CURRENT CT DOSE METRICS: MAKING CTDI SIZE-SPECIFIC

Keith Strauss, MSc, FAAPM, FACR
Cincinnati Children’s Hospital
University of Cincinnati College of Medicine
Acknowledgments

John Boone, PhD
Michael McNitt-Grey, PhD
Cynthia McCollough, PhD
Dianna Cody, PhD
Tom Toth, PhD
G. Donald Frey, PhD
INTRODUCTION

- CT Dose Indices
  - CTDI
  - CTDI\textsubscript{100}, CTDI\textsubscript{w}, CTDI\textsubscript{vol}
  - Displayed vs Measured CTDI\textsubscript{vol}
  - DLP
- Clinical Dilemma
- SSDE
- E Dose Limitations
- Simple Application of SSDE in the Clinic
- Estimating Organ Doses from SSDE
REAL WORLD ....

Radiation distribution crosses the imaged volume

- Peak dose
- “Tails” of dose distribution

Adapted from Frey
CTDI = Integral under the radiation dose profile along the z-axis from a single axial scan of width nT.

Adapted from Frey
Computed Tomography Dose Index (CTDI)

- Represents the average integrated absorbed dose along the z axis from a series of contiguous irradiations.

- CTDI_{100} represents accumulated multiple scan dose at center of 100 mm scan.
CT SCANNER DOSE INDICES

Measurement of CT Radiation Dose

Plastic cylindrical phantoms: CTDI Phantoms
  • (PMMA)
  • 16 & 32 cm diameter

• Pencil chamber moved into provided holes to measure radiation dose
  • Center of phantom

• Non measured holes plugged

Adapted from TG204
CT SCANNER DOSE INDICES

Measurement of CT Radiation Dose

Plastic cylindrical phantoms: CTDI Phantoms
• (PMMA)
• 16 & 32 cm diameter

• Pencil chamber moved into provided holes to measure radiation dose
  • Surface of phantom

• Non measured holes plugged

Adapted from TG204
CT SCANNER DOSE INDICES

Measurement of CT Radiation Dose

- 32 and 16 cm CTDI standard phantoms positioned to measure CT doses.

Images Courtesy of John Boone
CT SCANNER DOSE INDICES

Measurement of CT Radiation Dose

- Dose readings at two points in phantom
  - 1 cm below surface
  - Center
- Dose distribution depends on phantom diameter
Calculation of CTDI Values

- **Weighted CTDI**: $\text{CTDI}_w$
  - Average CTDI across the FoV
  - $\text{CTDI}_w = \frac{1}{3} \text{CTDI}_{100,\text{center}} + \frac{2}{3} \text{CTDI}_{100,\text{edge}}$
  - $\text{CTDI}_w = 17 + 66 = 83 \text{ mGy}$
    - for 32 cm CTDI phantom

Ave Dose over x & y direction
CT SCANNER DOSE INDICES

- Measured CTDI_{vol}
  - Measure CTDI_{vol} with **identical** scan parameters
    - kV
    - mA
    - Rotation time
    - **Bow Tie Filter**
  - Use phantom 10, 16, and 32 cm diameter
Measured CTDI$_{vol}$ increases 2.6 times as phantom size decreases!
CT SCANNER DOSE INDICES

Displayed CTDI$_{\text{vol}}$

- Dose that represents distribution of dose given to cross-sectional area of a slab of the CTDI phantom (16 or 32 cm diameter)
- Reflects changes in:
  - High voltage to x-ray tube (kV)
  - X-ray tube current (mA)
  - Rotation time (sec)
  - Pitch
  - Bow tie filter shape, thickness, material
  - Source to detector distance
CT SCANNER DOSE INDICES

Displayed CTDI$_{vol}$

- Standardized method to estimate and compare the radiation output of two different CT scanners to same phantom.
- Dose index of CT scanners if the fan beam width in z direction of the patient is small (< 1 cm)
- If fan beam width (> 1 cm), dose index addressed by AAPM TG111
CT SCANNER DOSE INDICES

Displayed $\text{CTDI}_{\text{vol}}$

- does not represent . . .

Patient dose!!
Measured $\text{CTDI}_{\text{vol}} = 47$

Displayed $\text{CTDI}_{\text{vol}16} = 37$
Displayed $\text{CTDI}_{\text{vol}32} = 18$

Displayed $\text{CTDI}_{\text{vol}16} = 37$
Displayed $\text{CTDI}_{\text{vol}32} = 18$

Measured $\text{CTDI}_{\text{vol}} = 18$

21.6 mGy
10.8 mGy
CTDI SHORTCOMING

Same radiographic technique
• 32 cm CTDI Phantom

• Displayed $\text{CTDI}_{\text{vol}} = 18 \text{ mGy}$ for both patients
CLINICAL DILEMMA

• Displayed $\text{CTDI}_{\text{vol}}$ on scanner is independent of patient size
  • 16 cm CTDI phantom: adult dose over while pediatric dose under estimated.
  • 32 cm CTDI phantom: adult and pediatric dose under estimated ~ 2.5 times!
• Propagated by DICOM Structured Reports and CT scanner dose reports.
CLINICAL DILEMMA

- CTDI Phantoms are not clinical models
CLINICAL DILEMMA

• Anthropomorphic Phantoms only approximate the human body
CT SCANNER DOSE INDICES

Displayed Dose Length Product (DLP)

- DLP (mGycm) = CTDI\textsubscript{vol} * Scan Length
  - Scan length is the length of phantom irradiated.
  - ‘Represents’ energy transferred.
  - DLP is \textbf{not} a patient dose index because CTDI\textsubscript{vol} does not represent patient dose.

- ‘SSDELP’ = SSDE * Scan Length
  - Better estimate of energy transferred.
DLP represents the greater biologic risk!

\[ \text{DLP} = 200 \text{ mGy} \cdot \text{cm} \]

\[ \text{CTDI}_{\text{vol}} = 20 \text{ mGy} \]

ten 1-cm slices

\[ \text{DLP} = 400 \text{ mGy} \cdot \text{cm} \]

\[ \text{CTDI}_{\text{vol}} \text{ STILL} = 20 \text{ mGy} \]

twenty 1-cm slices

DLP represents the greater biologic risk!

Adapted from Frey
Size Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations

Report of AAPM Task Group 204, in collaboration with the International Commission on Radiological Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging.
Report does not:

• Address correction factors for heads
• Correct small (< 1%) doses from scanned projection images.
• Correct for variation (~ 5%) in attenuation of thorax vs abdomen
• Correct small variation in pre and post contrast scans
So what is SSDE?:

- Estimate of the average patient dose within the entire scan volume of patient.
- Adjusts for patient size and varying attenuation from overlying tissue thickness.
- Uses average scanner radiation output during CT scan: $\text{CTDI}_{\text{vol}}$
  - Output varies along z axis
  - Output varies as beam rotates
  - Output varies based on bow tie filter
Data from four independent investigators studying patient size correction factors.

- **Physical measurements on phantoms**
  - Anthropomorphic Phantoms (McCollough Laboratory “Mc”)
  - Cylindrical PMMA phantoms (Toth / Strauss Collaboration “T-S”)
  - Monte Carlo Voxelized Phantoms (McNitt-Gray Laboratory “MG”)
  - Monte Carlo Mathematical Cylinders (Boone Laboratory “Z-B”)

- **Monte Carlo computer modeling**

Adapted from TG 204
TG 204

Adapted from TG 204

32 cm 120 kV

Normalized Dose Coefficient vs. Effective Diameter (cm)

\[ y = 3.7044e^{-0.0367x} \]

\[ R^2 = 0.9429 \]
Adapted from TG 204

\[ y = 1.8748e^{-0.0387x} \]

\[ R^2 = 0.9673 \]
What about scans performed at 80, 100, or 140 kV?

1. 5% difference overall
2. 3% difference between 1 yr old (15 cm) & adult (32 cm)

Combined TS / ZB: 80-140 kV from 120 kV only
What about scans performed in the thorax?

1. Thorax data from Huda et al.
2. 16% dif @ 12 cm
3. 7% dif @ 17 cm
4. < 3% dif > 17 cm

Adapted from Boone
What is an effective diameter?

- Circle with area of patient’s cross section
- Effective diameter can be estimated if the patient’s AP or lateral dimension is known.

circle of equal area

effective diameter

AP
lateral
AGE vs PATENT SIZE

Same age patients vary dramatically in size.

- Abdomens of:
  - Largest 3 year olds and
  - Smallest adults are the same size.

Patient cross section size, not age, should be used.
What if I am doing retrospective dose analysis and I only know age of patient?

- Corrections based on patient size are more accurate.
TG 204

Determining patient size

• Measure Lateral dimension with mechanical calipers.
• Measure Lateral or AP dimension from AP or Lateral projection scan.
  • Magnification Error
• Measure AP or LAT dimension from axial scan view.
Failure to identify correct phantom, 16 or 32 cm leads to a systematic error of up to 100%.

No standard exists. Choice may depend on:
- Selected protocol: adult or pediatric
- Selected scan field of view
- Year of manufacture
- Software level

Make no assumptions: contact manufacturer of your unit through their service organization.
SSDE Accuracy

• 20%
• Product is an *estimate* of patient dose
• Report doses with proper number of significant digits
  • SSDE $\geq 5 \text{ mGy}$: integers only, e.g. 7 or 23 mGy
  • SSDE $< 5 \text{ mGy}$: one decimal point, e.g. 2.7 or 4.5 mGy
SAMPLE CALCULATION: POST SCAN

- Determine size of patient
  - AP = 9.9 cm; LAT = 12.3 cm
  - AP + LAT = 22.2 cm
- 32 cm CTDI phantom assumed
- Displayed CTDI$_{vol}$ = 5.4 mGy
- 5.4 mGy x 2.5 = 13 mGy SSDE

Adapted from TG 204
Effective Dose Limitations

Caution:

- SSDE can **NOT** be substituted in place of CTDI$_{vol}$ when using k-factors to estimate Effective Doses from CT exam.
Effective Dose Limitations

Can Effective Dose be used to estimate:

• An individual patient’s radiation dose?
• Organ doses?

ABSOLUTELY NOT, despite the fact that one can find numerous published papers that make this error!!
Effective Dose Limitations

• Effective Dose was originally defined to address radiation protection concerns of occupationally exposed workers.

• Effective dose can be used to facilitate a comparison of biological effects between diagnostic exams of different types.
Effective Dose Limitations

Effective Dose Recommended Reading

- ICRP 103 Executive Summary
- CJ Martin, “Effective dose: How should it be applied to medical exposures?”, BJR 2007
- “Rational approach to the clinical use of effective dose estimates”, AJR 2011.
## CLINICAL APPLICATIONS OF SSDE

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Setting up reference values for all size patients based on CTDI$_{vol}$ results in odd patient doses.
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Setting up reference values for all size patients based on SSDE is more straightforward.
CLINICAL APPLICATIONS OF SSDE

SSDE estimates patient dose for both adult and pediatric patients.

- can be first approximation of some organ doses
  - Soft tissues only
  - Organ completely in scan volume in z direction.
CLINICAL APPLICATIONS OF SSDE

SSDE

- Can be first approximation of some organ doses:
  - Radial dose profiles
  - Range dependent on patient diameter
    - Pediatric vs Adult?
  - $\text{CTDI}_{\text{vol}}$ (83)
CLINICAL APPLICATIONS OF SSDE

SSDE

• Can be **first approximation of some organ doses:**
  • Increased error for small organs depending on location.
  • Less effect for pediatrics

Adapted from McCollough
CONCLUSIONS

Estimating and managing a patient’s CT dose as a function of their size is facilitated by the use of SSDE provided:

• $\text{CTDI}_{\text{vol}}$,
• CTDI phantom size assumed by the CT scanner, and
• Patient size are known.