Radiation Dosimetry and Dose Reduction Techniques in CT

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Learning Objectives
✓ Review radiation dose terminology and risks
✓ Outline strategies to reduce CT dose
✓ Become familiar with iterative reconstruction

Many thanks to: L. Gentry, F. Ranallo, and M. Lev

Disclosures – Howard Rowley
• Honoraria / consulting / agreements
  ▪ GE Healthcare → research, MR patents
  ▪ Bracco → contrast
  ▪ Bayer → contrast
  ▪ Guerbet → contrast
  ▪ Trial consulting: Lundbeck, HL Gore, Eli Lilly, ImagePace
• Off-label use of contrast
  ▪ Perfusion
• NIH 5R01 EB007021-04 (CT reconstruction)

Radiation Dosimetry & Terminology

- Measurements → Physiologic
  - Estimated exposure – phantom measurements
    • CTDI<sub>vol</sub> reported on all scanners
      - mGy
    • DLP = CTDI<sub>vol</sub> x length of scan
      - mGy-cm
  - Effective dose to pt – adjusted for region / tissue
    • Convert from DLP using ‘k’ factors
    • Units: mSv
  - This is the key metric of interest

CTD<sub>vol</sub> = standard CT phantom dose

CTDI: Dose Estimate - Acrylic Phantom


Radiation Dosimetry & Terminology

Absorbed Dose (mGy)
Equivalant Dose (mSv)

Phantoms

Effective Dose (mSv)

Humans

Individual Risk

Converting CTDI to Effective Dose

- CTDI\textsubscript{vol} x cm = DLP
- DLP x k-factor = E (mSv) = Pt Dose

Christner et al AJR 2010; 194:881–889

Organ-Specific Tissue Risk Estimation
Tissue Weighting Factors (W\textsubscript{T})

- Brain = 0.01

Christner et al AJR 2010; 194:881–889

Effective Dose Calculation by Region
DLP x k-factor = E (mSv)

- Quick Method to Estimate Dose from DLP:
  - Head CT: DLP / 100
  - Body CT: DLP / 100

Table 2: Published DLP to E “a” Conversion Coefficients

<table>
<thead>
<tr>
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<th>DLP (mGy)</th>
<th>E (mSv)</th>
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<td>0.0021</td>
<td>0.0023</td>
</tr>
<tr>
<td>Neck</td>
<td>0.0048</td>
<td>0.0054</td>
</tr>
<tr>
<td>Chest</td>
<td>0.0118</td>
<td>0.0137</td>
</tr>
<tr>
<td>Abdomen</td>
<td>0.0127</td>
<td>0.0145</td>
</tr>
<tr>
<td>Pelvis</td>
<td>0.0150</td>
<td>0.0169</td>
</tr>
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</table>

Phantom (cm)

- Head: 0.0021
- Head-neck: 0.0048
- Neck: 0.0118
- Chest: 0.0118
- Abdomen: 0.0127
- Pelvis: 0.0150

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 Radiation Risks in Perspective

- Routine Exposure mSv / year
  - Environment 3-30
  - Medical (population avg) 3
  - Worker (allowable) 50

- Medical Exams mSv / exam
  - Chest X-ray 0.1
  - Head CT 1-2
  - Coronary CT 9
  - Barium enema 15
  - Cardiac nuclear scan 41
Radiation Risks in Perspective

<table>
<thead>
<tr>
<th>Exposure / Activity</th>
<th>Lifetime Fatality Risk (per 1000 individuals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightning strike</td>
<td>0.013</td>
</tr>
<tr>
<td>1 mSv radiation (e.g. Head CT)</td>
<td>0.05</td>
</tr>
<tr>
<td>Bicycling</td>
<td>0.2</td>
</tr>
<tr>
<td>Drowning</td>
<td>0.9</td>
</tr>
<tr>
<td>Pedestrian accident</td>
<td>1.6</td>
</tr>
<tr>
<td>50 mSv (yearly worker allowance)</td>
<td>2.5</td>
</tr>
<tr>
<td>Arsenic in drinking water (2.5-50 μg/L)</td>
<td>1-13</td>
</tr>
<tr>
<td>Radon in home: (low – high exposure)</td>
<td>3-21</td>
</tr>
<tr>
<td>Passive smoking (low – high exposure)</td>
<td>4-10</td>
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<tr>
<td>Motor vehicle accident</td>
<td>12</td>
</tr>
<tr>
<td>Natural fatal cancer</td>
<td>212</td>
</tr>
</tbody>
</table>

Modified from Gerber et al. Circulation 2009;119:1056-65

Cancer Risk (Stochastic effects)

Risk Estimate using the Linear No-Threshold Model

If we look at age and sex as variables for cancer risk:

1 in 20,000 per mSv


CT / MR use for injury evaluation in ED

1998 = 6% → 2007 = 15%

Korley et al. JAMA 2010;304:1465-1471
Radiation Dose: Philosophy and Responsibility

- Justify exam
  - Right test for right reasons
  - Move from CT to MR over long term
- Optimize dose
  - ALARA, Image Gently, Image Wisely
- Audit
  - Best standard of care
  - Reference values / guidelines
  - ACR Registry

Golding, SJ  Radiology 2010; 255:683-6

CT Dose Reduction: Strategies

- Don’t do it
  - Judicious utilization, decision rules
  - Remove non-medical incentives
    - Self referral, defensive medicine
- Do it less often
  - Avoid repeats, decrease frequency
  - Upload outside scans to PACS
- Do something else
  - MR, US...
- Do it with lower dose
  - 1 mSv Challenge (NIBIB)

Canadian Head CT Rule

- High Risk for Neurosurgical Intervention
  - GCS < 15 at 2 hours after injury
  - Suspected open or depressed skull fracture
  - Any sign of basal skull fracture
  - Two or more episodes of vomiting
  - 65 years or older
- Medium Risk
  - Amnesia before impact of 30 or more minutes
  - Dangerous mechanism

Stiell, IG et al  JAMA 2005; 294:1511-1518

ACR Appropriateness Criteria

Overview: Searching for Clinical Conditions

This search engine allows you to search for terms found within the ACR Appropriateness Criteria® (ACR AC) documents so you can more easily find the clinical conditions you are interested in reviewing.

When searching for clinical conditions, you may wish to use the medical term and the common term. For example, searching for “absence of breath” OR “dyspnea” may reveal you a step by step searching and ensure a more complete listing of the topics.

http://acsearch.acr.org

CT Dose Reduction: Acquisition

- Lower tube current (mAs)
  - Decreased dose: linear
  - Automatic exposure control
- Lower tube voltage (kVp)
  - Decreased dose: > factor than mAs reduction
  - Excellent for CTA (closer to k-edge)
  - Limited by patient size / body region
- Improve collimation
  - Reduce overscanning / penumbra
- Reduce anatomic coverage
- Optimize patient positioning
CT Dose Reduction – Current Modulation

- Understand automatic exposure controls & pitfalls
- Explore new options from commercial partners


Table 1: Modular Tube Current Modulation Systems

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>GE Healthcare</th>
<th>Philips</th>
<th>Siemens</th>
<th>Toshiba</th>
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</thead>
<tbody>
<tr>
<td>Rotator mode</td>
<td>Auto, fix</td>
<td>Auto, fix</td>
<td>Auto, fix</td>
<td>Auto, fix</td>
</tr>
<tr>
<td>Regions/CT protocols</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Table rotation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Detector element</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Image quality</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Film readers available on the CT scanner</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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Table 2: Cylindrical Tube Current Modulation Systems

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Table 3: Combined Aperture and Longitudinal Tube Current Modulation Systems

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<td>Yes</td>
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<td>Yes</td>
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<tr>
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<td>Yes</td>
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Low Dose Shunt CT (63% reduction)

220 mAs → 1.6 mSv  80 mAs → 0.58 mSv

- Decreased mAs: linear reduction in dose

Udayasankar et al (Emory)  AJNR 2008; 29:802–06

‘Quick Brain’ Fast MR Alternative to CT

The use of quick-brain magnetic resonance imaging in the evaluation of shunt-treated hydrocephalus

BERNARD J. ISKANDAR, M.D., JASON M. SASSONI, B.S., JOSHUA MEADOW, M.D., AND HOWARD A. ROWLEY, M.D.

3-plane SSFSE, unsedated, < 5 minutes total time

Iskandar  J Neurosurg (Peds 2) 101:147-151 2004

Fast SS GRE improves shunt visibility

Miller et al  AJNR 2010; 31:430–35

CT Dose Reduction: Reconstruction

- For routine cine / helical images
  - Statistical iterative reconstruction
    - ASIR (GE), IRIS (Siemens), iDose (Philips)
    - Next generation
      - Dual energy
        - Model-based iterative reconstruction
  - For time series (perfusion) – above plus
    - Highly Constrained Projection Reconstruction
    - Prior Imaging Constrained Sensing
    - Consider alternate parameter maps

Beyond Filtered Back Projection...

Adaptive Statistical Iterative Reconstruction

ASIR → Noise Reduction

Adaptive Statistical Iterative Reconstruction

- User choices at console → mA reduction → dose reduction
  - Noise index
  - % Dose reduction
  - mA Range: min & max

Screenshot courtesy of Frank Ranallo, PhD

<table>
<thead>
<tr>
<th></th>
<th>mA</th>
<th>kV</th>
<th>Pitch</th>
<th>Rot'n Time</th>
<th>Noise Index</th>
<th>ASIR %</th>
<th>CTDI vol</th>
<th>DLP</th>
<th>E</th>
<th>mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>274</td>
<td>140</td>
<td>0.53</td>
<td>0.60</td>
<td>11.4</td>
<td>30%</td>
<td>42</td>
<td>1438</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>Old</td>
<td>201</td>
<td>140</td>
<td>0.63</td>
<td>1.0</td>
<td>11.4</td>
<td>0%</td>
<td>57</td>
<td>2054</td>
<td>6.4</td>
<td></td>
</tr>
</tbody>
</table>

DLP*0.0031 (for head & neck) = E (mSv)

Adaptive Statistical Iterative Reconstruction

Variable ‘blending’ of FBP with % ASIR


0.6 mSv Temporal Bone using iDose

Courtesy of Terry McGinn, Philips, and MetroHealth

Low Dose CT Reconstruction Methods

Evolution of Image Reconstruction

- FBP
- Statistical
- Model-based

Day 37 after 1st CTP: four CTA/CTP and two DSA exams in 2 weeks
120 kV, 100 mAs, and 50 rotations

FDA Warning: CTP Dose

CT Radiation Dose Reduction

- General CT strategies
  - Avoid CT - use alternate modality (MR, US)
  - Reduce mA – image gently!
    - Automated exposure modulation
    - New post-processing algorithms

- CT Perfusion strategies
  - Reduce kVp = 80 (close to k-edge; dose reduction)
  - Keep mA ≤ 200
  - Reduce temporal sampling (e.g. Shuttle mode)
  - Do NOT use auto mA
    - Alters kinetic modeling
    - May inadvertently increase dose (noise defaults)

Extended CTP Coverage: Shuttle Mode

Video courtesy of Mark Bowman, GE Healthcare

CT Perfusion at UW

- Technique
  - mAs = 200
  - kVp =80
  - 45 second acquisition

- Cine – 8 slices / 4 cm 4.9 mSv
- Shuttle – 16 slices / 8 cm 3.7 mSv

- Low dose shuttle mode (research)
  - 16 slices / 8 cm
  - mAs 10-64
  - Dose: 0.2 – 1.2 mSv

Alternate recon: HYPR - PICCS

Ultra low dose research protocol

3.7 mSv FBP

.75 mSv DR-PICCS

G-H Chen, S. Brunner, K. Pulfer, H Rowley

CT Dose Reduction: Summary

- Utilization Decision Rules
- Alternate Modality
- Acquisition
  - Low MA etc
- Reconstruction
  - ASIR, PICCS etc
- Audit
- QA

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