CT Radiation Dose Optimization

presented by

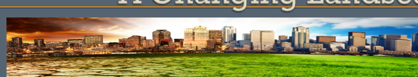
RADIOLOGY TRAINING ASSOCIATES

Anywhere. Anytime. It's that simple.

Outline

- New CT Rules, Regulations, & Standards
- Radiation Dose
- Radiation Biology & Cell Damage
- Risks From Medical Imaging
- CT Technical Parameters
- Dose Optimization Techniques
- Case Studies
- Practical Tips

A Changing Landscape



- The Joint Commission
- State Regulations
- NEMA XR-25, XR-26, XR-28 and XR-29
- A new and increased awareness that image quality should be balanced with radiation dose

Radiation Dose is Newsworthy!

Many people unaware of radiation risk from CT scans

October 16, 2009

Radiation Overdoses Point Up Dangers of CT S

By WALT BOGDANICH

At a time when Americans receive far more diagnostic radiation than ever before, two cases under scrutiny … — one involving a large, well-known Los Angeles hospital, the other a tiny hospital in the …

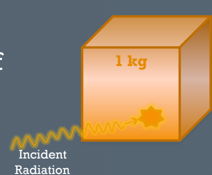
Radiation overdoses from CT scans lead to maladies in patients

By The New York Times

on August 01, 2010 at 4:00 AM

What is dose?

- Dose is defined as the energy deposited per unit mass
  - 1 J/kg = 1 Gray
- Measured in units of
  - Gy → absorbed dose
  - Sv → dose equivalent
  - 100 rad = 1 Gy
  - 100 rem = 1 Sv



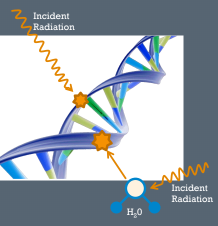
1.6×10^{-19} Joules = 1 eV

Non-Stochastic vs. Stochastic

- Non-stochastic effects (non-probabilistic)
  - A threshold dose exists!
  - Erythema
  - Epilation
  - Dermal Necrosis
- Stochastic effects (probabilistic)
  - A threshold does (might) not exist - LNT
  - Most common stochastic effect – cancer
  - Stochastic effects have a latency period
    - Most cancers ~ 20 – 40 yrs

How Does Radiation Cause Damage?

- Indirect Damage vs. Direct Damage
  - SSB vs. DSB
- 3 stages to forming cancer
  - Initiator – mutational event
  - Promoter – functional change
  - Progression – tumor invasion
- Radiation is a weak carcinogen because it acts only as an initiator.



Using the $CTDI_{vol}$ & DLP

- Computerized Tomography Dose Index ($CTDI_{vol}$)
  - $CTDI_{vol}$ is a dose index NOT patient dose
  - Related to the 16 cm head phantom or 32 cm body phantom
  - Accuracy of $CTDI_{vol}$ to patient dose depends on the size of the patient vs. phantom
    - Relation of $CTDI_{vol}$ to patient dose
  - Most useful for making comparisons between scanners and/or protocols
- Dose Length Product (DLP)
  - $CTDI_{vol}$ * Scan Length = DLP → mGy-cm
  - More useful in determining total dose to patient, but has many limitations
- Quality Assurance
  - Both $CTDI_{vol}$ and DLP have value, but in different ways

Technical Factors

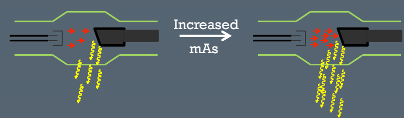
- Tube Potential (kV or kVp)
  - Electrical potential applied across the x-ray tube to accelerate electrons toward the target

$$CTDI_{vol} \propto \left(\frac{kV_{new}}{kV_{old}}\right)^n$$

  - As kVp decreases, patient dose decreases and tissue contrast increases
  - 120 kV → 140 kV gives $CTDI_{vol}$ ~ 1.58x higher
  - 100 kV → 120 kV gives $CTDI_{vol}$ ~ 1.73x higher

Technical Factors

- Tube Current Time Product (mAs)
  - Determines the number of electrons accelerated across the x-ray tube → x-ray fluence (Φ)
    - 1 A = 1 C/s
  - Dose is directly proportional to tube current
  - Reducing mAs is the most direct way to lower radiation dose, but may produce a lower quality image



Technical Factors

- Detector Configuration
  - Determines beam collimation (n x T)
    - n = number of detectors (32, 64, 128, etc)
    - T = detector (slice) thickness
  - MDCT allow for faster scan times and thinner slices
    - However, there is a tradeoff with spatial resolution, image noise, and radiation dose
- Beam Shaping Filters
  - Bowtie Filters

Technical Factors

- Pitch
  - Representation of how far the table moves for every gantry rotation divided by collimated beam width
  - As pitch increases, dose decreases (sort of)
    - It really depends on the scanner

Pitch < 1	Pitch = 1	Pitch > 1
Beam width has some overlap at each view angle	No overlap of beam width at each view angle and no view angles not covered at certain table positions	Some view angles are not covered by the beam width at certain table positions

Technical Factors

- Exposure Time per Rotation
  - Analogous to "beam on time"
  - Dose is directly proportional to rotation time
    - Affects x-ray flux
      - As time decreases, gantry speed increases, and flux decreases resulting in fewer x-rays being imparted in any one location
    - $CTDI_{vol}$ may not change depending on vendor

Enhanced Dose Control Strategies

- Tube Current Modulation
- Tube Potential Modulation
- Adaptive Dose Shielding
- Organ Based TCM
- Improved Detectors
- Iterative Reconstruction

Automatic Exposure Control

- Automatically adapts the Tube Current (or Tube Potential) according to patient attenuation to achieve a desired image quality
  - Angular and Longitudinal TCM
  - Centering the patient in the gantry is vital!
- Based on topogram and reference settings
  - Changing the image quality reference parameter will affect the $CTDI_{vol}$
- As x-rays pass through the body, they are attenuated. This attenuation is calculated from the topogram and the relative signal change is computed.


Image from Radimetrics eXposure

Patient Centering

- Patient attenuation is calculated assuming patient is at isocenter
  - Where exactly is the isocenter?
- Patient positioned above or below isocenter affects calculation of attenuation by changing the size/shape model and impacts the AEC
- Patient mispositioning to the left or right of isocenter will result in one side of body receiving more radiation dose than the other
- Scanners tend to be sensitive to magnification and minification of the patient in the localizer image

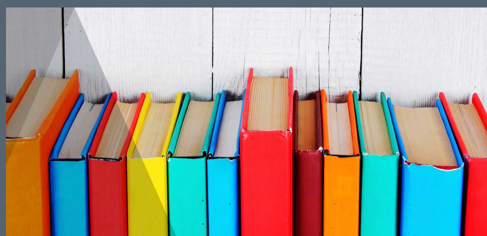
Scanning Outside the Localizer

- Tube current modulation is implemented using knowledge of patient attenuation from localizers
- If scan region extends outside of localizer, then there is no information to base modulation
- Four possible outcomes
  - Tube current goes to maximum
  - Tube current goes to minimum
  - Tube current stays what it was at edge of localizer
  - Tube current goes to a manual setting

Image from Radimetrics eXposure

Scanning Outside the Localizer

- When in doubt, do another scout!
- Takeaways
  - Scanning past the localizer can create significant radiation dose AND image quality issues
  - The scan length should only extend as far as medically necessary
  - Be generous with your scouts
    - A quick note on scouts



CASE STUDIES

Table Top Head CT

Mean mAs: 277
Max mAs: 333
$CTDI_{vol}$: 83.09 mGy

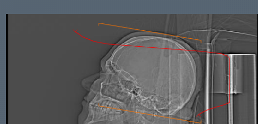


Image from Radimetrics eXposure

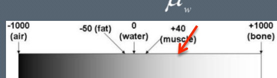
Mean mAs: 147
Max mAs: 172
$CTDI_{vol}$: 46.68 mGy

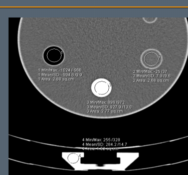
Image from Radimetrics eXposure

A Look at Hounsfield Units

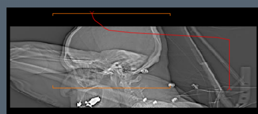
- CT Numbers
  - Air ~ -994.6
  - Water ~ 7.9
  - Teflon (Bone) ~ 927.9
  - Head Receiver ~ 284.2

$$CT\,Number = \frac{\mu_t - \mu_w}{\mu_w} \times K$$





Topograms Matter!

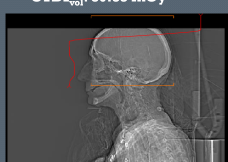


Images from Radimetrics eXposure

$CTDI_{vol}$ = 107.28 mGy

Scanning Past Your Localizer

Mean mAs: 301.7
Min mAs: 147
Max mAs: 658
$CTDI_{vol}$: 80.88 mGy



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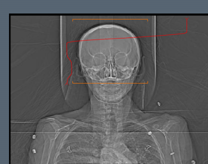

Image from Radimetrics eXposure

When information is missing from the topogram, the scanner does not have accurate information on which to base the tube current modulation. Can create image quality and radiation dose issues!

Compounding Issues

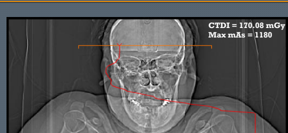

Image from Radimetrics eXposure

Total mAs 9286 Total DLP 3609 mGycm

	Scan	KV	mAs / ref.	CTDIvol* mGy	DLP mGycm	TI s	cSL mm
Patient Position H-SP							
Topogram	1	100	101 mA	0.23 L	10	4.6	0.6
PreMonitoring	2	120	100	5.93 L	6	0.33	10.0
Contrast							
Monitoring	3	120	100	29.65 L	30	0.33	10.0
PE CHEST	8	120	204 / 150	13.80 L	425	0.33	0.6
Topogram	9	100	101 mA	0.23 L	5	2.3	0.6
Facial Bones	10	120	1180 / 390	170.08 S	3133	1.0	0.6

Practical Tips for Providing Quality Exams

- Understand how TCM/AEC works
  - Effects of isocentering, importance of scouts, patient positioning, etc
  - Educate your team!
- Scan only the region necessary
- Do the scan right the first time
- Institute a protocol review process
  - Team approach
  - Use pediatric specific protocols

Final Thoughts

- We can always be better stewards of diagnostic radiation
  - Are we answering the diagnostic question?
- Understanding CT technical parameters is essential to providing the best care to your patients
- Radiation dose awareness is everyone's responsibility but image quality is the priority