CT and Radiation Risks

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Learning Objectives

• Describe concerns about CT and radiation
• Describe CT doses and measures
• Discuss radiation risks from CT
• Review strategies to minimize radiation exposure

Why is CT under scrutiny?

• Growth of CT continues to increase
  CT accounts for about 50% of the per capita exposure from diagnostic imaging
• Radiation exposure from CT has been linked to carcinogenesis

2006 Population Exposure Data
Estimates of the NCRP

<table>
<thead>
<tr>
<th>2006</th>
<th>Number of procedures (millions)</th>
<th>% of all exams</th>
<th>Per capita exposure %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiography</td>
<td>310</td>
<td>74</td>
<td>11</td>
</tr>
<tr>
<td>Interventional</td>
<td>13</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Nuclear medicine</td>
<td>21</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td><strong>CT</strong></td>
<td><strong>67</strong></td>
<td><strong>17</strong></td>
<td><strong>49</strong></td>
</tr>
</tbody>
</table>

CT largest source of medical radiation dose

2010 Population Exposure Data

- Smith-Bindman R et al. JAMA 2012
- Data from 6 U.S. healthcare systems from 1996 to 2010
- Evaluated use of CT, x-rays, angiography, fluoroscopy, nuclear medicine
- CT accounted for 68% per capita radiation dose


Learning Objectives
To Understand-

- Describe concerns about CT and radiation
- Describe CT doses and measures
- Discuss radiation risks from CT
- Review strategies to minimize radiation exposure

CT “Dose” Measurements

- CTDI\text{vol} = \text{volume CT dose index}
- DLP = \text{dose length product}
- THESE MEASURES ARE ON PATIENT INFORMATION SHEET

<table>
<thead>
<tr>
<th>Scan</th>
<th>kV</th>
<th>mAs</th>
<th>CTDI\text{vol}</th>
<th>DLP</th>
<th>cGy/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorax</td>
<td>120</td>
<td>93</td>
<td>7.25</td>
<td>251</td>
<td>5.3</td>
</tr>
<tr>
<td>Chest/ Routine</td>
<td>120</td>
<td>93</td>
<td>7.25</td>
<td>251</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Huda W, Mettler FA. Volume CT Dose Index and Dose-Length Product Displayed during CT. Radiology 2011; 258: 236-258

CTDi\text{vol}

- NOT a patient “dose”
- Measure of scanner radiation output
- Unit: mGy
- Describes amount of energy absorbed per kilogram of mass (tissue)
- Why use it? - allows comparison of different protocols

McCullough CH, et al. CT dose index and patient dose: they are not the same thing. Radiology 2011; 259:311-316
Dose Length Product (DLP)

- NOT a patient “dose”
- DLP takes into account scan length
- Product of the CTDI\(_{\text{vol}}\) x scan length (cm)
- Unit is the mGy.cm
- DLP used to obtain effective dose (ED)
- ED used to predict cancer risk to an individual from the partial-body exposure from CT

Estimating Effective Dose

- Effective dose = DLP x \(k\) (\(k\) is weighting factor)
- \(k\) based on region of body scanned
- Unit is sievert (mSv)
- Representative adult values for \(k\) are:
  - Head/Neck \(0.0031\)
  - Head \(0.0021\)
  - Neck \(0.0059\)
  - Chest \(0.014\)
  - Abdomen \(0.015\)
  - Trunk \(0.015\)

Effective Dose Estimate
example: chest CT

- DLP = 251 mGy-cm
- Effective dose = DLP x 0.014 (\(k\)) = 3.5 mSv

2012-more complicated
Size Specific Dose Estimate (SSDE)

- SSDE = CTDI\(_{\text{vol}}\) x conversion factor (\(f_{\text{size}}\))
  for AP or lateral diameters or sum of these diameters of the patient
- Reported in mGy
- Takes into account patient size
- Estimate of patient dose
Example: Abdominal CT

SSDE = 5.4 mGy (CTDI_{vol}) x 2.5 (f_{size}) = 13.0 mGy

What are the effective doses in Diagnostic Imaging?
Mettler FA. Radiology 2008; 248:254-263

Estimated Effective Doses For CT (mean mSv)

- Chest PA/Lat: 0.1-0.01
- Head: 2
- Chest: 7
- Abdomen: 8
- Pelvis: 6
- Coronary CTA (retrosp gating): 16
- Coronary CTA (pros trig): 3

Typical Radiation Doses per year (mSv)

- Natural background: 3.2*
- Medical population: 0.3-0.6

*From natural radiation in soil & rocks, radon gas which seeps into homes & other buildings, plus radiation from space

McCollough C, et al. Diagnostic Reference Levels from the ACR CT Accreditation Program JACR 2011; 8:795–803
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The Issue is Cancer

Atomic Bomb Survivor Data

- Largest longitudinal study to date
  - 35,000 survivors, 55 year follow up
  - exposed to doses < 150 mSv
  - exposures of 10 mSv associated with cancer risk of 1 in 2000 (0.05%)
- Diagnostic CT 2 - 20 mSv

Relative Risk Putting CT in Context

- To an individual:
  - Lifetime cancer risk: 20-25% (1 in 4 to 5)
  - Added risk for 10 mSv CT exam
    - 0.05% (1 in 2000)
- Younger patients at higher risk
  - More radiosensitive
  - More years to live
Risk is Age Dependent
Children & young adults are at greatest risk


Atomic Bomb - Additional Lessons

- Radiation-induced cancers appear at the same age as spontaneous cancers of the same type
- Risks persist throughout life
- Children are more sensitive to radiation induced cancers than adults (girls > boys)
- Bone marrow, thyroid, breast, and lung are at greatest risk

Controversies

- Atomic bomb exposure involved instantaneous whole body exposure to x-rays, neutrons, particulate radiation
- No consensus on whether high dose whole body exposure can be extrapolated to low dose partial body exposure

Data based on statistical modelling
Cancer Risk Factors Related to CT

- 1119 adults who had CT, 4 sites
- 20-year old patients: risks are doubled
- 60-year-old patients: risks 50% lower
- Females at great risk than males
- Coronary and thoracic CT had highest associated lifetime risk of cancer

Risk of 1 in ...... developing one cancer for a specific CT exam

<table>
<thead>
<tr>
<th></th>
<th>20 F</th>
<th>20 M</th>
<th>60 F</th>
<th>60 M</th>
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</thead>
<tbody>
<tr>
<td>Coronary</td>
<td>150</td>
<td>390</td>
<td>420</td>
<td>790</td>
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<tr>
<td>Chest, routine</td>
<td>390</td>
<td>1040</td>
<td>1090</td>
<td>2080</td>
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<tr>
<td>Chest CTA-PE</td>
<td>330</td>
<td>880</td>
<td>930</td>
<td>1770</td>
</tr>
<tr>
<td>Abdomen, routine</td>
<td>470</td>
<td>620</td>
<td>1320</td>
<td>1250</td>
</tr>
<tr>
<td>Head, routine</td>
<td>4360</td>
<td>7350</td>
<td>12250</td>
<td>14680</td>
</tr>
</tbody>
</table>

Key Points About Risk from Medical Imaging

- Ongoing controversy regarding magnitude of the risk from diagnostic doses of radiation
- No controversy regarding the fact that risk from diagnostic doses of radiation is real
- Thus, recommended to keep doses of diagnostic radiation as low as reasonably achievable (The ALARA principle)

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Dose Reduction: Basic Pillars

- Appropriate utilization
- Optimization of CT protocols
- Use of dose reduction technology
1. Appropriate Utilization

• Justify the study
• Avoid repetitive studies
• Use ultrasound or MRI when they offer comparable or more information
  BUT not always possible
• Benefit needs to outweigh risk

2. Optimization of CT protocols

• Limit scan range to region of interest
• Limit number of contrast phases
• Center the patient
• Increase the pitch
• Reduce kVp and mAs
  • 50% decrease in mA = 50% dose decrease
  • 80 kVp = 30% to 50% dose decrease

Appropriate Utilization
Avoid repetitive studies

• More likely to occur in ED
• Usually repeat visits for chest or abdominal pain
• 5-year ED study 2003-2008
  average radiation dose/patient was 45 mSv
  12% of patients received 100 or more mSv

Orlando Regional Medical Center

Limit Scan Range (Z-Axis)
“Image Creep”

• Easiest adjustment
• Use a low-dose “scout” scan to determine the range
• “shrink to size”
Increase the Pitch

- Table travel per rotation
  - Pitch < 1: overlap between acquisitions
  - Pitch > 1: gaps between acquisitions
  - Pitch = 1: acquisitions are contiguous
- Higher pitch – lower dose (varies with vendor)

Center the Patient

- Improper centering of patients (vertically or laterally) from isocenter can increase CTDIvol and image noise due to inaccurate AEC modulation
- Errors are more likely in smaller patients

3. Use Dose Reduction Technologies

- Tube current (mA) modulation
- Tube voltage (kV) reduction
- Iterative reconstruction

Automated Tube Current (mA) modulation

(Automated Real-time Exposure Control)
Tube Current (mA) Modulation

- mA is adapted to thickness of the area of interest (not weight or circumference)
- mAs selected meets a desired level of image quality based on a reference parameter, varies by vendor

<table>
<thead>
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<th>Trade name</th>
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<tr>
<td>General Electric</td>
<td>Smart mA</td>
</tr>
<tr>
<td>Philips</td>
<td>DoseRight</td>
</tr>
<tr>
<td>Siemens</td>
<td>CARE Dose4D</td>
</tr>
<tr>
<td>Toshiba</td>
<td>SureExposure</td>
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- mA selected based on the topogram
- Parts with less thickness need less radiation

Ex: Adult Quality Ref value 150 mA

Mean Dose Reduction

- Stone disease 64%  
  Mulkens AJR 2007; 188: 553
- Cardiac CT 60%  
  Herzog, AJR 2008; 190:1232
- Colonography 35%  
  Graser, AJR 2006; 187:695
A Tale of Two Technologies

Kilovoltage Adjustment

Why use low kV---Rationale

- Lowers radiation dose
- Increases contrast in contrast-enhanced CT
- Help lower volume of contrast material

Low kVp / Contrast

- Rationale: K-edge of iodine 32 keV
- Mean photon energy
  - 80 kVp 44 keV
  - 100 kVp 52 keV
  - 120 kVp 57 keV
  - 140 kVp 62 keV

KEY POINT - kV Reduction

- The effect of lower kV is highly dependent on patient size and diagnostic task
- Increases in contrast are seen with IODINATED substances
  - NOT water, soft tissue, bone
- Benefit greatest in children and small sized adults and contrast CT examinations

Limitation of decreased kV is increased noise

- Need to increase mA and/or use iterative reconstruction

How to Select the Optimal kV

- Manual kV selection: uses technique charts based on patient weight, BMI, or lateral width
  - charts also give reference mAs
- Automated kV selection technology

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<td>kV Assist</td>
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<tr>
<td>Siemens</td>
<td>CARE kV</td>
</tr>
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</table>

Hough et al. Lowering kVp to reduce radiation dose in abdominal CT. AJR 2012; 199:1070-1077

Automated kV Technology

- Selects best kV based on attenuation profile of topogram and diagnostic task (not weight)
- \textit{Chooses one kVp for entire scan}
- mAs is still modulated

Manual kV Selection

- Most experience in CT angiography
- Pulmonary embolus CTA
  - 80 kVp (vs. 120) 25-50% dose reduction
- Coronary CTA (retrospective gating)
  - 100 kVp (vs. 120) 40% dose reduction

Kalva, et al. Using the K-edge to improve contrast conspicuity and to lower radiation dose with flat-panel MDCT. JCAT 2006; 30:391-397
Pulmonary Embolism CTA

- 120 to 80 kV
- 25% dose reduction
- Better contrast

Szucs-Farkas et al. Diagnostic accuracy of pulmonary CT angiography at low tube voltages. AJR 2011; 197:852-859

Automated kV Selection: CTA

Automated Attenuation-Based Tube Potential Selection for Thoracoabdominal Computed Tomography Angiography

Investigative Radiology 2011

Automated kV selection provides diagnostic image quality for body CTA and reduces overall radiation dose by 25% compared with a 120 kV protocol

Auto kV vs. Image Quality

- 80 kV
  - N=1
  - 50 kg
- 100 kV
  - N=23
  - 74 kg
- 120 kV
  - N=16
  - 78 kg

Wiedenhofer et al. Invest Radiol 2011; 46:767

Automated kV Selection in Conventional Thoraco-abdominal CT

- Eller et al (Invest Radiol 2012; 47:559-565)
  - Abdominal CT: 11% dose reduction
- Mahler et al (AJR 2014; 203:292-299)
  - Chest/abdomen CT: 17% / 18% dose reduction
- Shin et al. (Korean J Radiol 2013; 14:886-893)
  - Abdomen CT: 20% dose reduction
ITERATIVE RECONSTRUCTION

Noise Reduction Reconstruction Algorithm (ASiR, Veo, Safire, Admire, iDose, IMR, AIDR)

Iterative Reconstruction

- Reduction in exposure occurs by scanning at lower mA (30-50%) or higher noise index
- Then IR “cleans up” the image noise
- Dose reductions between 30-80%

30% mA reduction

Iterative Image Reconstruction

- Reconstruct images with different noise levels, weak to strong, selected by user

Weak | Average | Strong

w/o IR: high noise

30% mA reduction

IR 3X less noise

30% Lower dose
Combination of IR and Auto kV?

- Gonzalez-Guindalini et al. AJR 2013; 201:1075
- 101 oncology patients, scanned with:
  - Fixed 120 kV w/o IR: mean CTDIvol 19.9 mGy
  - Auto kV + IR: mean CTDIvol 12.5 mGy (p < .0001)
- Image quality was similar (p > 0.05)

Gonzalez-Guindalini et al. AJR 2013; 201:1075-1082

Bottom Line

- Beautiful pictures do **NOT** need to come at the cost of higher radiation dose
- Need to decide what level of image quality is necessary to make an accurate diagnosis

CT and Computed Radiography: The Pictures are Great, but is the Radiation Dose Greater than Required?, AJR 2002; 179: 31-49

Summary

- Used optimally, CT is one of our most valuable tools
- The challenge is to dial down the dose and drive up imaging quality-ALARA
- The answer is to use body-size specific dose technology

Thank you