INVESTIGATING THE ESTIMATION OF $CTDI_{VOL}$ USING A HELICAL TECHNIQUE

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DISCLOSURES

- I have no relevant disclosures

CAN $CTDI_{VOL}$ BE ESTIMATED BY EXPOSING THE ENTIRE ION CHAMBER HELICALLY?

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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 protocol with an axial scan, which is not easily accomplished on many scanners and may lead to unmatched collimation settings and bowtie filters. This study assesses whether $CTDI_{vol}$ can be accurately measured with a helical scan and determines the impact of pitch, collimation width, and excess scan length.

Methods: $CTDI_{vol}$ was measured for 95 helical protocols on 31 CT scanners from all major manufacturers. $CTDI_{vol}$ was measured axially, then again helically, with the scan range set to the active area of the pencil chamber seen on the localizer image. $CTDI_{vol}$ measurements using each method were compared to each other and to the scanner-displayed $CTDI_{vol}$. To test the impact of scan length, the study was repeated on four scanners, with the scan range set to the phantom borders seen on the localizer.

Results: It was not possible to match the collimation width between the axial and helical modes for 12 of the 95 protocols tested. For helical and axial protocols with matched collimation, the difference between the two methods averaged below 1 mGy with a correlation of $R^2 = 0.99$. The difference between the methods was not statistically significant ($P = 0.81$). The traditional method produced four measurements that differed from the displayed $CTDI_{vol}$ by >20%; no helical measurements did. The accuracy of the helical $CTDI_{vol}$ was independent of protocol pitch ($R^2 = 0.0$) or collimation ($R^2 = 0.0$). Extending the scan range to the phantom bor-

SESSION OUTLINE

1. Limitations of measuring the $CTDI_{vol}$
2. Estimating $CTDI_{vol}$ with a helical acquisition
3. Results of a national generalizability study

QUANTITATIVE LIMITATIONS OF THE $CTDI_{vol}$

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

PRACTICAL LIMITATIONS OF THE $CTDI_{vol}$ MEASUREMENT

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

- In some cases, collimation or bowtie filter cannot be matched
  - ACR manual states to 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 is time consuming & error-prone

- Manufacturer's CTDI measurement mode may be unavailable or impractical
- Some Dual Energy CT protocols can't be acquired in axial mode

Scanners Evaluated

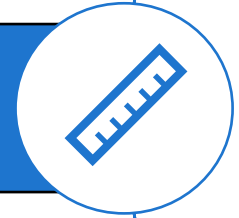
31 CT Scanners
10 GE, 10 Canon, 6 Siemens, 5 Philips

16 - 320 Detector Rows

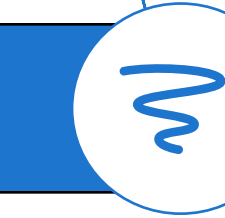
Manufactured 2005 - 2017

Protocols Evaluated

95 Clinical & Helical Protocols
Adult & Pediatric Head & Abdomen



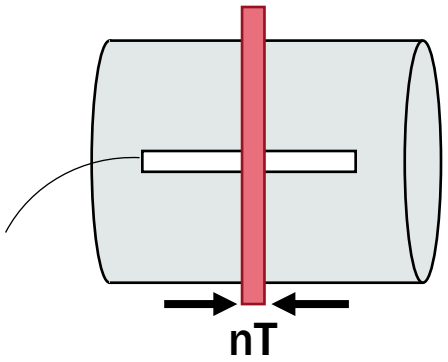
8 - 40 mm Collimations



0.29 - 1.73 Helical Pitch

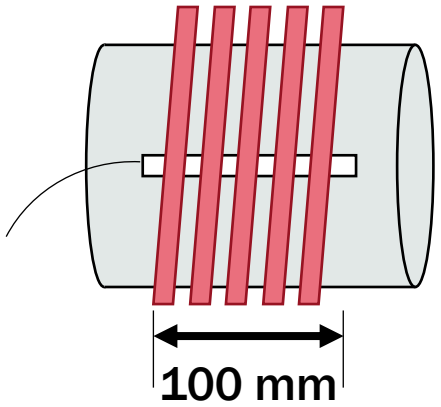
FOR EACH PROTOCOL, $CTDI_{VOL}$ WAS:

1. Measured with the Axial Method



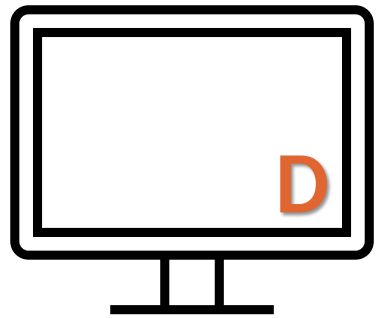
$CTDI_{vol}^{A}$

2. Measured with the Helical Method



$CTDI_{vol}^{H}$

3. Recorded from the Scanner Display



DETERMINE $CTDI_{VOL}{}^{A}$

Using the methodology described by the ACR

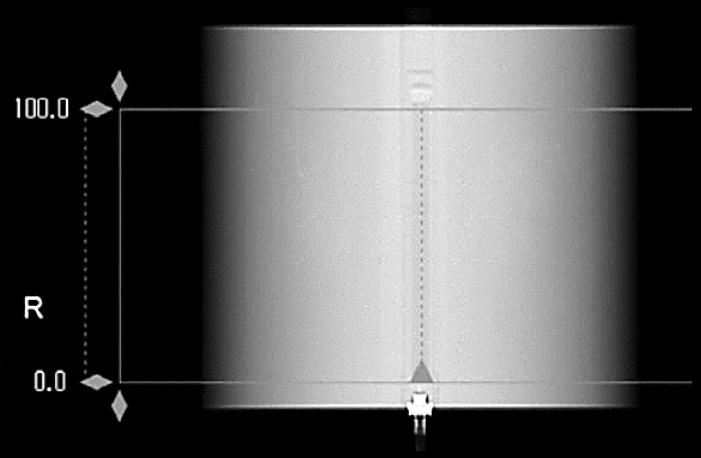
- Acquire a single axial slice at the center of the phantom
- If the clinical protocol is normally scanned helically, change to an axial scan with the same (or closest) beam width

$$CTDI_{100}(mGy) = \frac{100\ mm\ \cdot M\ (mGy)}{n \cdot T(mm)}$$

$$CTDI_{vol}^{A}(mGy) = \frac{1}{p}\left(\frac{1}{3}CTDI_{100,center}^{A} + \frac{2}{3}CTDI_{100,periphery}^{A}\right)$$

DETERMINE $CTDI_{VOL}^{H}$

MEASURE



1. Acquire a localizer image of the chamber in the CTDI phantom
2. Select the helical clinical protocol, set a fixed mA
3. Set the 100 mm scan length to cover the visible pencil chamber
4. Scan the chamber with a helical acquisition
5. Perform 3 times each in the central & peripheral holes

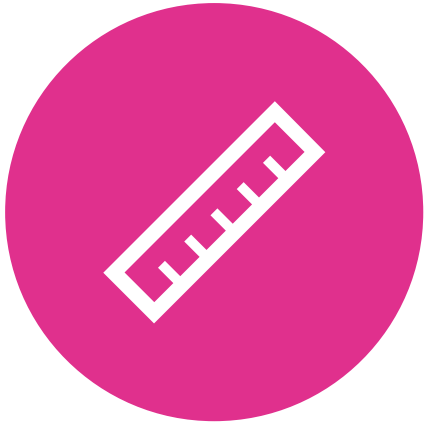
CALCULATE

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

M_H is the meter reading from the helical acquisition

Don't incorporate pitch (M_H was acquired with it)

DATA ANALYSIS



ASSESSED REPRODUCIBILITY OF MEASUREMENTS

EVALUATED DIFFERENCES BETWEEN METHODS

COMPARED MEASUREMENTS TO DISPLAYED $CTDI_{VOL}$

RESULTS

$CTDI_{vol}^{A}$ could not match collimation for 12 of the 95 protocols tested

The bowtie filter size was not always visible to user, difficult to ensure match

$CTDI_{vol}^{H}$ uses the clinical protocol, avoiding these complications

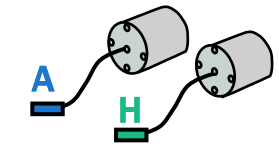
REPRODUCIBILITY

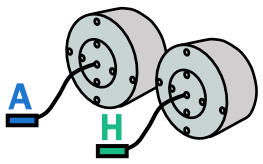
1) Measurements were repeated 5 times on 3 scanners

2) The mean coefficient of variation (CV) was calculated

$CTDI_{vol}^{H}$ produced less variation than $CTDI_{vol}^{A}$ for abdomen protocols

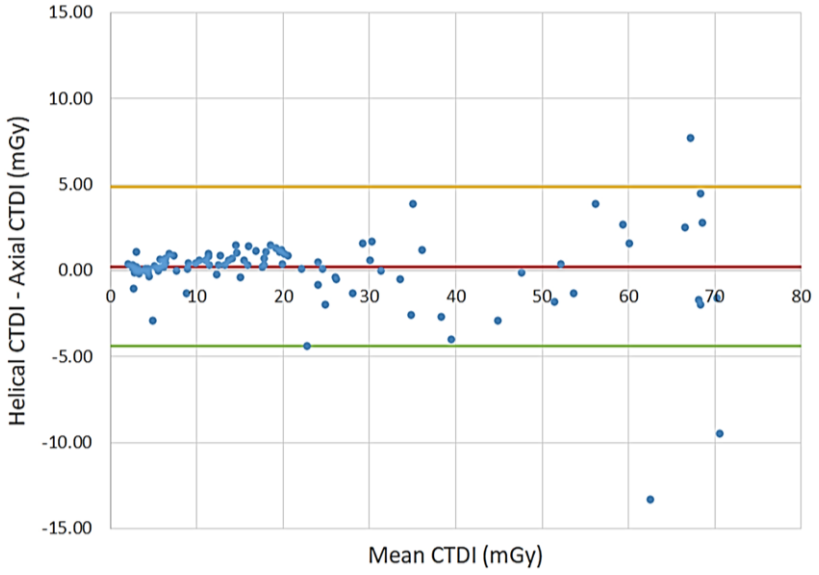
		Axial Method		Helical Method	
		Mean $CTDI_{vol}^{A}$ (mGy)	CV (%)	Mean $CTDI_{vol}^{H}$ (mGy)	CV (%)
Adult Head	Canon	39.7	0.15	37.0	0.17
	GE	53.9	0.42	55.0	0.30
	Siemens	46.3	0.04	43.4	0.09
Adult Abdomen	Canon	14.2	1.31	14.1	0.19
	GE	15.0	2.55	14.9	0.22
	Siemens	8.9	4.17	8.2	0.32

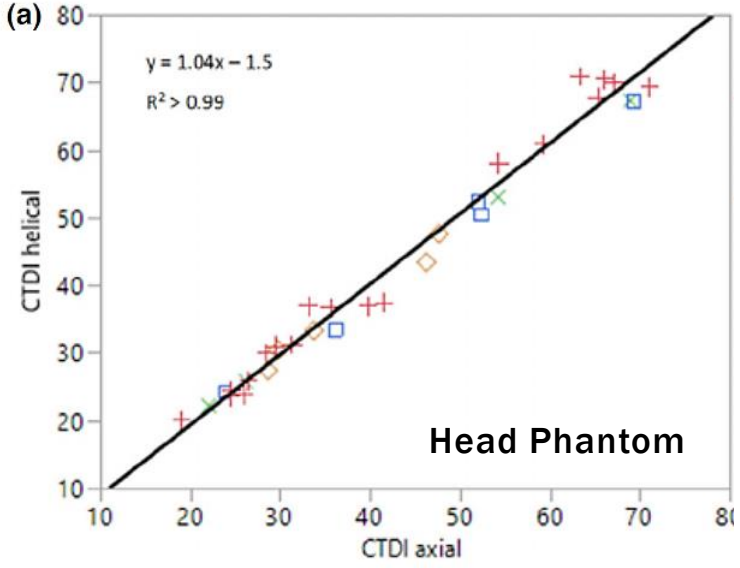


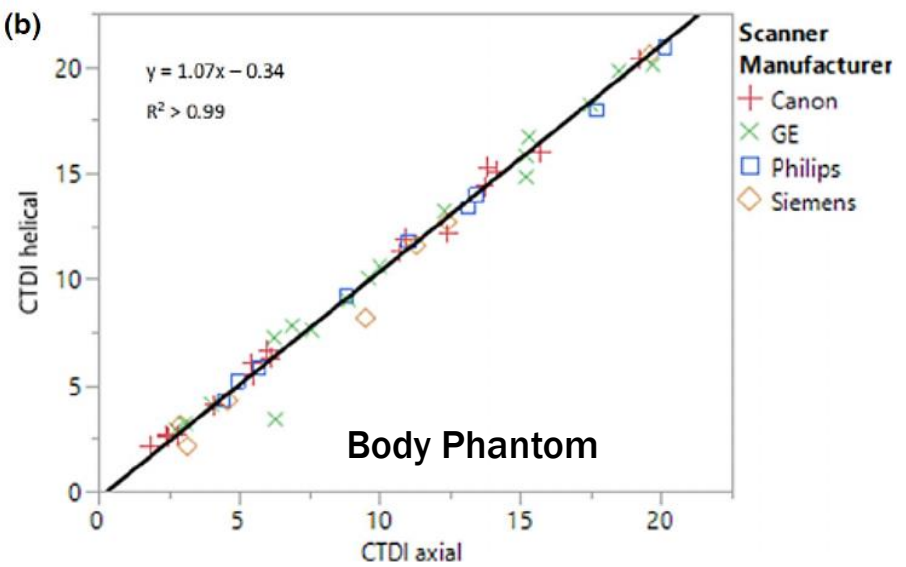


AXIAL & HELICAL METHODS SHOWED EXCELLENT AGREEMENT

- Mean difference between $CTDI_{vol}^{A}$ & $CTDI_{vol}^{H}$ ranged **0.0 to 0.6 mGy** for all protocols (95% CI = -4.4 to 4.9 mGy) with no significant differences between methods (p=0.81)
- Both methods had strong linear correlations





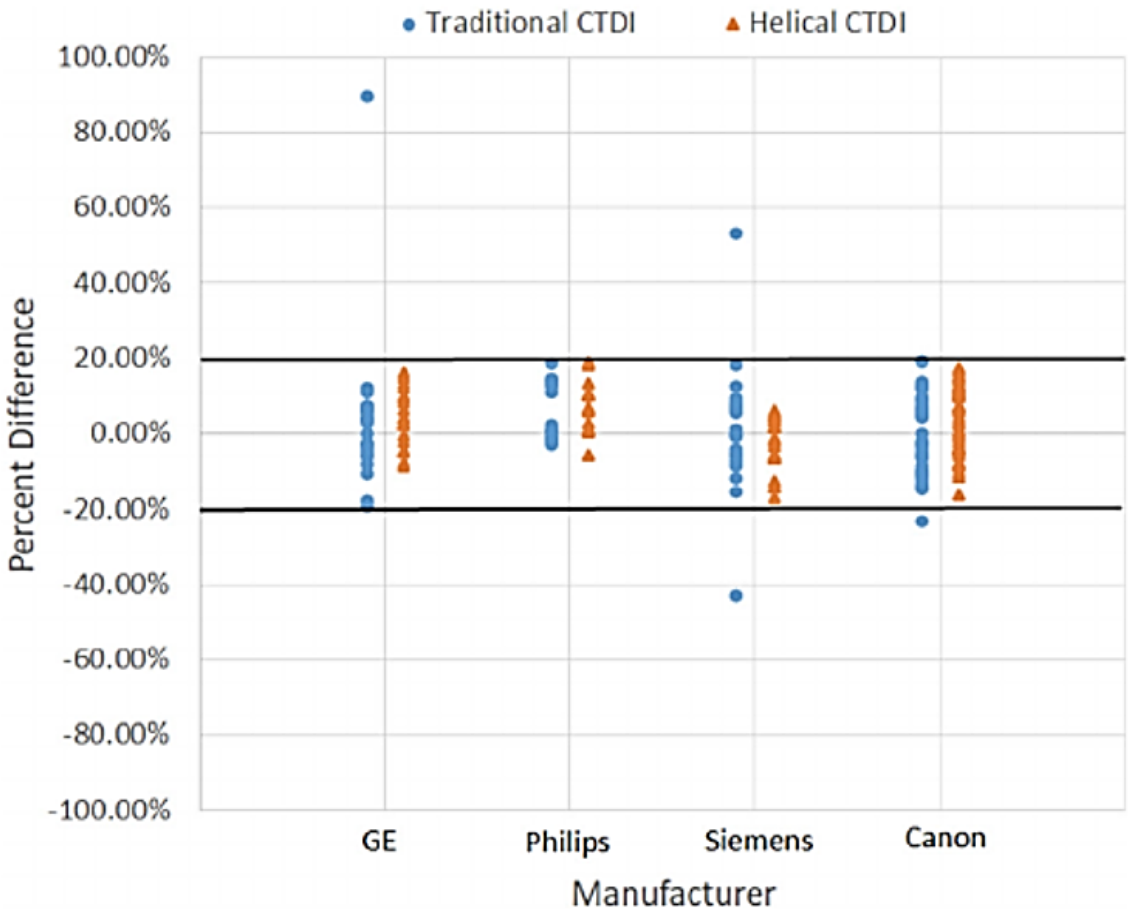


BOTH HELICAL & AXIAL MEASUREMENTS AGREED WITH DISPLAYED $CTDI_{VOL}$

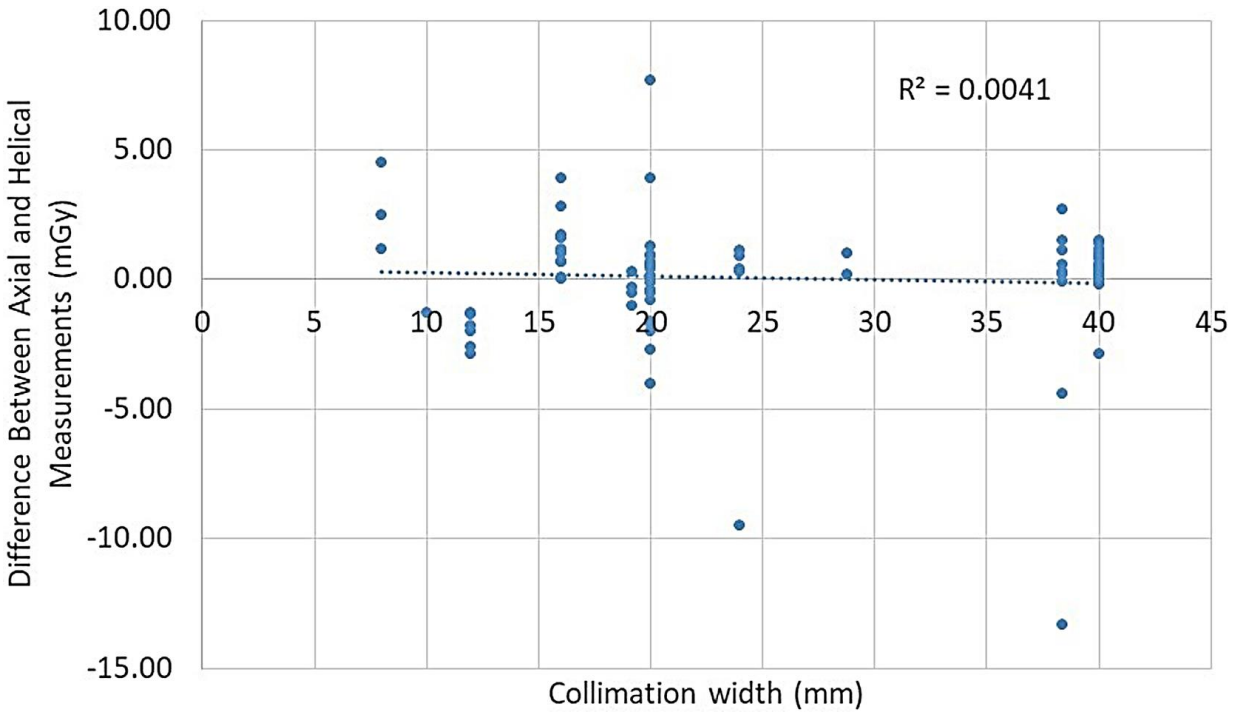
- Mean difference between measured and displayed $CTDI_{vol}$ ranged **-0.6 to 0.5 mGy** for both $CTDI_{vol}^{A}$ & $CTDI_{vol}^{H}$ methods

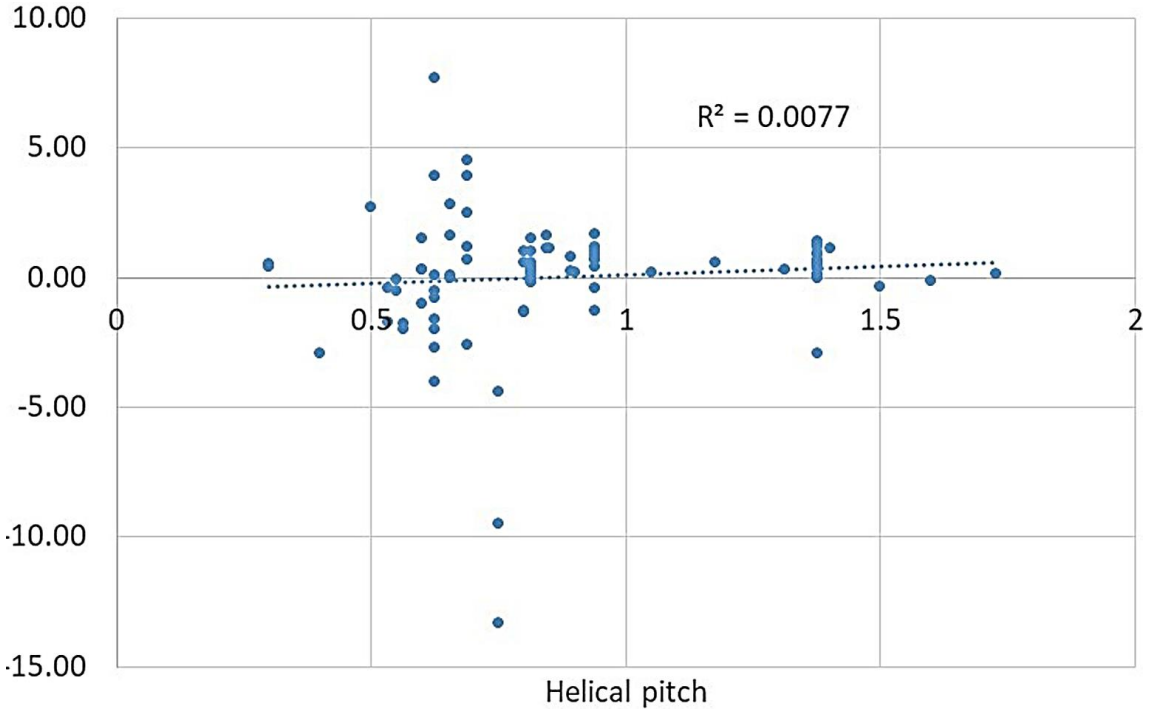
- 4 protocols differed >20% from the display when measured with $CTDI_{vol}^{A}$
  - 1 had unmatched collimation
  - 3 had low $CTDI_{vol}$ (2.1 - 3.2 mGy)

- However, these dropped to <20% when measured with $CTDI_{vol}^{H}$



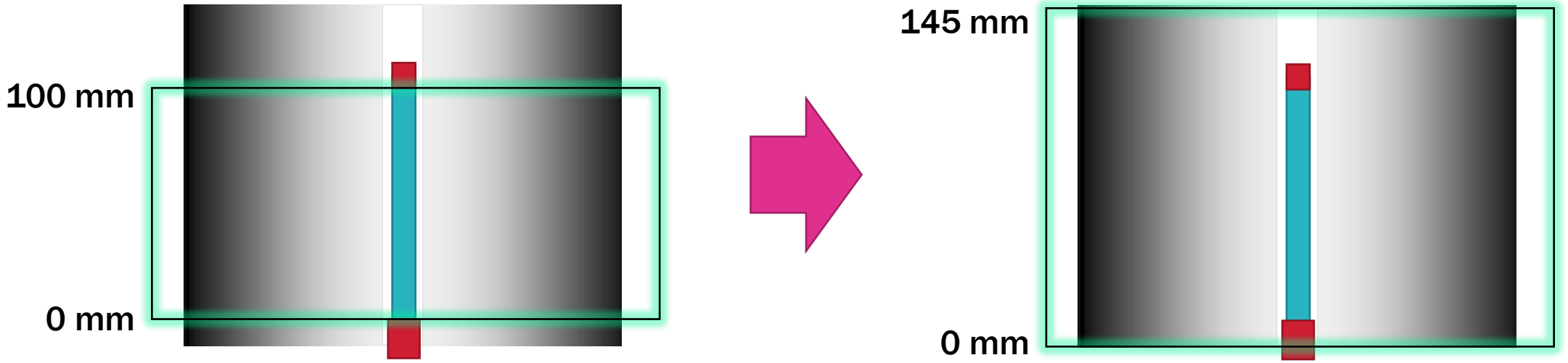
DIFFERENCES BETWEEN $CTDI_{VOL}^{A}$ & $CTDI_{VOL}^{H}$ WERE INDEPENDENT OF COLLIMATION WIDTH AND PITCH





IMPACT OF EXCESS SCAN LENGTH

- Since 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



CONCLUSIONS

The $CTDI_{vol}^{H}$ measurement

- had excellent agreement with $CTDI_{vol}^{A}$ and the scanner-reported $CTDI_{vol}$
- is independent of helical pitch and collimation width
- is based on a known & current metric: the $CTDI_{vol}$
- can be incorporated into current practice and accomplished more easily than the axial method

Limitations

- Protocols with DECT or >40 mm collimations were not tested
- Calculation of displayed $CTDI_{vol}$ varies with manufacturer
- $CTDI_{vol}^{A}$ is not mathematically equivalent to $CTDI_{vol}^{H}$
  - However, measurements suggest $CTDI_{vol}$ may be approximated helically

MEDICAL IMAGING

WILEY

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✓ THIS METHOD WORKED FOR THE CO-AUTHORS

3 faculty & 2 residents from the University of Florida

1 consulting physicist from National Physics Consultants

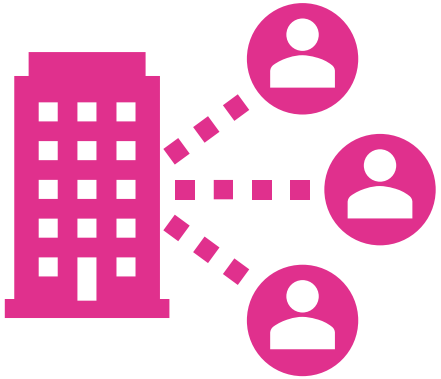
WILL IT WORK FOR EVERYONE?

A GENERALIZABILITY STUDY WAS DESIGNED AND LAUNCHED

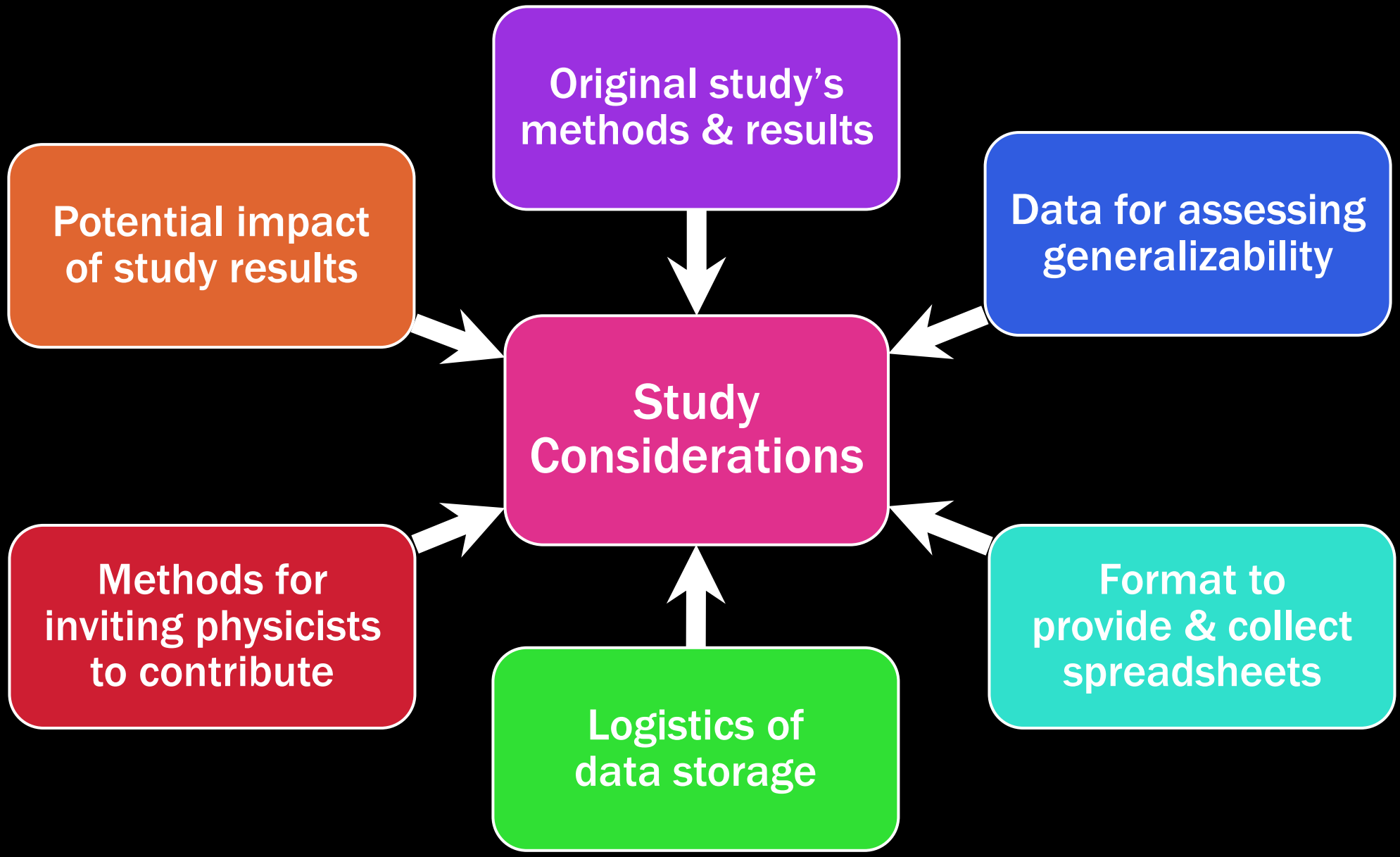
CO-AUTHORS DISCUSSED METHOD WITH ACR PHYSICISTS

TOGETHER, DESIGNED A FEASIBILITY STUDY

LAUNCHED STUDY ON A WEB-BASED PLATFORM



INVITED ALL PHYSICISTS TO CONTRIBUTE DATA


Original study's methods & results
Potential impact of study results
Data for assessing generalizability
Study Considerations
Methods for inviting physicists to contribute
Logistics of data storage
Format to provide & collect spreadsheets

STUDY DESIGN

Designed an excel spreadsheet to provide study participants with:

- Standardized instructions
- A form to collect data on CT scanner, dose meter, & protocol information
- CTDI measurement forms using ***both***
  1) Traditional axial method
  2) New helical method

STUDY LAUNCHED ON ONLINE PLATFORM

Description of feasibility study & original publication

Link to download & upload excel spreadsheet

Field to enter physicist name & measurement date

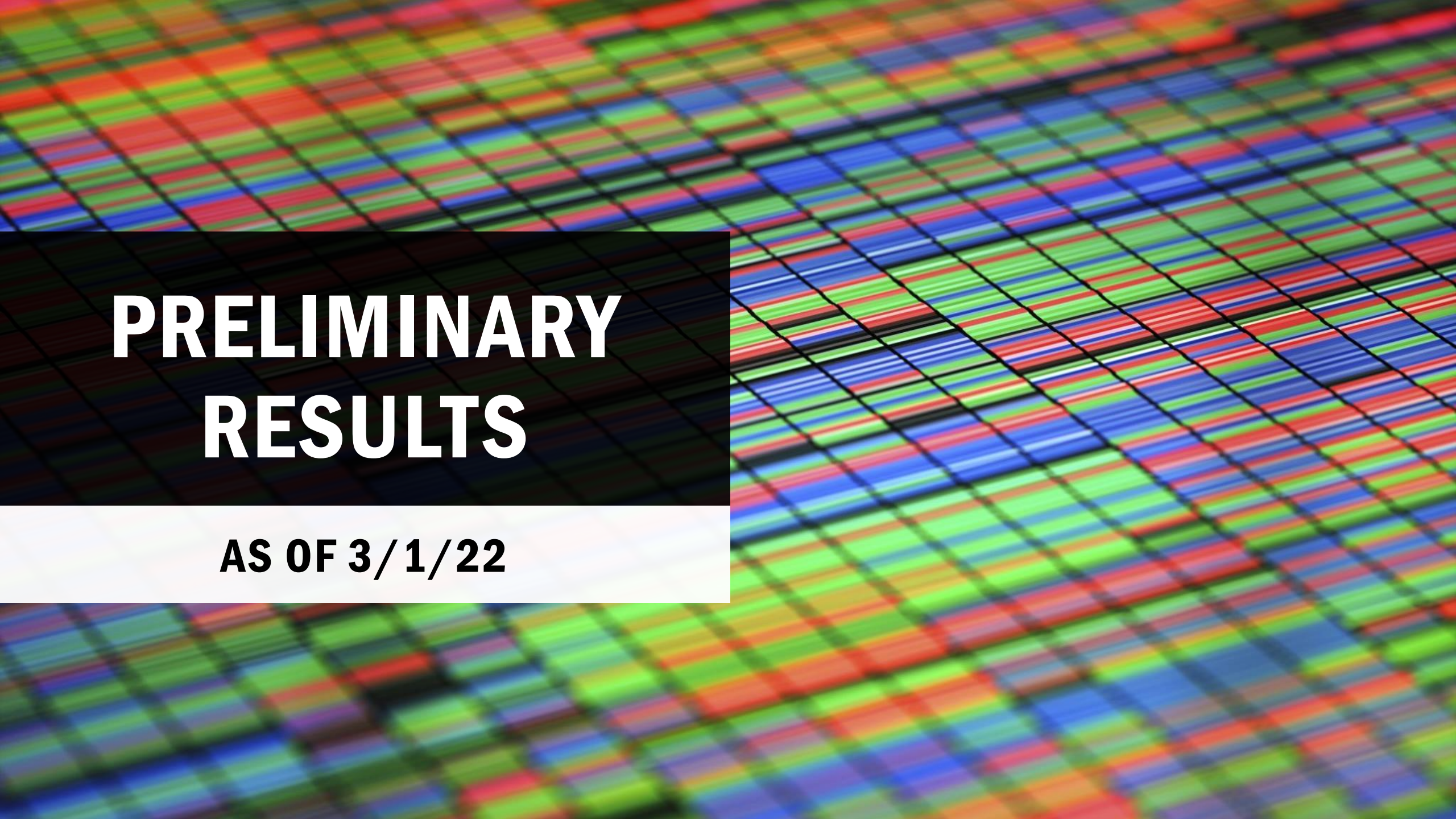
Physicist must attest that used calibrated dose meter
& not submitting PHI, facility or CT device identifiers

SURVEY DISTRIBUTION

SOCIAL MEDIA

CONFERENCE PRESENTATIONS

WORD OF MOUTH


PRELIMINARY RESULTS
AS OF 3/1/22

16 PHYSICISTS SUBMITTED 115 REPORTS WITH 326 CLINICAL PROTOCOLS

Scanner	Adult Head	Adult Abdomen	Pediatric Head	Pediatric Abdomen	Total
Siemens	31	33	25	24	113
GE	16	41	16	32	105
Canon	17	19	15	16	67
Philips	10	11	4	4	29
Other*	3	4	2	3	12
Total	**77**	**108**	**62**	**79**	**326**

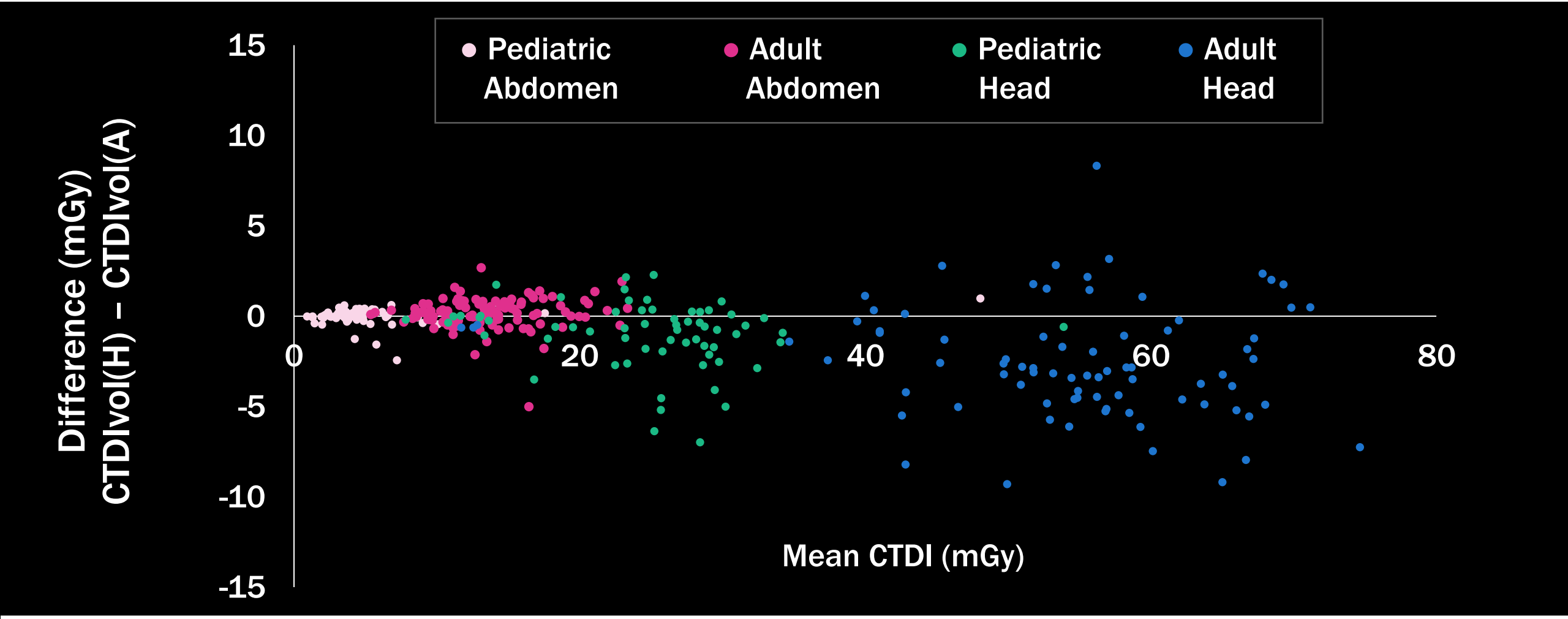
*Other: Hitachi, United Imaging, Analogic

All scanners were manufactured between 2001-2021

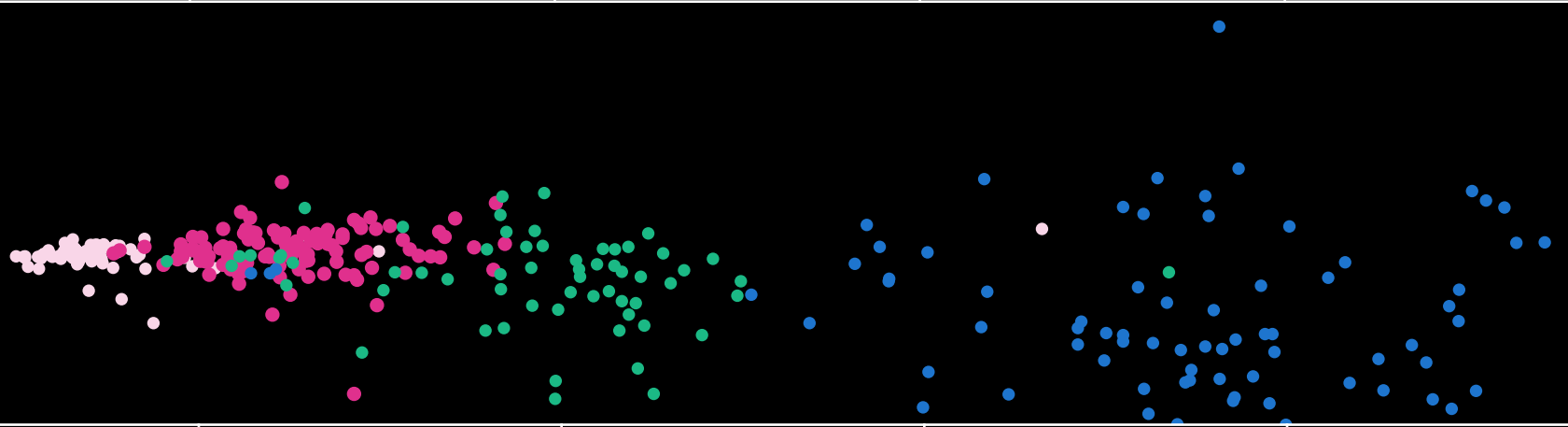
RANGE OF SCAN TECHNIQUES

	Adult Head	Adult Abdomen	Pediatric Head	Pediatric Abdomen
kVp	120 – 140	110 – 140	80 – 120	70 – 140
Rotation time (s)	0.4 – 1.5	0.3 – 1.0	0.4 – 1.5	0.3 – 1.0
Pitch	0.29 – 1.75	0.51 – 1.75	0.3 – 1.4	0.5 – 3.0
Collimation (mm)	5.5 – 25.5	10 – 80	8 – 80	8 – 80
Displayed $CTDI_{vol}$ (mGy)	12.4 - 73.8	5.4 - 32.9	6.9 - 58.5	0.9 - 41.9

AXIAL vs. HELICAL MEASUREMENTS



AXIAL vs. HELICAL MEASUREMENTS

Mean	Pediatric Abdomen	Adult Abdomen	Pediatric Head	Adult Head
				
Displayed $CTDI_{vol}$ (mGy)	5.15	13.45	25.61	56.20
$CTDI_{vol}{}^{H} - CTDI_{vol}{}^{A}$ (mGy)	-0.01	0.13	-1.05	-2.54

COMPARISON TO ORIGINAL STUDY

	Mean	Pediatric Abdomen	Adult Abdomen	Pediatric Head	Adult Head	All Protocols
National Generalizability Study (n=326)	Displayed $CTDI_{vol}$ (mGy)	5.15	13.45	25.61	56.20	-
	$CTDI_{vol}{}^{H} - CTDI_{vol}{}^{A}$ (mGy)	-0.01	0.13	-1.05	-2.54	-0.76 (95% CI: -0.53, -0.23)
Original Feasibility Publication (n=95)	Displayed $CTDI_{vol}$ (mGy)	4.6	14.2	27.4	57.4	-
	$CTDI_{vol}{}^{H} - CTDI_{vol}{}^{A}$ (mGy)	0.0	0.6	0.1	0.4	0.30 (95% CI: -4.4,4.9)

DISPLAYED VS. MEASURED $CTDI_{VOL}$

Mean	Pediatric Abdomen	Adult Abdomen	Pediatric Head	Adult Head
Displayed $CTDI_{vol}$ (mGy)	5.15	13.45	25.61	56.20
Displayed $CTDI_{vol}$ - $CTDI_{vol}$ [A] (mGy)	0.13	0.09	-0.40	0.61
Displayed $CTDI_{vol}$ - $CTDI_{vol}$ [H] (mGy)	0.12	0.22	-1.45	-1.94

DISPLAYED VS. MEASURED $CTDI_{VOL}$

	Mean	Pediatric Abdomen	Adult Abdomen	Pediatric Head	Adult Head
National Generalizability Study	Displayed $CTDI_{vol}$ - $CTDI_{vol}^{A}$ (mGy)	0.13	0.09	-0.40	0.61
	Displayed $CTDI_{vol}$ - $CTDI_{vol}^{H}$ (mGy)	0.12	0.22	-1.45	-1.94
Original Feasibility Publication	Displayed $CTDI_{vol}$ - $CTDI_{vol}^{A}$ (mGy)	0.1	0.0	-0.1	-0.1
	Displayed $CTDI_{vol}$ - $CTDI_{vol}^{H}$ (mGy)	0.1	0.5	-0.1	-0.6

DISPLAYED vs. MEASURED $CTDI_{VOL}$

The line marks the ACR and TJC limit of 20%

NUMBER OF MEASUREMENTS EXCEEDING 20% DIFFERENCE FROM DISPLAYED $CTDI_{VOL}$

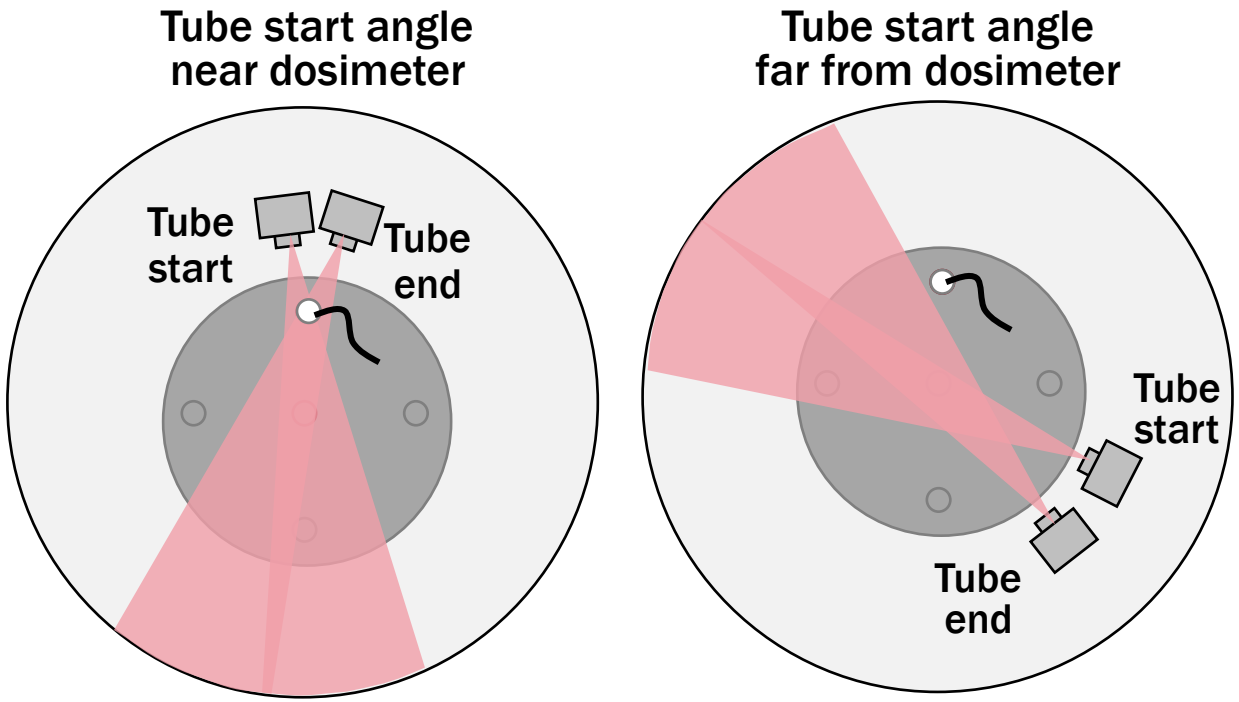
	Pediatric Abdomen	Adult Abdomen	Pediatric Head	Adult Head
Total number of protocols measured	77	107	62	79
Axial Method	3	1	0	1
Helical Method	4 (Includes 1 Axial)	6 (Includes 1 Axial)	3	2

NUMBER OF MEASUREMENTS EXCEEDING 20% DIFFERENCE FROM DISPLAYED $CTDI_{VOL}$

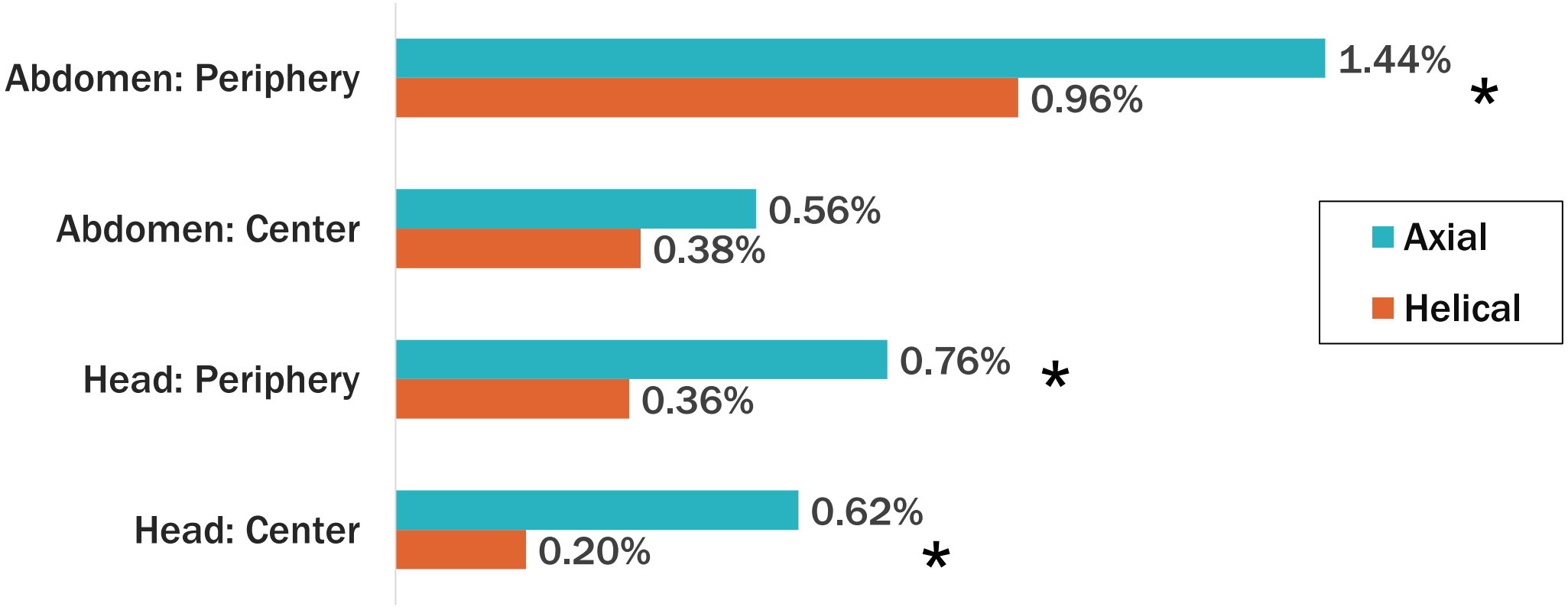
		Pediatric Abdomen	Adult Abdomen	Pediatric Head	Adult Head
National Generalizability Study	Axial Method	3	1	0	1
	Helical Method	4	6	3	2
Original Feasibility Publication	Axial Method	2	1	0	1
	Helical Method	0	0	0	0

PERIPHERAL MEASUREMENTS

- Peripheral measurements from a single axial slice are prone to variation due to variability in tube start location and beam overlap
- The helical method produced less measurement variability than the axial method

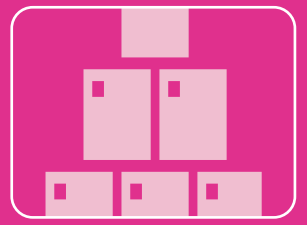


AVERAGE COEFFICIENT OF VARIATION (%)



* Indicates statistical significance ($p<0.05$)

CONCLUSIONS



421 clinical protocols from 7 CT manufacturers were evaluated by 22 investigators with a range of scan techniques: 0.3-1.75 pitch, 5.5 - 80 mm collimation, 80-140 kV, 0.3-1.5s rotation time.

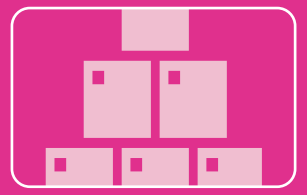
Difference between axial and helical measurements was greater in the generalizability study than in the feasibility study (-0.76 mGy vs 0.30 mGy). However, mean difference was less than 1 mGy.

Helical CTDI measurements exceeding 20% difference from displayed $CTDI_{vol}$ was higher in the generalizability study than in the feasibility study (13/326 vs 0/95). However, this includes less than 4% of the protocols, possibly due to variation in scan range.

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

NEXT STEPS?

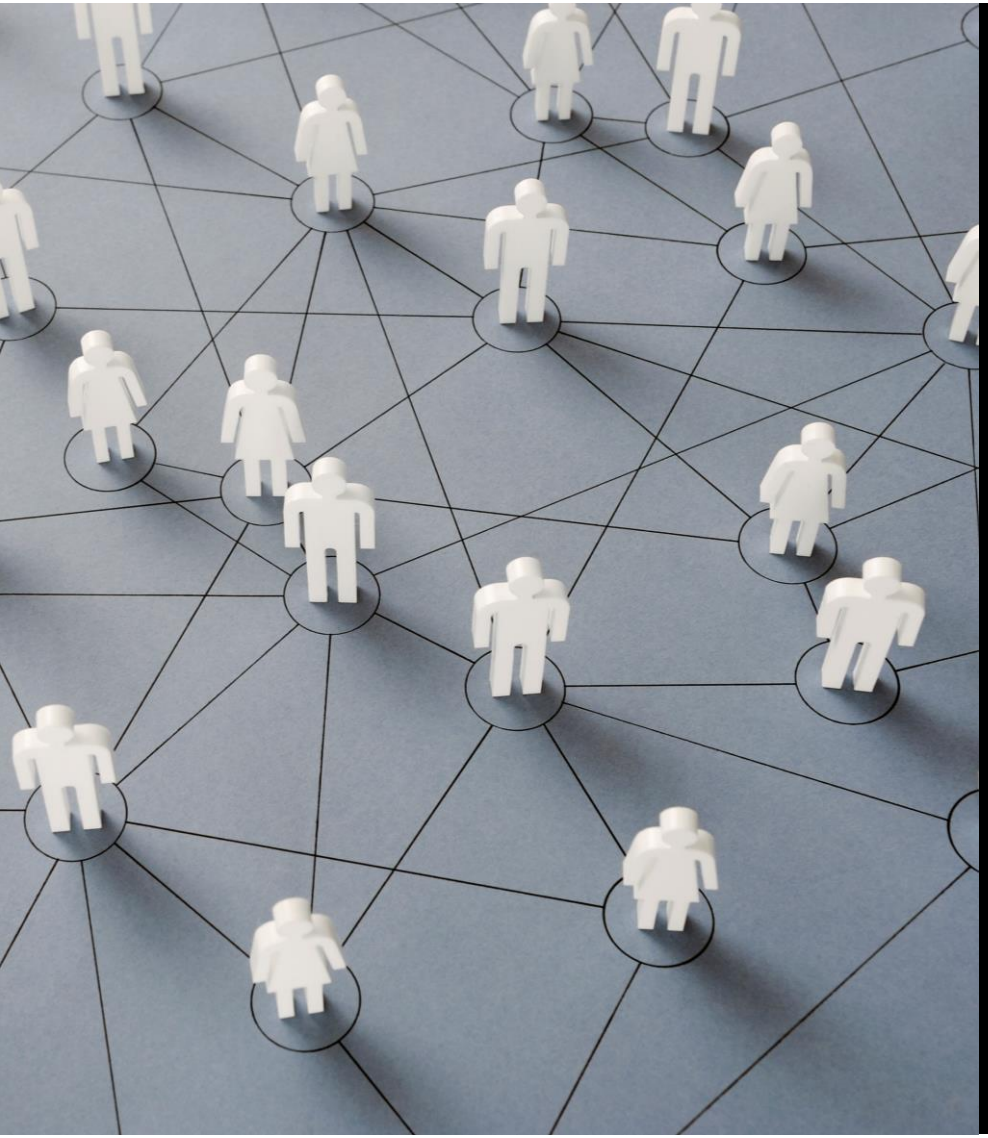


Complete data collection, analyze all submissions.

Discuss the need to investigate any remaining variables.

Publish study findings for public review and commentary

Continue communication with ACR to identify if results are acceptable



ACKNOWLEDGEMENTS

Helical CTDI Generalizability Study

Study participants who submitted data

Research Team:

- Dustin Gress
- Stephanie Leon
- Bryan (BC) Schwarz
- Izabella Barreto
- Robert (Bob) Kobistek
- Chad Dillon
- Jim Tomlinson
- Mahadevappa Mahesh
- Dina Hernandez

Original Helical CTDI Feasibility Study

Co-Authors:

- Stephanie Leon
- Robert (Bob) Kobistek
- Edmond Olguin
- Zhongwei Zhang
- Izabella Barreto
- Bryan (BC) Schwarz

THANK YOU

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Twitter: @BarretoPhd

We invite you to add your measurements to our study

https://bit.ly/3v3onjH