Should we be concerned about radiation doses from imaging during radiation therapy?

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Should we be concerned about radiation doses from imaging during radiation therapy?

- **Maybe**
  - Depends on the patient’s age, type of imaging
- **Yes**
  - Pediatric and Younger patients
- **No**
  - Imaging doses are considerably decreasing due to awareness, patient selection, technological advances

Outline

- Imaging Phases
- Biological Risks
- Imaging in radiation therapy patients
- Advances enabling lower dose

Imaging Phases in Cancer Patients

**Prior**
- CT
- Radiograph
- Fluoroscopy
- PET-CT
- Ultrasound

**During**
- DRR
- PORTAL
- EPI
- CT Simulator
- CBCT
- 4DCT

**Post**
- CT
- PET-CT
- Radiograph

Bad News
Cancer Risks

- Average risk for radiation induced cancer in general population is 5% per Sv
- Children are 2-3 times at higher risk than adults (as high as 15% per Sv)
- For persons aged > 50 years risk is 1/5th to 1/10th of that for younger adults

CT: Increasing Source of Radiation Exposure

- Nearly one-third of all CT may be inappropriate*
- Organ doses corresponding to common CT studies resulting in dose ranges of 30 to 90 mGy result in increase risk of cancer

MDCT Doses and Cancer Risks

- A-bomb survivors exposed to doses below 150 mSv (15 rem) shows a small but significant excess cancer incidence*
- MDCT doses fall in this range

Pediatric CT scans and subsequent risk for leukemia and brain tumors

- Retrospective study - 17 years data on children younger than 15 years who had CT scans
- Radiation Risk
  - Tripled for brain tumors with 2-3 head CTs (~60 mGy brain dose)
  - Tripled for leukemia with 5-10 head CTs (~50 mGy red bone marrow dose)
- One excess case of leukemia and one excess brain tumor per 10,000 head CT scans
- Radiation dose should be kept as low as possible and alternate procedures should be considered if appropriate

Awareness of Increased Cancer Risk with Medical X-ray Procedures*

- Less than 50% of Radiologists and only 9% ED physicians reported to be aware that CT was associated with increased risk of cancer
- Most ED physicians and radiologists were unable to accurately estimate radiation dose for one CT compared with that for one chest radiograph

CT and MRI obtained in diagnosis of Life-Threatening conditions during Emergency Department Visits

- CT or MRI use Tripled during 1998-2007
- Life-threatening condition diagnosed Admittance to ICU remained unchanged

* BEIR VII, 2005
* ISIR VII, 2005
* Radiology 2004; 231: 393-8
* JAMA 2010;304:1465-1471.
* Hall EJ. Ped Radiol, 2002
* Lancet, 2012
Radiation Injuries in CT – Rare but Possible!

Facts

Number of CT procedures in USA

Number of CT scanners per million population

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Radiation exposure to US population

- US 1982 (NCRP 93)
  - Medical 0.54 mSv per capita
  - Total 3.6 mSv per capita

- US 2006 (NCRP 160)
  - Medical 3.0 mSv per capita
  - Total 6.2 mSv per capita

NCRP 160 published March 2009

Imaging during Radiation Therapy

- Digitally Reconstructed Radiographs (DRR)
- Portal or Electronic Portal Imaging (EPI)
- Kilo-Voltage Imager
- CT Simulator
- Fluoroscopy Simulator
- Cone Beam CT – Variable Frequency
- Mega-Voltage CT with Helical Tomotherapy

Imaging Phases in Cancer Patients

- Case 1 - Head & Neck: June 2011- Sept 2012
  - Prior
    - CT
    - Radiograph
    - Fluoroscopy
    - PET-CT
    - Ultrasound
  - During
    - DRR
    - Portal
    - EPI
    - CT Simulator
    - CBCT
  - Post
    - CT
    - PET-CT
    - Radiograph

- Case 2 - Pediatrics: 2007-2010
  - Prior
    - CT – 6
      - H&N – 4
      - Chest – 2
      - Abd & Pelvis – 1
    - Radiographs
    - CXR – 5
    - Extremities – 6
    - Fluoroscopy – 1
    - Ultrasound – 4
  - During
    - DRR – 2
      - EPI – 3
  - Post
    - ?

Imaging Phases in Cancer Patients


<table>
<thead>
<tr>
<th>Examination</th>
<th>Effective dose (mSv)</th>
<th>Range in literature (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>2</td>
<td>0.9 – 4</td>
</tr>
<tr>
<td>Chest</td>
<td>7</td>
<td>4.0 – 18</td>
</tr>
<tr>
<td>Chest for Pulmonary Embolism</td>
<td>15</td>
<td>13 – 40</td>
</tr>
<tr>
<td>Abdomen</td>
<td>8</td>
<td>3.5 – 25</td>
</tr>
<tr>
<td>Pelvis</td>
<td>6</td>
<td>3.3 – 10</td>
</tr>
<tr>
<td>Spine</td>
<td>6</td>
<td>1.5 – 10</td>
</tr>
<tr>
<td>Coronary angiography</td>
<td>16</td>
<td>5.0 – 32</td>
</tr>
<tr>
<td>Calcium scoring</td>
<td>3</td>
<td>1.0 – 12</td>
</tr>
<tr>
<td>Virtual colonoscopy</td>
<td>10</td>
<td>4.0 – 13.2</td>
</tr>
</tbody>
</table>
Distribution of median (interquartile range) estimated effective dose by computed tomography study type:

Effective dose for CT procedure varied within and across institutions with a mean 13-fold variation between highest and lowest dose for each study type.

Research protocols with multiple CT scans

Radiation dose from CT scans: HCAP ~20 mSv per visit

Total effective dose*: >100 mSv in less than 200 days

Including 4 bone scans @ 7 mSv per scan

Adult Effective Doses: Radiographic procedures

<table>
<thead>
<tr>
<th>Examination</th>
<th>Effective Dose (mSv)</th>
<th>Range in Literature (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull</td>
<td>0.1</td>
<td>0.03 – 0.22</td>
</tr>
<tr>
<td>Cervical spine</td>
<td>0.2</td>
<td>0.07 – 0.3</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>1.1</td>
<td>0.6 – 1.4</td>
</tr>
<tr>
<td>Lumbosacral spine</td>
<td>1.5</td>
<td>0.5 – 1.8</td>
</tr>
<tr>
<td>Chest PA and Lateral</td>
<td>0.1</td>
<td>0.05 – 0.24</td>
</tr>
<tr>
<td>Abdomen</td>
<td>0.7</td>
<td>0.04 – 1.1</td>
</tr>
<tr>
<td>Pelvis</td>
<td>0.6</td>
<td>0.2 – 1.2</td>
</tr>
<tr>
<td>Hip</td>
<td>0.7</td>
<td>0.18 – 2.71</td>
</tr>
<tr>
<td>Intravenous urography</td>
<td>3.2</td>
<td>0.7 – 3.7</td>
</tr>
<tr>
<td>Small-bowel series</td>
<td>5.0</td>
<td>3.0 – 7.8</td>
</tr>
<tr>
<td>Upper GI series</td>
<td>6.0</td>
<td>1.8 – 12</td>
</tr>
<tr>
<td>Barium enema</td>
<td>8.0</td>
<td>2.0 – 18.0</td>
</tr>
</tbody>
</table>

Mettler FA, Huda W, Yoshizumi T and Mahesh M. Radiology, 2008

Topics of Concern in CT

- Multiphase CT exams
  - 3 phase liver study
  - Chest CT with and without contrast
  - Cardiac CT exam including functional studies that involves CTA + CT Perfusion
- Radiation dose per CT scan
- Repeat CT exams

Sample of CT dose reports

CT scan of abdomen and pelvis with and without contrast (arterial and venous scan series)

CT scan of abdomen and pelvis with and without contrast (arterial, venous and delay scan series)

CT Angiography scan of the Chest – includes test bolus, dual-source CTA

Recurrent CT, Cumulative Dose and Cancer Risks

- 22 year study - 31463 patients
- CT: 22 scans in 5%, 38 scans in 1%
- Cumulative Dose:
  - 15% received >100 mSv
  - 4% over 250 mSv
  - 1% over 399 mSv


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Differences in Organ Dose Distribution

- Diagnostic Imaging
  - All organs in the field of view are exposed
  - Effective Dose Estimation (mSv) – risk to whole body from exposure to certain region

- Radiation Therapy
  - Organ doses (mGy) are confined to region of interest
  - Surrounding organs are protected to a large extent

Organ or Tissue Weighting Factors (wT)

<table>
<thead>
<tr>
<th>Organ or Tissue</th>
<th>ICRP 60</th>
<th>ICRP 103</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>Red bone marrow, Colon,</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung, Stomach</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remainder tissues</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Gonads</td>
<td>0.20</td>
<td>0.08</td>
</tr>
<tr>
<td>Bladder, Liver, Thyroid &amp; Esophagus</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Skin &amp; Bone surface</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Brain &amp; Salivary glands</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Accounts additional tissues/organs such as adrenals, kidney, small and large intestine, muscles, pancreas, spleen, thymus and uterus*

Organ or Tissue Weighting Factors

- Breast: 0.05 (ICRP 60), 0.12 (ICRP 103)
- Red bone marrow, Colon: 0.12 (ICRP 60), 0.12 (ICRP 103)
- Lung, Stomach: 0.12 (ICRP 60), 0.12 (ICRP 103)
- Remainder tissues: 0.12 (ICRP 60), 0.12 (ICRP 103)
- Gonads: 0.20 (ICRP 60), 0.08 (ICRP 103)
- Bladder, Liver, Thyroid & Esophagus: 0.05 (ICRP 60), 0.04 (ICRP 103)
- Skin & Bone surface: 0.01 (ICRP 60), 0.01 (ICRP 103)
- Brain & Salivary glands: 0.01 (ICRP 60), 0.01 (ICRP 103)

Organ or Tissue Weighting Factors

- Breast: 0.05 (ICRP 60), 0.12 (ICRP 103)
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Factors affecting CT Radiation Dose and Image Quality

**Primary Factors**
- Tube Current (mA)
- Tube Voltage (kVp)
- Scan Time
- Pitch
- Scan Acquisition Type

**Secondary Factors**
- Scan Field of View (SFOV)
- Display Field of View (DOFOV)
- Beam Collimation
- Reconstructed Slice Width
- Reconstruction Interval
- Reconstruction Algorithms

**Other Factors**
- Patient Size
- Scan Length
- Patient Motion
- Geometry and Detector Efficiency
- Training and experience

**Radiation Dose Reduction Strategies**

- Optimal tube current (mA) selection
  - Dose modulation strategies
- Reduce tube voltage in suitable patients
- Minimize scan range
- Dynamic collimation
- Cardiac Imaging Acquisition Modes
  - ECG gated tube current modulation
  - Prospectively ECG-triggered axial scanning
- Dose Reports
- Dose Check...

**Technological advances enabling CT dose reduction**

- Prospective vs Retrospective CT acquisition
  - Step-and-shoot versus helical acquisition
- Improved dose modulation techniques
- Wide detector CT (256 and 320 MDCT)
- Dual source CT
- Improved detection efficiency
- Dynamic collimation, beam shaped filters
- Iterative Reconstruction

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Scan coverage - 320 vs 64 slice MDCT

Implications of wide detector CT

- Wide detector CT systems have large scan regions
  - For ex: 320 MDCT (Toshiba) has scan range of 160 mm
  - For ex: 256 MDCT (Philips) has scan range of 80 mm
- Minimizes patient motion
- Requires less contrast
- Reduces overall exam time

Dual Source CT: Definition FLASH

CT Dose Modulation

- X-ray attenuation lower in AP and higher in lateral projection
- However, CT doses are uniform on the surface and decreases radially towards center
- Various dose reduction options are been considered

Automatic Tube Current Modulation (ATCM)

- Spatial modulation: Based on modulating tube current (mA) at different spatial projections
- Utilized in most routine body CT protocols
- Temporal modulation: Based on modulating tube current (mA) at specified time points of an electrocardiographically gated (ECG) signal
- Utilized in cardiac CT protocols
Automatic Exposure Control (AEC)

Temporal Dose Modulation

- Constant tube current through entire R-R cycle can be modulated
- Tube current is lowered outside diastolic region enabling dose reduction during cardiac CT

Tube Current: Radiation Dose vs Image Noise

- Renal Cyst (white arrow) observed at all 4 radiation dose levels
- Conspicuity of small liver vessels is compromised at 50 mAs

Tube Voltage Modulation

- Lower tube voltage improves image contrast and reduce dose
- As tube voltage decreases, tube current may have to be increased to maintain image noise

Iodine CNR as function of Tube Potential

Iterative Reconstruction

Lower tube voltage is advantageous for medium and small patients

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**Iterative Reconstruction**

- Iterative reconstruction method makes several passes over the raw data (obtained at low dose techniques) to produce more accurate model of image and reduce amount of noise
- Can result in 40 to 80% reduction in radiation dose
- **Trade-off:** need for more processing power and additional time for processing

**Over-ranging in CT scans**

- Over-ranging is specific to reconstruction-algorithm
- Generally increases with collimation and pitch
- Over-ranging may lead to substantial but unnoticed exposure to radiosensitive organs

**Conventional and Adaptive Collimation**

- Organ based dose modulation reduces breast dose by 30-40%
- Noise level is maintained with dedicated reconstruction technique

**Dose reduction with X-CARE to Breast Tissue**

- X-ray tube current

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Image Gently®
- Increase awareness for need to decrease radiation dose to children during CT scans
- Down-size adult CT protocols to kids size
- Consider eliminating multi-phase scans

Image Wisely®
- Increase awareness for need to decrease radiation dose even in adult protocols

Impact after implementing radiation reduction techniques
- Distribution of Patients by Estimated Radiation Dose
- Percentage of Patients Achieving Target Dose of Less Than 15 mSv by Bimonthly Intervals

New model estimating radiation-induced cancer risk with age at exposure
- Initiation – Higher risk at younger age
- Promotion – Risk increases with age at exposure (especially greater at middle age)
- Initiation and Promotion result in very different variations in cancer risk as a function of age at exposure

Estimated Excess Relative Risk of Mortality among atomic bomb survivors exposed to doses less than 500 mSv

Good News

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Controversy with extrapolating effects of radiation at low doses

LNT – Model adopted for radiation protection standards

Cancer Death Rates 1930-2008

Leading New Cancer Cases and Deaths (2012 Estimates)

11

Potential impact of dose reduction strategies in CT

Impact of increase awareness about radiation risks

• 5 year follow-up study among members of Society of Pediatric Radiologists
• Significant decrease in tube current and tube voltage settings

CT Utilization Rates per 1000 Medicare Beneficiaries

Radiation Dose Trends from Coronary CT Angiography
Clinically proven low dose Cardiac
Published: AJR:195, September 2010 & AMJ Cardiol:106, December 2010

2 Multi-center studies:
ERASIR study
500+ unselected patients demonstrated 27% dose reduction with ASIR
PROTOCOL study
400+ consecutive unselected patients with a set protocol
Average Cardiac CT at 1.3 mSv

 Imaging Phases in Cancer Patients

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What can be done?
• Educate all stakeholders regarding radiation dose and risks
• Ensure x-ray imaging studies are justified and benefits outweigh the risks always
  – Avoid repeat studies
  – Minimize multi-phase studies
  – Decrease frequency of follow-up imaging
• Coordinate efforts with radiation oncologists, radiologists, medical physicists and technologists to optimize modalities and protocols to minimize radiation exposure

Key Questions to Ponder?
• Frequency of follow-up imaging
  – If follow-up scan once in 3 months replaced by follow-up scan once in 4 months
  – Then, even keeping all factors same, dose to patient is lowered by nearly 25%
Key Questions to Ponder?

- Normally PET-CT scan is followed by diagnostic CT scan
  - Reimbursement is not same for CT done during PET-CT compared to diagnostic CT, hence drive towards additional diagnostic CT
- If reimbursement for CT in PET-CT increased
  - Can the additional CT eliminated?

Conclusions

- Benefits of CT studies far outweighs radiation risks, as long as appropriateness is justified
- Novel technological advances are reducing CT dose significantly
- Challenge is to adapt such advances aimed at lowering CT dose into standard practice at faster pace

Conclusions

- Critical to understand various aspects of imaging in patients undergoing radiation therapy treatment
- Irrespective of patient type and age, all efforts are to be done to minimize risks from medical x-ray imaging procedures
- Radiation Therapy Physicists and Diagnostic Physicists need to work together

Concluding Statement

- Regardless of individual risk, increasing collective dose from CT and other imaging must signal possibility that we are creating future public health program
- No matter what the controversies are, it is important that all stakeholders in medical imaging have an obligation to strive to reduce doses in medical imaging without jeopardizing image quality

Apologies to Dr Stewart