Health effects of ionizing radiation

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Health effects of ionizing radiation

IPPNW expert meeting
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Interdisciplinary meeting of physicians, biologists, mathematicians, epidemiologists and physicists

Purpose: to compile all recent and authoritative data on the health effects of ionizing radiation.
Background radiation

Even background radiation causes measurable adverse health effects
Background radiation

Correlation between indoor radon gas concentration and lung cancer

11% higher risk per 100 Bq/m³ (95% CI 1 - 28 %)

Confounders like sex, education or smoking could be excluded
Background radiation

16% higher risk per 100 Bq/m³ (95% CI 5 - 31%)

Smoking is no confounder

No threshold

Linear dose-response correlation, far below current reference levels

Radon responsible for
• 9% of all cases of lung cancer
• 2% of all cancer deaths
Background radiation

Correlation between background radiation and leukemia risk

12% higher risk per mSv bone marrow dose (95% CI 3 – 22%)

A record-based case–control study of natural background radiation and the incidence of childhood leukaemia and other cancers in Great Britain during 1980–2006

G M Kendall, M P Little, R Wakeford, K J Bunch, J C H Miles, T J Vincent, J R Meara and M F G Murphy

We conducted a large record-based case–control study testing associations between childhood cancer and natural background radiation. Cases (27,447) born and diagnosed in Great Britain during 1980–2006 and matched cancer-free controls (36,793) were from the National Registry of Childhood Tumours. Radiation exposures were estimated for mothers' residence at the child's birth from national databases, using the County District mean for gamma rays, and a predictive map based on domestic measurements grouped by geological boundaries for radon. There was 12% excess relative risk (ERR) (95% CI 3%, 22%; two-sided P=0.01) of childhood leukaemia per millisievert of cumulative red bone marrow dose from gamma radiation; the analogous association for radon was not significant, ERR 3% (95% CI 1%, 11%; P=0.35). Associations for other childhood cancers were not significant for either exposure. Excess risk was insensitive to adjustment for measures of socio-economic status. The statistically significant leukaemia risk reported in this reasonably powered study (power ~50%) is consistent with high-dose rate predictions. Substantial bias is unlikely, and we cannot identify mechanisms by which confounding might plausibly account for the association, which we regard as likely to be causal. The study supports the extrapolation of high-dose rate risk models to protracted exposures at natural background exposure levels. P=0.01 of childhood leukaemia per millisievert of cumulative red bone marrow dose from gamma radiation; the analogous
Background radiation

15-20% of all cases of childhood leukemia probably caused by natural background radiation
Background radiation

Indoor radon gas, terrestrial radiation, ground water contamination and excess cosmic radiation (e.g. on intercontinental flights) increase cancer risk.
Medical radiation

The use of radiation for medical diagnostics causes measurable adverse health effects.
Medical radiation

More than 355,000 patients 1985-2002

One CT with 50-60 mSv can triple the risk of leukemia or brain tumors.

Confounders could not be identified
Medical radiation

10.9 million patients 1985-2005

One CT (4.5 mSv) increased cancer risk by 24%

Every additional CT increases the risk by another 16%

The younger, the higher the risk:
• 1-4 years: 35% higher cancer risk
• 5-9 years: 25% higher cancer risk
• 10-14 years: 14% higher cancer risk

Health effects of ionizing radiation

Cancer risk in 680 000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians

John D Mathews epidemiologist, Anna V Forsythe research officer, Zoe Brady medical physicist, Martin W Butler data analyst, Stacy K Georgan radiologist, Graham B Byrne statistician, Graham G Gilles epidemiologist, Anthony E Wallace medical physicist, PH Il P Anderson epidemiologist, Tenniel A Gunter data analyst, Feu McCabe statistician, Timothy M Cain radiologist, James G Dowty research fellow, Adrian C Bickerstaffe computer scientist, Sarah C Darby statistician

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Abstract

Objective To assess the cancer risk in children and adolescents following exposure below dose limits set by the International Commission on Radiological Protection (ICRP) for computed tomography (CT) scans.

Design Population-based, cohort, data linkage study in Australia.

Cohort members 10.9 million people identified from Australian Medicare records, aged 0-15 years in 1 January 1985 or born between 1 January 1985 and 31 December 2005, all exposed to CT scans funded by Medicare during 1985-2005 were identified for this cohort. Cancers diagnosed in cohort members up to 31 December 2007 were obtained through linkage to national cancer records.

Main outcome Cancer incidence rates in individuals exposed to a CT scan more than one year before any cancer diagnosis, compared with cancer incidence rates in unexposed individuals.

Results 68,674 cancers were recorded, including 3150 in 68,211 people exposed to a CT scan at least one year before any cancer diagnosis. The mean duration of follow-up after exposure was 9.5 years. Overall cancer incidence was 24% greater for exposed than for unexposed at younger ages (P<0.001 for trend). At 1-4, 5-9, 10-14, and 15 or more years since first exposure, IRRs were 1.35 (1.26 to 1.45), 1.26 (1.17 to 1.36), 1.14 (1.09 to 1.21), and 1.24 (1.14 to 1.34) respectively. The IRR increased significantly for many types of solid cancer (digestive organs, melanoma, soft tissue, larynx, palate, uterine, cervix, liver, thyroid, bone, brain and brainstem), leukaemia and myelodysplasia, and some other lymphoid cancers. There was an excess of 1686 cancers in people exposed to CT scans (1.47) brain, 356 other solid, 48 leukaemia or myelodysplasia, and 37 other (lymphoid). The absolute excess incidence for all cancers combined was 0.36 per 100 000 person years at risk, or 21 December 2007. The average effective radiation dose per scan was estimated as 4.5 mSv.

Conclusions The increased incidence of cancer after CT scan exposure in this cohort was mostly due to irradiation. Because the cancer excess was still ongoing at the end of follow up, the eventual lifetime risk from CT scans cannot yet be determined. Radiation doses from contemporary CT scans are likely to be lower than those in 1985-2005, but some increase in cancer risk is still likely from current scans. Future CT scans should be limited to situations where there is a definite clinical indication.
Medical radiation

Both conventional x-ray and CT examinations increase cancer risk.

Subpopulations with higher individual risk:

- children
- pregnant women
- patients with genetic risk factors
- patients with immunodeficiencies
- patients with suppressed immune systems
Nuclear industry

The use of nuclear energy and the testing of nuclear weapons cause measurable adverse health effects.
Health effects of ionizing radiation
Uranium mining

59,000 former uranium miners

Significant correlation between working time and cancer risk

21% higher cancer risk per working level month (95% CI 18 – 24)

Smoking not a confounder

True effects probably much higher

Health effects of ionizing radiation

From 1946 to 1998 extensive uranium mining was conducted in the southern part of the former German Democratic Republic. The overall workforce included several 100,000 individuals. A cohort of 39,001 former mine employees of the Wismut Company was established forming a large retrospective uranium miners' cohort for the time period 1946 – 1998. Mean duration of follow up was 30.5 years with a median 8.8, 182, 632 person-years. Loss to follow up was about 5.5%. Of the workers, 16,874 (41.1%) died during the study period. Based on 2008 lung cancer deaths, the radiation-induced lung cancer risk is evaluated. The excess relative risk (ERR) per working level month (WLM) was estimated as 0.01% (95% CI 0.01 – 0.02). It was dependent on time since exposure and on attained age. The highest ERR was observed 15 – 24 years after exposure and in the youngest age group (< 55 years of age). While a strong inverse exposure rate effect was detected for high exposures, no significant association was detected for exposures below 10 WLM. Lung cancer relative risk (RR) was not modified by duration of exposure. The results would indicate the need to re-estimate the effects of risk modifying factors in current risk models as duration of exposure did not modify the ERR/WLM and there was only a modest decline of ERR/WLM with increasing time since exposure.

Keywords: epidemiology, cohort study, uranium miners, lung cancer radiation
Uranium mining

11 cohort studies
- 65,000 miners
- 2,700 lung cancer deaths

Linear correlation between radon gas exposure and lung cancer

Long time exposure shows greater effects than short time exposure

Lung cancer cases from radon:
- miners 40%
- general population 10%

Health effects of ionizing radiation

Lung cancer in radon-exposed miners and estimation of risk from indoor exposure.

Abstract
BACKGROUND: Radioactive radon is an inert gas that can migrate from soils and rocks and accumulate in enclosed areas, such as homes and underground mines. Studies of miners show that exposure to radon decay products causes lung cancer. Consequently, it is of public health interest to estimate accurately the consequences of low-level exposure in homes to this known carcinogen. Epidemiologic studies of residential radon exposure are burdened by an inability to estimate exposure accurately, low total exposure, and subsequent small excess risks. As a result, the studies have been inconclusive to date. Estimates of the hazard posed by residential radon have been based on analyses of data on miners, with recent estimates based on pooling of four occupational cohort studies of miners, including 300 lung cancer deaths.

PURPOSE: To more fully describe the lung cancer risk in radon-exposed miners, we pooled original data from 11 studies of radon-exposed underground miners, conducted a comprehensive analysis, and developed models for estimating radon-associated lung cancer risk.

METHODS: We pooled original data from 11 cohort studies of radon-exposed underground miners, including 65,000 men and more than 2700 lung cancer deaths, and fit various relative risk (RR) regression models.

RESULTS: The RR relationship for cumulative radon progeny exposure was consistently linear in the range of miner exposures, suggesting that exposures at lower levels, such as in homes, would carry some risk. The exposure-response trend for never-smokers was threefold the trend for smokers, indicating a greater RR for exposure in never-smokers. The RR from exposure diminished with time since the exposure occurred. For equal total exposure, exposures of long duration (and low rate) were more harmful than exposures of short duration (and high rate).

CONCLUSIONS: In the miners, about 40% of all lung cancer deaths may be due to radon progeny exposure, 70% of lung cancer deaths in never-smokers, and 30% of lung cancer deaths in smokers. In the United States, 10% of all lung cancer deaths might be due to indoor radon exposure, 11% of lung cancer deaths in smokers, and 30% of lung cancer deaths in never-smokers. This risk model estimates that reducing radon in all homes exceeding the U.S. Environmental Protection Agency's recommended action level may reduce lung cancer deaths about 2%-4%. These estimates should be interpreted with caution, because concommitant exposures to agents such as arsenic or diesel exhaust may modify the radon effect and, when considered together with other differences between homes and mines, might reduce the generalizability of findings in miners.
Uranium mining

Rössing, Namibia

Saskatchewan, Canada

Jadugoda, India
Koide H. “Radioactive contamination around Jadugoda uranium mine in India“. Research Reactor Institute, Kyoto University, 08.07.02.
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Uranium mining

Radium Hill, Australia

Shiprock, USA

Elliot Lake, Canada
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Nuclear workers

154 locations
598,000 Arbeiter
> 90% had exposures of < 50 mSv

Solid tumors: 97% higher risk per Sv
(95% CI 14 - 197)

Leukemia: 193% higher risk per Sv
(95% CI 0 - 847)

1-2% of all cases of death amongst nuclear workers most probably radiation-related
Health effects of ionizing radiation
Health effects of ionizing radiation

Nuclear power

Significantly increased risk for cancer in children < 5 yrs within 50 km of nuclear power plants

No confounders could be identified

IJC
International Journal of Cancer

Leukaemia in young children living in the vicinity of German nuclear power plants

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A case control study was conducted where cases were children younger than 5 years (died between 1980 and 2003) registered at the German childhood cancer registry (GCCR). Population-based matched controls (1:3) were selected from the corresponding registrar’s office. Residency proximity to the nearest nuclear power plant was determined for each subject individually (with a precision of about 25 m). The report is focused on leukaemia and mainly on cases in the inner 5-km zone around the plants. The study includes 593 leukaemia cases and 1,766 matched controls. All leukaemia combined show a statistically significant trend for 1/distance with a positive regression coefficient of 1.75 (lower 95%-confidence limit (CL): 0.85); for acute lymphoid leukaemia 1.63 (lower 95%-CL: 0.38); for acute non-lymphoid leukaemia 1.90 (lower 95%-CL: 0.41). This indicates a negative trend for distance. Cases live closer to nuclear power plants than the randomly selected controls. A categorical analysis shows a statistically significant odds ratio of 2.19 (lower 95%-CL: 1.21) for residential proximity within 5 km compared to residence outside this area. This result is largely attributed to cases in previous studies of the GCCR (especially in the inner zone) as there is clearly some overlap between those studies. The result was not to be expected under current radiation-epidemiological knowledge. Considering that there is no evidence of relevant accidents and that possible confounders could not be identified, the observed positive distance trend remains unexplained.

Key words: childhood; leukaemia; nuclear power plants; population-based; cancer registry

reports prompted a study of almost identical design that was based on the data of the German Childhood Cancer Registry (GCCR) and was conducted in the late 1990s. This was an ecological study comparing disease rates within 15 km (roughly 10 miles) of German nuclear plants with those in specified control areas. The study period extended from 1980 through 1990 (Study 1). An increased rate of all cancer or, more specifically, leukaemia in children younger than 13 years within a 15-km zone of West German nuclear plants was not confirmed. However, exploratory analyses indicated that, for example, in children younger than 5 years living within the inner 5-km zone, the increase in leukaemia rate was statistically significant. 

As these results gave rise to controversial discussion and as at the same time a statistically significant leukaemia cluster was seen near the North German nuclear power plant of Knüllmöl, the study period was extended to cover the years 1991 through 1995 (Study 2).

Study 2 failed to reproduce statistically significant results regarding the subgroup for which results were significantly increased in the exploratory analysis of Study 1. Nevertheless, a tendency was seen towards an increased relative risk (RR) for leukaemia to occur in under-5-year-olds within the 5-km vicinity.

Even after these results had been published, discussions on a potential relationship between the occurrence of childhood leukaemia and close proximity to nuclear plants in routine operation have not ceased. For this reason, a case control study was initiated by the Federal government and started at the GCCR in 2003.
Nuclear power

Cancer risk was shown to correlate directly to distance from nuclear power plant.

- 50 km: 8–18 % more cases
- 10 km: 20–40 % more cases
- 5 km: 60–75 % more cases
Nuclear power

Similar relative risks for children living near nuclear power plants in the UK, Switzerland and Germany

<table>
<thead>
<tr>
<th>Data set</th>
<th>O</th>
<th>E</th>
<th>SIR</th>
<th>P-value*</th>
<th>RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switzerland (CH)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>0–5 km</td>
<td>11</td>
<td>7.87</td>
<td>1.40</td>
<td>0.3431</td>
<td>1.46</td>
</tr>
<tr>
<td>5–15 km</td>
<td>54</td>
<td>56.40</td>
<td>0.96</td>
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<tr>
<td>Great Britain (GB)</td>
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<tr>
<td>&lt;5 km</td>
<td>20</td>
<td>14.74</td>
<td>1.36</td>
<td>0.2216</td>
<td>1.41</td>
</tr>
<tr>
<td>&gt;5 km</td>
<td>1579</td>
<td>1640.44</td>
<td>0.96</td>
<td></td>
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<tr>
<td>Germany (D)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>&lt;5 km</td>
<td>34</td>
<td>24.09</td>
<td>1.41</td>
<td>0.0656</td>
<td>1.45</td>
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<tr>
<td>&gt;5 km</td>
<td>585</td>
<td>599.58</td>
<td>0.98</td>
<td></td>
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<tr>
<td>CH + GB + D</td>
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<td></td>
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<tr>
<td>&lt;5 km</td>
<td>65</td>
<td>46.70</td>
<td>1.39</td>
<td>0.0130</td>
<td>1.44</td>
</tr>
<tr>
<td>&gt;5 km</td>
<td>2218</td>
<td>2296.42</td>
<td>0.97</td>
<td></td>
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</tr>
</tbody>
</table>

**CANUPIS study strengthens evidence of increased leukaemia rates near nuclear power plants**

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**ARTICLE**

In their recent article on childhood cancer near nuclear power plants (NPPs) in Switzerland, Spycher et al. ¹ state that they found little evidence for an association between the risk of childhood cancer and living near NPPs. The IRR (incidence rate ratio) of leukaemia in children aged <5 years was 1.2 in the 5-km zone relative to distances >15 km from residence at birth. However, the 95% confidence interval for IRR was large (0.60–2.41) and includes the RR of 2.2 in the 5-km zone found in the German case-control study (KIKK).

In the abstract they say that the results were similar for residence at diagnosis and at birth. But the IRR for the 'residence cohort' is 1.41, so the increase of risk is twice as large as in the 'birth cohort'.

Recent ecological studies in Great Britain² and Germany³ also evaluated residence at diagnosis and found similar leukaemia risks in children <5 years of age living near (0–5 km) nuclear power stations (Table 1). The standardized incidence ratio (SIR) is 1.40 in Switzerland (CH), 1.36 in...
Nuclear disasters

Chernobyl:

- 16,000 (3,400-72,000) cases of thyroid cancer
- 25,000 (11,000-59,000) other cases of cancer
- > 15,000 excess cancer deaths

Epidemiological studies focusing on the most contaminated regions of the 5 most affected countries have confirmed a causal relationship between the observed increased risk of thyroid cancer and exposure to radioactive iodines from the Chernobyl fallout among those who were children or adolescents when the accident happened. Other types of cancer, including leukemia, have also been investigated, but as yet no association with radiation exposure has been clearly demonstrated. Recent studies suggest a possible doubling of the risk of leukemia among Chernobyl cleanup workers and a small increase in the incidence of premenopausal breast cancer in the most contaminated districts (with average whole-body doses above 40 mSv), both of which appear to be related to radiation dose. These findings need confirmation in further epidemiological studies with careful individual dose reconstruction.

The full extent of the health impact of Chernobyl on the population is difficult to gauge. Ten years ago, Cardis and collaborators estimated that about 9,000 deaths from cancers and leukemia might be expected over the course of a lifetime in the most exposed populations in Belarus, the Russian Federation and...
Health effects of ionizing radiation
Nuclear weapons

Mean excess radiation dose in Central Europe

mSv/year

Nuclear testing

Chernobyl

Health effects of ionizing radiation
Nuclear weapons


90 nuclear tests 1952-1957

5.55 Exa-Bq ($10^{18}$ Bq) I-131

Thyroid doses:
• max. 120-160 mSv
• average 20 mSv
Health effects of ionizing radiation
Non-cancer diseases

Low-dose radiation has also been identified as the cause of:

- benign tumors
- cardiovascular/cerebrovascular lesions
- respiratory problems
- gastrointestinal symptoms
- endocrinological disorders
- cataracts
- mental retardation
- genetic mutations in offspring
Non-cancer diseases

Meta-analysis of 10 peer-reviewed studies
- nuclear workers
- occupationally exposed
- hibakusha

Cardiovascular diseases 1 – 13 % per Sv

Correlation of cardiovascular mortality and radiation dose similar to correlation of cancer mortality and radiation dose (~5 % per Sv)

Systematic Review and Meta-analysis of Circulatory Disease from Exposure to Low-Level Ionizing Radiation and Estimates of Potential Population Mortality Risks

Mark P. Little,† Tamara V. Azieva,† Dimitry Bazik,† Simon D. Boyer,‡ Elisabeth Cardis,§ Sergey Chekin,∥ Vadim V. Chumak,∥ Frances A. Cucinotta,§ Fumio de Vathure∥ Per Hał,§ John D. Harrigan,∥ Guido Mikielbranck,∥ Mirko Victor Ivanov,∥ Valery V. Krasnov,∥ Sergey V. Krymski,∥ Mikhaila Kreider,∥ Olavard Lavrent,∥ Katara Ozaka,∥ Thirry Schneider,∥ Sosie Tapia,∥ Andrew W. Taylor,∥ Joanna Truskalskas,∥ Wendy V. Vandenbeeke,∥ Richard Wakefield,∥ Lydia B. Zabukotska,∥ Wei Zhang∥ and Steven E. Lipshultz∥

Health effects of ionizing radiation

Cardiovascular diseases 1 – 13 % per Sv

Correlation of cardiovascular mortality and radiation dose similar to correlation of cancer mortality and radiation dose (~5 % per Sv)
## Health effects of ionizing radiation

### Non-cancer diseases

<table>
<thead>
<tr>
<th>Data</th>
<th>Reference</th>
<th>Mean heart/brain dose (range) (Sv)</th>
<th>No. in cohort (person-years follow-up)</th>
<th>End point (mortality)*</th>
<th>ERR/Sv (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Japanese atomic-bomb survivors</strong>&lt;br&gt;Mortality</td>
<td>Shimizu et al. 2010</td>
<td>0.1 (0 to 4)d</td>
<td>86,611 (NA)</td>
<td>IHD (ICD-9 410–414)</td>
<td>0.02 (0.10, 0.15)</td>
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<tr>
<td></td>
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<td></td>
<td>Rheumatic heart disease (ICD-9 393–398)</td>
<td>0.86 (0.25, 1.72)</td>
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<td></td>
<td></td>
<td></td>
<td>Heart failure (ICD-9 428)</td>
<td>0.22 (0.07, 0.39)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Other heart disease (ICD-9 390–392, 415–427, 429)</td>
<td>-0.01 (-0.21, 0.24)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>CVA total (ICD-9 430–438)</td>
<td>0.12 (0.05, 0.19)</td>
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<td></td>
<td></td>
<td>Circulatory disease apart from heart disease and stroke (ICD-9 390–392, 401, 403, 405, 439–459)</td>
<td>0.58 (0.45, 0.72)</td>
</tr>
<tr>
<td><strong>Morbidity</strong></td>
<td>Yamada et al. 2004</td>
<td>0.1 (0 to 4)d</td>
<td>10,339 (NA)</td>
<td>Hypertension incidence, 1958–1998 (ICD-9 401)</td>
<td>0.05 (0.01, 0.10)</td>
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<td>Hypertensive heart disease incidence, 1958–1998 (ICD-9 402, 404)</td>
<td>-0.01 (-0.05, 0.09)</td>
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<td>IHD incidence, 1958–1998 (ICD-9 410–414)</td>
<td>0.05 (-0.05, 0.18)</td>
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<td>Aortic aneurism incidence, 1958–1998 (ICD-9 441, 442)</td>
<td>0.02 (-0.22, 0.41)</td>
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<td></td>
<td>CVA incidence, 1958–1998 (ICD-9 430, 431, 433, 434, 436)</td>
<td>0.07 (-0.08, 0.24)</td>
</tr>
<tr>
<td><strong>Occupational studies</strong></td>
<td>Azirova et al. 2010a, 2010b</td>
<td>0.83 (0 to 5.92)d</td>
<td>12,210 (205,249)</td>
<td>IHD morbidity (ICD-9 410–414)</td>
<td>0.119 (0.051, 0.186)</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td>CVA morbidity (ICD-9 430–432, 434, 436)</td>
<td>0.449 (0.338, 0.559)</td>
</tr>
<tr>
<td></td>
<td>Ivanov et al. 2006</td>
<td>0.109 (0 to &gt; 0.5)</td>
<td>61,017 (NA)</td>
<td>Hypertension (ICD-10 I10–I15) morbidity</td>
<td>0.26 (-0.04, 0.56)</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>IHD (ICD-10 I20–I25) morbidity</td>
<td>0.41 (-0.05, 0.78)</td>
</tr>
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<td></td>
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<td></td>
<td>Other heart disease (ICD-10 I00–I52) morbidity</td>
<td>-0.26 (-0.81, 0.28)</td>
</tr>
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<td></td>
<td>CVA (ICD-10 I60–I69) morbidity</td>
<td>0.45 (0.11, 0.80)</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td>Morbidity from diseases of arteries, arterioles, and capillaries (ICD-10 I70–I79)</td>
<td>0.47 (-0.15, 1.09)</td>
</tr>
<tr>
<td></td>
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<td>Morbidity from diseases of veins, lymphatic vessels, and lymph nodes (ICD-10 I80–I85)</td>
<td>-0.26 (-0.70, 0.18)</td>
</tr>
<tr>
<td><strong>German uranium miner study</strong></td>
<td>Kreuer et al. 2006</td>
<td>0.041 (0 to 0.909)d</td>
<td>59,001 (1,801,626)</td>
<td>CVA (ICD-10 I60–I69)</td>
<td>0.09 (-0.6, 0.8)</td>
</tr>
<tr>
<td><strong>EdF workers</strong></td>
<td>Laurent et al. 2010</td>
<td>0.0215 (0 to 0.6)</td>
<td>22,393 (440,984)</td>
<td>IHD (ICD-10 I20–I25)</td>
<td>4.1 (2.9, 13.7)</td>
</tr>
<tr>
<td></td>
<td>Lane et al. 2010</td>
<td>0.0522 (&lt; 0.0234 to &gt; 0.1215)</td>
<td>16,236 (508,673)</td>
<td>CVA (ICD-10 I60–I69)</td>
<td>17.4 (2.4, 43.9)</td>
</tr>
<tr>
<td><strong>Eldorado uranium miners and processing (male) workers</strong></td>
<td>0.15 (0 to 0.29, 0.27)</td>
<td>174,541 (3,900,000)</td>
<td>IHD (ICD-10 I20–I25)</td>
<td>-0.29 (&lt; -0.29, -0.27)</td>
<td></td>
</tr>
<tr>
<td><strong>Third analysis of UK National Registry for Radiation Workers</strong></td>
<td>Muihead et al. 2009</td>
<td>0.0249 (&lt; 0.01 to &gt; 0.4)</td>
<td>174,541 (3,900,000)</td>
<td>IHD (ICD-9 410–414)</td>
<td>0.259 (-0.05, 0.61)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CVA (ICD-9 430–436)</td>
<td>0.161 (-0.42, 0.91)</td>
</tr>
<tr>
<td><strong>IARC 15-country nuclear worker study</strong></td>
<td>Vrijheid et al. 2007</td>
<td>0.0207 (0.0 to &gt; 0.5)</td>
<td>275,312 (4,067,861)</td>
<td>IHD (ICD-10 I20–I25)</td>
<td>-0.01 (-0.59, 0.69)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Heart failure (ICD-10 I50)</td>
<td>-0.03 (&lt; 0.4, 0.91)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CVA (ICD-10 I60–I69)</td>
<td>0.88 (0.67, 1.16)</td>
</tr>
</tbody>
</table>
Non-cancer diseases

Approx. 3,000 children who received radiation therapy for cutaneous hemangioma

Meticulous dose calculations (mean brain dose < 100 mGy)

Negative dose-response relation:
- learning ability
- logical reasoning
- spatial recognition
- high school attendance

Abstract

Objective To determine whether exposure to low doses of ionising radiation in infancy affects cognitive function in adulthood.

Setting Sweden.

Participants 3034 men who had received radiation for cutaneous hemangiomas before age 18 months during 1959-83.

Main outcome measures Radiation dose to frontal and posterior parts of the brain and association between dose and intellectual capacity at age 18 or 19 years based on cognitive tests (learning ability, logical reasoning, spatial recognition) and high school attendance.

Results The proportion of boys who attended high school decreased with increasing doses of radiation to both the frontal and the posterior parts of the brain from about 80% among those not exposed to about 70% in those who received 2-290 mGy. For the frontal dose, the multivariate Odds ratio was 0.47 (95% confidence interval 0.28 to 0.80; P for trend 0.0029) and for the posterior dose it was 0.93 (0.29 to 1.47; 0.0005). A negative dose-response relation was also evident for the three cognitive tests for learning ability and logical reasoning, but not for the test of spatial recognition.

Conclusions Low doses of ionising radiation to the brain in infancy influence cognitive abilities in adulthood.

We analysed cognitive function in a large population based cohort of men at the time of military enlistment who had received low dose ionising radiation for cutaneous hemangiomas before age 18 months. Based on previous experiences, we hypothesised that damage to the frontal part of the brain would have a more severe effect on mental capacity than damage to the posterior part.

Participants and methods

Our cohort comprised all boys treated by radiotherapy for cutaneous hemangiomas aged under 18 months at the Karolinska University Hospital in Stockholm. This cohort has been described in detail previously.

About 50% of Swedish men aged 18 or 19 years are tested before military service. During the period of our study, about 9% of the men tested were exempted from military service for medical or psychological reasons. We were given permission to search the Swedish war archives from the military register we obtained information on age at enlistment, education, number of siblings, birth order, father's occupation, and cognitive test results. Father's occupation, a proxy for socioeconomic status, was categorised into five groups: unknown and farmers, blue collar workers, low level white collar workers, and high level white collar workers. Categorisation was based on the six socioeconomic index, which takes economic status into consideration.

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Non-cancer diseases

Relative risk for birth defects after radiation exposure of mothers 3.2 (CI 1.2-8.7)

Relevant confounders could not be identified
Calculation of risks

On the basis of epidemiological studies that use the concept of collective dose, health risks of low-dose radiation can be predicted and quantified.
Calculation of risks

The ICRP risk factors derived from studies of Hiroshima and Nagasaki survivors are not suitable to adequately predict health effects of low-dose ionizing radiation.
Calculation of risks

Radiation doses from nuclear fallout and neutron activation were not considered in the dose estimates.

Populations that received low dose ionizing radiation were taken as control groups in the Lifetime Span Study (LSS).

Calculation of risks

This led to a systematic underestimation of the risk attributable to radiation.
Calculation of risks

Brief exposure to high-energy penetrating gamma-radiation is less damaging to human tissue than continuous irradiation with alpha- or beta-particles after incorporation of radioisotopes.

A reduction of the risk factor by two, as practiced by the ICRP, is therefore not acceptable.
Calculation of risks

Consideration of uncertainty led to the development of probability distributions of DDREF for use in risk assessment (89). Still there is a lack of a full understanding of the processes leading to cancer after low-dose radiation exposure. The solid cancer risk in 12 epidemiological studies of radiation-exposed workers and of the population residing at the contaminated Techa River in the Southern Urals, Russia, was compared to cancer risks among the Japanese atomic bomb survivors (74). Overall, risk estimates were similar to those among the atomic bomb survivors, suggesting that a DDREF of 1 would be reasonable. A meta-analysis has considered recent epidemiological evidence on leukaemia mortality and incidence risks from protracted low-dose and low-dose-rate exposures to γ-rays. It included an extensive literature review of studies on groups of people who were either occupationally or environmentally exposed (92). The main risk measure value reported in this meta-analysis (ERR) indicated that the baseline leukaemia risk (i.e. risk for a group of unexposed persons) increases by 19% after exposure to a dose of 100 mGy. This increase was reported to agree closely with the risk from acute exposure of the Japanese atomic bomb survivors and is therefore an indication that leukaemia risks are similar for protracted and acute exposures.

World Health Organization (WHO): Health risk assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami based on a preliminary dose estimation. 2013, 32
Calculation of risks

Data was only collected from 1950 onwards

False answers were given in questionnaires to avoid discrimination as Hibakusha
Calculation of risks

The survivors were a selected group of the most resilient

This led to an additional underestimation of radiation risk by about 30%
Calculation of risks

Linear non-threshold model (LNT)
Calculation of risks

Incidence for all types of cancer except thyroid-cancer and melanoma:

• Low estimate:
  \[ \frac{615}{10,000} \text{ PSv} \times 1.5 \text{ DDREF-correction} = \frac{923}{10,000} \text{ PSv} = 9\% \text{ per PSv} \]

• Mean:
  \[ \frac{1,190}{10,000} \text{ PSv} \times 1.5 \text{ DDREF-correction} = \frac{1,785}{10,000} \text{ PSv} = 18\% \text{ per PSv} \]

• High estimate:
  \[ \frac{2,305}{10,000} \text{ PSv} \times 1.5 \text{ DDREF-correction} = \frac{3,458}{10,000} \text{ PSv} = 35\% \text{ per PSv} \]

BEIR VII report, table 12-5A, p. 279
Calculation of risks

Mortality for all types of cancer except thyroid-cancer and melanoma:

• Low estimate:
  \[
  \frac{305}{10,000} \text{ PSv} \times 1.5 \text{ DDREF-correction} = \frac{458}{10,000} \text{ PSv} = 5\% \text{ per PSv}
  \]

• Mean:
  \[
  \frac{610}{10,000} \text{ PSv} \times 1.5 \text{ DDREF-correction} = \frac{915}{10,000} \text{ PSv} = 9\% \text{ per PSv}
  \]

• High estimate:
  \[
  \frac{1,240}{10,000} \text{ PSv} \times 1.5 \text{ DDREF-correction} = \frac{1,860}{10,000} \text{ PSv} = 19 \% \text{ per PSv}
  \]

*BEIR VII report, table 12-5B, p. 280*
Calculation of risks

Newer studies suggest even higher risk factors:
• 40% per PSv for cancer incidence
• 20% per PSv for cancer mortality


Calculation of risks

These risk factors pertain to the average population.

“The relative risks for certain cancers in certain population groups (notably following exposure as fetus, or during infancy and childhood) are higher than for the population Average." (UNSCEAR, 2014)

Radiation protection must look beyond adult-based models and take into consideration the special vulnerability of certain population subgroups, especially embryos and children.
Health effects of ionizing radiation

Thank you for your attention