Cancer Risks from Occupational Radiation Exposures

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Overview

1. Cohort studies of medical radiation workers
2. Nuclear worker studies
3. Risk projection using NCI-RISK

Why Study Medical Radiation Workers?

- Assess adequacy of radiation protection measures
- Assess risks from protracted low-dose exposure
  - among earliest radiation-exposed populations
  - substantial exposures before 1950
  - exposures decreased time

History: Medical radiation workers and cancer

- 1902 observation of skin cancers in radiologists
- 1931 Case-report of leukaemia in 5 radiologists
- 1944 US epidemiological study of radiologists
  - confirms link between radiation & leukaemia
- 1956 British radiologists study set-up
- 1958-present 8 epidemiological studies
Study | Subjects | Years 1st worked | Follow-up
--- | --- | --- | ---
UK radiologists | 2,700 | 1897-1979 | 1897-1997
US radiologists | 6,500 | 1920-1969 | 1920-1969
US technologists | 146,000 | 1926-1982 | 1926-2003
US army technologists | 6,600 | 1940s | 1946-1974
Canadian radiation workers | 73,100 | <1950-1983 | 1951-1987
**Total** | **278,300**

- 1338 radiologists registered with British radiological societies
  - Membership registers 1897 – 1955
  - Followed-up until 1956 for cause of death
- Cohort expanded to 1897-1977 registrations (n=2698)
  - Followed-up until 1997 for cause of death

**Expanded UK cohort: 1897-1997**

<table>
<thead>
<tr>
<th>Status on 1.1.1997</th>
<th>n</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alive and living in U.K.</td>
<td>963</td>
<td>(36)</td>
</tr>
<tr>
<td>Dead</td>
<td>1158</td>
<td>(43)</td>
</tr>
<tr>
<td>Emigrated</td>
<td>550</td>
<td>(20)</td>
</tr>
<tr>
<td>Lost to follow-up</td>
<td>27</td>
<td>(1)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2698</strong></td>
<td><strong>(100)</strong></td>
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<tr>
<td>Person years at risk</td>
<td>69,615</td>
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[Standardized mortality ratio (SMR)]

- ‘External’ comparison with death rates in general population – unexposed group
- UK medical practitioners
  - reported occupation on death certificate
- Healthy-worker effect
- Confounding – eg smoking

**BRITISH MEDICAL JOURNAL**

EXPECTATION OF LIFE AND MORTALITY FROM CANCER AMONG BRITISH RADIOLOGISTS  

[Updated by L.L. Berrington et al, Br J Radiology 2001]
Results - Mortality from all cancers compared to medical practitioners

Mortality from all cancers compared to medical practitioners (1920+)

Site-specific cancer deaths

- 1st registered <1920
  - Skin SMR=4.4 (n=2)
  - Pancreatic cancer SMR=3.9 (n=5) p<0.05
  - Leukemia (n=1), Bladder (n=3), Lung (n=7) SMR=2.5

- 1st registered 1920+
  - NHL SMR=3.1 (n=9) p<0.01
  - Leukaemia SMR=2.4 (n=8) p<0.05
  - Prostate SMR=1.6 (n=22) p<0.05

US radiologists: study design

- RSNA: radiologists (n=6,500)
- ACP, AAOO: non-exposed (n=23,500)

- 'Internal' comparison group of 'unexposed' physicians
- Relative risk (instead of SMR)
- Both groups subject to healthy-worker effect
- Confounding still possible
**US radiologists results**

- Cancer mortality by year 1st registration
  - 1920-9 RR=1.5
  - 1930-9 RR=1.6
  - 1940-9 RR=1.3

- Cancer sites (p<0.05)
  - 1920-39
    - Skin RR=3.4, Leukemia RR=2.0, Lymphoma RR=2.7
  - 1940-49
    - Lung RR=1.2

**US Radiologic Technologists cohort**

- 146,022 US Technologists certified at least two years between 1926 and 1982
- Two postal surveys (mid-1980's and mid-1990's)
  - 110,000 answered one or both surveys
- Third survey 2003-2005
  - 73,000 surveys completed

**Demographics:**
- Female: 73%
- Average age: 58 years
- Race: 95% White
- Distribution: Entire US

**Site-specific risks**

- Breast cancer – increased risk <1940 (SMR=1.5)
- Leukemia – increased risk <1940 (SMR=1.3)
- Lung cancer – no increase

[Doody et al, 2006; Linet et al, 2005; Rajaraman et al, 2005]

**Occupational Radiation Dosimetry**

- Dose reconstruction
  - Pre-1960
    - literature review
  - 1960-1976
    - 2,800 badge readings taken on outside of apron
  - 1977 to 2005
    - 350,000 annual computerized badge dose readings available for cohort members
Dose reconstruction cont.

- Surveys queried
  - Procedure type by time period
  - Intensity of work (procedures per week by job)
  - Apron and shield use by job
  - Jobs by time period worked
  - Other: Holding patients by job
- Dosimetry is nearly “finished”

[Simon et al., 2006]

USRT Breast Organ Doses

Estimated cumulative mean female breast dose (mGy) through 1984 by decade first worked

Personal Diagnostic Exposures

- Self-reported numbers and calendar time periods of procedures based on survey reports
- Weighted by nominal estimates of organ doses
- Cumulative Organ Dose “Score” with units approximating cGy

Radiation Dose Corroboration

- How “good” are the occupational and personal diagnostic dose estimates?
- Biodosimetry for 152 technologists
  - Radiation estimates for red bone marrow
  - FISH whole chromosome painting for translocations
  - Expressed per 100 cell equivalents (CE) as if the entire genome had been scored
Translocation frequency vs occupational dose

Trend line = 0.97 excess translocations/100 CE/cGy
p <0.001

[Bhattia et al, 2007]

Translocation frequency vs diagnostic dose

0.04 excess translocations/100 CE/dose score
P = 0.003

Ongoing and Future work in USRT

- Dose-response assessment for site-specific cancers using dosimetry
  - Breast
  - Leukemia
  - Skin
- Gene-radiation interaction studies
- Cancer risks associated with diagnostic exposures

Physicians Performing Fluoroscopically-Guided (FG) Procedures

- Cardiologists
- Interventional radiologists
- Interventional neuroradiologists
- Orthopedic surgeons
- Urologists
- Pain management physicians
- Others
**Background: Health Concerns**

- Clinical reports: radiation dermatitis on hands, hair loss, cataracts, cancers (brain tumors and leukemia)
- Apparent epidemic of musculoskeletal problems: attributed to heavy lead aprons
- Reduction of apron thickness: ↓ musculo-skeletal symptoms BUT ↑ cancer risks?

**To date, no epidemiological study of**

practitioners performing FG procedures

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**New cohort: US radiologists and Physicians who perform FG procedures**

- INFOH
  - 50,000 physicians from specialist societies
  - SCAI, SIR, ACC, SNIS, HRS
- 100,000 family practitioners and psychiatrists from AMA
- 50,000 US radiologists from AMA
- Mortality follow-up 1979-2006

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**Objectives**

- 1. Compare mortality from 1979-2006 in US radiologists and physicians who perform fluoroscopically guided procedures with US physicians who have a low probability of occupational exposure to ionizing radiation
- 2. Survey of annual badge doses in these specialties for the period 1979-2006

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**Methods: Follow-up & Matching**

1. Acquire AMA Masterfile/Societies listings
2. Vital Status Confirmation
3. Acquire Dosimetry Records from Landauer
4. Match Deceased with NDI
5. Finalize Cohorts
6. Acquire AMA Masterfile/Societies listings
Dose survey

- Landauer linkage
  - Annual dose by specialty over time
  - Complete dosimetry difficult (USRT experience)
  - Non-compliance

- ‘Indirect’ dose estimation
  - Dose per procedure
  - Annual workload (HMO database)

Estimated Effective Doses in μSv for Common FG Procedures

<table>
<thead>
<tr>
<th>Procedure</th>
<th>No. studies</th>
<th>Median</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary angiography</td>
<td>37</td>
<td>2.5</td>
<td>5.3</td>
</tr>
<tr>
<td>Percutaneous coronary intervention</td>
<td>16</td>
<td>3.2</td>
<td>4.7</td>
</tr>
<tr>
<td>Cardiac ablation</td>
<td>6</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Pacemaker implant</td>
<td>5</td>
<td>1.5</td>
<td>5.7</td>
</tr>
<tr>
<td>Vascular interventional angiography</td>
<td>10</td>
<td>2.2</td>
<td>3.7</td>
</tr>
<tr>
<td>Vascular embolization</td>
<td>3</td>
<td>2.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Endovascular therapeutic head/neck</td>
<td>6</td>
<td>2.2</td>
<td>3.4</td>
</tr>
</tbody>
</table>

[Kim KP et al., 2008]

Comparison with nuclear worker studies

- Exposures generally lower
- Individual dosimetry available
- 15 country study [Cardis et al., 2007]
  - 400,000 (mostly) nuclear workers
  - Mean dose = 19mSv
  - 10% > 50mSv
  - All solid cancers mortality
    - ERR=0.87 (0.03-1.88) per Sv
    - LSS ERR=0.32 (0.01-0.50) per Sv

3. Risk projection – ‘indirect’ assessment

- Life Span Study
  - Range of doses
  - Range of ages at exposure
  - Long term follow-up
  - Large cohort (100,000+)
  - Single-acute exposure
  - Japanese cancer rates differ from US
3. Risk projection - methods

- LSS risk models
- Exposure history
- LNT assumption
- 'Underlying' cancer incidence rate
- Sum risk over expected lifetime

### Results – Excess lifetime cancer risk

<table>
<thead>
<tr>
<th>Cancer Type</th>
<th>Mean</th>
<th>95% Uncertainty Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>2 per 1000</td>
<td>1 to 4 per 1000</td>
</tr>
<tr>
<td>Lung</td>
<td>3 per 1000</td>
<td>1 to 7 per 1000</td>
</tr>
<tr>
<td>Leukemia</td>
<td>1 per 1000</td>
<td>0.5 to 1.5 per 1000</td>
</tr>
<tr>
<td>Colon</td>
<td>1 per 1000</td>
<td>0.3 to 1.5 per 1000</td>
</tr>
<tr>
<td>Other</td>
<td>3 per 1000</td>
<td>1 to 6 per 1000</td>
</tr>
<tr>
<td>Total</td>
<td>10 per 1000</td>
<td>4 to 15 per 1000</td>
</tr>
</tbody>
</table>
NCI-RISK

- Modified BEIR VII risk models
  - 17 cancer sites
  - Additional sites: esophagus, kidney, brain, pancreas, oral, rectum, gallbladder
  - Models cover 80% US cancer incidence
  - Monte Carlo uncertainty intervals

Summary

- Protracted/low dose exposures most common in general population
- Elevated cancer risks in earliest medical workers
  - Leukemia, skin, lymphoma?
- Cancer risks decreased over time
  - Improved radiation protection
- Current levels of exposure very low
  - FG procedures physicians?
  - Risk projection to estimate risks
- New findings
  - INFOH, USRT dosimetry

Medical Worker study strengths/limitations

- Protracted low-dose
- Range of doses
- Healthy population
- Long-term follow-up
- Rare cancers in LSS
- Lack of dosimetry
- Healthy worker effect
- Confounding
- Sample size

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