Introduction

- United States, 2006: estimated 62 million CT (CT: 15% imaging procedures, 50% collective radiation dose)


In the patients:
- 30% > 3 times of CT
- 7% > 5 times of CT
- 4% > 9 times of CT

Specific populations: chronic conditions (Crohn disease, and renal colic) high rates of repeat imaging

Attention has recently focused on the potential risks of radiation-induced carcinogenesis from diagnostic radiology

Materials and Methods

- Study Design and Setting:
  - retrospective cohort study
  - 752-bed adult urban tertiary academic medical center and its associated outpatient cancer center.

- Cohort Selection:
  - All patients who underwent diagnostic CT from January 1, 2007 ~ December 31, 2007, in any care setting (inpatient, outpatient, or emergency department).

- Data Collection and Analysis:
  - Radiology information system (RIS) database: 21.8-year (May 28, 1986, and March 10, 2008), excluding interventional CT procedures
  - Sex and date of birth were obtained, and exposure ages were calculated as the difference between each examination completion date and the date of birth.

<table>
<thead>
<tr>
<th>CT Effective Dose Estimates Based on Anatomic Coverage Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomical Coverage Region</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>Head, Face</td>
</tr>
<tr>
<td>Cervical spine, neck</td>
</tr>
<tr>
<td>Chest, pulmonary arteries, thorax, spine</td>
</tr>
<tr>
<td>Abdomen, ileum (in abdomen)</td>
</tr>
<tr>
<td>Pelvis (in abdomen)</td>
</tr>
<tr>
<td>Abdomen and pelvis, lumbar spine</td>
</tr>
<tr>
<td>Extremity</td>
</tr>
</tbody>
</table>
2. Risk estimation from effective doses:

Biological Effects of Ionizing Radiation (BEIR) VII methodology

3. Clinical classification of high-risk patients:
   - Use billing and electronic order entry data
     → the highest estimated levels of cancer risk from CT exposures
     (LAR of cancer incidence > 1%)
   - Collect all ICD9 (RIS database)
     → radiology study: November 5, 1999–September 9, 2008
   - Malignancy history: ICD9 malignant neoplasm categories 140–208
   - Metastatic disease: ICD9 categories 197–198

Results

- Cohort Characteristics:

<p>| Table 2 |
| Patient Demographics in the Cohort |</p>
<table>
<thead>
<tr>
<th>Sex</th>
<th>No. of Patients</th>
<th>Minimum Age (y)</th>
<th>Mean Age (y)</th>
<th>Maximum Age (y)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>17,093</td>
<td>11</td>
<td>59.5</td>
<td>106</td>
<td>17.5</td>
</tr>
<tr>
<td>Male</td>
<td>13,859</td>
<td>16</td>
<td>57.4</td>
<td>101</td>
<td>17.4</td>
</tr>
<tr>
<td>Both</td>
<td>31,952</td>
<td>11</td>
<td>59.9</td>
<td>108</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Note.—Cohort of all patients undergoing a diagnostic CT examination in 2007.

- Cumulative CT Survey Results:

<p>| Table 3 |
| Summary Data for the Distributions in Figures 3-5 |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cumulative CT Examination Count</th>
<th>Cumulative Effective Dose (mSv)</th>
<th>LAR of Cancer Incidence (%)</th>
<th>LAR of Cancer Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>3</td>
<td>24</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>Mean</td>
<td>8.1</td>
<td>54.3</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>10th Percentile</td>
<td>36</td>
<td>389</td>
<td>2.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Maximum</td>
<td>132</td>
<td>175</td>
<td>12.0</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Figure 2: Distribution of anatomic locations for the 190,712 CT examinations captured over the 22-year study period in the cohort of 140,462 patients. Chest = Thorax.

- Cumulative CT Examination Counts:

33% ± 5 CT examinations; 5% ± 22 examinations; 1% ± 38 examinations.
Estimated Cumulative Effective Doses:

- 15% ≥ 100 mSv, 4% ≥ 250 mSv, and 1% ≥ 399 mSv

Estimated Cumulative Radiation-induced Cancer Risks:

- **Cancer incidence**:
  - 7% LAR ≥ 1%
  - 1% LAR ≥ 2.7%

- **Cancer mortality**:
  - 3% LAR ≥ 1%
  - 1% LAR ≥ 1.6%

Estimated Cumulative Risks to the Cohort (Total 31462):

1. **BEIR VII**:
   - Baseline cancer incidence of 42%, cancer mortality of 20% (U.S.)
   - Baseline cancer rates: 13,214 cancers, 6,292 fatal cancers.

2. **98 additional radiation-induced cancers, 62 fatal cancers.**
   - (0.7% of expected cancer incidence, 1% of cancer mortality)

3. **315 patients in the top percentile of cumulative LAR**:
   - LARs: 2.7% ~ 12% above the 42% baseline
   - Equates to 6%–22% total expected cancer incidence

Disease Classification in Frequently Imaged Patients:

- Since March 2008: electronic order pertaining to malignancy
  - 469 (30%) history of malignancy (no evidence of disease)
  - 1679 (90%) known active malignancy (under/plan for treatment)

- 584 cancer patients without evidence of disease, or 25% of the cohort with LAR greater than 1%

- 350 patients (15%):
  - No malignancy history
  - Estimated LAR > 1%
  - Only 12% had all of their repeat imaging of the same anatomic region
Discussion

- High rates of recurrent CT imaging:
  - 33% ≥ 5 CT, 5% ≥ 22 CT
  - 1.5% cumulative CT effective doses ≥ 100 mSv (convincing epidemiologic evidence of increased cancer risk)


  - 1.5%–2.0% of all U.S. population cancers may be caused by CT radiation exposure.
  - BEIR VII : 0.7% of our cohort’s lifetime cancers may be caused by CT includes only past exposures at a single institution, purely adult population

Limitations and Underlying Controversies:

1. Cohort setting:
   - single adult tertiary care institution
   - may not be generalizable to other institutions
   - different patient mixes, different provider attitudes to CT imaging

2. Underestimated cumulative examination counts and doses:
   - no data before 22-year records
   - only diagnostic CT (half of the collective population dose), excluding interventional radiology, nuclear medicine, fluoroscopy, and radiography studies.

3. Dosimetry:
   - CT radiation doses: depend on scanner technology and imaging parameters used and may vary with patient size
   - No-dose adjustment: particular scanner type or date of examination
   - Universal dosimetry estimation: might alter the shape and scale of the cumulative dose distribution.
   - The effects of organ-specific absorbed doses better than effective dose estimates for individual
   - Better still would be to capture and archive dose parameters
   - patient-specific dose estimates

Summary and Recommendations

- Patients who undergo large amounts of recurrent CT:
  - measures to control subsequent exposures
    - technical developments (automated tube current modulation, beam filtration, and adaptive collimation)
    - imaging parameter selection (decreasing tube potential, tube current)
    - protocol modifications (reducing duplicate coverage regions, multiple-pass scanning)
    - reduce CT utilization: broadly applicable imaging algorithms, nonionizing imaging alternatives
The risks of an individual study should be viewed as part of the patient’s past (and predicted future) cumulative exposure.

Educate physicians and inform the risk-benefit decision:

As a first step:
Inspection of the CT history

As a next step:
The developing real-time decision support tools to identify high-risk patients, provide cumulative exposure and risk estimates

~Thank you~