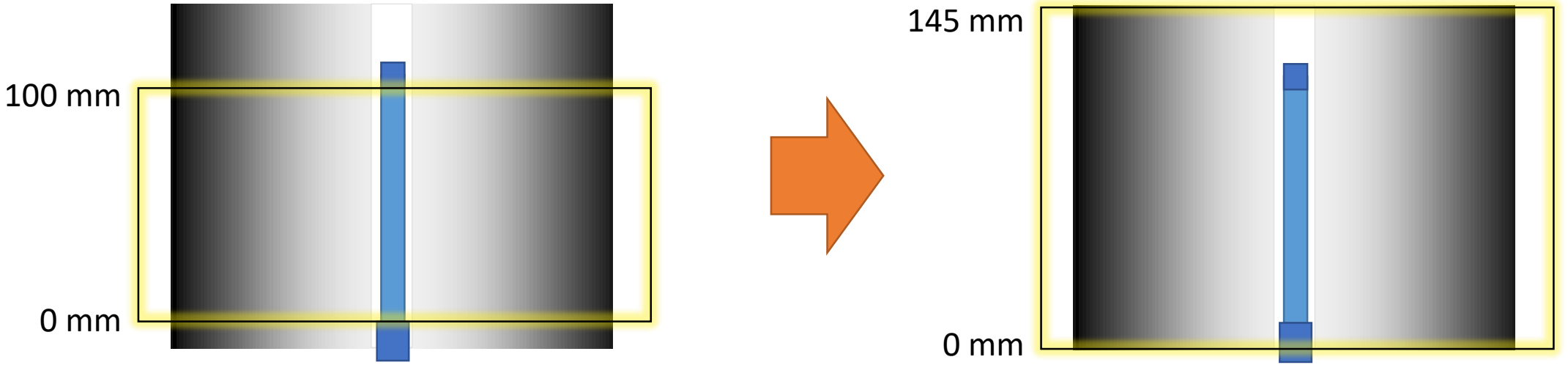
Differences between $CTDI_{vol}$(A) and $CTDI_{vol}$(H) were independent of collimation width and pitch





Impact of Excess Scan Length

- It can be difficult to visualize the pencil chamber
- The procedure was repeated with the scan range set to the phantom borders rather than the chamber volume
- The measured $CTDI_{vol}(H)$ increased in all cases (range 2.1%–9.7%)
- Recommend adherence to chamber-only protocol



Conclusion

- **Excellent agreement**
  - between axial and helical $CTDI_{vol}$ methods
  - between $CTDI_{vol}(H)$ and the scanner-reported $CTDI_{vol}$

- **The $CTDI_{vol}(H)$ measurement**
  - does not depend on helical pitch or collimation width
  - can be accomplished more easily than the axial method

Limitations

- Collimation widths >40 mm were not tested
- Dual energy protocols were not tested
- Calculation of displayed $CTDI_{vol}$ varies with manufacturer
- 100 mm scan length still underestimates scatter tails

Caveats

- Not yet accepted as a measurement methodology by the ACR
- Potential option in the future if supported
- Option for annual surveys in unaccredited scanners

Thank you

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