Image-Based Size-Specific Dose Estimate From CT Scans: An Automatic Extraction Approach

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COI Disclosure

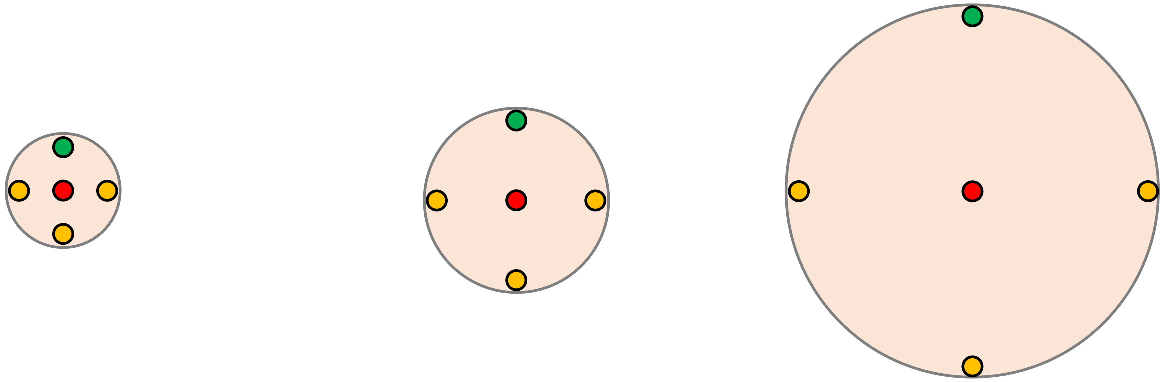
- The authors have no financial conflicts of interest to disclose concerning the presentation.

What is Size-Specific Dose Estimate (SSDE)?

- (IEC) SSDE is an estimate of the average absorbed dose to the scan volume that takes into account the attenuation of the anatomy being scanned (using the water-equivalent diameter - D_w) and the radiation output of the CT scanner (using $CTDI_{vol}$).
- SSDE is intended to provide a dose estimate for patients of all sizes.
- SSDE is especially important for small pediatric patients since the corresponding applied level of radiation does not adequately indicate the absorbed radiation dose.

Why is SSDE needed?

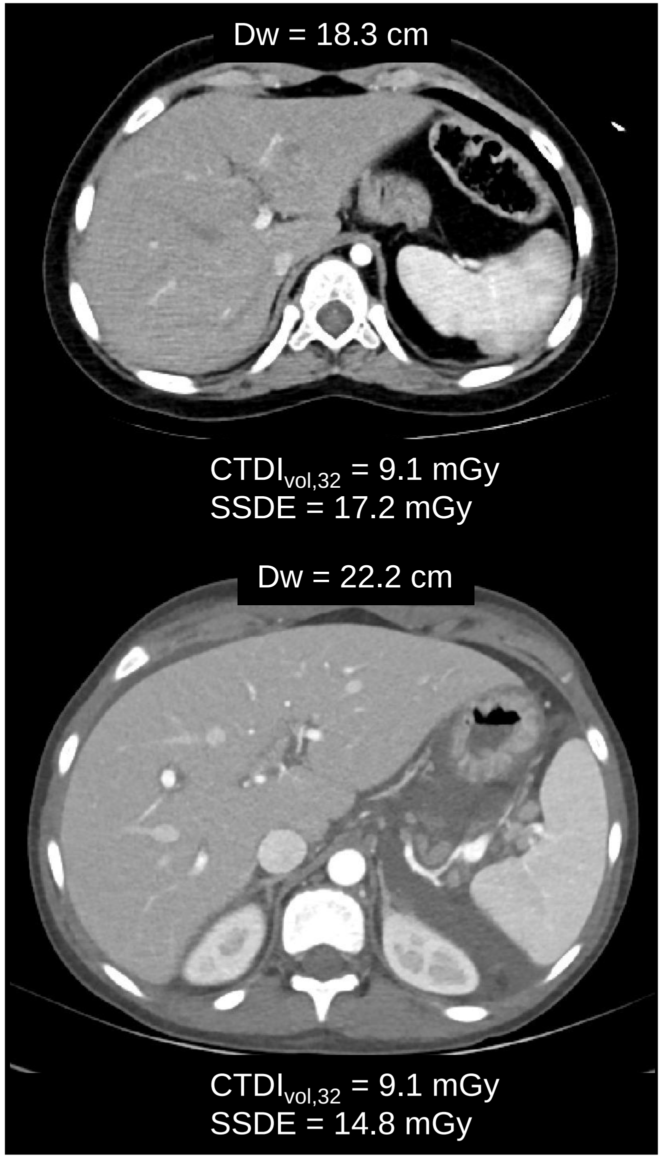
Measured $CTDI_{vol}$ = 47 mGy | Measured $CTDI_{vol}$ = 37 mGy | Measured $CTDI_{vol}$ = 18 mGy



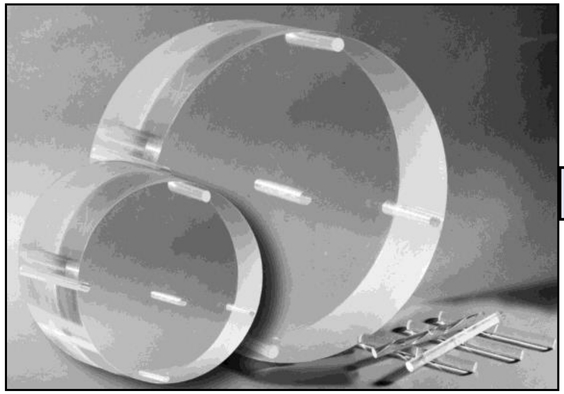
● 47 mGy	● 38 mGy	● 21.6 mGy
● 47 mGy	● 35 mGy	● 10.8 mGy
∅10 cm Phantom	∅16 cm Phantom	∅32 cm Phantom

Displayed $CTDI_{vol,16}$ = 37
Displayed $CTDI_{vol,32}$ = 18

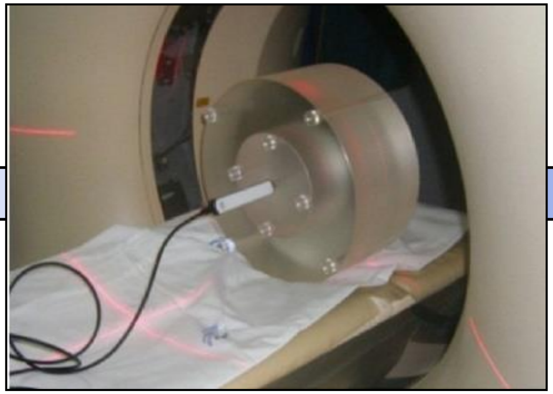
- $CTDI_{vol}$ is the standardized method to estimate and compare the radiation output of different CT scanners to same phantom.
- The displayed $CTDI_{vol}$ is independent of the patient size, it assumes either 16 or 32 cm CTDI phantom;
- $CTDI_{vol}$ and Patient Dose are not the same thing



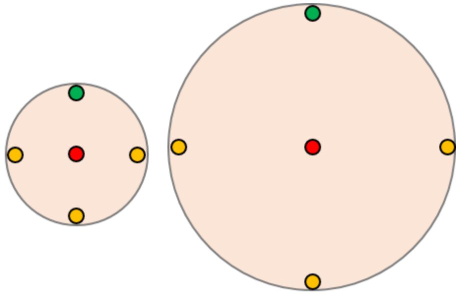
SSDE Calculation



Physics world: CTDI Phantom



Methods: Direct measurement



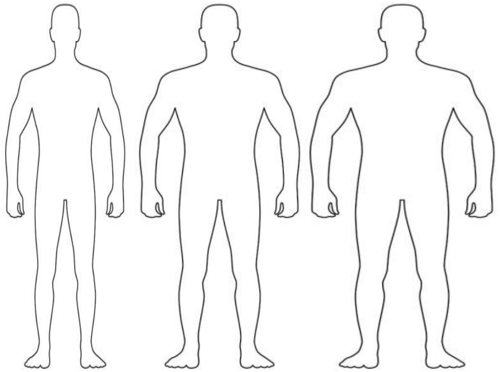
38 mGy
35 mGy
21.6 mGy
10.8 mGy

∅16 cm Phantom

∅32 cm Phantom

$CTDI_{vol}$

SSDE



Real world:

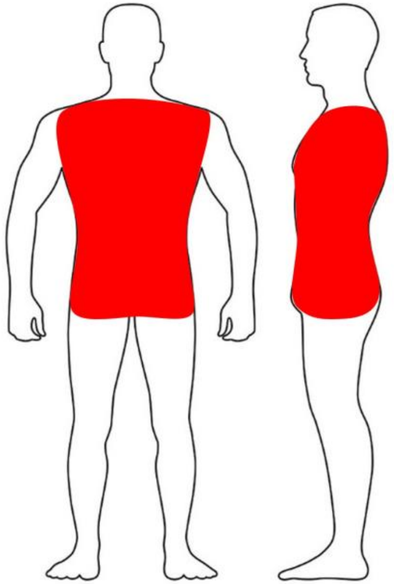
Human with different sizes

- Methods:
  - Physical Anthropomorphic Phantoms
  - Cylindrical PMMA Phantoms
  - Monte Carlo Voxelized Phantoms
  - Monte Carlo Mathematical Cylinders
  - …

- AAPM Report 204 (2011)
  - Body CTDIvol,16 -to-SSDE conversion factors
  - Body CTDIvol,32 -to-SSDE conversion factors
- AAPM Report 220
  - water-equivalent diameter
- AAPM Report 293:
  - Head CTDIvol,16 -to-SSDE conversion factors

$CTDI_{vol}$-to-SSDE conversion factors

AAPM Report 293 Recommended Nomenclature for SSDE



$$f^{B32} = \alpha \cdot e^{-\beta D_w}$$

α=3.704369 mGy/$CTDI_{vol,32}$ (mGy)
β = 0.03671937 cm^{-1};
D_w = water-equivalent diameter (in cm)

$$SSDE = f^{B32} \times CTDI_{vol,32}$$
$$SSDE = f^{B16} \times CTDI_{vol,16}$$

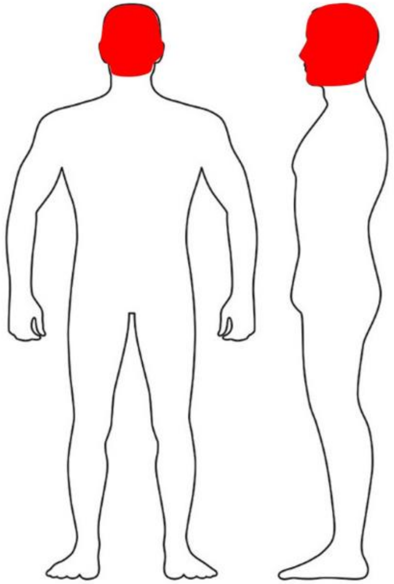
$$f^{B16} = \alpha \cdot e^{-\beta D_w}$$

α=1.874799 mGy/$CTDI_{vol,32}$ (mGy)
β = 0.03871313 cm^{-1};
D_w = water-equivalent diameter (in cm)

$$f^{H16} = \alpha \cdot e^{-\beta D_w}$$

α=1.9852 mGy/$CTDI_{vol,32}$ (mGy)
β = 0.0486 cm^{-1};
D_w = water-equivalent diameter (in cm)

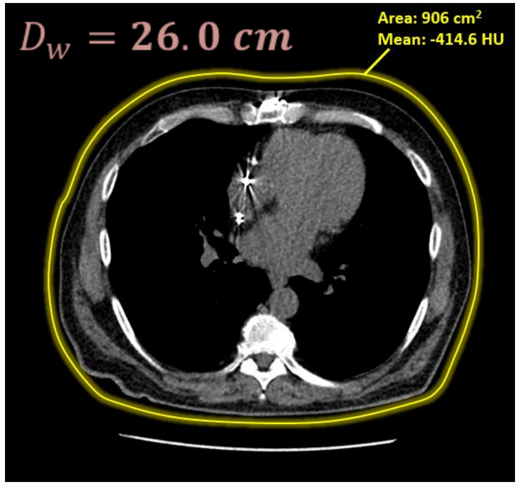
$$SSDE = f^{H16} \times CTDI_{vol,16}$$



f = function(Dw)

SSDE Calculation Methods

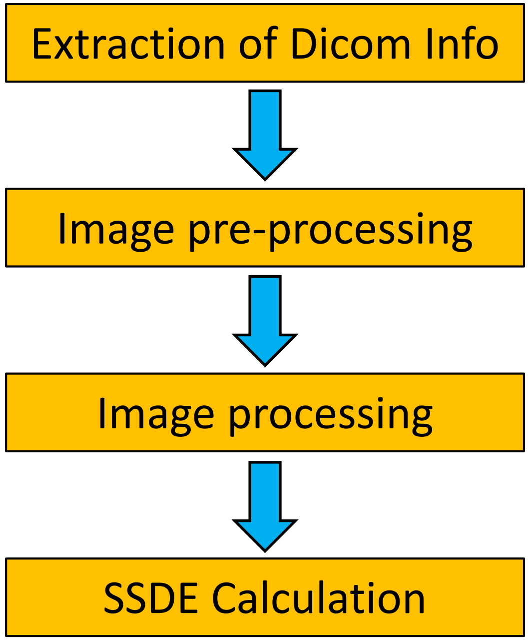
- Calculation of SSDE requires knowledge of the patient Dw
- Dw estimation methods
  - ►Based on CT localizer radiograph (i.e., AAPM TG 220);
  - ►Based on acquired images
    - either at the center of the scan range,
      - as an average for a certain anatomical region (e.g., head, abdomen, or pelvis),
      - as an average over an organ-specific region (e.g., liver),
    - or at the reconstructed image level (i.e., AAPM TG 246)
  - ►Based on body weight, instead of body diameter
    - Body weight as a surrogate to estimate size-specific dose in children, making dose estimation clinically simpler and more rapid.



Purpose

- To develop an efficient image-driven method to automatically extract scan-related information and image from CT examinations for size-specific dose estimation using the nomenclature recommended by AAPM TG293;
- To provide a promising tool for patient dose calculation, optimization and image quality improvement

Materials and Methods - 1



- The proposed automatic extraction approach for SSDE includes
  - Dicom information extraction,
  - Image pre-processing,
  - Image processing,
  - SSDE calculation.
- Water Equivalent Diameter (Dw) was determined, TG 204 AP, Lateral and Eff. Diameter as well.
- Image Position Patient and Slice Location were used to determine the scanned range and the mean SSDE over the entire scan range.
- Validation study was performed on ACR CT accreditation phantom.
- To test the performance, we retrospectively studied
  - 37 Head CT with dual energy protocols (80kV+Sn150kV);
  - 41 body CT with single energy protocols (100kV).

Materials and Methods - 2

Extraction of Dicom Info

↓

Image pre-processing

↓

Image processing

↓

SSDE Calculation

Dicom Tag	Description
(0018, 0015)	Body part examined
(0008, 0070)	Manufacturer
(0020,0032)	Image Position Patient
(0028,0030)	Pixel Spacing
(0018,0050)	Slice Thickness
(0020,1041)	Slice Location
(0018, 9345)	Volume CTDI (CTDIvol) in mGy. It describes the average dose for this image for the selected CT conditions of operation.
(0018,9346)	The type of phantom used for CTDI measurement (IEC Dosimetry Phantom)
(0028,1052)	Rescale Intercept. The value b in relationship between stored values (SV) and the output units. Output units = m*SV+b.
(0028,1053)	Rescale Slope. m in the equation specified in Rescale Intercept

Materials and Methods - 3

Extraction of Dicom Info
↓
Image pre-processing
↓
Image processing
↓
SSDE Calculation

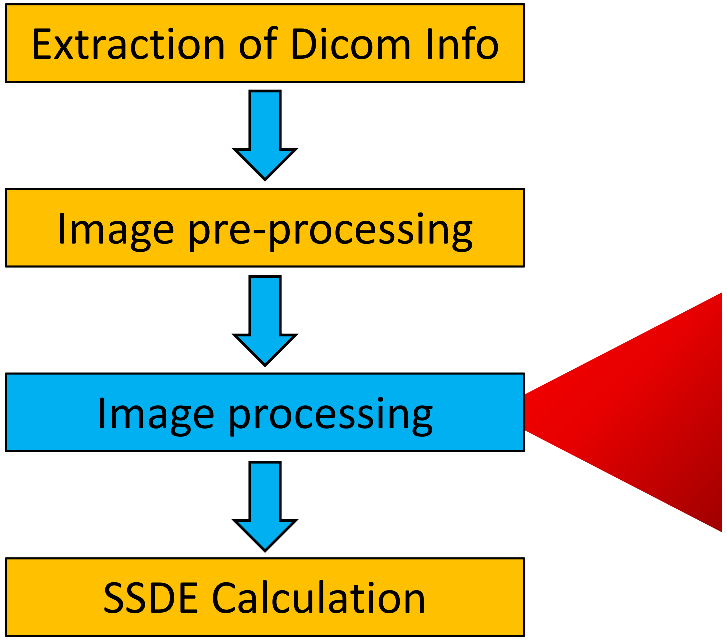
- Recon Algorithm
- Imaging Sharpening
- Image Smoothing

Image reconstruction filters offer reduced image noise but at the expense of more image blur.

Vendor reconstruction method names and their approaches

	Edge-preserving noise reduction (in one domain)	Iterative recon including model of data statistics	Iterative recon modeling statistics and physics
GE	ASIR	ASIR-V	VEO
Philips	iDose	IMR	
Siemens	IRIS, SAFIRE	ADMIRE	
Canon	QDS/BOOST	AIDR 3D	FIRST

Materials and Methods - 4



- Background Removal
- Active Contour Based Segmentation
- Dw Determination

i) Mean HU value of the pixels, $\mu(z)$:

$$\mu(z) = \frac{1}{XY} \sum_{x=1}^{X} \sum_{y=1}^{Y} V(x, y, z) \quad (1)$$

This value allows us to automatically separate the air and the background from the rest of the image. After threshold $\mu(z)$ applied, one can obtain image with background removal (V').

$$V'(x, y, z) = \left(V(x, y, z) > \mu(z)\right) \quad (2)$$

ii) Mean HU of the pixels within $V'(x, y, z)$

$$\mu'(z) = \frac{1}{XY} \sum_{x=1}^{X} \sum_{y=1}^{Y} V'(x, y, z) \quad (3)$$

iii) Standard deviation of HU of pixels in $V'(x, y, z)$ with an HU level higher than $\mu'(z)$,

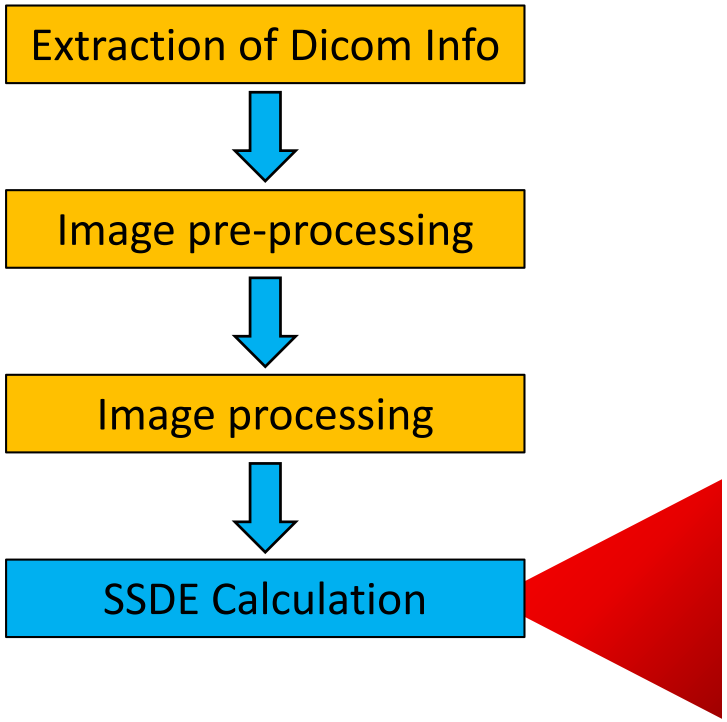
$$\sigma(z) = \sqrt{\frac{1}{XY-1} \sum_{x=1}^{X} \sum_{y=1}^{Y} \left(V'(x, y, z) - \mu'(z)\right)^2} \quad (4)$$

iv) Mean of the parameter $\mu'(z)$ minus the standard deviation of $\sigma(z)$ as the threshold for soft tissue

$$D_w = 2\sqrt{\left[\frac{1}{1000} \overline{CT(x, y)}_{ROI} + 1\right] \frac{A_{ROI}}{\pi}} \quad (5)$$

Where AROI is the total area of the ROI, $\overline{CT(x, y)}_{ROI}$ is the mean CT number in the ROI.

Materials and Methods - 5



SSDE was given by:

$$SSDE = f^{B32} \times CTDI_{vol,32} \quad (8)$$

$$SSDE = f^{B16} \times CTDI_{vol,16} \quad (9)$$

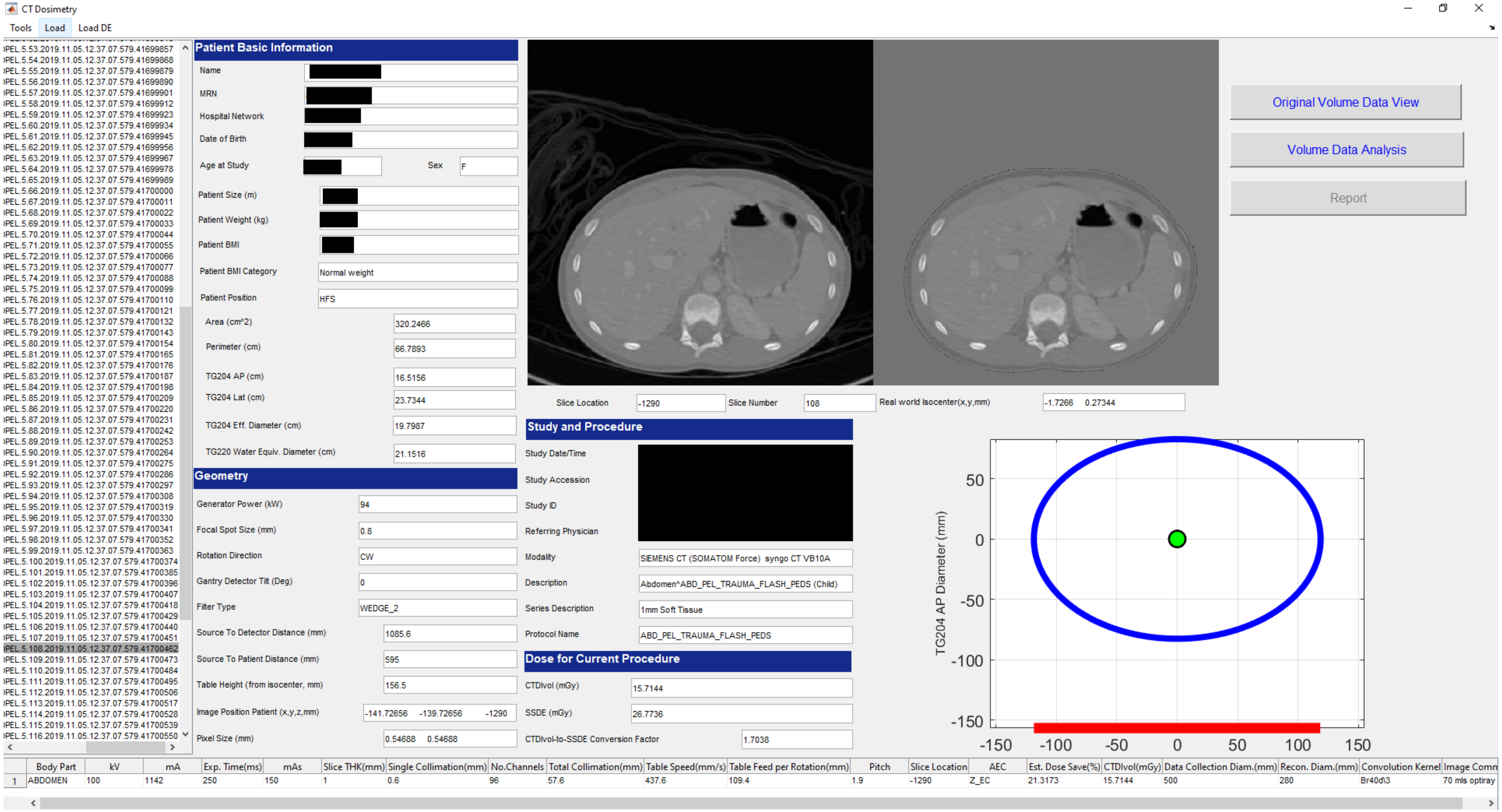
$$SSDE = f^{H16} \times CTDI_{vol,16} \quad (10)$$

Image Position Patient and Slice Location were used to determine the scanned range and the mean SSDE over the entire scan range can be expressed as:

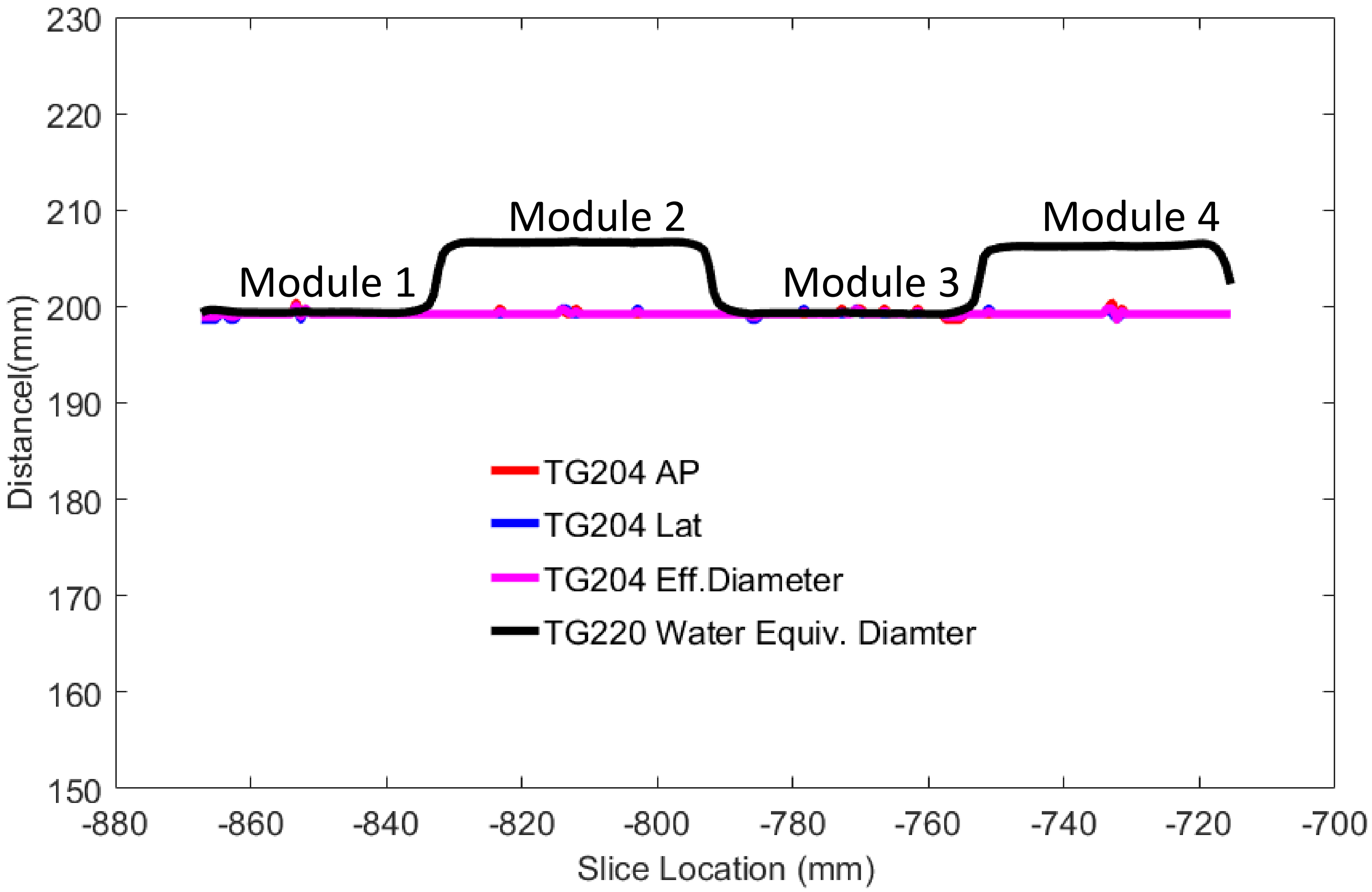
$$\overline{SSDE} = \frac{\sum_{z=1}^{N} SSDE(z)}{N} \quad (11)$$

where N is the total number of images.

Software Interface



ACR CT Accreditation Phantom and Validation Study

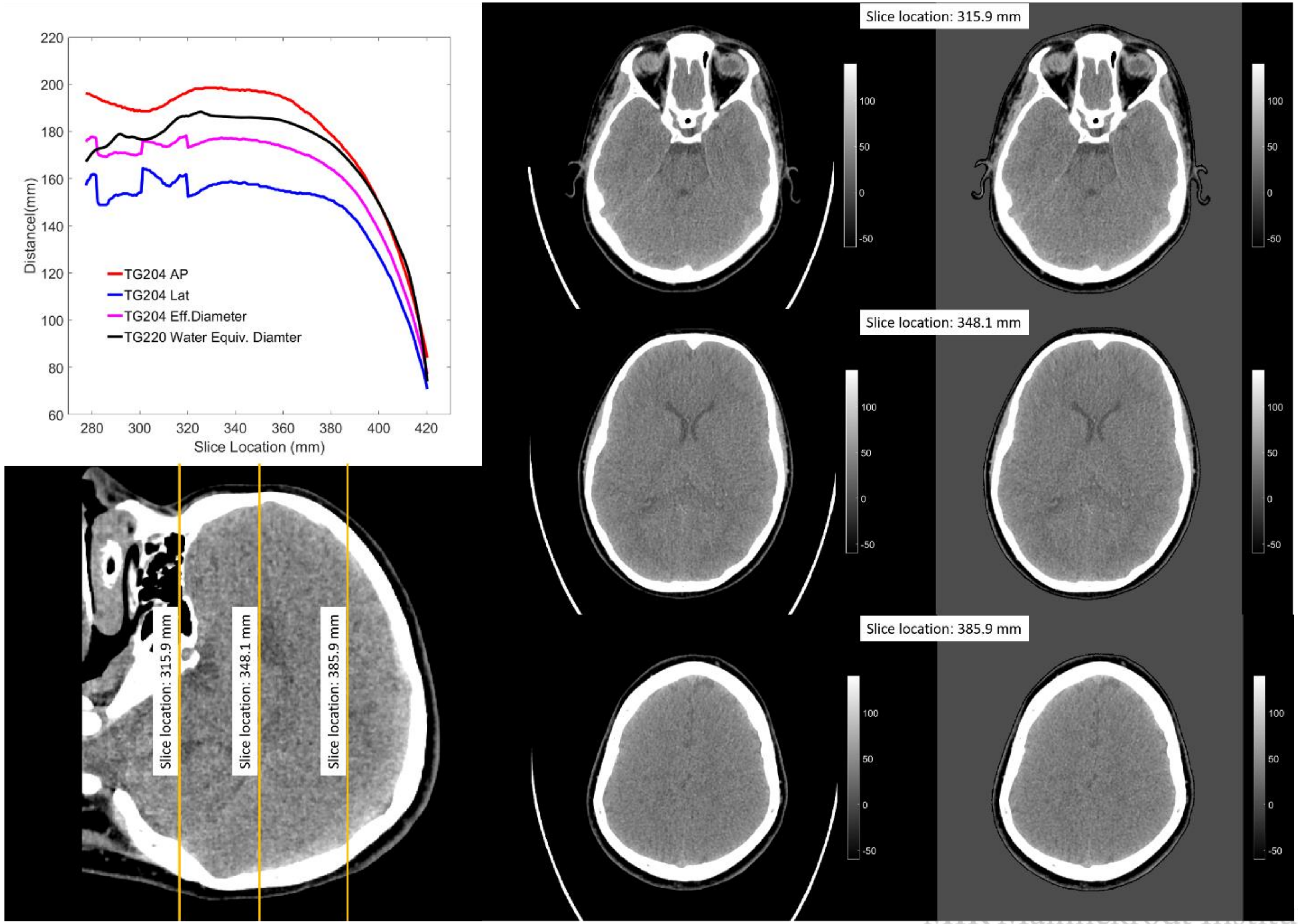


	AP (mm)	Lat (mm)	Eff.Dia (mm)	Dw (mm)
Module 3	200.0±0.3	199.9±0.2	200.0±0.2	199.8±0.3

Head CT examination

- Dual energy protocol was used: tube potential, 80kV and 150kV with Tin filter (Sn 150kV); automatic exposure control (CareDose 4D); detector configuration, 64 × 0.6 mm; pitch, 0.5; section thickness, 0.75 mm; and gantry rotation time, 0.5 second. Patients were scanned from vertex down through the base of the skull. The images were reconstructed with an advanced modeled iterative reconstruction algorithm (advanced modeled iterative reconstruction, ADMIRE) using strength 3.

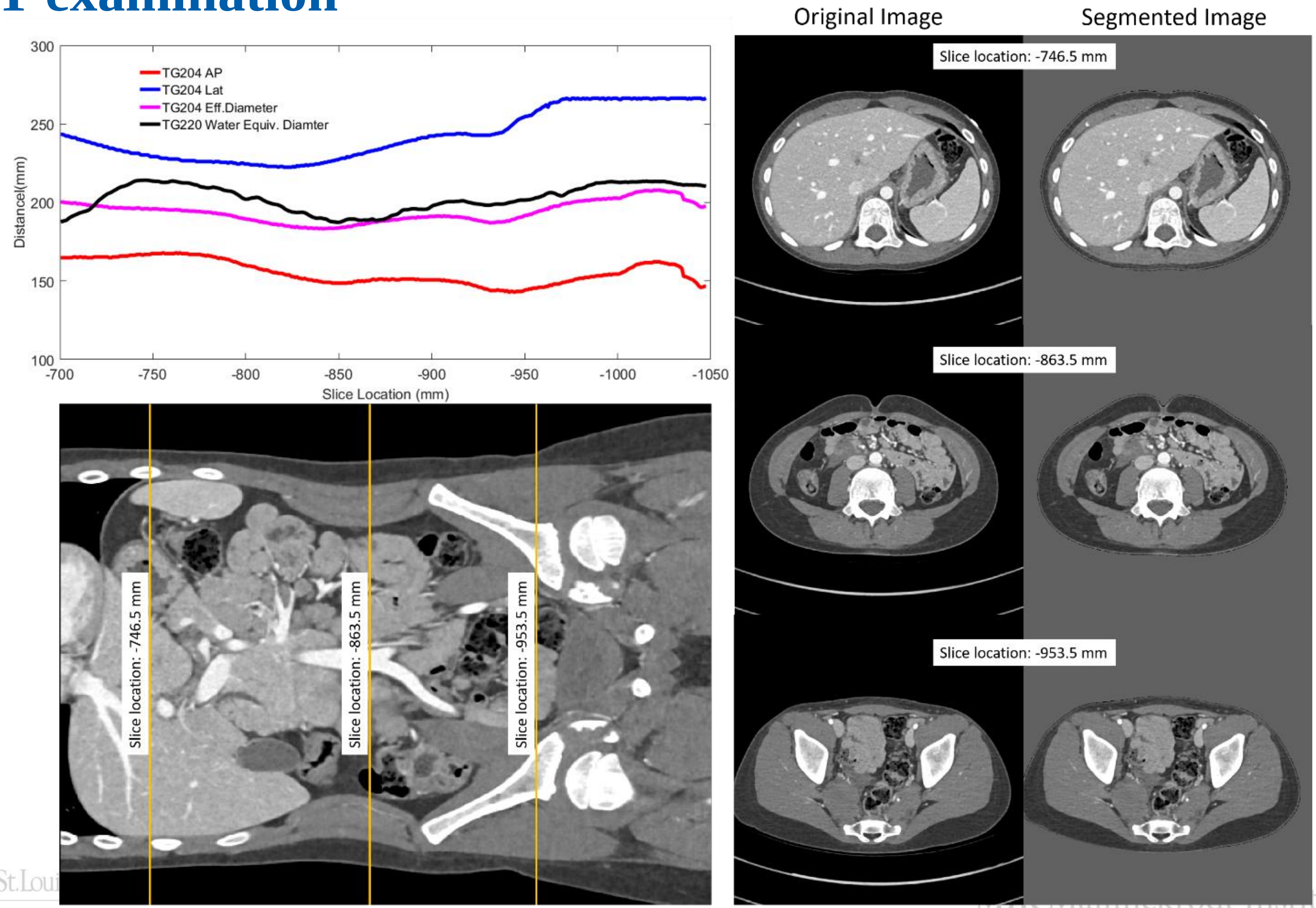
Head CT examination



Body CT examination

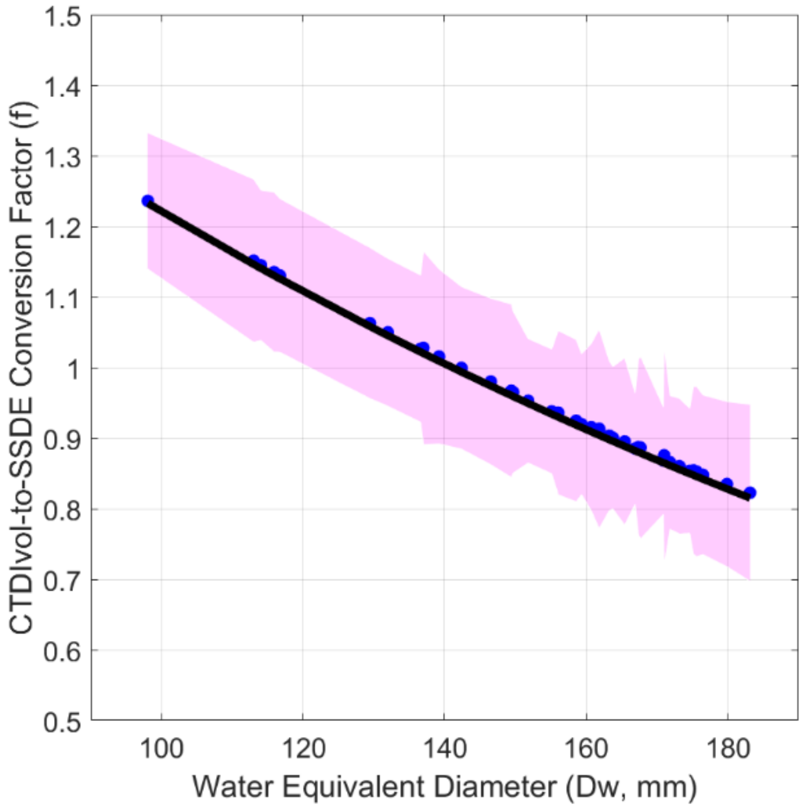
- Single energy protocol was used: tube potential, 100kV; CareDose 4D; detector configuration, 96 × 0.6 mm; pitch, 1.55; section thickness, 1 mm; and gantry rotation time, 0.25 second. The images were reconstructed with ADMIRE algorithm using strength 3.
- Patient scanning range depends on the clinical problems:
  - ►For chest CT, right below chin down past costaphrenic angles to include all chest anatomy side to side; for abdomen CT, approximately 1cm above the highest diaphragm down to the pubic symphysis to include all abdomen/pelvis anatomy side to side;
  - ►For pelvis CT, above the iliac crest down through the ischium to include all pelvis anatomy side to side;
  - ►For Chest-Abdomen-Pelvis (CAP), right below chin down to pubic symphysis to include all chest abdomen pelvis anatomy side to side.

Body CT examination



Descriptive Statistics for head CT group (N = 37)

Statistic	Age (y)	AP (cm)	Lat (cm)	Eff.Diameter (cm)	Dw (cm)	f factor (a.u.)	CTDIvol (mGy)	SSDE (mGy)
Mean	5.8	15.8	13.3	14.5	15.3	0.95	36.8	34.7
SD	6.1	2.3	1.7	1.9	2.2	0.10	8.4	6.7
Minimum	0.0	10.2	8.9	9.5	9.8	0.82	17.3	15.8
Maximum	17.0	19.2	15.7	16.8	18.3	1.24	52.8	47.5
5th quantile	0.0	12.0	10.0	11.1	11.4	0.85	22.8	24.8
Median	2.0	16.3	13.8	15.0	15.9	0.92	36.0	34.2
95th quantile	16.4	18.8	15.1	16.7	17.7	1.15	50.8	45.0

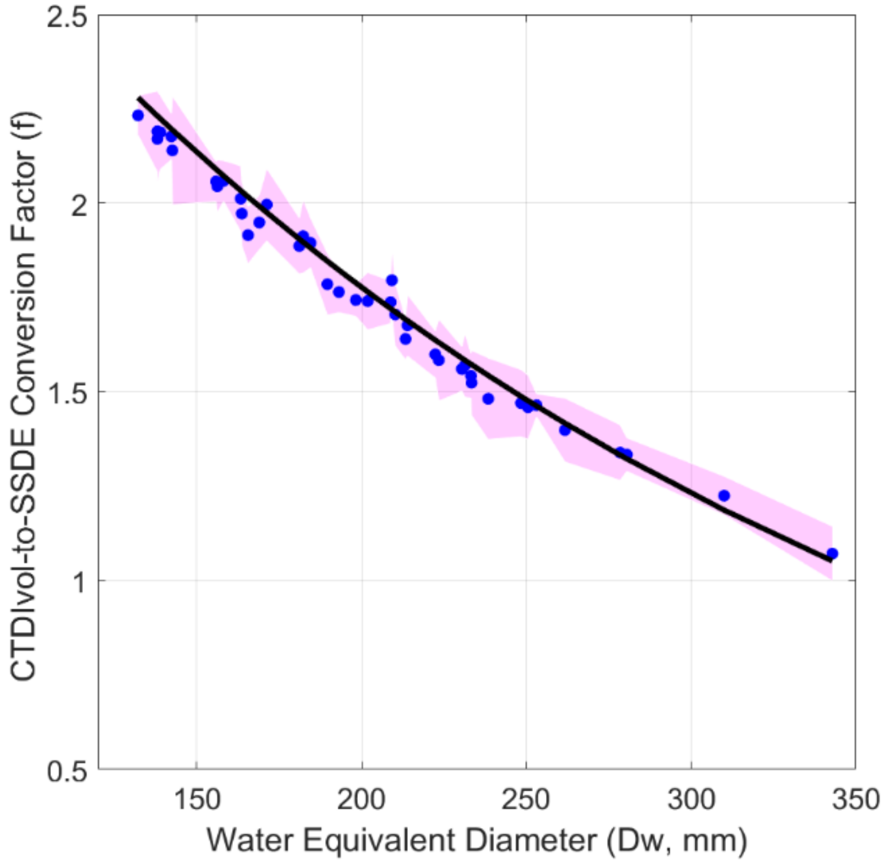


- For Siemens CT scanner, the CTDIvol was calculated using ∅ 16cm head phantom as a reference.
- In our study, f has an average of 0.95 which is closer to 1.
- Therefore, for pediatric head CT examinations, the CTDIvol can be approximated as SSDE even an overall overestimation of CTDIvol in Head CT was found.

Descriptive Statistics for body CT group (N = 41)

Statistic	Age (y)	AP (cm)	Lat (cm)	Eff.Diameter (cm)	Dw (cm)	f factor (a.u.)	CTDIvol (mGy)	SSDE (mGy)
Mean	10.1	16.7	25.1	20.4	20.8	1.76	8.0	12.8
SD	5.8	4.2	6.0	5.0	4.8	0.29	5.4	6.6
Minimum	0.0	10.7	16.3	13.2	13.8	1.07	2.3	4.9
Maximum	19.0	28.9	40.9	34.3	33.8	2.23	25.0	27.4
5th quantile	1.0	11.5	16.6	13.8	14.4	1.33	3.0	6.2
Median	10.0	16.3	24.4	20.2	20.5	1.74	6.4	10.6
95th quantile	18.0	23.2	35.6	28.1	27.8	2.19	15.7	26.8

- For Siemens CT scanner, the CTDIvol was calculated using ∅ 32cm body phantom as a reference.
- An average f of 1.76 was found in body CT group.
- As expected, the CTDIvol for pediatric CT examinations was lower than the SSDE, because pediatric patients have a smaller average Dw of 20.8 cm than a 32-cm reference phantom.
- Note that the small patients need the biggest correction for body size in radiation dose estimation.



Conclusion

- CTDIvol does not consider the effects of patient factors on the radiation dose. While the mean SSDE simultaneously considers the scanning protocol and the effects of the geometric shape of the patient and tissue attenuation on the radiation dose and is more representative and can characterize the radiation dose of patient with specific body size.
- In this study, we proposed an image-based automatic extraction approach for SSDE from CT scans based on dynamic threshold and active contour methods.
- The measurement accuracy was validated by ACR CT phantom study.
- It provide a promising tool for patient dose calculation, optimization and image quality improvement

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* AAPM Report 204

* AAPM Report 220

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Thanks for your attention

Source code is available upon request,

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