Outline

- Purpose and Goals of NCRP SC 6-2
- NCRP Report 160
  - Medical Exposure – data sources and results
- Computed Tomography
NCRP SC 6-2: Purpose

- To update NCRP Report 93 published in 1987
- Evaluate radiation exposure to members of US population exposed annually from
  - Medical procedures
  - Background radiation exposure including Radon
  - Consumer products and activities
  - Industrial, security, medical, educational and research activities and
  - Occupational exposure

NCRP SC 6-2: Medical Subgroup Members

Chairperson: B. Thomadsen, University of Wisconsin

- M. Bhargavan, American College of Radiology
- D. Gilley, State of Florida
- J. Gray, DIQUAD, LLC
- J. Lipoti, State of New Jersey
- M. Mahesh, Johns Hopkins University
- J. McCrohan, US FDA
- F. Mettler, Univ of New Mexico VA
- T. Yoshizumi, Duke University
- M. Rosenstei, Scientific NCRP Consultant
- K. Kase, Stanford SC 6-2 Chair

NCRP Scientific Committee 6-2

- Kenneth R. Kase - Chairman
- Subcommittees:
  - Industrial Exposures
    - Dennis M. Quinn - Chairman
  - Occupational exposures
    - Kenneth L. Miller - Chairman
  - Medical Patient Exposures
    - Bruce Thomadsen - Chairman
  - Natural Background Radiation
    - Daniel J. Strom - Chairman
  - Consumer Products and Miscellaneous Sources
    - Orhan H. Suleman - Chairman

NCRP Report 93*:

Annual effective dose equivalent to US population circa 1980-82

- Natural Sources 3.0 mSv
  - Radon 2.0 mSv
  - Other 1.0 mSv
- Man-made Sources 0.6 mSv
  - Occupational, Consumer products, nuclear fuel cycle and other miscellaneous products 0.07 mSv
  - Medical
    - X-rays 0.39 mSv
    - Nuclear Medicine 0.14 mSv

* Published in 1987
Goals

• Estimate current radiation exposure to US population
  - Number and types of medical procedures
  - Effective radiation dose per procedure
• Examine past and future trends of medical exposures
• Modalities
  - Radiography, Fluoroscopy, Mammography, Dental
  - Interventional
  - CT
  - Nuclear Medicine
  - Radiation Therapy

Methods

• Collective doses estimated independently for each modality
• Modality groups:
  - CT, Nuclear medicine, Radiography & Fluoroscopy, Mammography, Interventional, Dental, Chiropractic Radiology, Bone Densitometry, and Radiation Therapy
• Procedures within each modality categorized by body part or organ system

Assumptions

• Benefit exceeds risk: Issue not examined in this report
• Data sources:
  - Multiple data sets
  - Incomplete data sets required assumptions and cross checking between data sets
• Weighting Factors: Used ICRP 60 (1990). Past reports used older ICRP 26 (1977) and new factors are suggested

Major and minor data sources

• Commercial (IMV Benchmark)
• Medicare payment data (2003-2005)
• VA Health Care System
• Claims data from large national employer plan
• US FDA
• CRCPD
• State radiation programs
• Large hospitals
• American College of Radiology
• Literature
### IMV Benchmark Reports

- Based on responses from hospitals and estimated to identified universe of US hospitals (~7000)
- Surveys had high response rates (~60%)
- Reports used: CT, nuclear medicine, cardiac catheterization, radiography-fluoroscopy, angiography, mammography, PET and radiation therapy
- Reports between 2003-2006
- Data includes all ages

### Medicare Payment Data

- Claims data for Medicare fee-for-service enrollees
- Summarized procedure counts for each modality and sorted by Common Procedure Coding System (HCPCS) Common Procedural Terminology (CPT) code
- 100% medical claims from 1997-2004
- Accounts for nearly 40 million enrollees
- Mainly covers persons >65 years old and disabled
- Represents one-third of all utilization and one-seventh of US population

### Data: Reconciliations and Limitations

- Procedure counts and distribution from IMV reports
- Distribution of procedure counts across body part or organ system was matched with data from other data sources
- Limited data available on volumes of chiropractic and dental imaging

### Results
NCRP Report 160:
Results presented as annual values for:

- **Average effective dose** to an individual exposed to a specific source ($E_{eff}$) (mSv)

- **Collective effective dose** ($S$) (person-Sievert) is cumulative dose to a population of individuals exposed to a given radiation source or group of sources

- **Effective dose per individual** in US population ($E_{ind}$) (mSv), computed by dividing $S$ by total number of individuals in US (300 million in 2006) whether exposed to the specific source or not

**Computed Tomography**

**Computed Tomography (CT)**

- Annual growth over 1993-2006:
  - CT Procedures > 10% vs US population < 1%
- Nearly 62 million CT procedures in US in 2006
- Data correlated to nearly 7649 hospitals in US
- Pediatric CT ~ 8-10% of total procedures

**Number of CT procedures in US**
### Collective doses for CT (2006)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number (millions)</th>
<th>%</th>
<th>Collective dose</th>
<th>Person Sv</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>19.0</td>
<td>28%</td>
<td>38,000</td>
<td>8.7%</td>
<td>88%</td>
</tr>
<tr>
<td>Chest</td>
<td>10.0</td>
<td>16%</td>
<td>74,000</td>
<td>17.0%</td>
<td></td>
</tr>
<tr>
<td>Abd/Pelvis</td>
<td>25.4</td>
<td>39%</td>
<td>254,000</td>
<td>58.0%</td>
<td></td>
</tr>
<tr>
<td>Extremity</td>
<td>3.5</td>
<td>5%</td>
<td>500,000</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td>CT Angiogram</td>
<td>4.3</td>
<td>6%</td>
<td>56,000</td>
<td>12.8%</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>4.2</td>
<td>6%</td>
<td>15,000</td>
<td>3.4%</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>67</td>
<td></td>
<td>438,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### CT: Procedures vs Collective Dose

- **Collective dose** ~438,000 person Sv
- **Effective dose per person from CT** ~1.46 mSv

### Radiation dose from CT: Then (1980) and Now (2006)

- According to NCRP report 100
  - Collective dose for CT ~3,700 person Sv
- According to current estimations
  - Collective dose for CT ~440,000 person Sv
  - Effective dose per capita ~1.5 mSv

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Nuclear Medicine

- Annual growth over 1993-2005:
  - Nuclear Medicine Procedures > 5% vs US population < 1%
- Nearly 17 million nuclear medicine procedures in US in 2005
- Data correlated to nearly 7200 hospitals in US
- Largest increases in cardiac procedures
  - 1% in 1973 to 57% in 2005

Nuclear Medicine: Procedures vs Collective Dose

- Collective dose ~231,000 person Sv
- Effective dose per person ~0.80 mSv

Radiation doses from Nuclear Medicine: Then (1980) and Now (2006)

- According to NCRP report 100
  - Collective dose for Nuclear Medicine 32,000 person Sv
- According to current estimations
  - Collective dose for Nuclear Medicine 231,000 person Sv
  - Effective dose per capita ~0.80 mSv

Interventional
**Interventional Fluoroscopy**

- **Procedures considered**
  - Noncardiac diagnostic and therapeutic procedures
  - Cardiac catheterization procedures
  - Other interventional fluoroscopy procedures such as ERCP, Urinary studies, ...
- **Effective dose estimations varies by order of magnitude**

**Preliminary Results for Interventional**

<table>
<thead>
<tr>
<th>Procedures</th>
<th>Number (millions)</th>
<th>%</th>
<th>Collective dose Person Sv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noncardiac diagnostic</td>
<td>2.0</td>
<td>12.1</td>
<td>12,120</td>
</tr>
<tr>
<td>Noncardiac therapeutic</td>
<td>1.4</td>
<td>8.5</td>
<td>25,840</td>
</tr>
<tr>
<td>Cardiac</td>
<td>4.6</td>
<td>27.8</td>
<td>68,226</td>
</tr>
<tr>
<td>Nonvascular</td>
<td>8.6</td>
<td>52</td>
<td>22,208</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>16.7</strong></td>
<td></td>
<td><strong>128,394</strong></td>
</tr>
</tbody>
</table>

**Interventional: Procedures vs Collective Dose**

- Collective dose ~128,000 person Sv
- Effective dose per person ~0.03 mSv
**Radiography & Fluoroscopy**

- Data includes mammography, dental, chiropractic radiographic procedures, bone densitometry & certain fluoroscopy procedures
- Limited data available for dental and chiropractic procedures

**Radiography: Procedures vs Collective Dose**

- **Collective dose**
  - ~100,000 person Sv
- **Effective dose per person from Radiography**
  - ~0.33 mSv

**Radiation dose from conventional radiography and fluoroscopy: Then (1980) and Now (2006)**

- **According to NCRP report 100**
  - Collective dose: 84,000 person Sv
- **According to current estimations**
  - Collective dose: 100,000 person Sv
  - Effective dose per capita: ~0.33 mSv

**Radiation Therapy**

- Different source of exposure to population than other medical exposures
- Form of risks are different from diagnostic applications
  - Concern for failure of function of target organ due to high dose
  - Likelihood of secondary cancer
- Even though data on number of radiation therapy procedures are available, the dose delivered varies widely and often unknown
- Uncertainty in estimating an average dose is very high, therefore not included in final estimation of radiation exposure to US population
Medical Exposure Overall Results

Estimated number and collective doses from various medical imaging categories using ionizing radiation*

<table>
<thead>
<tr>
<th>Modalities</th>
<th>Number Procedures (millions)</th>
<th>%</th>
<th>Collective Dose (Person-Sv)</th>
<th>%</th>
<th>Per capita (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>67†</td>
<td>17</td>
<td>440,000</td>
<td>49</td>
<td>1.50</td>
</tr>
<tr>
<td>Nuclear Medicine</td>
<td>18</td>
<td>5</td>
<td>231,000</td>
<td>26</td>
<td>0.80</td>
</tr>
<tr>
<td>Radiography &amp; Fluoroscopy*</td>
<td>293</td>
<td>74</td>
<td>100,000</td>
<td>11</td>
<td>0.30</td>
</tr>
<tr>
<td>Interventional</td>
<td>17</td>
<td>4</td>
<td>125,000</td>
<td>14</td>
<td>0.40</td>
</tr>
<tr>
<td>Total</td>
<td>~395</td>
<td>~900,000</td>
<td>~3.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Number of CT scans
* Includes dental imaging and full mouth procedures, but includes 250 person-Sv for collective dose

NCRP 160: Medical Exposure Procedures vs Effective dose contributions

Collective Dose comparisons of Medical Exposures

Effective dose per capita from medical radiation exposure is ~ 3.0 mSv

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Radiation dose from Medical Exposure: Then (1980) and Now (2006)

- According to NCRP report 93
  - Collective dose: 123,000 person Sv
  - Effective dose: 0.53 mSv per capita
- According to current estimations
  - Collective dose: 899,000 person Sv
  - Effective dose: 3.0 mSv per capita

Ubiquitous Background Exposure

- External exposure from terrestrial radiation (primarily 40K and 238U and 238Th decay series)
- External exposure from space radiation (solar particles and cosmic rays)
- Internal exposure from inhalation of radon and thoron and their progeny and
- Internal exposure from radionuclides in the body

Ubiquitous Background Radiation

- Collective effective dose (S): 930,000 person-Sv
- Effective dose per individual in E∞: 3.1 mSv
- Percent of total E∞ for the US population: 50%

Occupational Exposure

- Medical
- Aviation
- Commercial and nuclear power
- Industry and commerce
- Education and research
- Government, DOE and military
Occupational Exposure: Medical Category

- Collective effective dose ($S$): 1400 person-Sv
- Effective dose per individual in $E_{eq}$: 0.005 mSv
- Percent of total $E_{eq}$ for the US population: <0.1%

Industrial, Security, Medical, Educational and Research Activities

- Nuclear-power generation
- DOE installations
- Decommissioning and radioactive waste
- Industrial, medical, educational and research activities
- Care-giving or other contact with nuclear-medicine patients
- Security inspection systems

Occupational Exposure

- Collective effective dose ($S$): 1000 person-Sv
- Effective dose per individual in $E_{eq}$: 0.003 mSv
- Percent of total $E_{eq}$ for the US population: <0.1%
Consumer Products and Activities

- Building materials
- Commercial air travel
- Cigarette smoking
- Mining and agriculture
- Combustion of fossil fuels
- Highway and road construction materials
- Glass and ceramics

Collective effective dose (S): 39,000 person-Sv
Effective dose per individual in E_u: 0.01 mSv
Percent of total E_u for the US population: 2%
What does NCRP report 160 does?

- Report describes relative dose contributions to individuals and to population from various radiation sources
- Report does not attempt to quantify associated health risks nor specify the actions that should be taken in light of these latest data

How to use NCRP report at individual level?

- Report provides some information on doses that individuals may experience due to their specific circumstances
  - For ex: patients undergoing specific medical procedures using ionizing radiation can in many cases obtain nominal value of dose for a medical procedure
  - General idea of the total dose from multiple procedures by summing the values

Computed Tomography

"This is all pretty experimental stuff, you know... all we're really certain of is that it's going to cost you $9.99..."
CT examination make up only 17% but contributes 49% of collective dose

Frequency of radiological examinations
CT: 17% Real: 83%

Proportion of collective effective dose
CT: 49% Real: 51%

Probable causes for increase in medical exposures
- Advances in medical technology
- Demand of improved patient care
- Easy to use - Out of the box solution, for ex: CT
- Accessibility - Emergency Rooms - Outpatient - Doctor’s offices - …
- Overall Benefits outweighs Risks!

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

MDCT growth in US as percent CT scanners in clinical use

Survey Year| 2004 | 2006 | 2007 |
---|---|---|---|
Total CT installed in US| 9,380 | 10,110 | 10,300 |
MDCT| 51% | 71% | 81% |
SDCT| 42% | 28% | 18% |
Other| 7% | 1% | 1% |

1 Sv = 100 rads, 10 mSv = 1 rem
Hall CJ, Ped Radiol, 2002
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
- 10 mSv CT may be associated with an increase in possibility of fatal cancer of ~1 in 2000 cases**

Topics of Concern in CT

- Multiphasic 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

* BEIR VII, 2005
** US FDA

CT exam of abdomen and pelvis: Sample dose reports

Arterial and Venous scan series

<table>
<thead>
<tr>
<th>Technique</th>
<th>Total DLP (mGy.cm)</th>
<th>Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam A</td>
<td>52 mSv</td>
<td></td>
</tr>
<tr>
<td>Exam B</td>
<td>74 mSv</td>
<td></td>
</tr>
</tbody>
</table>

Arterial, Venous and Delay scan series

<table>
<thead>
<tr>
<th>Technique</th>
<th>Total DLP (mGy.cm)</th>
<th>Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam C</td>
<td>52 mSv</td>
<td></td>
</tr>
<tr>
<td>Exam D</td>
<td>74 mSv</td>
<td></td>
</tr>
</tbody>
</table>

Radiation Dose Report - CT Angiography Exam

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTA</td>
<td>2.4 mSv</td>
</tr>
<tr>
<td>CT Scan</td>
<td>1.0 mSv</td>
</tr>
<tr>
<td>Total</td>
<td>3.4 mSv</td>
</tr>
</tbody>
</table>

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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

Radiation induced cancers in adult undergoing
single CT exam delivering 40 mSv effective dose

Estimation based on radiation induced cancer at 5% per Sv
- 20 people

Radiation induced cancers in adult undergoing
10 CT exam delivering 40 mSv effective dose

Estimation based on radiation induced cancer at 5% per Sv
- 20 people

Radiation induced cancers in adult undergoing
100 CT exam delivering 40 mSv effective dose

Estimation based on radiation induced cancer at 5% per Sv
- 20 people
CT Dose – Positive Developments

- Dose modulation techniques
- American College of Radiology
  - Relative Radiation Levels as part of Appropriateness Criteria
  - CT Accreditation program
- Increased awareness
  - Such as *Image Gently* campaign

- 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

We have been seeing ‘Slice Wars’ in MDCT so far –

Are we going to see ‘Dose Wars’ in coming years?

Conclusions

- Overall, medical imaging procedures have increased in past three decades
- According to NCRP 160, medical exposure contributes to nearly 48% of all exposures to US population
- CT contributes to nearly 49% of all medical exposures
- Understanding radiation issues and justifying the appropriateness of each medical x-ray imaging procedure is critical
Categories of CT procedures
(62.0 million in 2006)

- HCAP: ~80% of all CT procedures
- IMV 2006

CT scans of Abdomen and Pelvis
Exam distribution vs US Population*

- ~20% of population >55 years, receives >55% of CT scans
- LNEP 2003

* LNEP 2003

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### Organ or Tissue Weighting Factors (w,)

<table>
<thead>
<tr>
<th>Organ or Tissue</th>
<th>Weighting factor</th>
<th>ICRP 60</th>
<th>ICRP 103*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>0.05</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Red bone marrow, Colon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lung, Stomach</td>
<td>0.12</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Remainder tissues</td>
<td>0.12</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Gonads</td>
<td>0.20</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Bladder, Liver, Thyroid &amp; Esophagus</td>
<td>0.05</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Skin &amp; Bone surface</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Brain &amp; Salivary glands</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

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

* ICRP 103, 2007

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### Impact of increased 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

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### Pediatric Body MDCT: A 5-Year Follow-Up Survey of Scanning Parameters Used by Pediatric Radiologists

Michael E. Arch
Donald P. Frush

**OBJECTIVE:**
The purpose of this study was to evaluate how pediatric body MDCT scanning parameters (i.e., the principal determinants of radiation dose) have changed since a prior survey conducted in 2011.

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### Contents

- Introduction
- Methods
- Data Provenance
- Radiation Dose Estimates
- Summary

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NCRP SC 6-2:
Radiation Exposure of U.S. population

Modalities & procedures considered in the report
- Computed Tomography (CT)
- Nuclear Medicine Procedures
- Radiography and Fluoroscopy
- Interventional Radiography
- Mammography
- Dental and Chiropractic
- Bone Densitometry
- Radiation Therapy

Annual Effective Dose ($S$) for 2006
Industrial, Security, Medical, Educational and Research Activities

- 720 person-Sv Nuclear Medicine Patients
- 153 person-Sv Nuclear Power
- 125 person-Sv Medical (120), Industrial and Commerce (3), Educational and Research activities (2)
- ~1000 person-Sv Collective Effective Dose