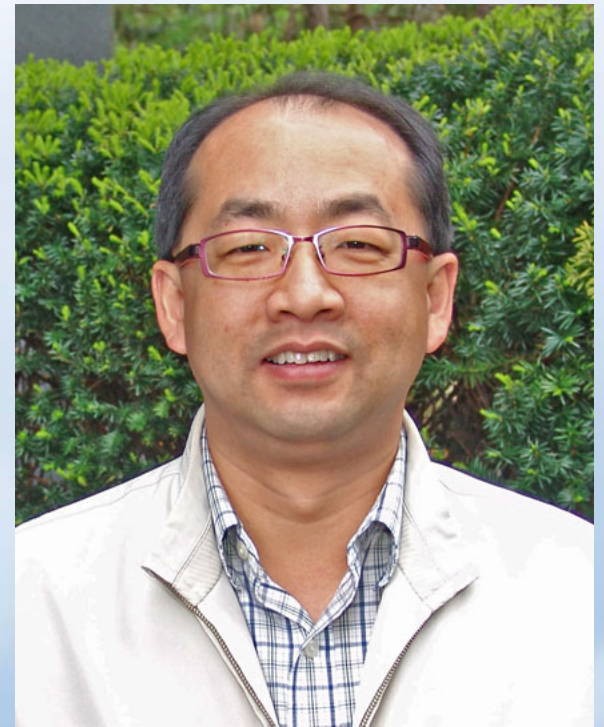


Choonsik Lee, Ph.D.
Investigator, DCEG

Organ Doses from CT Imaging



Radiation Epidemiology & Dosimetry Course

National Cancer Institute

www.dceg.cancer.gov/RadEpiCourse

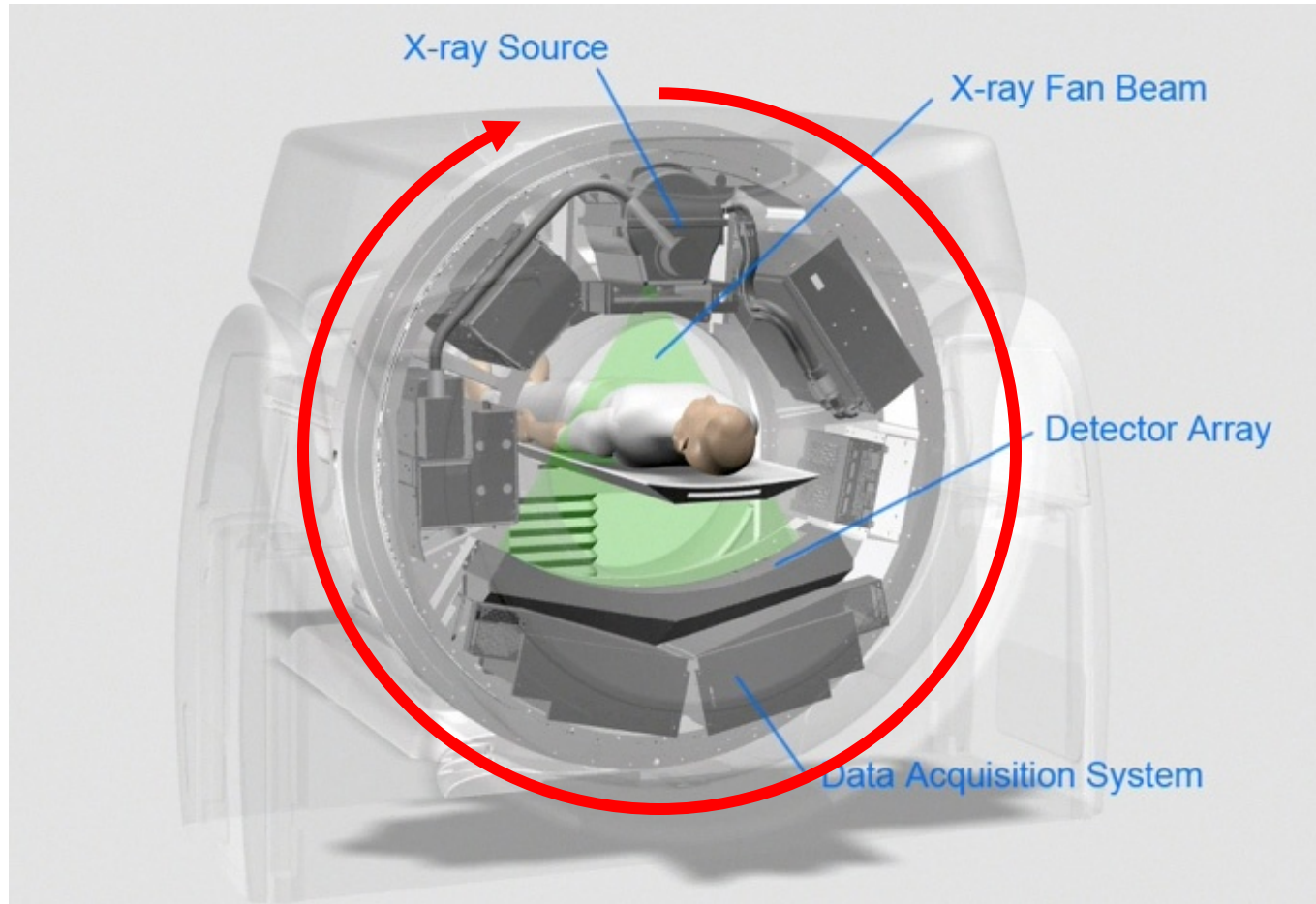
Content

- Basics in CT dosimetry
- Development of NCICT
- Selected applications
- Ongoing efforts

Content

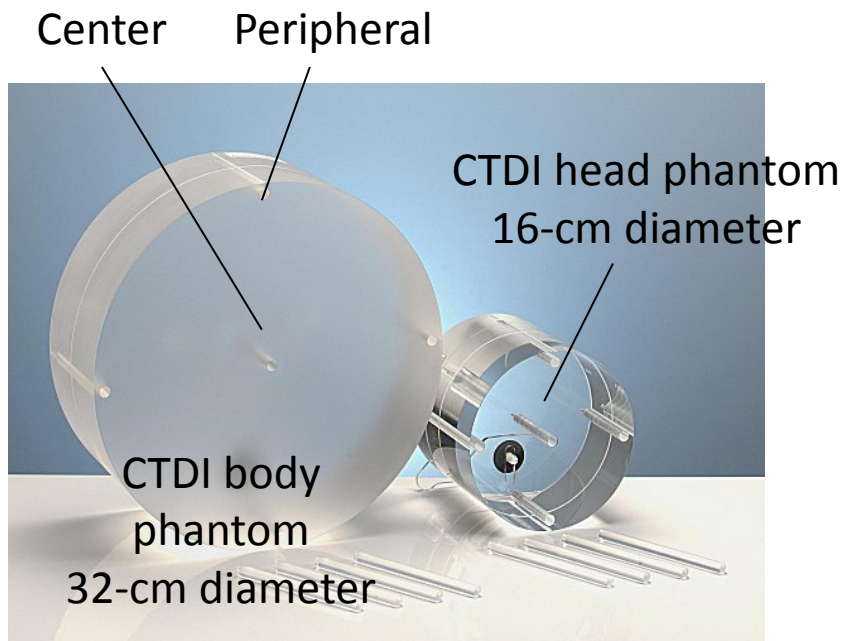
- Basics in CT dosimetry
 - Dose descriptors from CT scanner
 - Major factors affecting CT dose
- Development of NCICT
- Selected applications
- Ongoing efforts

Computed Tomography



Dose descriptors from CT scan

- Computed Tomography Dose Index (CTDI)₁₀₀
 - 100-mm long ion chamber measurement for a single axial rotation
- $CTDI_w = 1/3 CTDI_{100,center} + 2/3 CTDI_{100,peripheral}$



Dose descriptors from CT scan

$$DLP = CTDI_{vol} \times l = \frac{CTDI_w}{pitch} \times l = \frac{nCTDI_w \times mAs}{pitch} \times l$$

Patient Name:		Exam no: 215			
Accession Number:		Feb 14 2008			
Patient ID:		LightSpeed VCT			
Exam Description: PRE/POST KIDNEY					
Dose Report					
Series	Type	Scan Range (mm)	CTDI _{vol} (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Axial	S0.000-I97.500	94.69	946.93	Head 16
2	Helical	I61.650-I101.650	60.81	371.96	Head 16
2	Cine	S12.490-I2.510	121.14	242.29	Head 16
3	Axial	S0.000-I97.500	94.69	946.93	Head 16
3	Helical	I61.650-I101.650	60.81	371.96	Head 16
3	Cine	S12.490-I2.510	121.14	242.29	Head 16
Total Exam DLP:				3122.36	

Dose descriptors from CT scan

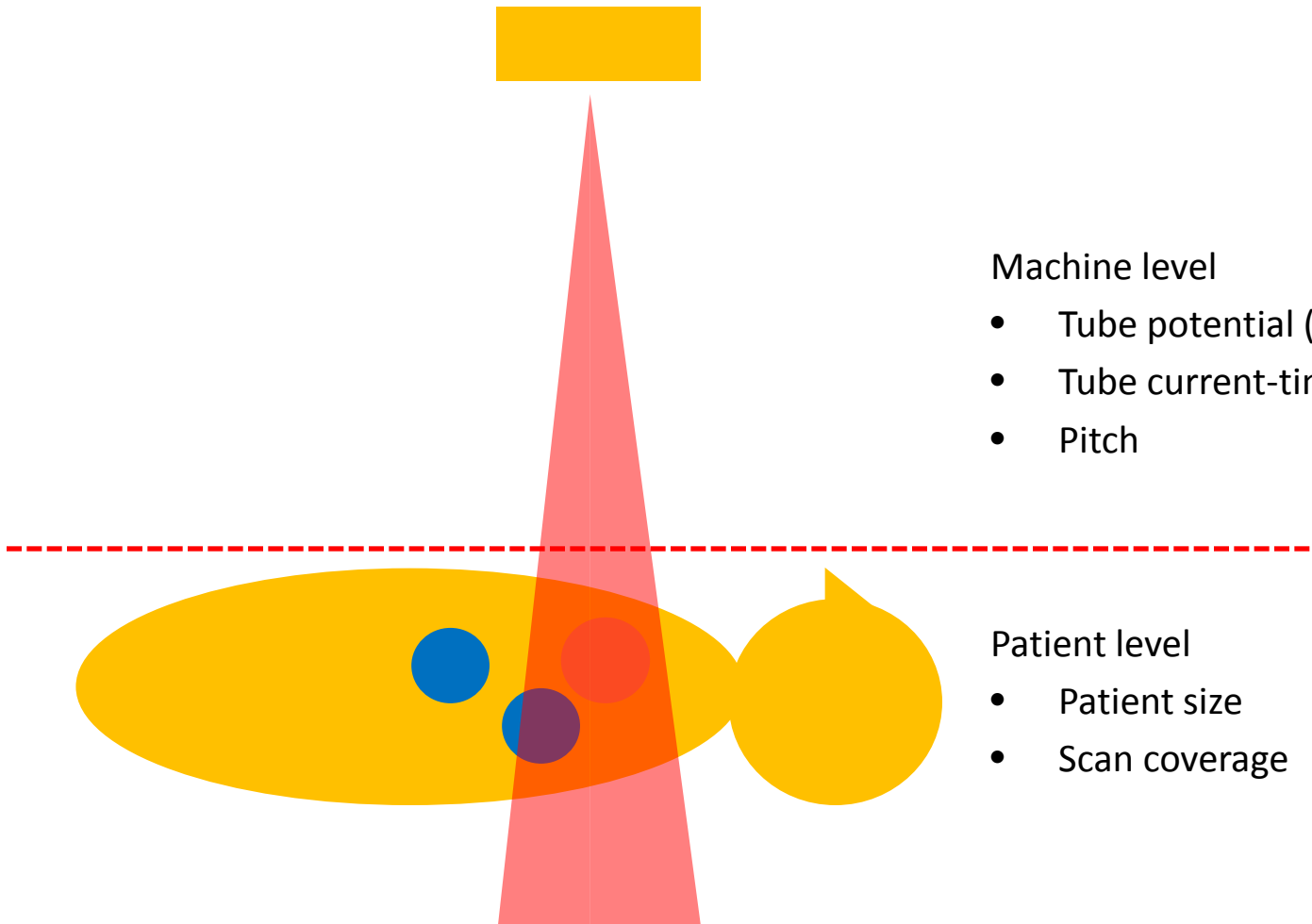
$$E (mSv) = DLP(mGycm) \times k \left(\frac{mSv}{mGycm} \right)$$

Table 3. Normalized values of effective dose per dose-length product (DLP) over various body regions and (standard) patient ages [33]

Region of body	Effective dose per DLP (mSv (mGy cm) ⁻¹) by age				
	0 year old ^a	1 year old ^a	5 year old ^a	10 year old ^a	Adult ^b
Head and neck	0.013	0.0085	0.0057	0.0042	0.0031
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen and pelvis	0.049	0.030	0.020	0.015	0.015
Trunk	0.044	0.028	0.019	0.014	0.015

* Shrimpton et al. BJR (2006), AAPM TG Report No. 96 (2008)

Factors affecting CT dose



Factors affecting $CTDI_w$ in CT: Energy (kVp)

Table 1
Changes in $CTDI_w$ in Head and Body
Phantoms as a Function of Kilovolt Peak

Beam Energy (kVp)	$CTDI_w$ in Head Phantom (mGy)	$CTDI_w$ in Body Phantom (mGy)
80	14	5.8
100	26	11
120	40	18
140	55	25

$$CTDI_{vol} \propto \left(\frac{kVp_2}{kVp_1} \right)^n, n = 2 \sim 3$$

1.8-fold

3.9-fold

4.3-fold

Note.—All other factors were held constant at 300 mA, 1 sec, and 10 mm. Results are from a single-detector CT scanner.

Factors affecting $CTDI_w$ in CT: Fluence (mAs)

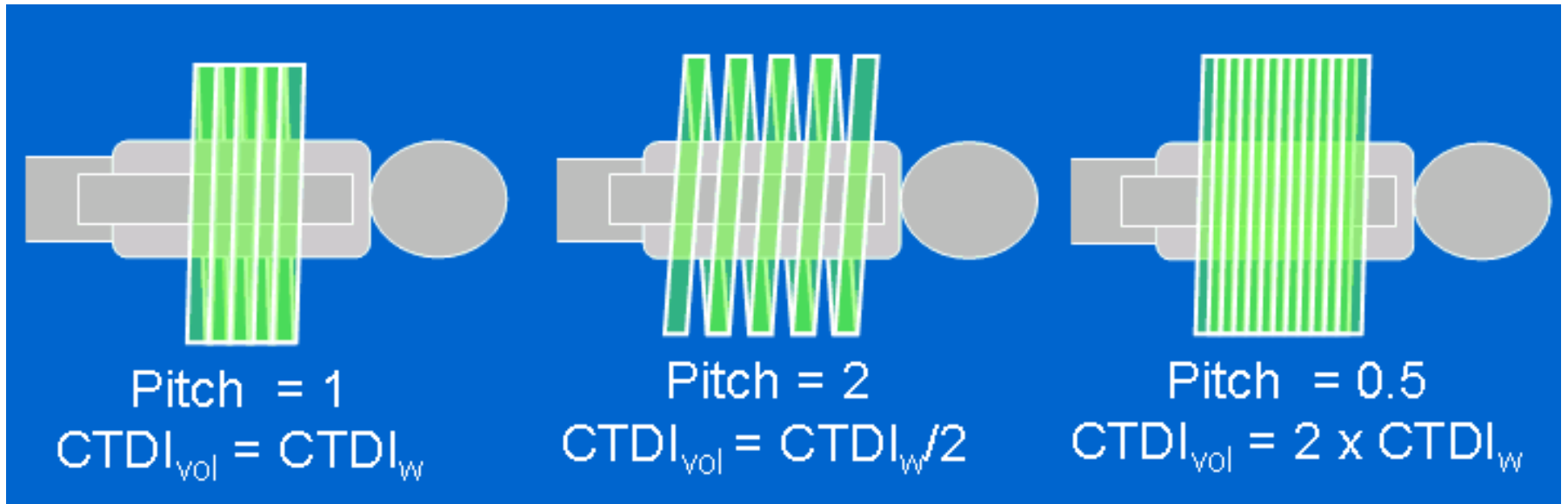
Table 2
Changes in $CTDI_w$ in Head and Body
Phantoms as a Function of Milliampere-
Seconds Setting

Tube Current– Time Product (mAs)	$CTDI_w$ in Head Phantom (mGy)	$CTDI_w$ in Body Phantom (mGy)
100	13	5.7
200	26	12
300	40	18
400	53	23

Note.—All other factors were held constant at 120 kVp and 10 mm. Results are from a single-detector CT scanner.

* McNitt-Gray Radiographics (2002)

Factors affecting $CTDI_w$ in CT: Pitch



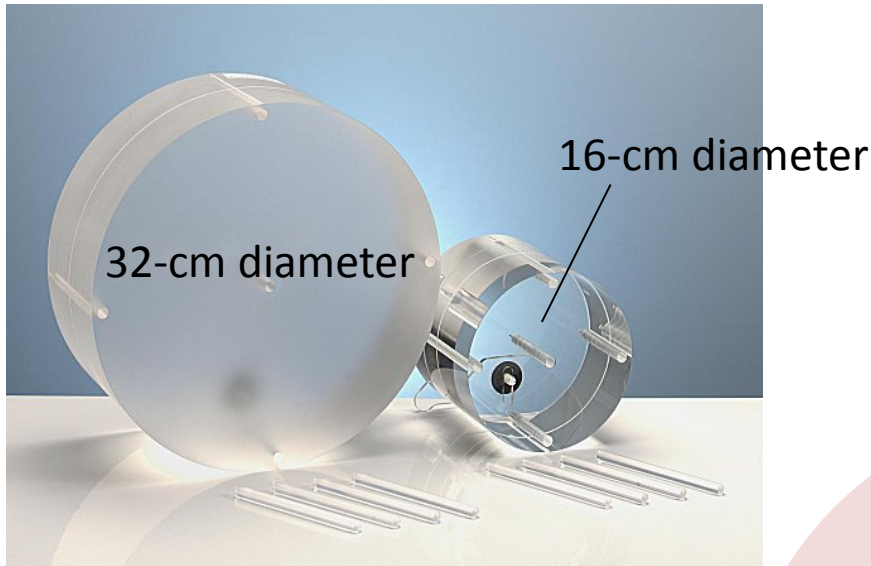
Factors affecting $CTDI_{vol}$ in CT: Pitch

Table 3
Changes in $CTDI_{vol}$ in Head and Body Phantoms as a Function of Pitch

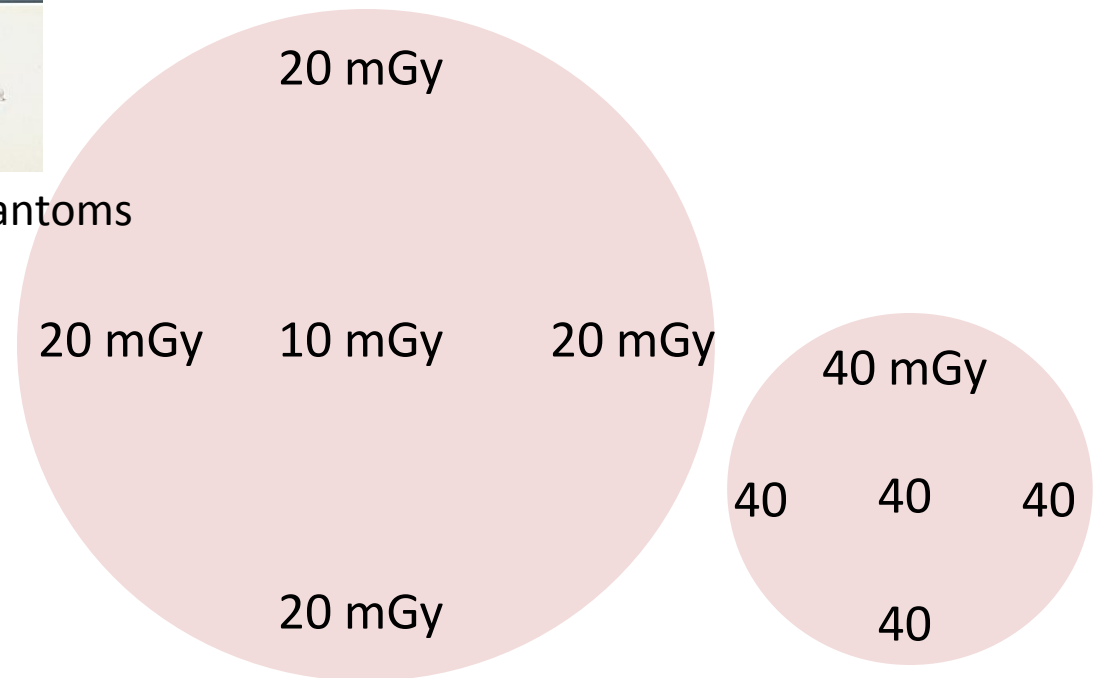
Pitch	$CTDI_{vol}$ in Head Phantom (mGy)	$CTDI_{vol}$ in Body Phantom (mGy)
0.5	80	36
0.75	53	24
1.0	40	18
1.5	27	12
2.0	20	9

Note.—All other factors were held constant at 120 kVp, 300 mA, 1 sec, and 10 mm. Results are from a single-detector CT scanner.

Factors affecting dose in CT: Patient size



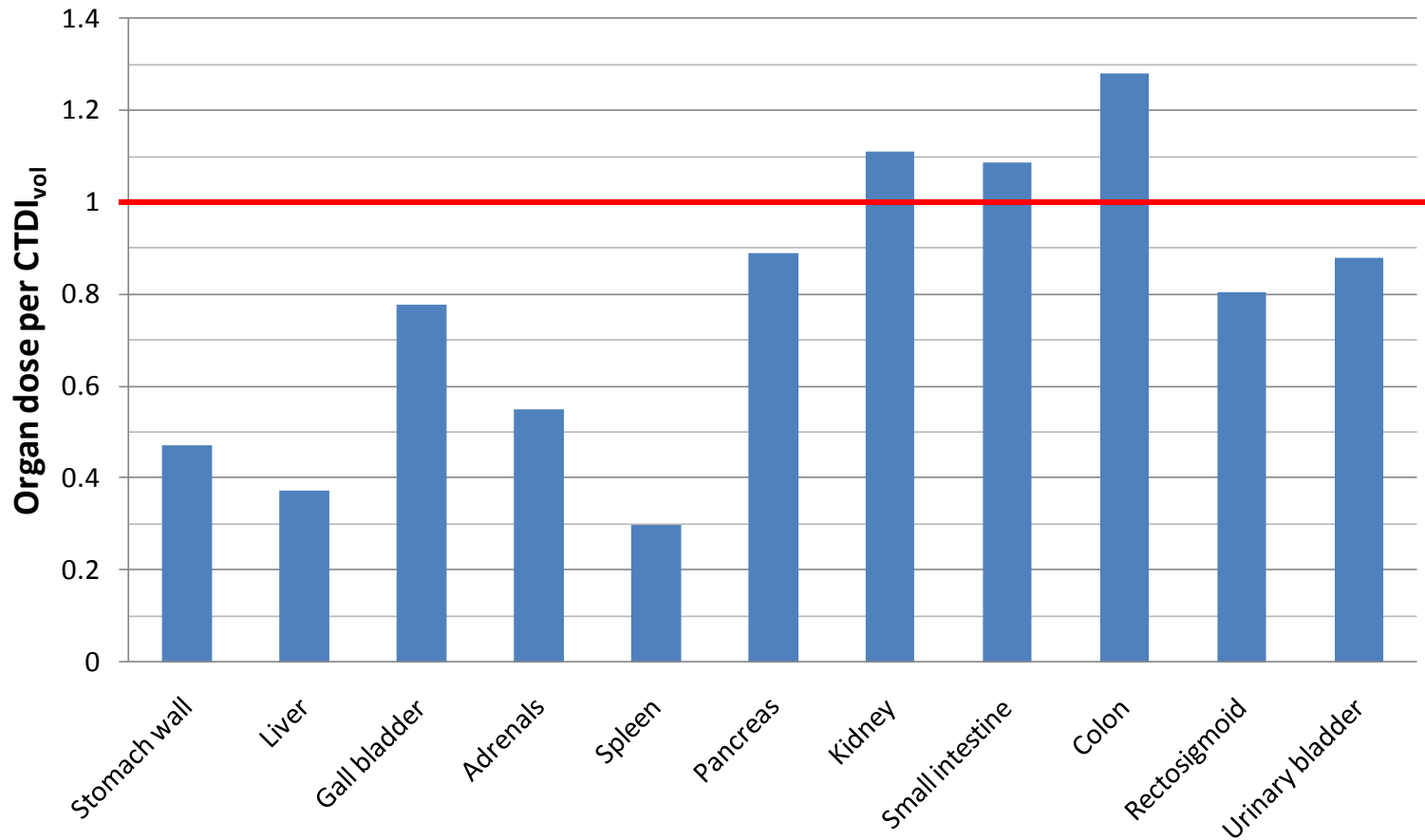
CTDI body (left) and head (right) phantoms



* ImPACT group (<http://impactscan.org>)

CTDI_{vol} vs. organ dose

Organ dose per CTDI_{vol} 32 cm (AP scan of adult male)*



* Lee et al. Medical Physics (2011)

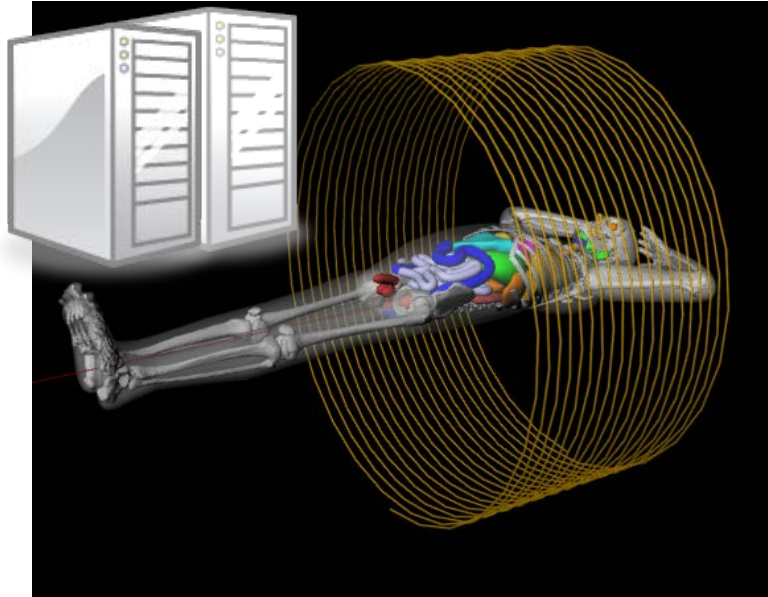
Two approaches to organ dose estimation in CT

MEASUREMENT



- **Reliable**
- Expensive
- Substantial man-hour
- Not flexible

CALCULATION



- **Validation required**
- Cost-effective
- Fewer man-hour
- More flexible

Content

- Basics in CT dosimetry
- Development of NCICT
 - Algorithm
 - Dose libraries
 - Graphical User Interface
- Selected applications
- Ongoing efforts

Algorithm for organ dose calculations

Scanner Model 1



Scanner Model 2



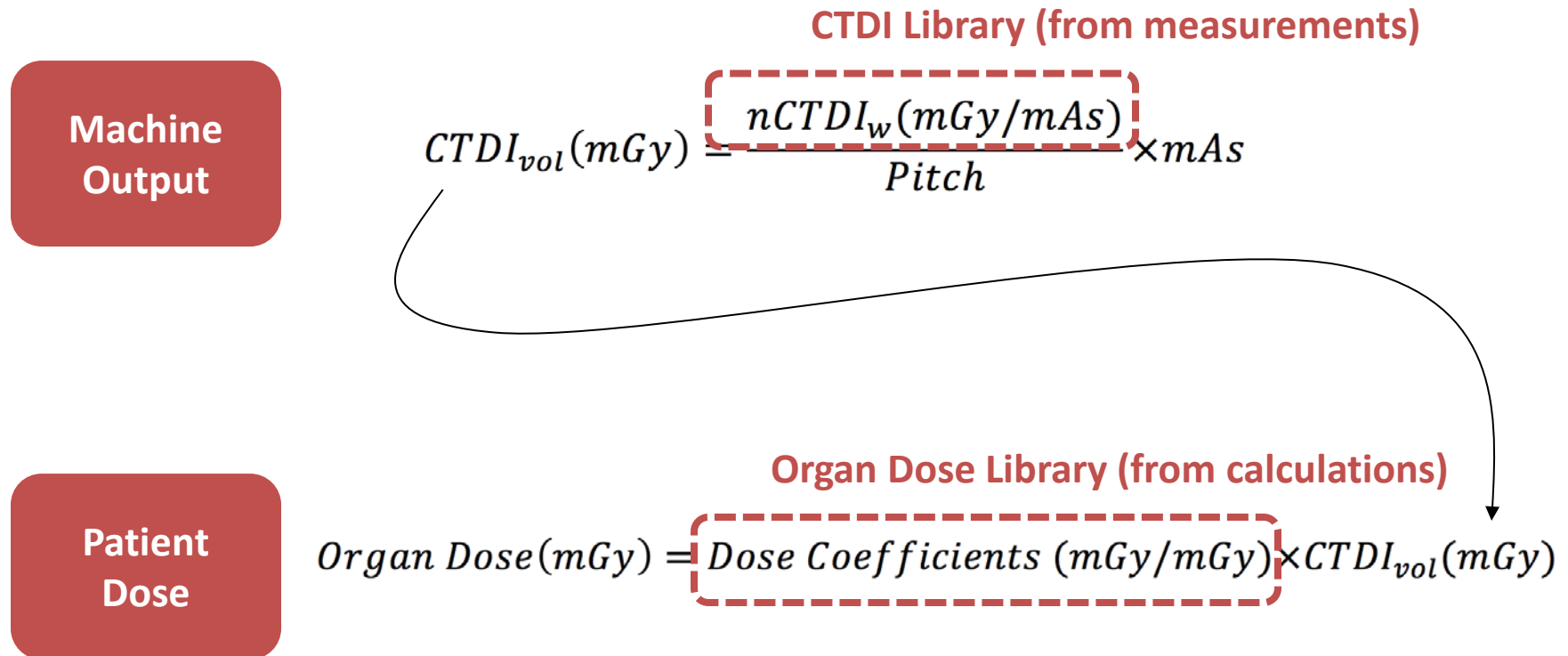
Scanner Model 3

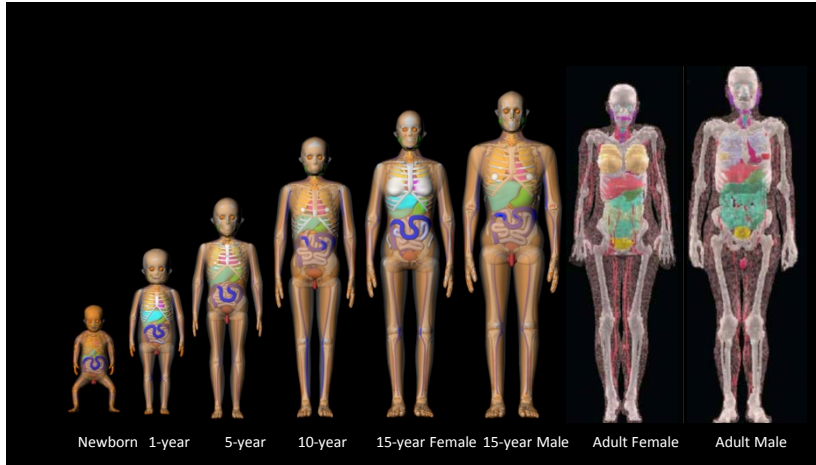


$$\frac{\text{Organ Dose 1}}{CTDI_{vol1}} \cong \frac{\text{Organ Dose 2}}{CTDI_{vol2}} \cong \frac{\text{Organ Dose 3}}{CTDI_{vol3}}$$

*COV less than 5% (Turner et al. MP 2010)

Algorithm for organ dose calculations



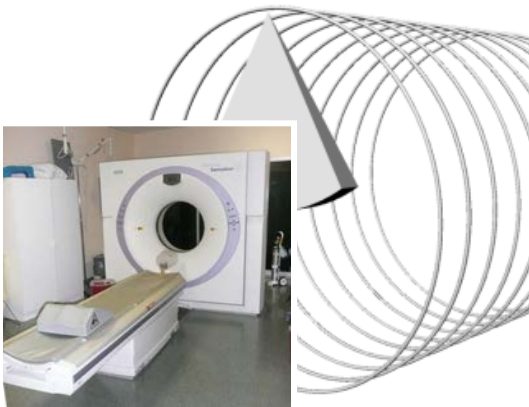


ICRP Reference Phantoms

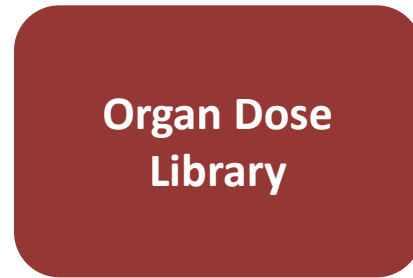


Experimental Validation

- UK Survey
- German Survey
- NEXT Survey (US FDA)
- NLST measurement



Reference CT Scanner Model
(Siemens Sensation 16)



Organ dose normalized to $CTDI_{vol}$ (mGy/mGy)



$CTDI_w$ normalized to mAs (mGy/mAs)

Experimental validation: 9-month and adult physical phantoms



Fiber-optic coupled plastic
scintillator dosimeter

9-month (left) and adult (right) male physical phantoms
(University of Florida)

Comparison of organ dose (mGy) for the 9-month physical phantom
between simulation and measurement

Organ	Simulated Dose (mGy)	Measured Dose (mGy)	Percent Difference
Brain	11.4	12.0	-5.2
Thyroid	15.9	16.9	-5.9
Thymus	13.5	13.8	-2.3
Lungs	14.1	13.8	2.1
Heart	14.6	15.1	-3.3
Liver	13.2	14.0	-6.0
Stomach	13.5	13.8	-2.1
Gall Bladder	13.3	12.8	3.9
Pancreas	13.1	14.9	-12.3
Kidneys	13.2	12.5	5.6
Adrenals	12.2	12.5	-2.3
Urinary Bladder	14.0	14.9	-6.2
Testes	13.8	12.2	12.8

* Long et al. Medical Physics (2013)

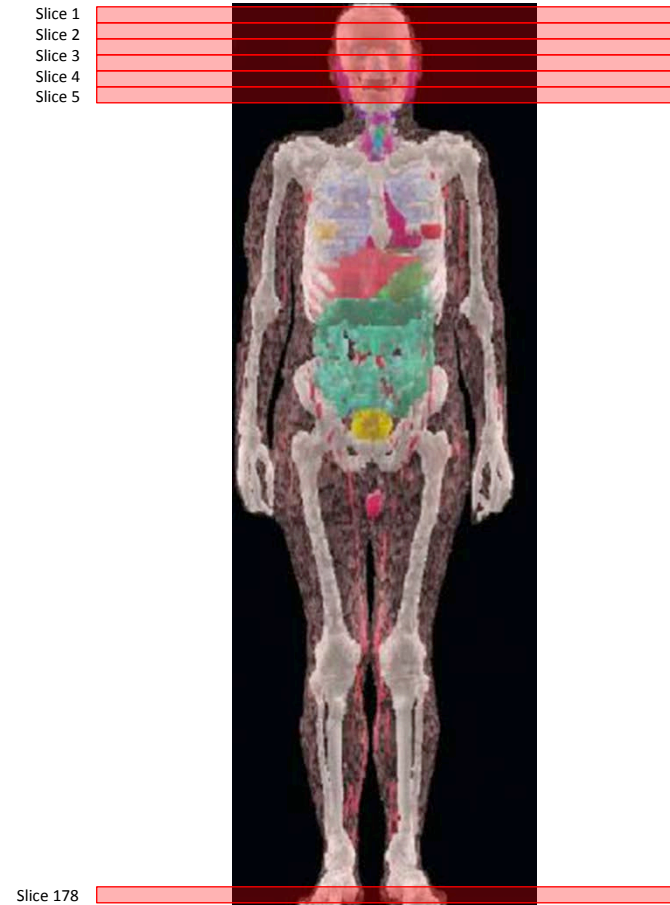
Comparison of organ dose (mGy) for the adult male physical phantom between simulation and measurement

Scan	Organ	Measured Dose (mGy)	Simulated Dose (mGy)	Relative Error
Head (Head Filter)	Brain	14.21	13.77	-3.1%
	Salivary glands	17.25	16.20	-6.1%
	Thyroid	2.54	2.42	-4.7%
	Eyeballs	18.95	17.37	-8.3%
Head (Body Filter)	Brain	11.64	10.19	-12.5%
	Salivary glands	13.64	11.99	-12.1%
	Thyroid	2.00	1.79	-10.5%
	Eyeballs	14.84	12.86	-13.3%
Chest	Thyroid	8.65	7.70	-11.0%
	Lungs	7.81	7.10	-9.1%
	Breast	11.19	7.20	-35.7%
	Esophagus	5.65	5.50	-2.7%
	Heart	7.97	7.30	-8.4%
Abdomen/Pelvis	Stomach	4.80	4.20	-12.5%
	Liver	3.43	3.60	5.0%
	Kidneys	6.92	6.90	-0.3%
	Colon	7.92	7.60	-4.0%
	Small Intestines	7.30	6.30	-13.7%
	Bladder	5.93	5.50	-7.3%
	Testes	0.74	0.80	8.1%
	Prostate	2.79	3.20	14.7%

* Long et al. Medical Physics (2013)

Organ dose library

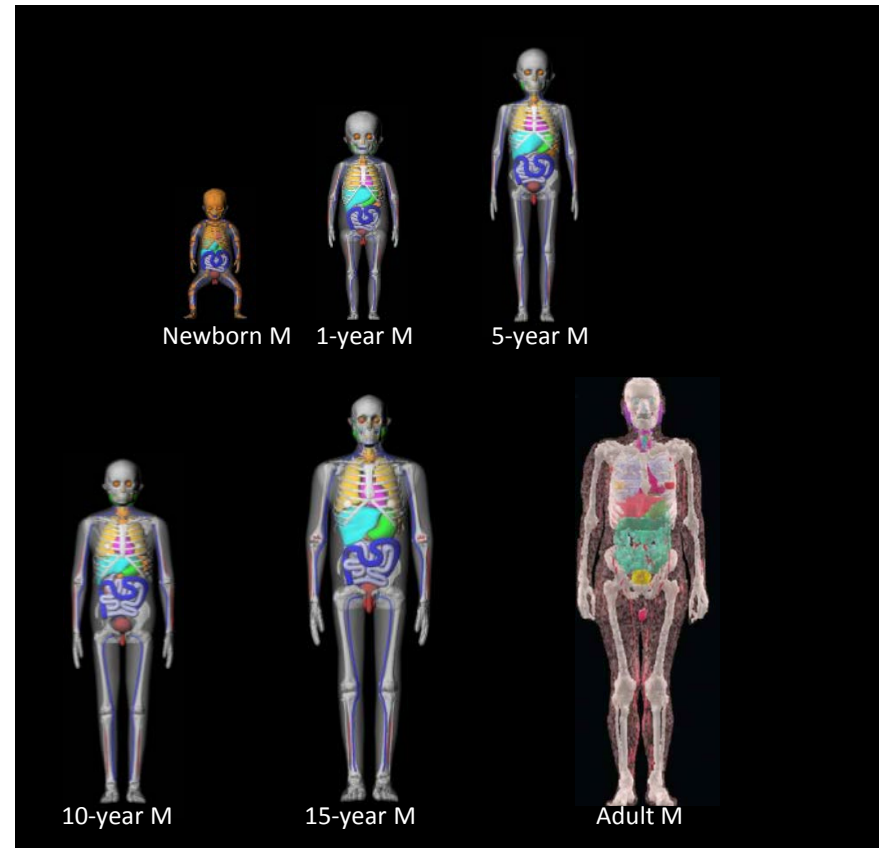
Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4	Slice 5	Slice 176
Brain	3.55E-02	1.42E-01	3.29E-01	5.61E-01	7.71E-01	9.35E-01
Pituitary Gland	1.55E-02	6.49E-02	1.10E-01	1.73E-01	2.51E-01	2.94E+00
Lens	3.01E-03	1.22E-02	2.08E-02	4.19E-02	6.71E-02	6.99E-01
Eye balls	4.02E-03	1.49E-02	2.99E-02	5.19E-02	7.40E-02	1.30E+00
Salivary Glands	2.74E-03	5.43E-03	8.98E-03	1.28E-02	1.63E-02	6.25E-02
Oral cavity layer	2.15E-03	5.65E-03	1.12E-02	1.38E-02	1.97E-02	8.13E-02
Spinal Cord	1.32E-03	1.62E-03	2.32E-03	2.64E-03	3.58E-03	9.84E-03
Thyroid	1.92E-03	3.22E-03	2.56E-03	3.77E-03	4.03E-03	1.09E-02
Esophagus	9.43E-04	1.15E-03	9.77E-04	1.55E-03	1.83E-03	3.42E-03
Trachea	2.26E-03	2.53E-03	1.81E-03	2.44E-03	3.42E-03	8.00E-03
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03	2.08E-03	5.16E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03	2.08E-03	4.33E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04	5.72E-04	1.98E-03
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04	9.12E-04	1.74E-03
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04	2.14E-04	3.78E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04	2.42E-04	5.10E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05	9.66E-05	2.58E-04
Adrenal	3.15E-04	3.75E-04	1.34E-04	6.73E-05	2.47E-04	2.62E-04
Spleen	1.50E-04	2.54E-04	2.65E-04	2.04E-04	2.26E-04	5.55E-04
Pancreas	4.58E-05	5.84E-05	8.11E-05	7.46E-05	8.37E-05	2.11E-04
Kidney	4.56E-05	7.83E-05	7.10E-05	5.23E-05	1.35E-04	1.64E-04
SI W	1.99E-05	3.19E-05	2.35E-05	1.80E-05	2.31E-05	5.67E-05
Colon W	1.37E-05	1.30E-05	2.49E-05	3.38E-05	2.55E-05	9.40E-05
Rectosigmoid	4.51E-06	9.17E-06	2.86E-05	2.36E-05	1.58E-07	1.78E-05
Urinary bladder	4.92E-07	5.18E-06	1.96E-07	1.49E-05	4.66E-06	5.42E-06
Prostate	0.00E+00	6.95E-05	7.97E-07	0.00E+00	1.06E-04	6.47E-05
Testes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Skin	1.56E-02	2.77E-02	3.72E-02	4.35E-02	4.78E-02	5.71E-02
Muscle	1.94E-03	4.68E-03	7.24E-03	8.36E-03	8.68E-03	1.36E-02
Active marrow	1.08E-02	7.84E-02	1.07E-01	1.03E-01	9.62E-02	8.61E-02



Organ dose library

Expand to 6 ages (male)

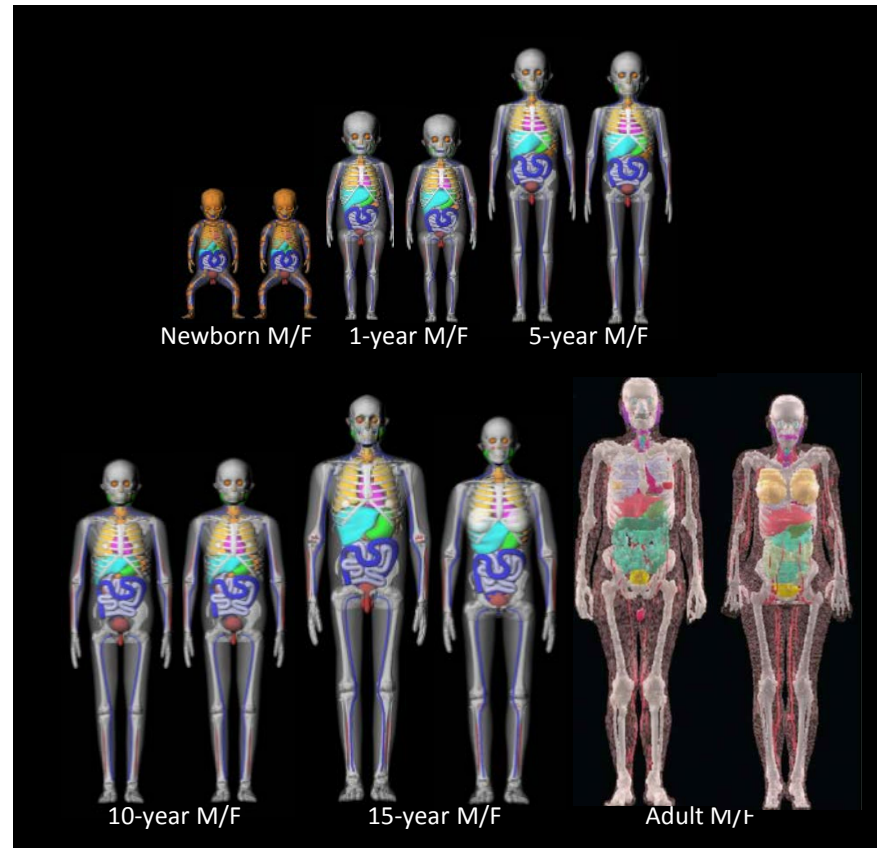
Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4
Brain	3.55E-02	1.42E-01	3.29E-01	5.61E-01
Pituitary Gland	1.55E-02	6.49E-02	1.10E-01	1.73E-01
Lens	3.01E-03	1.22E-02	2.08E-02	4.19E-02
Eye balls	4.02E-03	1.49E-02	2.99E-02	5.19E-02
Salivary Glands	2.74E-03	5.43E-03	8.98E-03	1.28E-02
Oral cavity layer	2.15E-03	5.65E-03	1.12E-02	1.38E-02
Spinal Cord	1.32E-03	1.62E-03	2.32E-03	2.64E-03
Thyroid	1.92E-03	3.22E-03	2.56E-03	3.77E-03
Esophagus	9.43E-04	1.15E-03	9.77E-04	1.55E-03
Trachea	2.26E-03	2.53E-03	1.81E-03	2.44E-03
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05



Organ dose library

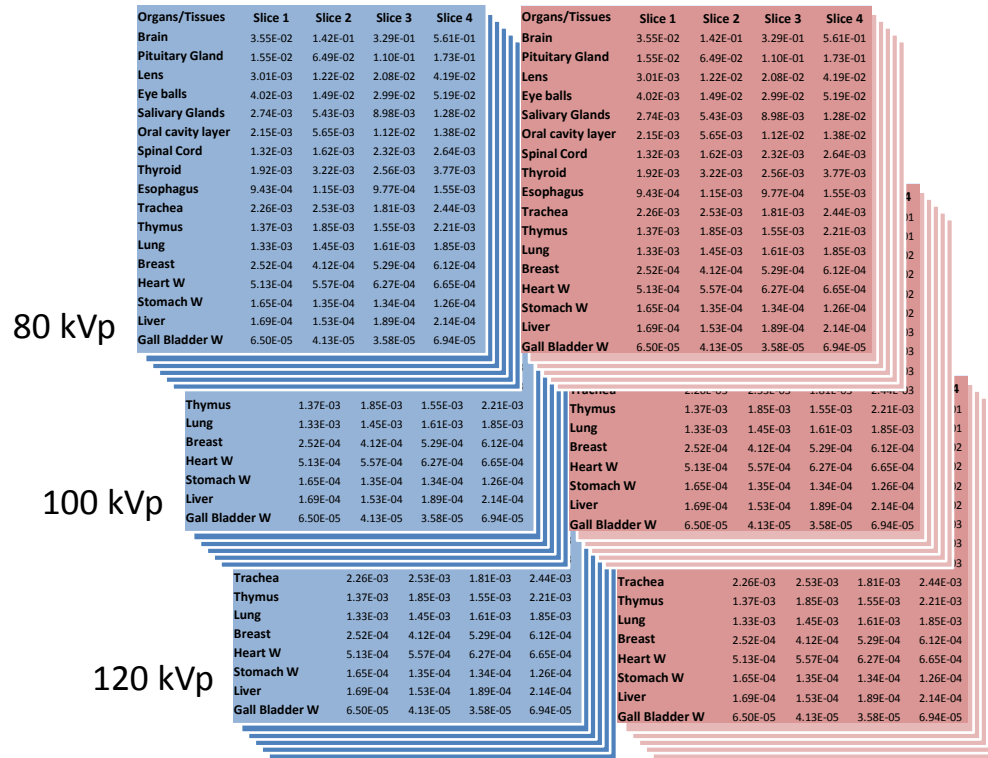
Expand to female phantoms

Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4
Brain	3.55E-02	1.42E-01	3.29E-01	5.61E-01
Pituitary Gland	1.55E-02	6.49E-02	1.10E-01	1.73E-01
Lens	3.01E-03	1.22E-02	2.08E-02	4.19E-02
Eye balls	4.02E-03	1.49E-02	2.99E-02	5.19E-02
Salivary Glands	2.74E-03	5.43E-03	8.98E-03	1.28E-02
Oral cavity layer	2.15E-03	5.65E-03	1.12E-02	1.38E-02
Spinal Cord	1.32E-03	1.62E-03	2.32E-03	2.64E-03
Thyroid	1.92E-03	3.22E-03	2.56E-03	3.77E-03
Esophagus	9.43E-04	1.15E-03	9.77E-04	1.55E-03
Trachea	2.26E-03	2.53E-03	1.81E-03	2.44E-03
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05



Organ dose library

Expand to 80, 100, and 120 kVp



Organ dose library

Expand to Head and Body filters

Head Filter

Body Filter

80 kVp

Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4
Brain	3.55E-02	1.42E-01	3.29E-01	5.61E-01
Pituitary Gland	1.55E-02	6.49E-02	1.10E-01	1.73E-01
Lens	3.01E-03	1.22E-02	2.08E-02	4.19E-02
Eye balls	4.02E-03	1.49E-02	2.99E-02	5.19E-02
Salivary Glands	2.74E-03	5.43E-03	8.98E-03	1.28E-02
Oral cavity layer	2.15E-03	5.65E-03	1.12E-02	1.38E-02
Spinal Cord	1.32E-03	1.62E-03	2.32E-03	2.64E-03
Thyroid	1.92E-03	3.22E-03	2.56E-03	3.77E-03
Esophagus	9.43E-04	1.15E-03	9.77E-04	1.55E-03
Trachea	2.26E-03	2.53E-03	1.81E-03	2.44E-03
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05

100 kVp

Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05

120 kVp

Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4
Trachea	2.26E-03	2.53E-03	1.81E-03	2.44E-03
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05

80 kVp

Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4
Brain	3.55E-02	1.42E-01	3.29E-01	5.61E-01
Pituitary Gland	1.55E-02	6.49E-02	1.10E-01	1.73E-01
Lens	3.01E-03	1.22E-02	2.08E-02	4.19E-02
Eye balls	4.02E-03	1.49E-02	2.99E-02	5.19E-02
Salivary Glands	2.74E-03	5.43E-03	8.98E-03	1.28E-02
Oral cavity layer	2.15E-03	5.65E-03	1.12E-02	1.38E-02
Spinal Cord	1.32E-03	1.62E-03	2.32E-03	2.64E-03
Thyroid	1.92E-03	3.22E-03	2.56E-03	3.77E-03
Esophagus	9.43E-04	1.15E-03	9.77E-04	1.55E-03
Trachea	2.26E-03	2.53E-03	1.81E-03	2.44E-03
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05

100 kVp

Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05

120 kVp

Organs/Tissues	Slice 1	Slice 2	Slice 3	Slice 4
Trachea	2.26E-03	2.53E-03	1.81E-03	2.44E-03
Thymus	1.37E-03	1.85E-03	1.55E-03	2.21E-03
Lung	1.33E-03	1.45E-03	1.61E-03	1.85E-03
Breast	2.52E-04	4.12E-04	5.29E-04	6.12E-04
Heart W	5.13E-04	5.57E-04	6.27E-04	6.65E-04
Stomach W	1.65E-04	1.35E-04	1.34E-04	1.26E-04
Liver	1.69E-04	1.53E-04	1.89E-04	2.14E-04
Gall Bladder W	6.50E-05	4.13E-05	3.58E-05	6.94E-05

Organ dose library

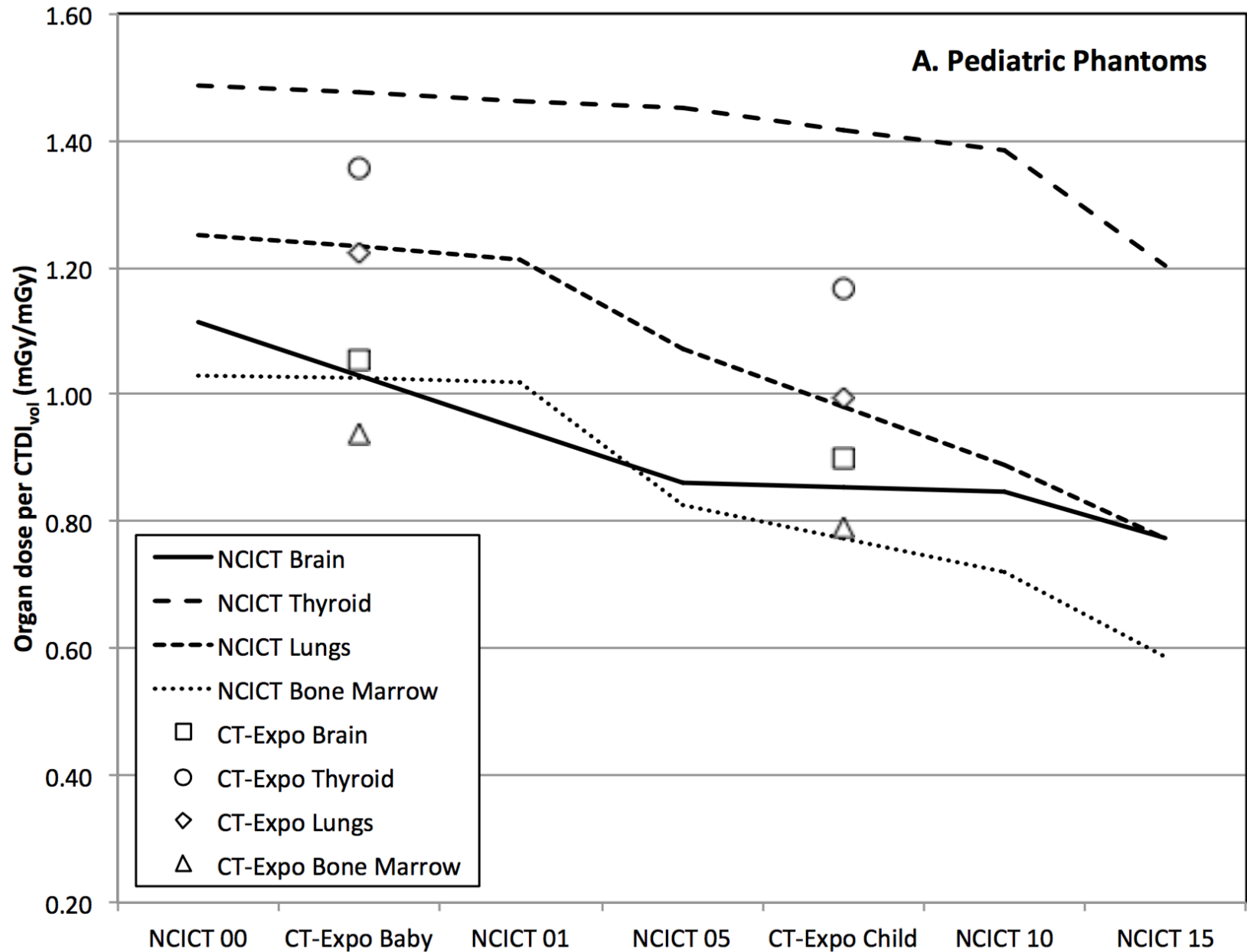
- Dose (organ, slice, age, sex, spectra) (5 dimensional array)
 - Organ: 31 organs and tissues including active marrow
 - Slice: 49 (newborn) – 178 (adult male) slices with 10 mm thickness
 - Age: 6 ages (newborn, 1, 5, 10, 15, and adult)
 - Sex: 2 genders (male and female)
 - Spectra: 3 tube potentials (80, 100, and 120 kVp) and 2 filters
- MCNPX runs
 - 8,520 input files
 - Took two weeks using Mac Pro server (24 cores)
 - 277,080 organ doses + 5,325,006 skeleton fluence
 - Automated pre- and post-processing using MATLAB script



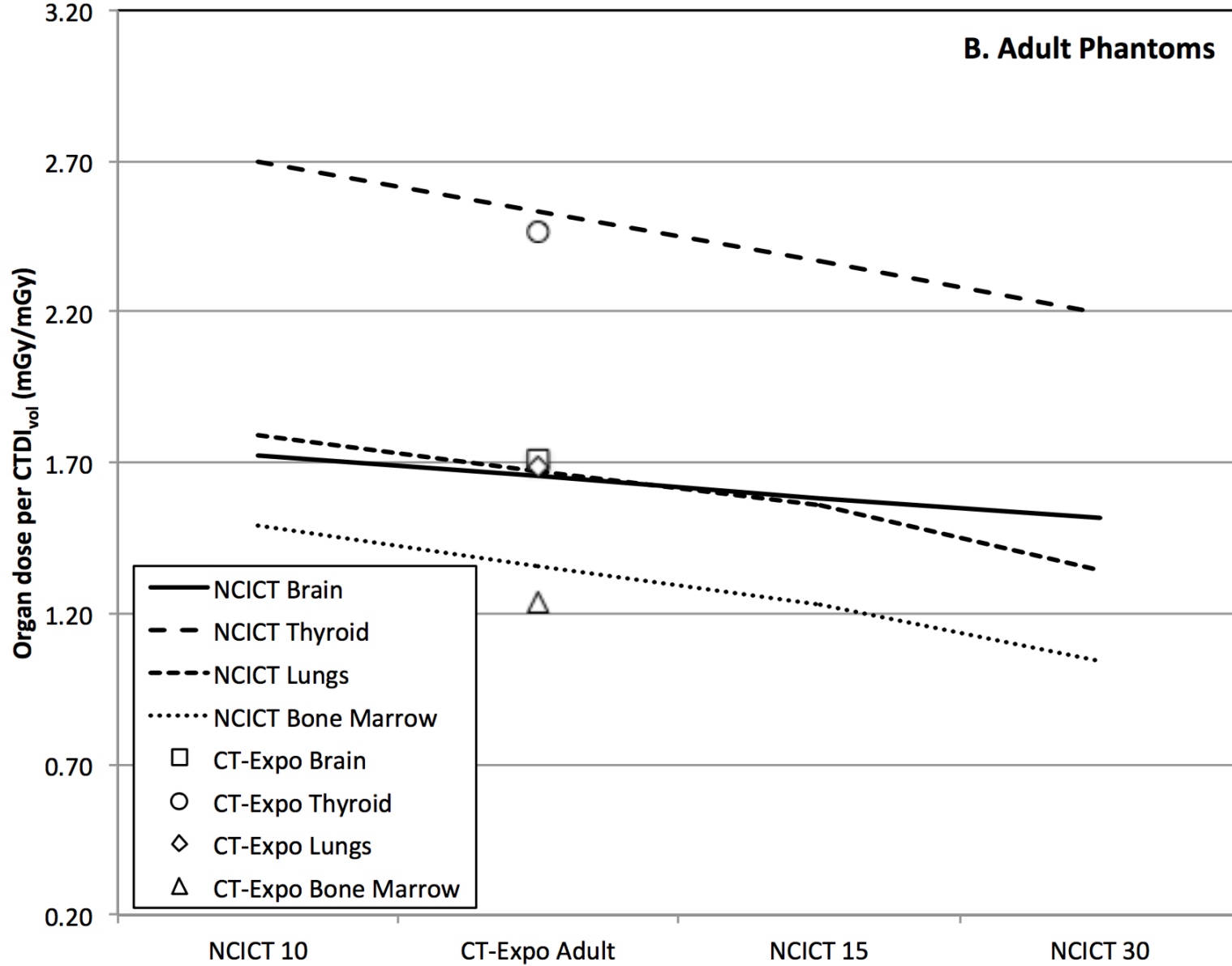
Mac Pro server with 12 cores and 64 GB RAM

Comparison of organ doses with CT-Expo

A. Pediatric Phantoms



Comparison of organ doses with CT-Expo



CTDI library

- Measurements of n CTDI_w (mGy/mAs) for
 - Head and body CTDI phantoms
 - 80, 100, 120, and 140 kVp
 - Collimation of 10 mm

	UK	Germany	USA	Merged
GE	17	27	10	28
Philips	13	17	2	23
Siemens	16	35	3	38
Toshiba	16	34	8	42
Elscint	2	7	5	10
Picker	3	7	2	9
Shimadzu	1	6	0	6
Hitachi	0	5	0	5
Total	68	138	30	161

NCICT version 1.0
File Batch Help

Patient parameters

Age: Adult

Gender: Male Female

Height: 178

Weight: 73

Scanner parameters

Manufacturer: Siemens

Model: Somatom Definition Flash (flash)

Head filter Body filter

nCTDIw (mGy/100mAs): 5.521

Total collimation (mm): 38.4

Pitch: 1

Tube potential (kVp): 120

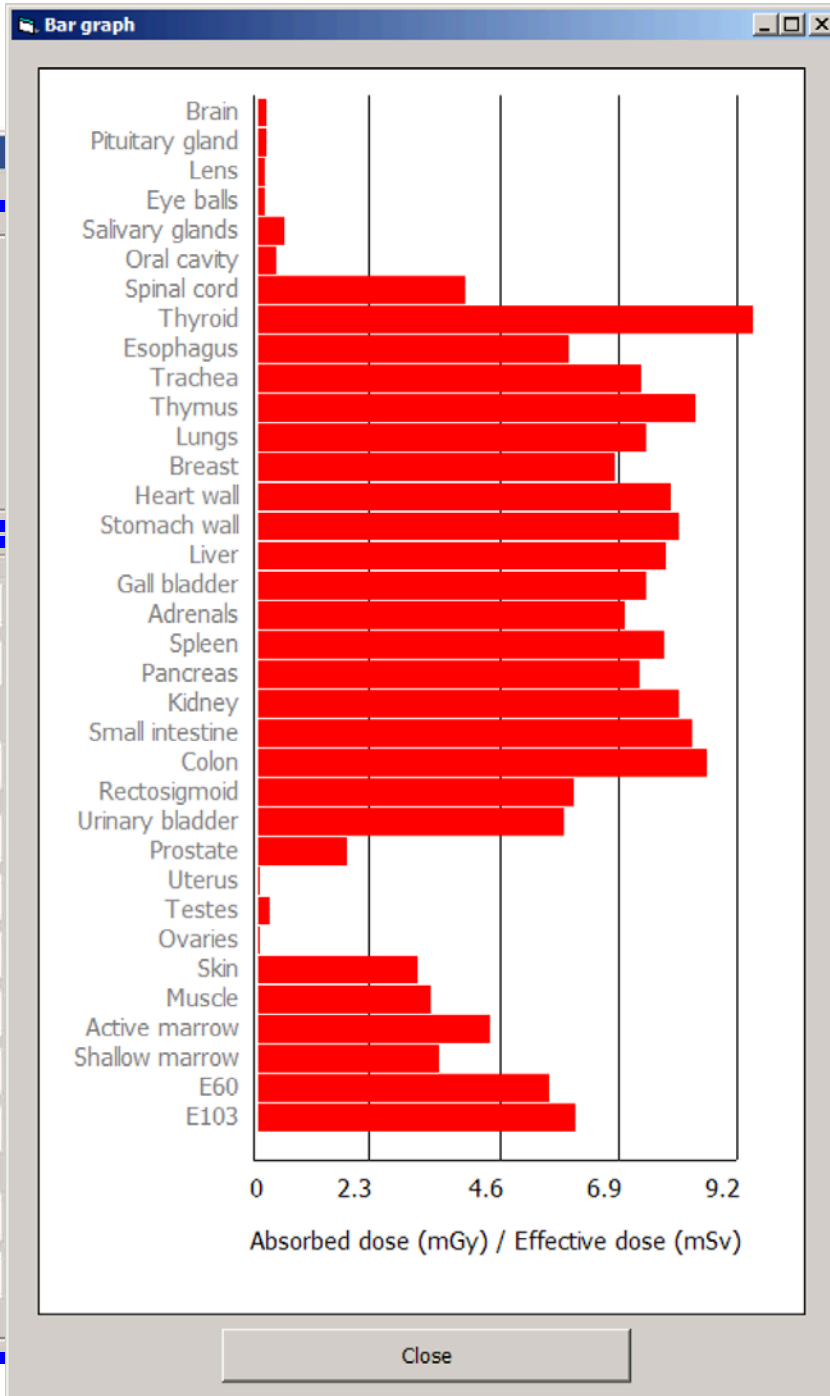
Current x Time (mAs): 100

CTDIvol (mGy): 5.521

DLP (mGycm): 320.218

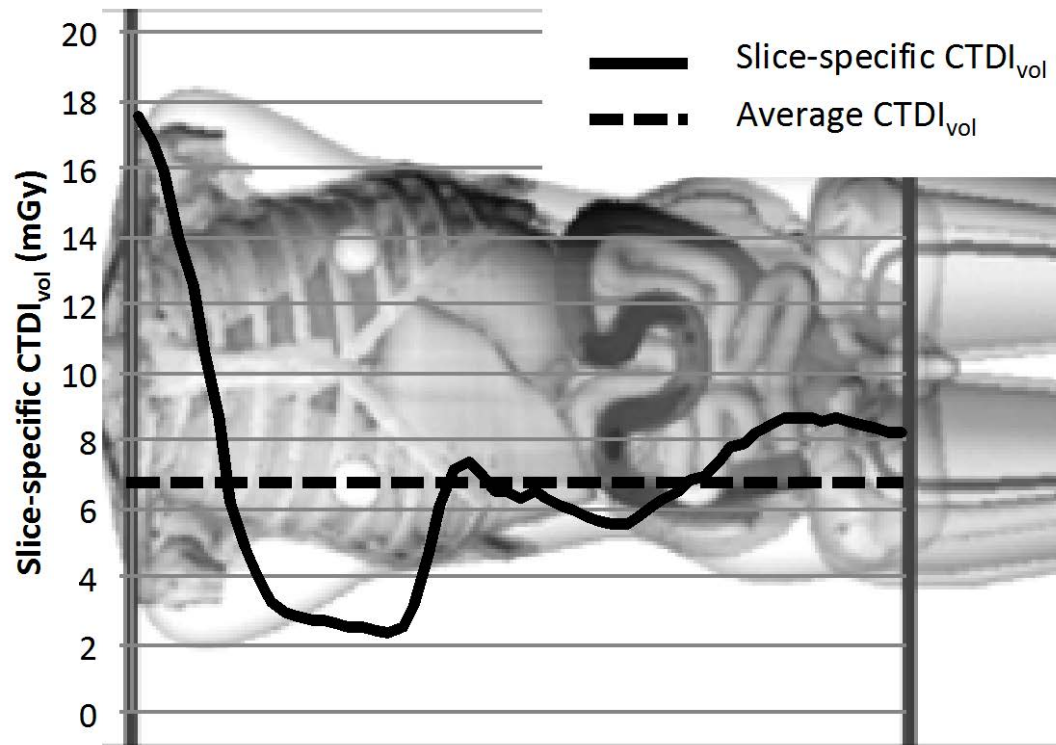
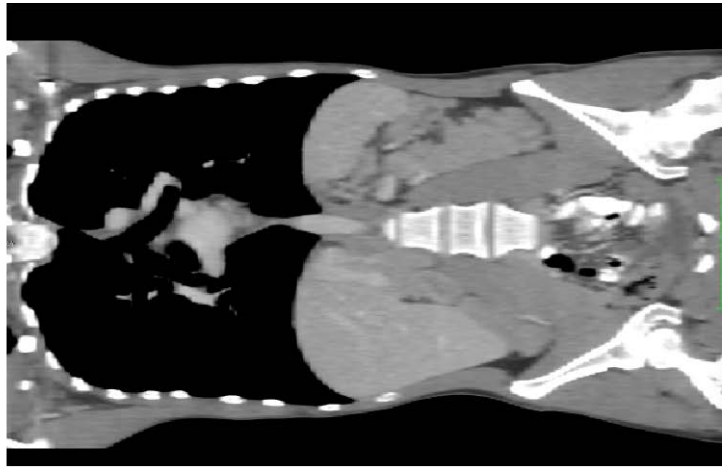
Effective Diameter (cm): 42.32

SSDE (mGy): 4.275



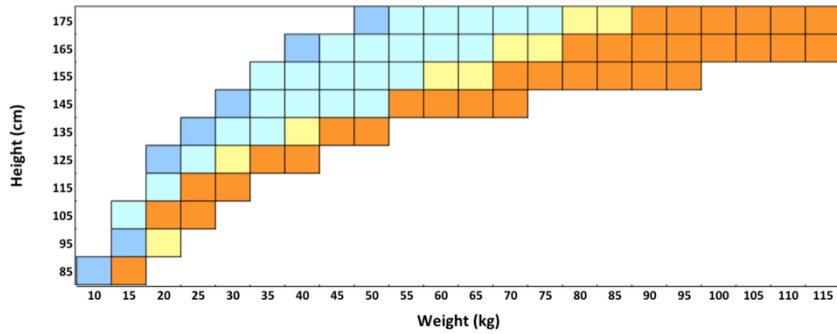
Organ absorbed dose (mGy)

Organ	Dose (mGy)
Brain	0.104
Pituitary gland	0.121
Lens	0.095
Eye balls	0.087
Salivary glands	0.457
Oral cavity	0.28
Spinal cord	3.826
Thyroid	9.213
Esophagus	5.73
Trachea	7.058
Thymus	8.077
Lungs	7.175
Breast	6.599
Heart wall	7.622
Stomach wall	7.812
Liver	7.554
Gall bladder	7.184
Adrenals	0
Spleen	7.569
Pancreas	7.057
Kidney	7.853
Small intestine	8.041
Colon	8.332
Rectosigmoid	5.862
Urinary bladder	5.638
Prostate	1.6
Uterus	0
Testes	0.165
Ovaries	0
Skin	2.929
Muscle	3.175
Active marrow	4.277
Shallow marrow	3.343
E60	5.353
E103	5.811

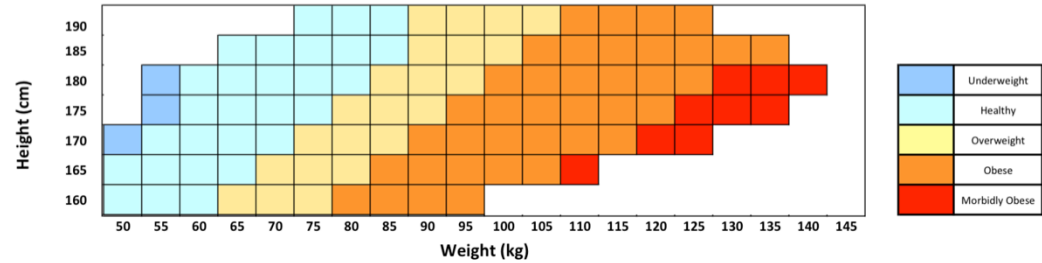


NCICT-eXtended

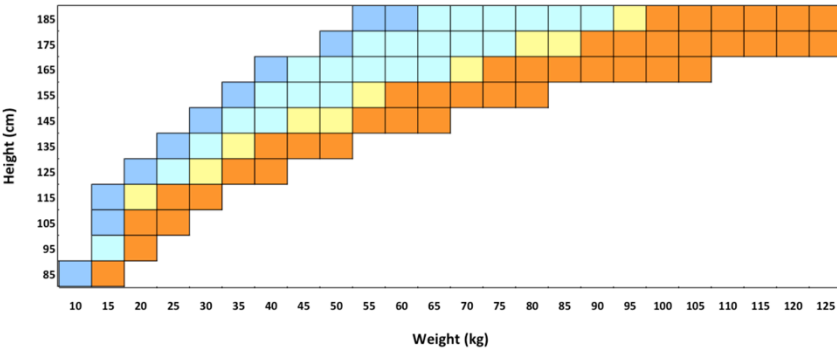
Pediatric Female



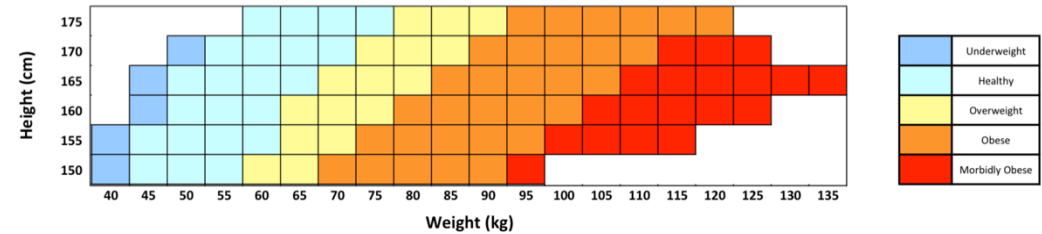
Adult Female



Pediatric Male



Adult Male



Extension of Organ Dose Library

Dose (organ, slice, **6 ages, 2 genders**, spectra)



Dose (organ, slice, **pediatric/adult, 170 phantoms**, spectra)

- Dose library calculations completed (took 7 months)
- NCICT-eXtended will be published/released in 2016

Improvements over the existing tools

	Existing Tools	NCICT
Phantoms	Unrealistic stylized or non-reference phantoms	Most realistic ICRP reference phantoms
Scanner models	Limited scanner library	Extend from literatures
Body size	Fixed body size phantoms	Size-dependent phantoms
Bone marrow dosimetry	Developed in 1980s	Up-to-date ICRP model
Tube current modulation	Partially available	Available
Accessibility	Commercial	Publicly available

Content

- Basics in CT dosimetry
- Development of NCICT
- **Selected applications**
- Ongoing efforts

I. Dosimetry for UK-NCI CT Cohort Study

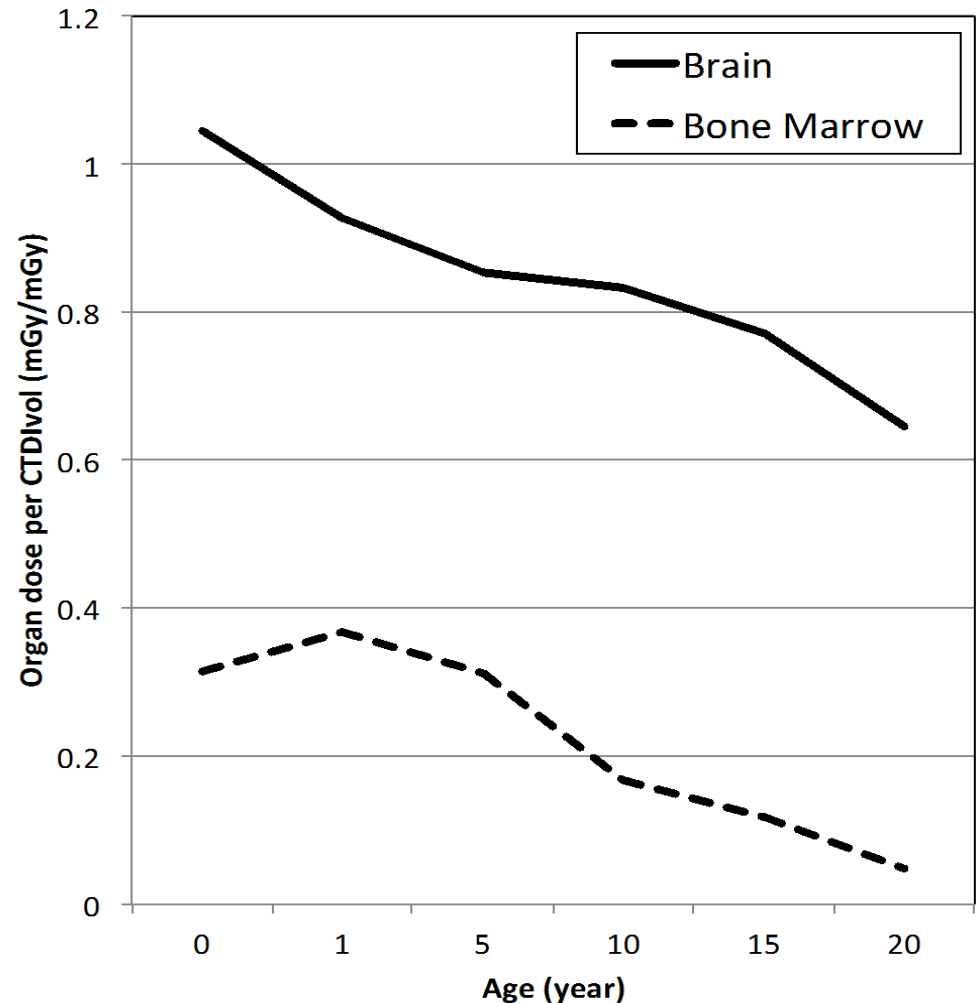
- Retrospective epidemiological cohort study*
 - 180,000 pediatric and young adults (< 22 years) in the UK
 - CT scans performed 1985 – 2002
 - With no prior history of malignancy
- Organ dosimetry for the cohort**
 - Patient age, sex, scan region, and scan year collected
 - Scanner parameters from 1989 and 2003 UK survey data
 - Brain and bone marrow doses calculated by NCICT

*Pearce, Little ... Lee ... Berrington *The Lancet* 2012

**Kim et al. *Rad Prot Dosim* 2012

Example dose calculated for head CT

- Brain and bone marrow dose normalized by scanner output
- Newborn receives 1.6× and 6.5× greater brain and marrow doses than adult, respectively.
- Newborn brain dose is 3.6× greater than the newborn bone marrow.



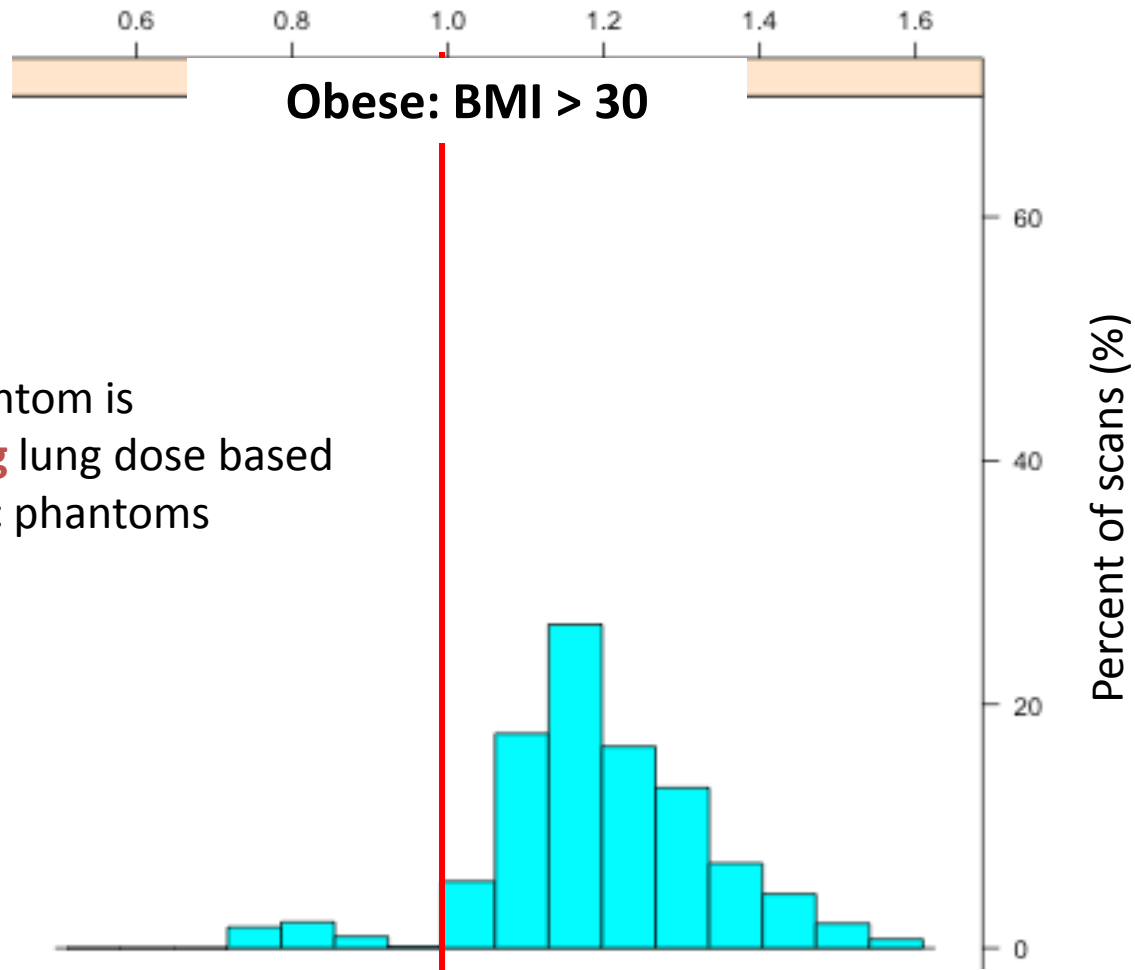
II. Dosimetry for National Lung Screening Trial

Collaborators: NLST Physics Group

- National Lung Screening Trial (NLST)
 - Compares two ways of detecting lung cancer: CT vs. chest x-ray
 - 53,454 current or former heavy smokers (ages 55 – 74)
 - Found that CT screening will reduce lung cancer mortality 15-20% more than chest X-rays*
- 23,773 CT scans (body size available) identified.
- Patient ID, gender, height, weight, scan length, kVp, mAs, and $CTDI_{vol}$ were collected from DICOM data
- Calculate organ doses using NCICT-X

Results: Lung dose comparison

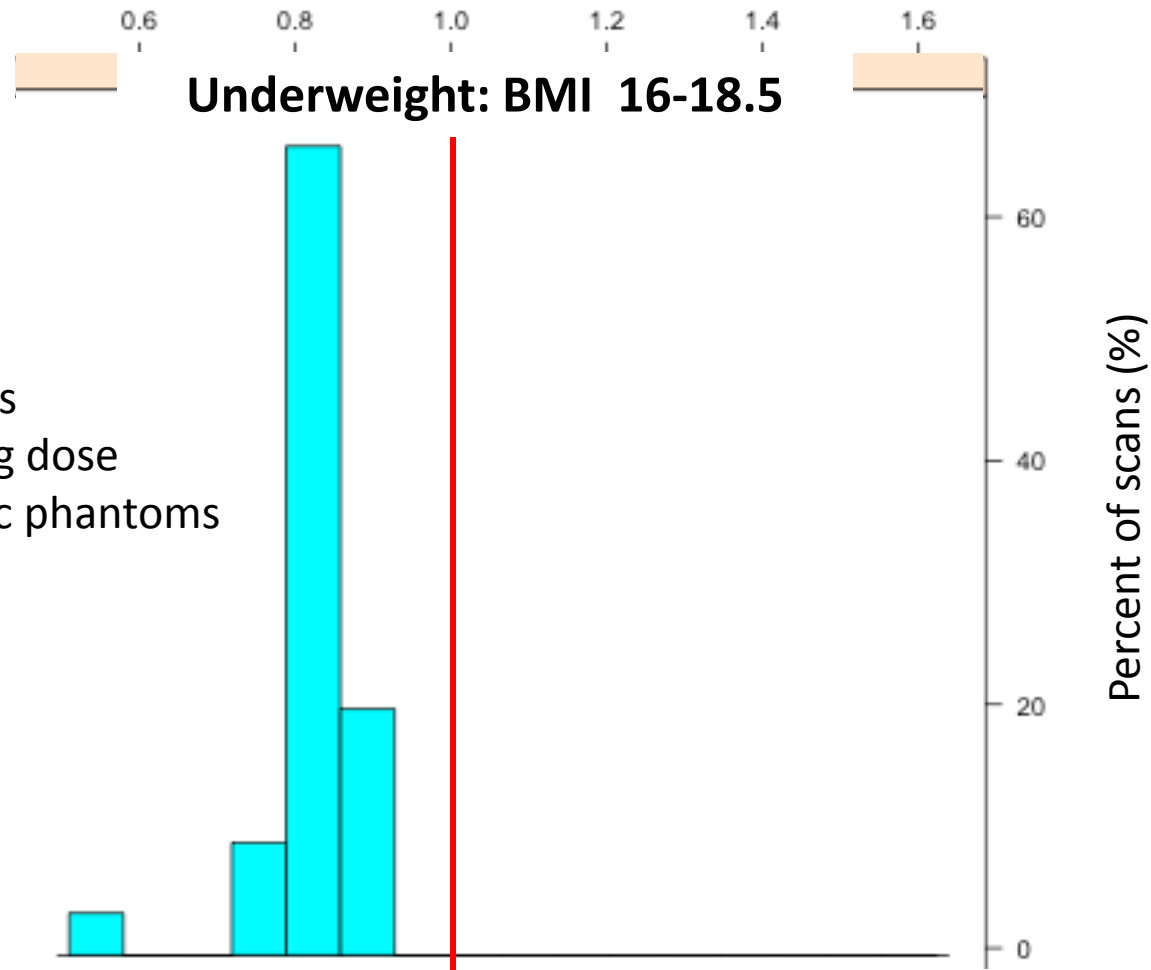
Ratio of lung doses from reference phantoms to those from size-specific



Reference phantom is **overestimating** lung dose based on size-specific phantoms

Results: Lung dose comparison

Ratio of lung doses from reference phantoms to those from size-specific



Reference phantom is **underestimating** lung dose based on size-specific phantoms

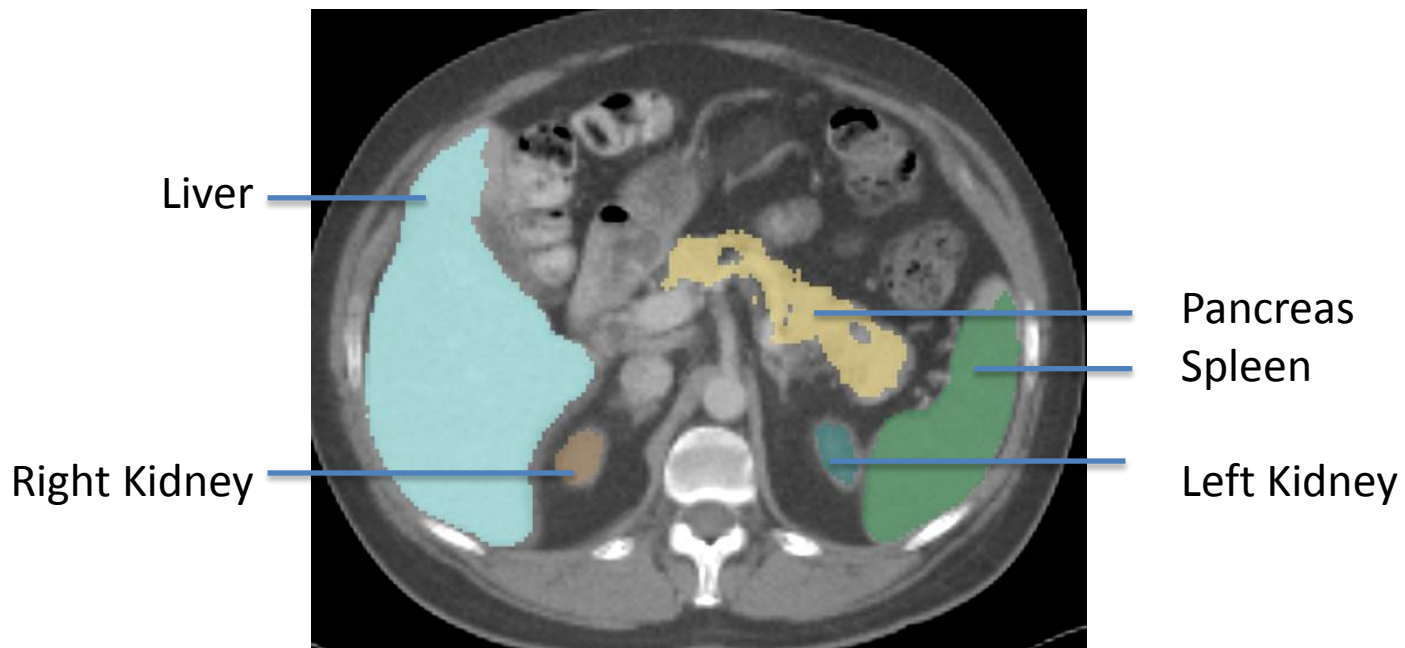
Content

- Basics in CT dosimetry
- Development of NCICT
- Selected applications
- Ongoing efforts
 - On-time organ dose calculations

On-time dose calculations

- Semi-automatic contouring of 8 different structures took less than 30 minutes per patient.

Organ volume (cm³)	1	2	3	4	5	6	7	8
Liver	2098	1244	1412	1356	1283	1833	1433	1260
Kidneys	165	152	179	150	123	182	146	138
Spleen	346	175	135	137	211	255	230	157
Pancreas	96	47	63	58	56	74	46	51



Methods

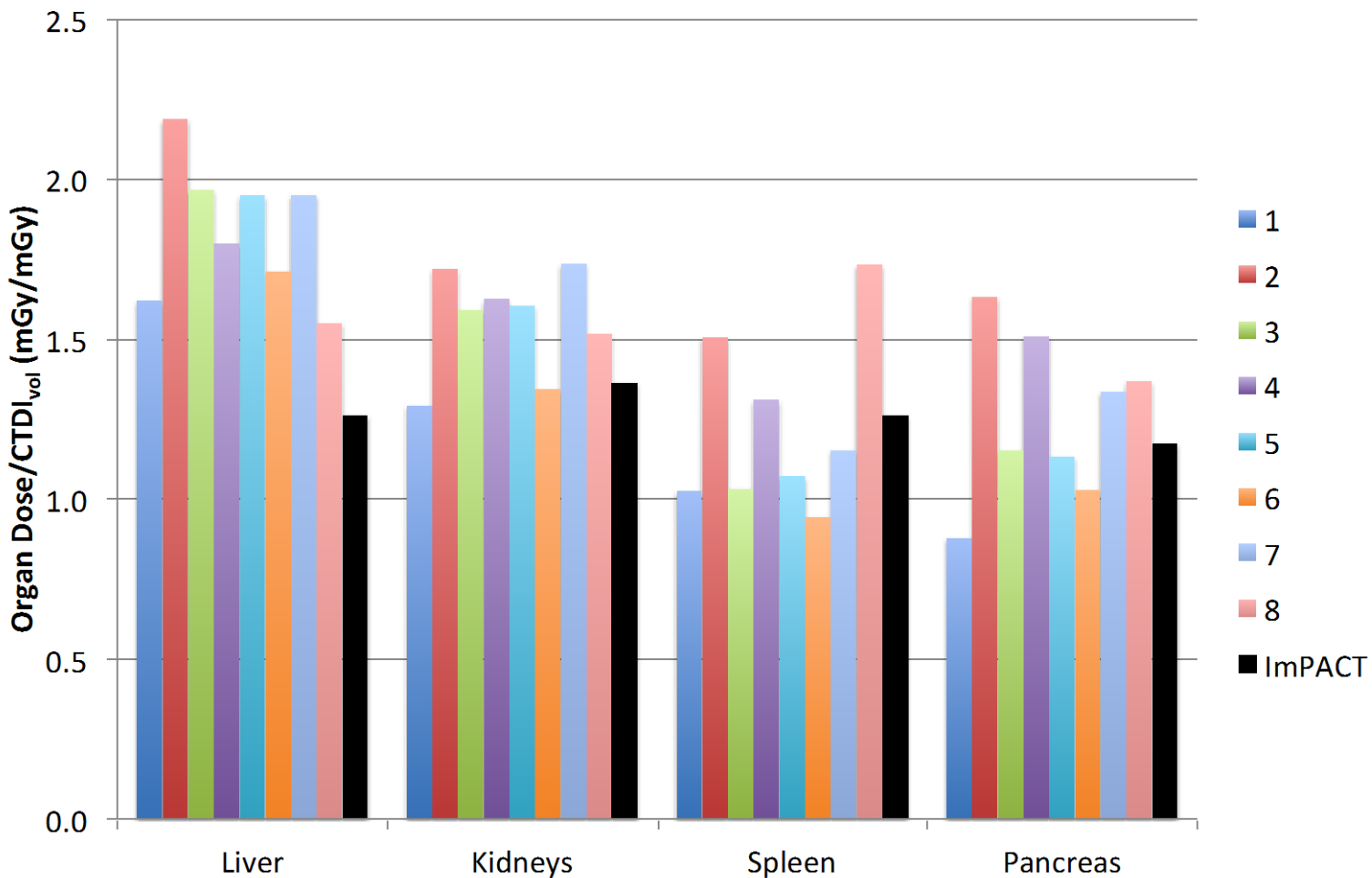
- Scan parameters were automatically abstracted from DICOM headers by using an in-house script.
- Scanner make and model, average mAs, and pitch were used to derive patient-specific $CTDI_{vol}^*$
- Abstracted parameters
 - 5 Siemens / 3 Phillips scanners
 - 24 – 29 cm scan length
 - 120 kVp
 - 171 – 330 average mAs
 - Pitch 0.8 – 1.08

Results

- The whole process (organ contouring, CT parameter abstraction, and Monte Carlo calculations) took less than an hour per patient.
- Maximum organ doses are up to 3-times (spleen, pancreas) greater than minimum organ doses.
- The dose variation across the patients is majorly attributed to different mAs, locations of organs, and patient body sizes.

Results

- Organ dose normalized to $CTDI_{vol}$ (mGy/mGy) vs. ImPACT



Content

- Basics in CT dosimetry
- Development of NCICT
- Selected applications
- Ongoing efforts

Quiz #1

Which of the following parameters have the least impact on lung doses in a chest CT scan?

1. Tube current-time product (mAs)
2. Tube potential (kVp)
3. Patient weight
4. Patient height

Quiz #1

Which of the following parameters have the least impact on lung doses in a chest CT scan?

1. Tube current-time product (mAs)
2. Tube potential (kVp)
3. Patient weight
4. Patient height (answer)

Quiz #2

If you want to calculate thyroid dose in a chest CT scan, which of the following information would be most useful?

1. CT scanner manufacturer
2. CT scanner model
3. $CTDI_{vol}$
4. Tube potential (kVp)

Quiz #2

If you want to calculate thyroid dose in a chest CT scan, which of the following information would be most useful?

1. CT scanner manufacturer
2. CT scanner model
3. $CTDI_{vol}$ (answer)
4. Tube potential (kVp)

Questions and Answers

U.S. Department of Health and Human Services
National Institutes of Health | National Cancer Institute

www.dceg.cancer.gov/RadEpiCourse

1-800-4-CANCER

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