Strategies for Reducing Radiation Dose in CT
With Rise in Radiation Exposure, Experts Urge Caution on Tests

By RONI CARYN RABIN
Published: June 19, 2007

Advances in radiology have radically transformed medical practice, with CT scans and nuclear medicine exams providing physicians with the ability to quickly pinpoint internal bleeding, diagnose kidney stones or confirm appendicitis, assess thyroid function and identify and open blockages in the blood vessels to the heart.

The downside is that Americans are being exposed to record amounts of ionizing radiation, the most energetic and potentially hazardous form of radiation.

According to a new study, the per-capita dose of ionizing radiation from clinical imaging exams in the United States increased almost 600 percent from 1980 to 2006. In the past, natural background radiation was the leading source of human exposure; that has been displaced by diagnostic imaging procedures, the authors said.

The CT -- short for computerized tomography scan -- can detect injuries and tumors. Its use has tripled in the U.S. since the early 1990s to more than 70 million in 2007. Though it has long been known that radiation increases a person's chance of getting cancer, the exact risk of these scans wasn't clear.

One of the studies, which examined more than 1,000 adult patients at four hospitals, projected that the dose of radiation received in a single head scan at age 40 would later
7 Practical Steps for Reducing Radiation Dose in CT

Disclosures: None
1. Avoid Unnecessary CTs
Use e-POE with Decision Support

**MGH Radiology Order Entry - Windows Inter**

Patient Name: CLAUSE, SANTA  
MRN: 0000004

<table>
<thead>
<tr>
<th>Exam Request / Protocol</th>
<th>Includes the following examinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdominal CTA</td>
<td>CTA Abdomen (requires contrast)</td>
</tr>
<tr>
<td>Liver prior to resection</td>
<td>CTA Abdomen (requires contrast), plus CT Abdomen with contrast, and CT Pelvis with contrast and 3D reconstructions</td>
</tr>
<tr>
<td>Liver donor</td>
<td>CTA Abdomen (requires contrast), plus CT Abdomen with contrast, and CT Pelvis with contrast and 3D reconstructions</td>
</tr>
<tr>
<td>Renal donor</td>
<td>CTA Abdomen (requires contrast), plus CT Abdomen with contrast, and CT Pelvis with contrast and 3D reconstructions</td>
</tr>
<tr>
<td>Mesentery</td>
<td>CTA Abdomen (requires contrast), plus CT Abdomen with contrast, and CT Pelvis with contrast and 3D reconstructions</td>
</tr>
<tr>
<td>Portal vein</td>
<td>CTA Abdomen (requires contrast), plus CT Abdomen with contrast, and CT Pelvis with contrast and 3D reconstructions</td>
</tr>
<tr>
<td>Pancreatic Cancer (pre-op staging)</td>
<td>CTA Abdomen (requires contrast), plus CT Abdomen with contrast, and CT Pelvis with contrast and 3D reconstructions</td>
</tr>
<tr>
<td>Abdominal CTA with MMS</td>
<td>CTA Abdomen (requires contrast), plus CT Abdomen with contrast, and CT Pelvis with contrast and 3D reconstructions and aneurysm measurements (MMS)</td>
</tr>
</tbody>
</table>

**EXAM REQUESTED Pick only ONE of the Following**

At least one box MUST be selected from either of the following groups

**SIGNS / SYMPTOMS**

- Dimensioned pulse Arm
- Bruit (specify location)
- Diminished pulse Leg
- Pulsatile mass
- Anemia
- Venous obstruction (compression)
- Dissection
- Arterial occlusion
- Arterial stenosis
- Ischemia
- Atherosclerosis
- Thrombosis
- Embolism

**KNOWN DIAGNOSES (NOT Rule/out)**

- Portal vein thrombosis (Budd-Chiari Syndrome)
- Chronic Kidney disease
- Treatment resistant hypertension
- Liver transplant
- Paroxysmal hypertension
- Neoplasm: specify primary

Information for Radiologist (only 140 characters allowed):

- [ ]

- [ ] Funded Research Study - Enter Fund (7 digits beginning with 9):

How to add a missing exam indication:
E-POE with Decision Support

Ref: Sistrom C L et al. Radiology 2009;251:147-155
2. Avoid z-creep: anatomy

- Radiation dose is proportional to total scan length
- Targeted CT scans
  - Indeterminate renal mass w/u: abdomen only
    - Ref: Prasad et al JCAT 2002
  - Kidney stone low-dose protocol: mid-liver
  - Abd-Pel CT: Average 12 extra slices
    - Ref: Kalra et al, Radiology 2004
2. Avoid z-creep: phases

- Radiation dose is proportional to total scan length
  - Limit number of phases
    - 1 to 2 phases: 2x dose
    - CT Urography in patients with hematuria: 2 phases
      - Non-CM + combined Nephrographic & Excretory
        - Ref: Chai et al. Australas Radiol. 2001 Nov;45:536-8
      - I- only if stones seen in patients aged <40 years
3. Lower mAs: leverage technology

- Decreasing mAs lowers radiation dose

Ref: McNitt-Gray; Radiographics 2002
Use Automatic Current Modulation

- mA determined from size & density on scanogram
- Radiologist decides ‘noisy’ vs. ‘smooth’ images
  - Clinical question
    - Soft-tissue contrast

<table>
<thead>
<tr>
<th></th>
<th>SMOOTH</th>
<th>NOISY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benign</td>
<td>Renal Cyst</td>
<td>Renal Stone, CTA</td>
</tr>
<tr>
<td>Malignant</td>
<td>Liver Met</td>
<td>Colonography</td>
</tr>
</tbody>
</table>

- Operator selects ‘reference mA’ or ‘noise index’ or...
- Scanner picks mA: size and density
Use Automatic Current Modulation

• mA modulation in abdominal CT
  – Radiation dose with a 16-channel MDCT
    • 54/62 pts: _ mean 37.9%, but 8/62 pts: _ mean 11.6%
    • Ref: Kalra et al; Radiology Oct 2004
Low mA CT

- Hx: Flank pain; ? Kidney Stone
  - Noise Index: 20
  - Effective Dose: ~1.5 mSv

Ref: Kalra et al. Radiology 2004
### Lower mA further with IR Algorithms

<table>
<thead>
<tr>
<th></th>
<th>FBP</th>
<th>Partial IR</th>
<th>Full IR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>200 mAs</strong></td>
<td><img src="image1" alt="FBP" /></td>
<td><img src="image2" alt="Partial IR" /></td>
<td><img src="image3" alt="Full IR" /></td>
</tr>
<tr>
<td><strong>100 mAs</strong></td>
<td><img src="image4" alt="FBP" /></td>
<td><img src="image5" alt="Partial IR" /></td>
<td><img src="image6" alt="Full IR" /></td>
</tr>
<tr>
<td><strong>50 mAs</strong></td>
<td><img src="image7" alt="FBP" /></td>
<td><img src="image8" alt="Partial IR" /></td>
<td><img src="image9" alt="Full IR" /></td>
</tr>
</tbody>
</table>

Lower mA significantly reduces radiation dose while maintaining image quality with IR Algorithms.

*Courtesy: M. Kalra*
Lowering mAs with IR

c/w Historical: 50%  30%  15%
4. Consider Lowering kVp

- Decreasing kVp also lowers radiation dose
- Effect on image quality differs

mA: effects noise only

kVp: effects noise & attenuation

Ref: McNitt-Gray; Radiographics 2002
CT Technique Physics

- **kVp:** 80 100 120 140
- **mAs (iso-fluence; 70kg):** 1000 430 200 120
- **Relative Dose (CTDIw):** 1.9 1.6 1.2 1.0
  - Refs: Huda, Rad 00; McNitt-Gray, RadioGraph 02;

Low kVp: Pediatric CT

- kVp: 80 100 120 140
- mAs (iso-fluence; 70kg): 1000 430 200 120
- 10Kg (=120/200 70Kg): 65 33 17 11

Singh et al., Radiology 2009

Siegel et al., Radiology 2004
Low kVp sub-mSv Stone CT
Low kVp: CTA

- Peak kilo-voltage (kVp): 80 100 120 140
- Iodine attenuation 1.0 0.75 0.60 0.50
  - Mean keV 43.7 51.6 56.8 61.5
  - K-edge I: 33.2 keV
- Low kVp w/o _ mAs
  - High contrast CT

Nyman et al. Radiology 2002
Low kVp: Donor CTA

- Sahani et al, AJR 2006

### TABLE 1: Image Quality and Radiation Dose in Study Groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>140 kV</th>
<th>120 kV</th>
<th>100 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean attenuation (H)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aorta</td>
<td>283</td>
<td>340</td>
<td>399</td>
</tr>
<tr>
<td>Main renal artery</td>
<td>292</td>
<td>338</td>
<td>384</td>
</tr>
<tr>
<td>Mean image quality score&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axial images</td>
<td>4.6</td>
<td>4.5</td>
<td>3.4</td>
</tr>
<tr>
<td>3D images</td>
<td>4.8</td>
<td>4.75</td>
<td>4.66</td>
</tr>
<tr>
<td>Mean image noise (H)</td>
<td>21.8</td>
<td>21.9</td>
<td>47.9</td>
</tr>
<tr>
<td>Mean radiation dose (CTDI&lt;sub&gt;vol&lt;/sub&gt;) (mGy)</td>
<td>25</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Mean score for visibility of branch order&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior mesenteric artery</td>
<td>5.2</td>
<td>4.9</td>
<td>4.6</td>
</tr>
<tr>
<td>Main renal artery</td>
<td>3.4</td>
<td>3.2</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Note—CTDI<sub>vol</sub> = CT dose index volume.
<sup>a</sup>On a 5-point scale, with 1 being unacceptable quality and 5 being excellent quality.
5. Technique: indication, age & weight

- Pink: routine (95-190)
- Green: _ f/u benign e.g. abscess (70-140)
- Red: ___ bone CT (50-100)
- Yellow: kidney stone (95-190)
- Blue: _subtle lesions (120-240)
- Grey: CTA (95-190)

Singh et al, Radiology 2009
6. Dose Monitoring

Example: Effective Dose = DLP/100 * 1.5 = 24 mSv

Typical body CT DLP 700 mGy.cm or ~10 mSv

Annual Non-medical background radiation: ~3 mSv

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Scan Range (mm)</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy-cm)</th>
<th>Phantom cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scout</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>Helical</td>
<td>38.250–1489.250</td>
<td>27.75</td>
<td>1643.48</td>
<td>Body 32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1643.48</td>
<td></td>
</tr>
<tr>
<td>Total Exam DLP:</td>
<td></td>
<td></td>
<td></td>
<td>1643.48</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Estimated radiation-related absolute cancer mortality risk/10^5 individuals in the United States exposed at different ages to a whole-body dose of 10 mSv. Estimates from the 1990 NAS BEIR-V report.46

Ref: Brenner et al, Gastroenterology 2005
Summary

• Right Test
• Focused Protocols
• Optimized kVP & mA
  – Technology
  – Indications, age
• Monitor Dose
• Understand Risk

Culture trumps Strategy