Patient Dose Calculations: Computed Tomography

Karen Brown, MHP CHP, DABR
Penn State College of Medicine

Email: kbrown4@pennstatehealth.psu.edu

Disclosures

- None

Objectives

1. Describe the limitations of displayed dose metrics for estimating patient dose
2. Review methods to estimate effective dose for a generic patient
3. Discuss how patient specific risk estimates may be performed

The patient:

- 58 yo female
- Weight 85 kg
- History of adrenal mass

Protocol:

What dose information do we have?

- Dose metrics displayed on the CT scanner:
  - $CTDI_{VOL}$ & DLP
    - Projected value displayed prior to scan
    - Average value displayed post scan
  - Based on:
    - Technique parameters
    - Planned scan range
    - Phantom size

Displayed $CTDI_{VOL}$

- Useful for comparing output across scanners, protocols, facilities
- E.g. Comparison of reported values from patient scans

Median $CTDI_{VOL}$ - Routine Abdomen/Pelvis scans

Displayed $CTDI_{VOL}$

- Useful for benchmarking
- E.g. ACR Dose Index Registry

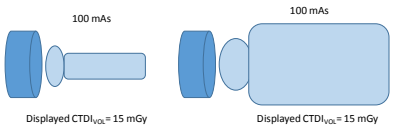
Displayed $CTDI_{vol}$

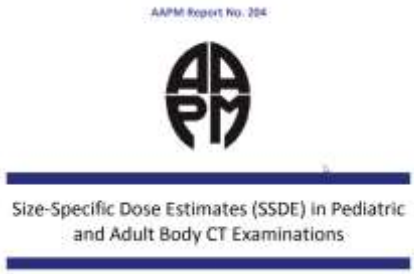
- Limitations:
  - Length of 100 mm pencil chamber is not sufficient to capture all of the scatter produced
  - Based on average mA used with dose modulation
  - Air kerma, not dose to tissue
  - Typical patient scan length doesn't correspond to the length of phantom
  - Diameter of the patient is often different than the diameter of the phantom
- **Does not represent patient dose**

Limitations of Displayed $CTDI_{vol}$

CTDI is a measure of scanner output (air kerma) as measured using one of two sized phantoms

- Overestimates dose for patients larger than the phantom
- Underestimates dose for patients smaller than the phantom

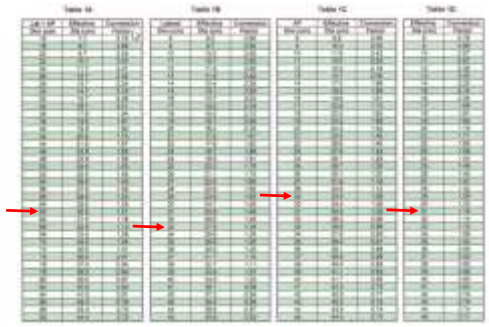




Calculation of SSDE

$$SSDE = f_{size}^{AUX} \times CTDI_{vol}^{Ex}$$

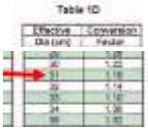
Patient AP diameter = 292.2 mm
Patient lat diameter = 331.5 mm
Sum = 623.7 mm
Effective diameter = 311.2 mm



Calculation of SSDE

$$SSDE = f_{size}^{AP} \times CTDI_{vol}^{Lat}$$

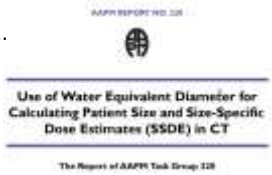
Patient AP diameter =	292.2 mm
Patient lat diameter =	331.5 mm
Sum =	623.7 mm
Effective diameter =	311.2 mm



$$SSDE = 1.19\ x\ 12.16\ mGy = 14.5\ mGy$$

A more robust estimate…

- Method for estimating patient size that accounts for attenuation properties of tissues.
- Intended for use by scanner manufacturer's and other software vendors



Manual calculation:
Effective diameter = 31 cm
SSDE = 14.5 mGy

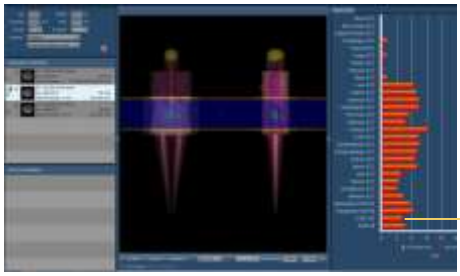
Dose Monitoring Software calculation:
Effective diameter = 32.2 cm
Water equivalent diameter: 30.9 cm
SSDE = 14.9 mGy

Estimating Patient Dose

- SSDE provides an estimate of patient absorbed dose
- Dose not provide information about the risk of the procedure or risk to the patient
- Determination of effective dose:

$$\text{Effective Dose (mSv)} = \sum_{T} w_T H_T$$

Effective Dose Estimates – Monte Carlo Simulations

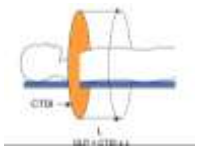


Effective dose estimates – DLP Method

- Dose Length Product (mGycm)
  - Multiply $CTDI_{VOL}$ by the scan length
  - Total energy imparted during the scan
- E (mSv) = k x DLP

Region	0 yrs	1 yr	5 yr	10 yr	Adult
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.0012	0.0011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abd/pelvis	0.049	0.030	0.020	0.015	0.015

AAPM Report 96: Measurement, reporting, and management of dose in CT



Verdun F R et al. Radiographics 2008;28:1807-1816

Effective dose estimates – DLP Method

- E (mSv) = k x DLP

Region	Adult
Head	0.0021
Neck	0.0059
Chest	0.014
Abd/pelvis	0.015

$$E = 0.015\ x\ 388\ mGycm = 5.82\ mSv$$

Limitations of the DLP Method

- DLP is calculated from $CTDI_{VOL}$
- k-factors were determined
- Derived using a pitch of 1 only
- k-factors were not based of ICRP 103 weighting factors
  - Updated in 2011 -

$$E = 0.015\ x\ 0.92\ x\ 388\ mGycm = 5.35\ mSv$$

E_{103}/E_{60} - abdomen/pelvis

Huda, W. , Magill, D. and He, W. (2011), CT effective dose per dose length product using ICRP 103 weighting factors. Med. Phys., 38: 1261-1265. doi:10.1118/1.3544350

Protocol:

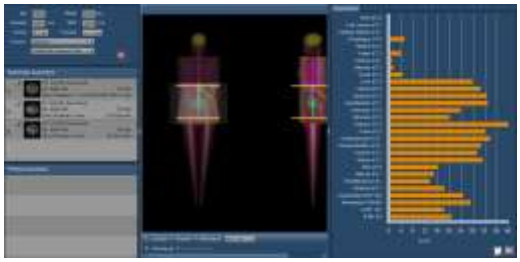
Effective Dose Estimates

How to Appropriately Calculate Effective Dose for CT Using Either Size-Specific Dose Estimates or Dose-Length Product

Protocol:

Protocol:

Total Effective Dose – 18.2 mSv



Dose Calculations

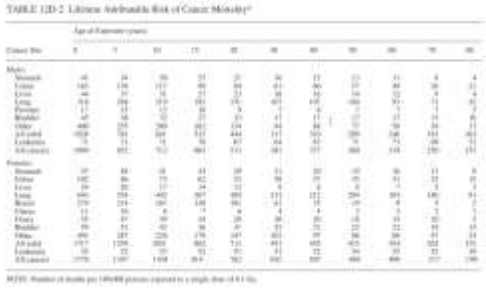
Common requests / requirements for dose estimates:

- Equipment performance testing
- Regulatory / Accreditation reporting & standards
- Protocol optimization
- QA / Benchmarking
- IRB Risk Estimates
- Patient / physician request

Patient Risk

BEIR VII:

"This chapter presents models that allow one to estimate the lifetime risk of cancer resulting from any specified dose of ionizing radiation and applies these models to example exposure scenarios for the U.S. population."



Patient Risk

- Lifetime attributable risk of cancer mortality from liver cancer

$$\frac{0.032\ \text{Gy}}{0.1\ \text{Gy}} \text{ x } 31 = 9.92 \text{ per } 100{,}00 \text{ exposed}$$

$$= 0.0000992 = \frac{1}{10{,}000}$$

Compute for each organ and sum $= \frac{1}{2{,}700}$

Patient Risk

BEIR VII:

"Risk estimates are subject to several sources of uncertainty due to inherent limitations in epidemiologic data and in our understanding of exactly how radiation exposure increases the risk of cancer. In addition…"

Does not provide a patient specific risk estimate!

References

- AAPM Report 96, The Measurement, Reporting, and Management of Radiation Dose in CT, January 2008.
- AAPM Report 204, Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations, 2011.
- AAPM Report 220, Use of Water Equivalent Diameter for Calculating Patient Size and Size-Specific Dose Estimates (SSDE) in CT, September 2014.
- McCollough et al. CT dose index and patient dose: they are not the same thing. Radiology 2011;259(2):311-316.

References

- Brady, et al. How to appropriately calculate effective dose for CT using either size-specific dose estimates or dose-length product. AJR 2015;204:953-958.
- Huda, et al. CT effective dose per dose-length product using ICRP 103 weighting factors. Med. Phys. 38(3), March 2011.
- Health risks from exposure to low levels of ionizing radiation : BEIR VII, Phase 2 / Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, Board on Radiation Effects, Research Division on Earth and Life Studies, National Research Council of the National Academies, 2006.