NCRP 184:
Medical Radiation Exposure of Patients in the United States

Mahadevappa Mahesh, MS, PhD, FAAPM, FACMP, FACR, FSCCT, FIOMP
Co-Chair of NCRP 184
Professor of Radiology and Cardiology
Johns Hopkins University School of Medicine
Chief Physicist – Johns Hopkins Hospital
Joint Appointment - Johns Hopkins School of Public Health
Baltimore, MD

AAPM Virtual Meeting in the Time of COVID-1
mmahesh@jhmi.edu * July 16th, 2020 * @mmahesh1
Disclosures

• Royalties
  • Lippincott Williams and Wilkins (book)

• Council Member
  • National Council on Radiation Protection and Measurements (NCRP)

• Travel Funding
  • American College of Radiology (ACR) (Board Member)
  • American Association of Physicists in Medicine (AAPM) (Board Member)
Session on NCRP 184

- Dr M. Mahesh – Moderator & Speaker
  - Overview with focus on CT and Nuclear Medicine
- Dr Donald P Frush – Pediatric Imaging
- Dr Donald Miller – Interventional Fluoroscopy
Purpose

• Prepare report to evaluate changes in medical radiation exposures for US population since 2006 (NCRP 160)

• NCRP 160
  • Published officially in 2009
  • Data from 2006

• This report (NCRP 184)
  • Published officially in November 2019
  • Data from 2016
Past: Radiation Exposures to US population

1980
- Medical: 0.54 mSv per capita
- Total: 3.6 mSv per capita
- Background: 3.0 mSv
- Occupational: 0.01 mSv
- Consumer products: 0.07 mSv

2009
- Medical: 3.0 mSv per capita
- Total: 6.2 mSv per capita
- Natural...
- Other...
- CT: 1.5 mSv
- Interventional: 0.4 mSv
- Nuclear Medicine: 0.8 mSv
- Radiography: 0.3 mSv
- Other...
NCRP PAC 4-9 Committee Members

- **Chair** F. Mettler  Univ of New Mexico  (Diagnostic Radiology)
- **Co-Chair** M. Mahesh  Johns Hopkins Univ.  (Medical Physics)

- H. Royal  Wash Univ. St. Louis,  (Nuclear Medicine)
- C. Chambers  Penn. State  (Interventional cardiology)
- D. Miller  U.S. FDA CDRH  (Interventional radiology)
- D. Frush  Duke Univ.  (Pediatric Radiology)
- M. Milano  Univ of Rochester  (Radiation Oncology)
- D. Spelic  U.S. FDA  (NEXT and Dental)
- M B. Chatfield  Exec. VP, Am Coll Radiol.  (Medicare & data sources)
- J. Elee  State of Louisiana  (CRCPD + State data)

- Advisors: A. Ansari, W. Bolch, G. Guebert, R. Sherrier, J. Smith
- R. Vetter, L. Atwell, SciMetrika (literature related) and NCRP staff
NCRP Report 184
U.S. population data are reported in four metrics

• Number and type of diagnostic and interventional medical radiation procedures
• Procedures: Exams vs Scans
  • Scans w multiple exposures (dual-phase studies)
  • 1 exam but 2 scans
• Effective dose (E) per procedure
• Collective Effective Dose (S) per procedure
• U.S. Annual Average Individual Effective Dose ($E_{US}$)*

*allows comparison of the magnitude of medical radiation exposure to that from various non-medical sources
Calculations

• Number of Imaging Procedures \( (N) \)

• Effective dose \( (E) \) per procedure (mSv)

• Collective Effective Dose \( (S) \) (person-Sievert) = \( E \times N \)

• Average Individual Effective dose \( (E_{US}) \) (mSv)

• \( E_{US} = \frac{S}{\text{US population}} \)

* 323 million in 2016
What is not included the NCRP 184?

• Discussion of benefits or risks
• Discussion of appropriateness in medicine
• Radiation therapy treatment doses
Major and minor data sources

• Commercial (IMV Benchmark)
• Medicare payment data (2003-2016)
• VA Health Care System
• US FDA
• CRCPD
• State radiation programs
• Large hospitals
• American College of Radiology
• Industry sources
• Literature
Results
Number of Procedures: 2006 vs 2016

2006: Total: 377 million

- Radiography & Fluoroscopy, 281
- Cardiac Interventional Fluoroscopy, 12
- Noncardiac Interventional Fluoroscopy, 4.1
- Nuclear Medicine, 17
- Computed Tomography, 62

2016: Total: 371 million

- Radiography & Fluoroscopy, 275
- Cardiac Interventional Fluoroscopy, 4.1
- Noncardiac Interventional Fluoroscopy, 4
- Nuclear Medicine, 13.5
- Computed Tomography, 74
Computed Tomography
Number of CT procedures*

Increased by ~20% over 10 years!

* 2018 IMV Report

NCRP 184
CT: Procedures vs Collective Dose*

**Percent CT scans in US for 2016**
- Brain, 18.9%
- Head & Neck, 9.2%
- Chest, 15.9%
- Abdomen/Pelvis, 26.3%
- Spine, 7.7%
- Extremity*, 2.0%
- CT Angiography - Non-cardiac, 15.5%
- CT Angiography - Cardiac, 0.4%
- Interventional, 1.0%
- PET/CT, 2.1%
- SPECT/CT, 0.4%
- Calcium Scoring, <0.1%
- Miscellaneous, 0.4%

**Collective Effective Dose Effective Dose per Person**
- 444,000 person-Sv
- 1.37 mSv

**Percent Collective Effective Dose**
- Brain, 5.7%
- Head & Neck, 2.1%
- Chest, 18.5%
- Abdomen/Pelvis, 38.4%
- Spine, 12.8%
- Extremity*, 1.1%
- CT Angiography - Non-cardiac, 15.0%
- CT Angiography - Cardiac, 0.6%
- Interventional, 1.0%
- PET/CT, 4.1%
- SPECT/CT, 0.2%
- Calcium Scoring, <0.1%
- CT Colonography, 0.3%
- Miscellaneous, 0.3%

* For 2016 using ICRP 103 w Ty's

**NCRP 184**
E_{US} for CT

1.45 mSv (2006) vs 1.37 mSv (2016)

• CT procedures increased: 62 million (2006) to 74 million (2016)
• CT scans increased: 67 million (2006) to 84 million (2016)

• Average Individual Effective Dose ($E_{US}$) for CT decreased by 
  ~6% per person in the United States
Probable causes for decrease in CT dose

- CT procedures higher by ~20% than in 2006
- US population higher by 23 million than in 2006
- Decrease in effective dose per CT procedure is real!

- All this contributes towards ~6% reduction in individual effective dose

1.46 mSv (2006) vs 1.37 mSv (2016)
Nuclear Medicine
Number of Nuclear Medicine Procedures

* 2015 IMV Report

Decreased by ~20% over 10 years!
Trend in PET and PET/CT scans
Nuclear Medicine: Procedures vs Collective Dose*

Percent Nuclear Medicine Procedures in US for 2016

- Cardiac: 58.7%
- PET-Tumor: 23.5%
- Bone: 6.3%
- GI: 2.5%
- Thyroid: 2.5%
- Tumor: 1.5%
- Infection: 1.5%
- Brain: 1.2%
- Lung: 1.6%
- Renal: 0.5%

Collective Effective Dose

- Cardiac: 47.6%
- PET-Tumor: 14.6%
- Lung: 5.1%
- Renal: 2.7%
- Brain: 1.5%
- Infection: 1.5%
- GI: 6.9%
- Bone: 12.3%
- Thyroid: 4.4%
- Tumor: 3.0%

Effective Dose per Person

- 0.32 mSv

Collective Effective Dose

- 106,000 person-Sv

* For 2016 using ICRP 103 w\textsubscript{T}s

NCRP 184
**$E_{US}$ for Nuclear Medicine**

0.73 mSv (2006) vs 0.32 mSv (2016)

- Nuclear Medicine procedures decreased from ~17 million (2006) to 13.5 million (2016)
- However, there was substantial increase in PET/CT scans
- Average Individual Effective Dose ($E_{US}$) for NM decreased by ~56% per person in the United States
Probable causes for decrease in NM dose

- Decrease in number of procedures: 20% lower than 2006
- Use of radioactivity injected after optimized for weight
- Use of new models to estimate effective dose

All 3 together may have contributed towards >50% reduction in individual effective dose

0.73 mSv (2006) vs 0.32 mSv (2016)
Impact of Tissue Weighting Factors
ICRP 60 vs ICRP 103

• Effective dose per person estimated using both ICRP 60 and 103 weighting factors, in order to compare results with NCRP 160

• Effective dose per procedure
  • Decrease for procedures that includes pelvis region
  • Increase for procedures that includes chest region
# Tissue Weighting Factors ($w_t$)

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

† Accounts additional tissues/organs such as adernals, kidney, small and large intestine, muscle, pancreas, spleen, thymus and uterus

*ICRP 103, 2007
## Effective doses for CT exams

*(Impact of ICRP 103)*

<table>
<thead>
<tr>
<th>Type of CT Scan</th>
<th>Eff dose (mSv) ICRP 60</th>
<th>Choice of $E_{103}/E_{60}$</th>
<th>Eff dose (mSv) ICRP 103</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>1.9</td>
<td>0.84</td>
<td>1.6</td>
</tr>
<tr>
<td>Head &amp; Neck</td>
<td>1.4</td>
<td>0.87</td>
<td>1.2</td>
</tr>
<tr>
<td>Chest CT</td>
<td>5.4</td>
<td><strong>1.14</strong></td>
<td>6.1</td>
</tr>
<tr>
<td>Cardiac CT</td>
<td>7.6</td>
<td>1.14</td>
<td>8.7</td>
</tr>
<tr>
<td>Abdomen &amp; Pelvis</td>
<td>8.7</td>
<td><strong>0.88</strong></td>
<td>7.7</td>
</tr>
<tr>
<td>CT Colonography</td>
<td>7.5</td>
<td>0.88</td>
<td>6.6</td>
</tr>
<tr>
<td>Spine</td>
<td>9.2</td>
<td>0.96</td>
<td>8.8</td>
</tr>
<tr>
<td>CT Angiography (non-cardiac)</td>
<td>5.4</td>
<td>0.94</td>
<td>5.1</td>
</tr>
<tr>
<td>Interventional</td>
<td>5.2</td>
<td>0.96</td>
<td>5.0</td>
</tr>
<tr>
<td>PET-CT</td>
<td>10.0</td>
<td>1</td>
<td>10.0</td>
</tr>
</tbody>
</table>
Summary
Number of Procedures: 2006 vs 2016

2006: Total 377 million
2016: Total 371 million
<table>
<thead>
<tr>
<th>Procedures</th>
<th>%</th>
<th>$S$ (person-Sv)</th>
<th>%</th>
<th>$E_{US}$ (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computed Tomography</td>
<td>20</td>
<td>440,000</td>
<td>63</td>
<td>1.37</td>
</tr>
<tr>
<td>Nuclear Medicine</td>
<td>4</td>
<td>106,000</td>
<td>15</td>
<td>0.32</td>
</tr>
<tr>
<td>Radiography &amp; Fluoroscopy</td>
<td>74</td>
<td>71,000</td>
<td>10</td>
<td>0.22</td>
</tr>
<tr>
<td>Cardiac Interventional Fluoroscopy</td>
<td>1</td>
<td>42,000</td>
<td>6</td>
<td>0.13</td>
</tr>
<tr>
<td>Non-cardiac Interventional Fluoroscopy</td>
<td>1</td>
<td>40,000</td>
<td>6</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>703,000</strong></td>
<td><strong>2.16</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based on ICRP 103 tissue-weighting factors
Results

2006_{ICRP60}
885,000 person-Sievert
2.92 mSv/person

2016_{ICRP60}
755,000 person-Sievert
2.33 mSv/person

2016_{ICRP103}
717,000 person-Sievert
2.16 mSv/person
Percent Procedures vs Average Individual Effective Dose for US during 2016

% Radiation Imaging Procedures in US during 2016

- Radiography & Fluoroscopy, 74%
- Nuclear Medicine, 4%
- Computed Tomography, 20%
- Noncardiac Interventional Fluoroscopy, 1%
- Cardiac Interventional Fluoroscopy, 1%

% Average Effective Dose per capita for US population in 2016

- Computed Tomography, 63%
- Nuclear Medicine, 15%
- Radiography & Fluoroscopy, 10%
- Noncardiac Interventional Fluoroscopy, 6%
- Cardiac Interventional Fluoroscopy, 6%

*using ICRP 103 tissue weighting factors

*values are not per patient, but per person in the US population

NCRP 184
Average effective dose per person for US Population*
(Comparison between 2006 and 2016 computed with ICRP publications 103 and 60 Tissue Weighting Factors)

*values are not per patient, but per person in the US population
Average effective dose per person for US Population*  
2006 vs 2016

*values are not per patient, but per person in the US population

NCRP 134
The Dream Team
Key Messages

Compared to 2006 (NCRP 160), 2016 data (NCRP 184) demonstrates that medical radiation dose to US population

- Decreased by ~15-20% across all x-ray imaging modalities
- Decreased by >50% for Nuclear Medicine, predominantly due to decrease in procedures
- Decrease by ~6% for Computed Tomography, in-spite of 20% increase in CT procedures
Summary

Decrease in Medical Radiation Exposure to Patients in the United States may be due to:

• Advances in medical imaging technologies
• Optimization of imaging protocols and accreditation of modalities
• Increase awareness about radiation by Image Gently®, Image Wisely®, Choosing Wisely® and others

Medical community can continue to leverage benefits of radiological procedures for patients in the United States while lowering dose
U.S. Medical Radiation Doses Are Decreasing

Annual non-therapeutic medical radiation dose to the U.S. population in 2016 is 15-20% lower than it was in 2006.

- **2.92 (mSv)**
  - Estimated Average Individual Effective Dose (E<sub>eff</sub> per person)
  - 2006
- **2.16 (mSv)**
  - Estimated Average Individual Effective Dose (E<sub>eff</sub> per person)
  - 2016

Noncardiac Interventional Fluoroscopy: 0.23 (mSv) Per person 0.13 (mSv)
Cardiac Interventional Fluoroscopy: 0.23 (mSv) Per person 0.13 (mSv)
Radiography & Fluoroscopy: 0.3 (mSv) Per person 0.22 (mSv)
Nuclear Medicine: 0.73 (mSv) Per person 0.32 (mSv)
Computed Tomography: 1.46 (mSv) Per person 1.37 (mSv)

Percent of collective effective dose from different modalities for 2006:
- Noncardiac Interventional Fluoroscopy: 6%
- Cardiac Interventional Fluoroscopy: 8%
- Radiography & Fluoroscopy: 34%
- Nuclear Medicine: 25%
- Computed Tomography: 50%

Percent of collective effective dose from different modalities for 2016:
- Noncardiac Interventional Fluoroscopy: 6%
- Cardiac Interventional Fluoroscopy: 8%
- Radiography & Fluoroscopy: 10%
- Nuclear Medicine: 19%
- Computed Tomography: 63%

The number of CT exams increased 20% from 2006 to 2016, and the overall dose from CT procedures went down by a small amount.

Note: When current data are compared with NCRP Report 165 utilizing CRP weighting factors from CRP Publication 60, the results are the same except for Nuclear Medicine (0.41 mSv), Computed Tomography (3.45 mSv) and total dose (2.39 mSv). For more detail, please see Figures 14.2 in the report.
“Life on earth has developed with an ever present background of radiation. It is not something new, invented by the wit of man; radiation has always been there.”

Eric J. Hall, Professor of Radiology, College of Physicians and Surgeons, Columbia University, New York. "Radiation and Life"