Overview of Medical Diagnostic and Interventional Imaging:

Usage Patterns

Beebe Symposium

Washington DC, December 9, 2009

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Usage and Dose Patterns

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Why are radiology and nuclear medicine used so much?

Patients are a bit like Christmas presents….

• You can poke them
• You can feel them
• You can talk to them
• You can weigh them
• You can listen to them

………but there is nothing like a look inside without needing to unwrap it
Recent reports on U.S. and worldwide usage

- **U.S. 2006 data**
  - NCRP REPORT No. 160
  - IONIZING RADIATION EXPOSURE OF THE POPULATION OF THE UNITED STATES
  - 2009

- **International (UN) 2007 data**
  - 2008
  - SOURCES AND EFFECTS OF IONIZING RADIATION
    - United Nations Scientific Committee on the Effects of Atomic Radiation
    - UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes
    - In press

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Bruce R. Thomadsen, PhD
Terry T. Yoshizumi, PhD

The U.S. National Council on Radiation Protection and Measurements and United Nations Scientific Committee on Effects of Atomic Radiation each conducted respective assessments of all radiation sources in the United States and worldwide. The goal of this article was to summarize and combine the results of these two publicly available surveys and to compare the results with historical information. Institutional review board approval was obtained; informed consent was waived. In the United States in 2006, about 377 million diagnostic and interventional radiologic examinations and 18 million nuclear medicine examinations were performed. The United States accounts for about 12% of radiologic procedures and about one-half of nuclear medicine procedures performed worldwide. In the United States, the frequency of diagnostic radiologic examinations has increased almost 10-fold (1950–2006). The U.S. per-capita annual effective dose from medical procedures has increased about sixfold (0.5 mSv [1980] to 3.0 [2006]). Worldwide estimates for 2000–2007 indicate that 3.6 billion medical procedures with ionizing radiation (3.1 billion diagnostic radiologic, 0.5 billion dental, and 37 million nuclear medicine examinations) are performed annually. Worldwide, the average annual per-capita effective dose from medicine (about 0.6 mSv of the total 3.0 mSv received from all sources) has approximately doubled in the past 10–15 years.

* RSNA, 2009

From the Radiology and Nuclear Medicine Service, New Mexico VA Health Care System, 1501 San Pedro Blvd SE, Albuquerque, NM 87108 (F.A.M.); Department of Research, American College of Radiology, Reston, Va (M.B.); Department of Quality Assurance, WHS/Quality Assurance Reference Centre, Wallasea, England (K.F.); Department of Health, State of Florida, Tallahassee, Fla (D.B.G.); D Quinn, Steiger, III (J.E.G.); Department of Radiation Physics, University of Texas, MD Anderson Cancer Center, Houston, Tex (E.S.I.); Department of Radiation Protection Programs, New Jersey Department of Environmental Protection, Trenton, NJ (J.A.L.); Johns Hopkins University.
U.S. compared to the world

• Worldwide there are about
  - 3.1 billion diagnostic x-ray examinations
  - 37 million nuclear medicine procedures
  - 5.5 million radiation therapy patients annually

• In the U.S. with 5% of the worlds population, there are about
  - 0.5 billion diagnostic x-ray examinations ~ 25% of the world
  - 19 million nuclear medicine procedures ~ 50%
  - 1 million radiation therapy patients ~ 20%
~25% of the world's population gets 75% of the procedures.

~50% of the population.

25%
Worldwide temporal trends in diagnostic radiology

Frequency per 1000 population

Health care level

U.S. 2006

Radiol. 2009, 253(2);520-531
Collective annual population dose from medicine has increased over 700 percent.

$124,000 \text{ Person Sv} \times 7.1 = \sim 900,000 \text{ person-Sv}$

Radiol. 2009, 253(2);520-531
Preliminary estimate of changes in U. S. medical radiation exposure

U.S. 1980
- Natural: 2.8 mSv
- Medical: 0.54 mSv
- Total: 3.6 mSv per capita

U.S. 2006
- Natural: 3.0 mSv
- Medical: ~3.0 mSv
- Interventional: 0.4 mSv
- Radiography: 0.3 mSv
- Nuclear medicine: 0.8 mSv
- CT scanning: 1.5 mSv
- All other ?? mSv
- Total: ~6.0 mSv
Medical exposure is 94% of man-made sources of radiation U.S. 2006

Medical exposure is 94% of man-made sources of radiation U.S. 2006

Per capita effective dose

TOTAL ~ 3.2 mSv
(94% from medical)
Major changes in imaging over the last decade that involve substantial radiation doses

• New uses of CT
  – Clinical
  – Screening
  – CT combined with other procedures
• Cardiac nuclear medicine
• Digital radiography
• Increasing use of radiation by non-radiologists
Changes in medical usage are mostly from exams that have high effective doses

<table>
<thead>
<tr>
<th>Exam</th>
<th>Effective Dose (mSv)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest x-ray</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Abdomen x-ray</td>
<td>0.7</td>
<td>7</td>
</tr>
<tr>
<td>Nat. bkd (annual)</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Chest CT</td>
<td>7</td>
<td>70</td>
</tr>
<tr>
<td>Rest/stress NM perfusion</td>
<td>12</td>
<td>120</td>
</tr>
<tr>
<td>Whole body CT</td>
<td>30</td>
<td>300</td>
</tr>
<tr>
<td>PET/CT</td>
<td>45</td>
<td>450</td>
</tr>
</tbody>
</table>
## Results (U.S. 2006)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number procedures</th>
<th>%</th>
<th>Collective dose (Person-Sv)</th>
<th>%</th>
<th>Per capita (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiography</td>
<td>293 million</td>
<td>74</td>
<td>100,000</td>
<td>11</td>
<td>0.33</td>
</tr>
<tr>
<td>Interventional</td>
<td>17 million</td>
<td>4</td>
<td>128,000</td>
<td>14</td>
<td>0.43</td>
</tr>
<tr>
<td>CT</td>
<td>67 million</td>
<td>17</td>
<td>440,000</td>
<td>50</td>
<td>1.5</td>
</tr>
<tr>
<td>Nuclear Medicine</td>
<td>18 million</td>
<td>5</td>
<td>231,000</td>
<td>26</td>
<td>0.8</td>
</tr>
<tr>
<td>Radiotherapy</td>
<td>1 million pts</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>--</td>
</tr>
</tbody>
</table>

**Total x-ray + NM = ~ 375 million ~ 900,000 ~ 3.0**

Radiol. 2009, 253(2):520-531
Computed tomography (CT scan)

Recent advances in machine technology have led to more applications and markedly increased usage.
Rates of CT scanning
(scans per 1000 persons annually)

- Well developed countries: 116 (average)
- UK: 21
- Spain: 51
- Sweden: 70
- Austria: 75
- Switzerland: 91
- Norway: 99
- Germany: 111
- United States: 223
- Japan: 349

UNSCEAR 2008
CT procedures by year (millions)

- Annual growth > 10%/yr
- U.S. population < 1%/yr

Year | No. of procedures (millions)
-----|-----------------------------
1993 | 18.3
1994 | 19.5
1995 | 21.0
1996 | 22.6
1997 | 25.1
1998 | 26.3
1999 | 30.6
2000 | 34.9
2001 | 39.6
2002 | 45.4
2003 | 50.1
2004 | 53.9
2005 | 57.6
2006 | 62.0
Who gets CT scans?

CT scans of abdomen and pelvis

Exam distribution vs U.S. population

<table>
<thead>
<tr>
<th>Age Group</th>
<th>% of CTs</th>
<th>% of Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 0-10</td>
<td>15.0%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Age 11-17</td>
<td>10.1%</td>
<td>2.2%</td>
</tr>
<tr>
<td>Age 18-24</td>
<td>10.0%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Age 25-34</td>
<td>7.2%</td>
<td>13.7%</td>
</tr>
<tr>
<td>Age 35-44</td>
<td>15.3%</td>
<td>12.4%</td>
</tr>
<tr>
<td>Age 45-54</td>
<td>18.0%</td>
<td>14.0%</td>
</tr>
<tr>
<td>Age 55-64</td>
<td>19.0%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Age 65-74</td>
<td>19.4%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Age 75-84</td>
<td>16.1%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Age 85 and older</td>
<td>0.7%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

2003
# CT (U.S. 2006)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number (millions)</th>
<th>%</th>
<th>Collective dose person Sv</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>19</td>
<td>28.4</td>
<td>38,044</td>
<td>8.7</td>
</tr>
<tr>
<td>Chest</td>
<td>10.6</td>
<td>15.9</td>
<td>74,326</td>
<td>17.0</td>
</tr>
<tr>
<td>Abd/Pelvis</td>
<td>21.2</td>
<td>31.7</td>
<td>212,538</td>
<td>48.6</td>
</tr>
<tr>
<td>Spinal</td>
<td>4.1</td>
<td>6.2</td>
<td>41,369</td>
<td>9.5</td>
</tr>
<tr>
<td>Extremity</td>
<td>3.5</td>
<td>5.2</td>
<td>515</td>
<td>0.1</td>
</tr>
<tr>
<td>CT Angiogram</td>
<td>4.3</td>
<td>6.4</td>
<td>56,000</td>
<td>12.8</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>4.2</td>
<td>6.2</td>
<td>14,730</td>
<td>3.3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>67</strong></td>
<td><strong>100</strong></td>
<td><strong>437,523</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Radiol. 2009, 253(2):520-531

Effective dose per capita 1.46 mSv
EP CT Ordering Variability

- 18.7% ED pts had CT

Melanson NCRP 2009 Temple Univ
### Variation in doses for exactly the same protocol (120 kVp pitch of 1)

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Model</th>
<th>CTDI (mGy/mAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>HiSpeed</td>
<td>52</td>
</tr>
<tr>
<td>GE</td>
<td>LS Ultra</td>
<td>100</td>
</tr>
<tr>
<td>Philips</td>
<td>CX/S</td>
<td>63</td>
</tr>
<tr>
<td>Philips</td>
<td>EG</td>
<td>298</td>
</tr>
<tr>
<td>Siemens</td>
<td>Plus</td>
<td>57</td>
</tr>
<tr>
<td>Siemens</td>
<td>Sensation Open</td>
<td>87</td>
</tr>
<tr>
<td>Toshiba</td>
<td>X-Speed II</td>
<td>46</td>
</tr>
<tr>
<td>Toshiba</td>
<td>Asteion Multi</td>
<td>164</td>
</tr>
</tbody>
</table>

Factor of 6 between manufacturers and a factor of 5 for the same manufacturer.
CT scanning delivers high radiation doses

Hair loss from excessive dose of a CT angiogram

Eur J Radiol 2005
Radiation erythema from 151 slices of CT in a 2 year old
CT scanning of the chest

- Breast dose in thorax CT may be as much as 30-50 mGy, even though breasts are not the target of imaging procedure
- Breast dose from chest CT equals that from about 10-15 sets of 2 view mammograms
The lawyers are looking at this too..

CT Scans and Radiation Exposure: Emerging Legal Considerations for Imaging Manufacturers
Charles F. Rysavy and Roger P. Shaw

In hospitals, clinics, and unaffiliated radiologists’ offices throughout the world, computed tomography (CT) scans are increasingly the diagnostic tool of choice. The reason for the explosive growth in these procedures is understandable, since the precision and clarity of newer generation CT scans make diagnoses quicker and more accurate, reduce the need for exploratory surgery (with all of its risks and potential complications), and save lives.

Over the past quarter century, the number of CT scans performed in the United States each year has increased more than 20 fold.¹ Some physicians and clinics even promote whole-body CT scans as screening tools for asymptomatic patients. And as the technology continues to evolve, what is considered suitable for obtaining a diagnosis expands.


Design defect
Failure to warn
RBE 2 (BEIR VII)
WHO carcinogen
Why has there been such spectacular growth in procedures ..

 ..........and such an increase in dose ??
Single slice CT scanner

Tube rotates, image is obtained, then table moved incrementally and another tube rotation and another image obtained. **Scan time ~ 10-20 minutes**
Multislice multidetector helical CT scanner

Constant motion, constant tube rotation, constant table feed. More detectors.

Scan time 0.3-5 seconds. Now 300 slices/images in 0.3 second
New widespread uses of CT

• Clinical
  – Appendicitis
  – Renal colic/stones
  – Pulmonary embolism
  – Trauma
• Screening
  – Coronary arteries
  – Colonoscopy
  – Lung cancer

• Most of these improve confidence in diagnosis

• Few of these uses have been studied sufficiently to show a significant change in patient outcome

• They are clearly easy to interpret and fast to do
Appendicitis

Normal

Abnormal
Renal stones/colic

Intravenous urogram (IVP)

Requires injection of intravenous contrast

Contrast reactions in 5% of patients

Death from contrast 1/40,000 to 1/100,000
Dilated ureter
4mm stone in distal ureter
Stranding and edema around kidney
Many patients have more than CT examination

This 35 year old had 18 CT exams
Nuclear medicine lung perfusion scan

Chest CT scan with intravenous contrast

Reduced blood flow to one lung - nonspecific

Large clot in right main pulmonary artery – clear diagnosis
Trauma

- Liver laceration
- Small pneumothorax
Coronary artery calcium scoring and screening

Calcified left anterior descending coronary artery
Coronary artery stenosis

Contrast invasive coronary angiogram

3-D CT scan
CT screening for lung cancer and followup of lung nodules

Nodules as small as 2-3 mm are easily seen on CT. On regular chest x-ray most non-calcified nodules need to be 8-10 mm to be reliably visualized.
CT (virtual) colonoscopy

CT scout image

3-D image of colon

CT virtual fly-through

Fiber-optic colonoscopy
Incidental findings on CT scans

- Gallstones: ~5%
- Renal cysts: ~50% older
- Fatty liver: ~5-10%
- Congenital: ~5%
What would we do without CT?
What is digital radiography?

- Filmless radiography. Exactly like your digital cameras.
Essentially all x-ray departments are completely digital and no longer use film at all.
Digital Radiography

Underexposed:
Cannot fix

Overexposed by up to 100x:
Simply adjust window on computer

Therefore tendency is to overexpose
What they did

What you see

Without dose indices: radiologist has no idea if patient was overexposed
What you see          What they did
Currently approximately 1 nuclear medicine procedure annually per 15 persons
<table>
<thead>
<tr>
<th>Organ</th>
<th>Number millions</th>
<th>%</th>
<th>Collective dose Person Sv</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>0.11</td>
<td>&lt;1</td>
<td>272</td>
<td>0.1</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.42</td>
<td>&lt;1</td>
<td>420</td>
<td>0.2</td>
</tr>
<tr>
<td>Lung</td>
<td>0.78</td>
<td>4</td>
<td>2113</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Cardiac</strong></td>
<td><strong>10.3</strong></td>
<td><strong>57</strong></td>
<td><strong>197,311</strong></td>
<td><strong>85.2</strong></td>
</tr>
<tr>
<td>GI</td>
<td>1.27</td>
<td>7</td>
<td>3711</td>
<td>1.6</td>
</tr>
<tr>
<td>Renal</td>
<td>0.49</td>
<td>3</td>
<td>675</td>
<td>0.3</td>
</tr>
<tr>
<td>Bone</td>
<td>3.62</td>
<td>20</td>
<td>21543</td>
<td>9.3</td>
</tr>
<tr>
<td>Infection</td>
<td>0.40</td>
<td>2</td>
<td>1395</td>
<td>0.6</td>
</tr>
<tr>
<td>Tumor</td>
<td>0.36</td>
<td>2</td>
<td>4121</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18.6</strong></td>
<td><strong>100</strong></td>
<td><strong>231,500</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Radiol. 2009, 253(2);520-531
Cardiac nuclear medicine

Ischemic area seen at stress fills in at rest
Cardiac nuclear medicine (wall motion)

Diastole

Systole

Poor motion of inferior wall due to prior myocardial infarct
Cardiac nuclear medicine

- Techniques have been available for over a decade but number of procedures has almost doubled

- Cardiologists now own equipment and self-refer almost 2/3 of the cases

- New for-profit “Heart Hospitals” in almost every city in the U.S.
Combined CT and other modalities
Post colon cancer surgery
Rising tumor marker (CEA)
Positron emission (PET) scan

$^{18}$F-FDG
fluorodeoxyglucose

Heart
Kidneys
Bladder
Combined PET/CT scan
Lung metastasis from laryngeal cancer

CT scan

PET/ CT scan

Nodules must be > 8 mm to be reliably visualized
What is the effective dose from one PET/CT scan?

- 740 MBq $^{18}$F-FDG: 14 mSv
- Head CT: 2 mSv
- Neck CT: 3 mSv
- Chest CT: 7 mSv
- Abdomen CT: 8 mSv
- Pelvis CT: 6 mSv

**Total**: 40 mSv
Manufacturers are now advertising directly to self-referring clinicians

<table>
<thead>
<tr>
<th>Procedures Per Day</th>
<th>Days Per Month</th>
<th>Average CPT</th>
<th>Income</th>
<th>FMVL Cost</th>
<th>ROI* Per Month</th>
<th>ROI for 5 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8</td>
<td>20</td>
<td>$220</td>
<td>$7,950</td>
<td>$7,950</td>
<td>Break Even</td>
<td>Break Even</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>$220</td>
<td>$22,000</td>
<td>$7,950</td>
<td>$14,050</td>
<td>$843,000</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>$220</td>
<td>$44,000</td>
<td>$7,950</td>
<td>$36,050</td>
<td>$2,163,000</td>
</tr>
</tbody>
</table>

Sample computation – Basic SOMATOM Spirit configuration, based on a 5-year Fair Market Value Lease (FMVL). Prices will vary with additional options. Please consult your Siemens Account Executive for details.

*Return on Investment.
Gift Certificates for Radiation Exposure ????

CT Scan

Procedure Name:
Computed Tomography

Description:
A CT scan, or CAT scan, is a common term for computerized spiral tomography, a painless diagnostic imaging test that displays two-dimensional images of internal structures of the body on a computer screen. This test often takes less than 30 minutes to perform. Patients can receive a CT scan on an outpatient basis or as part of an inpatient hospital stay.

Basic Facts:

- Computed tomography (CT) scanners are diagnostic testing devices that use x-rays to obtain horizontal and vertical cross-sectional views of internal areas of the body. In addition to creating diagnostic images, the CT scanner can be used to guide needle or catheter placement.
- The CT scanner consists of a gantry, a control console, and a computer that displays images on a monitor.
- CT scans have a fine degree of detail.

CT scans can be taken of many sections of the body, including the abdomen, chest, and brain. The images come from the reflection of x rays off tissues of varying densities. Sometimes a contrast dye is given to a patient intravenously, rectally, or orally to make hollow or fluid-filled structures such as blood vessels more visible. The use of contrast material during CT scanning
How does the typical physician view radiation protection?

How bad is the patient bleeding?

Will the test or therapy affect outcome?

Is it available?

What is my experience?

What is the downside if I don’t order it?

Have I seen anything in the literature lately?

What is my gut feeling?

Radiation risk?? Is that an issue??
Didn’t anybody see this huge increase coming?
Currently > 67 million U.S.
Does anybody, or should anybody, regulate this, the largest (and controllable) source of radiation exposure?

The largest radiation source in the U.S. remains largely unregulated and appears likely to continue to grow with minimal constraints.
Will national health care affect these issues?

Currently patterns of practice in the VA are essentially the same as in the private sector.
<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical</td>
<td>2,519,000</td>
</tr>
<tr>
<td>Aviation</td>
<td>173,000</td>
</tr>
<tr>
<td>Commercial nuclear power</td>
<td>116,000</td>
</tr>
<tr>
<td>Industry &amp; commerce</td>
<td>505,000</td>
</tr>
<tr>
<td>Research &amp; education</td>
<td>437,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,750,000</strong></td>
</tr>
</tbody>
</table>
# Occupational doses

<table>
<thead>
<tr>
<th>Industry</th>
<th>Persons with recordable doses</th>
<th>Collective eff (Person-Sv)</th>
<th>Average (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical</td>
<td>735,000 (60%)</td>
<td>546 (39%)</td>
<td>0.75</td>
</tr>
<tr>
<td>Aviation</td>
<td></td>
<td>531</td>
<td>3.07</td>
</tr>
<tr>
<td>Comm Nuc Pwr</td>
<td>59,000</td>
<td>110</td>
<td>1.87</td>
</tr>
<tr>
<td>Industry</td>
<td>134,000</td>
<td>109</td>
<td>0.81</td>
</tr>
<tr>
<td>Educ/Research</td>
<td>84,000</td>
<td>60</td>
<td>0.72</td>
</tr>
<tr>
<td>Govt/Military</td>
<td>31,000</td>
<td>39</td>
<td>0.59</td>
</tr>
<tr>
<td>Total</td>
<td>1,215,000</td>
<td>1399</td>
<td>1.13</td>
</tr>
</tbody>
</table>

NCRP 160, 2009
International groups currently working on the issue of increased dose and usage

IAEA, WHO, PAHO, EC, IEC, IOMP, ISR, IOMP, ISR, WFN

ICRP Reports beginning in 2000.
CT ( # 87,102)
fluoroscopic injuries (# 85)
radiation protection in medicine (# 105)
U.S. groups currently examining the issue of increased dose and usage

American College of Radiology Appropriateness Criteria

“Image Gently” Consortium. Society of Pediatric Radiology


ACR/RSNA Working Group Nov 15-16, 2009

IOM Beebe Symposium Nov 15-16, 2009
Thank you