Mortality of British Radiologists: A Lecture Note

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The precautions introduced after the first 23 years experience of the use of x-rays for medical diagnosis proved adequate to eliminate the acute hazards of exposure, but it was much longer before it was realized that small doses that did not produce any acute effect could increase the risk of cancer. British radiologists who took up the specialty at different periods have, therefore, been studied to see if the risk has now been adequately controlled. Four groups have been studied starting respectively before 1921, in 1921–34, 1935–54, and 1955–77, corresponding approximately to periods when different limits of exposure were applied. Altogether 2698 male radiologists have been identified and all but 27 followed successfully to emigration, death, or survival to January 1\textsuperscript{st} 1997. Of the 1198 who had died, 228 are known to have died of cancer.

Two problems arise in evaluating the carcinogenic hazard to which they were exposed: the assessment of the doses received and the selection of an appropriate control group with which to compare their mortality. The most appropriate comparison group would seem to be medical practitioners in general. In comparison with them, radiologists entering in the first 3 periods had increased risks of death from cancer though appreciably less than would have been predicted from the expected effect of the radiation they had received. Those who joined in the latest period had a relatively reduced risk, irrespective of any effect of the small dose of radiation they are likely to have received. Independent evidence suggests, however, that since 1951 radiologists have smoked less than other doctors and the lower than predicted risk in the groups exposed since 1920 is limited to smoking related cancers, the mortality from other cancers being higher than in doctors generally. In assessing the risk of occupational exposure to radiation, life-style has to be taken into consideration, as well as dose of radiation.

INTRODUCTION

Conrad Röntgen’s discovery of the power of x-rays to penetrate the human body and depict the skeleton was made on November 1895 and an account of it appeared in print in the astonishingly short time of one week – a rapidity of publication that has been made possible again only with the introduction of the worldwide web.\textsuperscript{1} The discovery promised to be so helpful for medical purposes that its use was taken up almost equally rapidly throughout the developed world and a specialist society, the X-ray Society, was founded in the UK within two years.

Unfortunately harmful effects were detected even more quickly: painful skin erythema, loss of hair, gastro-intestinal symptoms, and, a little later but within four years, squamous carcinomas on the hands of workers that were already the site of chronic dermatitis.\textsuperscript{2} More and more harmful effects were reported subsequently and progressively more and more stringent precautions were taken, first to avoid the obvious dermatological and general symptoms and then to avoid anemia and a progressive reduction in the number of white cells in the blood. Cancer, it was long thought, could be avoided by avoiding macroscopic damage to tissues, but eventually the evidence from occupational exposure in mines and pre-eminently from the experience of the survivors of the atomic bomb explosions in Hiroshima and Nagasaki showed that this was not so and long term observations of the health of people repeatedly exposed to x-rays came to be seen as imperative.

One obvious source of information was the fate of radiologists and several studies of the mortality of radiologists were consequently undertaken in China, the US\textsuperscript{3} and the UK.\textsuperscript{4} I report here an account of the accumulated observations that have been made on British radiologists for the first 100 years of the specialty from 1897 to 1996 inclusive. Valuable though this information is, it is not easy to interpret; for

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first there is difficulty in quantifying the doses that the radiologists are likely to have received and, secondly, it is unclear what the norm should be against which the experiences of the radiologists can be compared. Both of these problems will be discussed; but first the facts.

**POPULATION STUDIED**

The population we have studied has been described in detail in previous reports. In brief it consists of 2698 male radiologists who registered with the British Institute of Radiology or the Royal College of Radiologists, or one or other of the organizations that gave rise to them, and were registered between 1897 and 1979. Importantly, it includes 339 men who registered before 1921, when the British X-ray and Radium Protection Committee issued its first formal recommendations for avoiding radiation damage.

**Follow up**

For the radiologists not known from our previous studies to have died intensive efforts have been made to follow them up to January 1, 1997. Identifying details (full names, date of birth, and last known address) when not known previously were obtained from the Royal College of Radiologists membership lists and were sent to the Office of National Statistics or, when appropriate, to the Central Services Agency in Northern Ireland to obtain notification of deaths, emigrations, or current National Health Service Central Register registration. If no notification of death or emigration was received, radiologists were assumed to be alive and living in the UK on January 1, 1997 if they were listed with a UK address in the 1998 editions of either the Royal College of Radiologists Handbook or the National Medical Directory. If the individual’s status could not be confirmed from one or other of these sources, we searched for an address in the previous editions of the Handbook, Medical Directory, and the Medical Register maintained by the General Medical Council, the UK’s medical licensing authority, and we wrote to the individuals personally asking for confirmation of their address or, if they were listed with a foreign address, we assumed that they had emigrated. If all the above methods failed to provide definite information, the individuals were regarded as lost to follow-up from the last date to which they had been previously traced. The results are shown in Table 1, divided into four periods of registration chosen so as to reflect changes in the conditions of exposure. Those exposed before 1920 are likely to have received relatively high doses; all, in fact, have died, including the 18 classed as emigrated. Men registered in the succeeding three periods, in which increasing care was taken to prevent exposure, are thought to have received medium doses (1921–1935), comparatively low doses (1936–1954) and very low doses (1955–1979). Just how large (or small) these doses may have been will be considered later.

### Table 1. Vital status of radiologists on January 1, 1997

<table>
<thead>
<tr>
<th>Period of registration</th>
<th>Alive in UK</th>
<th>Dead</th>
<th>Emigrated</th>
<th>Lost to follow-up</th>
<th>All radiologists</th>
</tr>
</thead>
<tbody>
<tr>
<td>1897–1920</td>
<td>0</td>
<td>321</td>
<td>18</td>
<td>0</td>
<td>339</td>
</tr>
<tr>
<td>1921–35</td>
<td>3</td>
<td>319</td>
<td>35</td>
<td>0</td>
<td>357</td>
</tr>
<tr>
<td>1936–54</td>
<td>158</td>
<td>404</td>
<td>84</td>
<td>4</td>
<td>650</td>
</tr>
<tr>
<td>1955–79</td>
<td>802</td>
<td>114</td>
<td>413</td>
<td>23</td>
<td>1352</td>
</tr>
<tr>
<td>All periods</td>
<td>963 (36)</td>
<td>1158 (43)</td>
<td>550 (20)</td>
<td>27 (1)</td>
<td>2698 (100)</td>
</tr>
</tbody>
</table>

The high proportion of the most recently registered radiologists who have emigrated (31%) can be attributed to the large number who came to the UK to be trained. They would have been included as residents in the UK at the time of their registration, but are likely to have returned to their home countries soon after.

**Methods**

Apart from the difficulty of estimating the doses these men are likely to have received, we are immediately up against the problem of determining how many deaths might have been expected to occur in the absence of exposure to radiation. For this purpose we need to examine the deaths separately from cancer and from other causes, as the production of cancer is the characteristic effect of exposure to ionizing radiation that is below the level likely to cause obvious acute effects. Causes of death were, therefore, sought from official death certificates and obtained successfully in all but 10 instances. But with what should the number of deaths be compared?

Initially we sought to obtain the number that might have been expected if the radiologists had experienced the same mortality as the population of the country as a whole and expressed our findings as standardized mortality ratios (SMRs) that is the ratios obtained by dividing the observed numbers by the numbers expected. Expected numbers were obtained separately for four groups of radiologists, those registered respectively before 1921, from 1921 to 1935, from 1936 to 1954, and from 1955 to 1979 by calculating expected numbers by the numbers expected. Expected numbers were obtained separately for four groups of radiologists, those registered respectively before 1921, from 1921 to 1935, from 1936 to 1954, and from 1955 to 1979 by calculating them for each five year age group from ages 20–24 years to 80–84 years for each of the calendar periods 1897–1905, quinquennia from 1906–1900 to 1986–1990 and for 1991–1996 and the results summed. Deaths over 84 years of age have been omitted for two reasons. First because causes of death may be recorded less accurately in the very old, but secondly and most importantly because ages 85 years and over (the oldest age group for which data have been given in UK statistics until recently) is an open-ended age group in which mortality increases rapidly with each single year of age, while the distribution of ages above 85 years is likely to be materially different for men in a high social class category, in which radiologists would certainly fall, and for the
population as a whole, containing a substantial proportion of unskilled and impoverished men with shorter expectation of life. This reduces the number of deaths in the four registration periods by respectively 31, 48, 36 and 1, which occurred in radiologists aged 85 years or over.

RESULTS

Mortality by registration period

The results are shown in Table 2. Some of the ratios for the last three periods and for all periods combined are very slightly too low as there were 10 deaths for which we were unable to secure a cause (1 in the registration period 1921–35, 5 in the period 1936–54, and 4 in the period 1955–79).

From this comparison it appears that the radiologists who were registered before 1921 did have some excess risk of death from cancer though the excess was not statistically significant (60 observed, 47.16 expected, p = 0.09), but that all subsequent groups experienced fewer such deaths than expected, the deficiencies for those registered after 1935 being statistically highly significant. We must ask, however, whether the comparison was appropriate – in other words would the radiologists’ mortality from cancer, in the absence of exposure to ionizing radiation, have been expected to be the same as that of the general population of the whole country and the answer must be no. For cancer mortality in the UK is highly dependent on economic status and relatively wealthy people have for many years consistently had lower mortality from cancer than the poor. A more appropriate comparison would, therefore, be with the relatively wealthy in the British category of socio-economic class one. Even this, however, may be less than ideal for medically qualified doctors have consistently had lower mortality from cancer than others in the same socio-economic category and the better comparison would be with medical practitioners.

Fortunately, the British mortality data allows some such comparisons to be made, if not perfectly at least reasonably well, for mortality rates are published every 10 years by socio-economic class and by occupation in supplements to the national mortality reports.\(^8\)\(^–\)\(^14\) It was possible, therefore, with some minor modifications to estimate the expected numbers of death from cancer and from all other causes, had the radiologists suffered the same risks of death as medical practitioners in general, by multiplying the number of deaths expected from comparison with the general population by the standardized mortality ratios for medical practitioners for each of the relevant periods. The results are shown in Table 3. With this comparison the radiologists’ mortality from cancer is seen to have been greater than that for all medical practitioners, for all groups who registered before 1955 and highly significantly so (p < 0.001) with an increase of 75% for those who registered before 1921. For this early group, moreover, the types of cancer that showed the greatest relative increases were, as Smith and Doll showed previously,\(^6\) cancer of the skin (SMR 7.79 based on 6 deaths) from the time when radiologists directly exposed their hands without any protection and leukemia (SMR 6.15 based on 4 deaths) a malignant disease now known to be particularly susceptible to induction by ionizing radiation. For the most recently qualified group, in contrast, the cancer mortality based on only 32 cases, was nearly 30 percent lower than expected, but not quite statistically significantly so (SMR 0.71, p = 0.06).

Other causes of death, some of which have recently been shown also to be capable of causation by ionizing radiation,

### Table 2. Mortality from cancer and other causes: Radiologists compared to population of England and Wales

<table>
<thead>
<tr>
<th>Period of registration</th>
<th>Standardized mortality ratio (no. of deaths observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cancer</td>
</tr>
<tr>
<td>1897–1920</td>
<td>1.27 (60)</td>
</tr>
<tr>
<td>1921–35</td>
<td>0.76 (51)</td>
</tr>
<tr>
<td>1936–54</td>
<td>0.66*** (85)</td>
</tr>
<tr>
<td>1955–79</td>
<td>0.46*** (32)</td>
</tr>
<tr>
<td>All periods</td>
<td>0.73* (228)</td>
</tr>
</tbody>
</table>

*p < 0.05 ***p < 0.001

### Table 3. Mortality from cancer and other causes: Radiologists compared to medical practitioners.

<table>
<thead>
<tr>
<th>Period of registration</th>
<th>Standardized mortality ratio (no. of deaths observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cancer</td>
</tr>
<tr>
<td>1897–1920</td>
<td>1.75*** (60)</td>
</tr>
<tr>
<td>1921–35</td>
<td>1.24 (51)</td>
</tr>
<tr>
<td>1936–54</td>
<td>1.12 (85)</td>
</tr>
<tr>
<td>1955–79</td>
<td>0.71 (32)</td>
</tr>
<tr>
<td>All periods</td>
<td>1.16* (228)</td>
</tr>
</tbody>
</table>

*p < 0.05 ***p < 0.001

### Table 4. Mortality from cancer and other causes: Radiologists compared to medical practitioners.

<table>
<thead>
<tr>
<th>Period of registration</th>
<th>Standardized mortality ratio from cancer (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
</tr>
<tr>
<td>1897–1920</td>
<td>1.75 (1.40–2.17)</td>
</tr>
<tr>
<td>1921–35</td>
<td>1.24 (0.97–1.57)</td>
</tr>
<tr>
<td>1936–54</td>
<td>1.12 (0.93–1.34)</td>
</tr>
<tr>
<td>1955–79</td>
<td>0.71 (0.52–0.95)</td>
</tr>
</tbody>
</table>
show smaller differences. The standardized mortality ratios are consistently less than one for all four periods of registration and significantly less than one for the period 1954–79. I shall, however, say no more about them as their relationship with exposure to ionizing radiation is, at the most, weak, except for noting that they imply that even the comparison with medical practitioners may be less than perfect and that the very low mortality for radiologists registered in the last period indicates that they must be regarded as having been, for one reason or another, a peculiarly healthy group.

**Predicted effect of radiation**

Further analysis of our findings, as with those for all other groups of radiologists who have been studied, is hampered by lack of information about the doses that the individuals received. The best estimates that we have been able to find are, for radiologists as a group, of the order of 1Sv a year in the 1920s and 1930s. Exposure was certainly lower in the 1940s and 1950s, reduced perhaps to 100 to 50 mSv a year by the mid 1950s to less than 5 mSv a year by 1964, and to an average of 0.5 mSv a year by 1993.

![Fig. 1. Mortality ratios for diseases not related to smoking versus smoking ratios. Slope of the line: 0.14 ± 0.11. Bars indicate 95% confidence limits. Longer confidence intervals corresponding to groups with fewer deaths are given by broken lines only to emphasize visually that they are unreliable and that attention should be directed chiefly to shorter, solid lines, which describe more reliable SMRs. (Ref. 19. quoted with permission from British Medical Journal)](image-url)
servative assumption that exposure began on average at about 35 years of age and would persist for 20 years, Berrington et al.\textsuperscript{7) made crude estimates of the increased mortality from cancer than might have been anticipated, using the dose-response relationship derived from the Life Span Study of the atomic bomb survivors.\textsuperscript{18) Exposure in the case of the radiologists was, however, fractionated and spread out over time and these estimates should probably, in consequence, be at least halved. The results, on this assumption, are shown in Table 4. The observed effect was consistently less than that predicted, but the dose estimates are far from certain, as is the justification for extrapolating upwards from the observations in the Life Span Study for those exposed before 1935.

Modifying effects of life-style
Another weakness of the comparison is the suitability of medical practitioners to provide the estimate of the expected number of deaths. They are certainly more suitable than the whole population of the country and, I have suggested, better than all members of socio-economic class one, to which the classical professions are allocated in the national records. But all sections of the medical profession do not have the same mortality rates and, other things being equal,

![Fig. 2](https://example.com/fig2.png)

**Fig. 2.** Mortality ratios for diseases related to smoking versus smoking ratios. Slope of the line: 0.78 ± 0.11. (Ref. 19. quoted with permission from British Medical Journal).
specialists tend to have lower mortality rather than general practitioners. This was made clear in the study of British doctors that was initiated in 1951 to test the conclusion that had been drawn from a case-control study about the importance of smoking as a cause of lung cancer. Examination of the mortality over 20 years of 24,540 male doctors aged 35 years and over, by which age they might be expected to have settled in one or other branch of medicine, showed marked heterogeneity between the rates for the different branches of the profession, which seems to depend essentially on differences in smoking habits, the effect of which had been brought to the attention of British doctors in 1950. Little difference was observed between the mortality rates for diseases not clearly related to smoking (Fig. 1), but there were marked differences in the mortality from smoking related diseases, as is shown in Fig. 2, radiologists having a ‘smoking ratio’ of 86% (the average of the reported cigarette consumption in 1951 to 1966 compared to that of all doctors, standardised for age) and a mortality from the main smoking related diseases that was 14% lower than that of all doctors though with wide confidence limits.\(^1\)

Fortunately we can test whether this observed difference is likely to be a material explanation of the relatively low mortality from cancer compared to that predicted from their radiation exposure by examining the types of cancer from which they suffered. Berrington et al.\(^2\) had examined the mortality of the radiologists from different types of cancer more than 20 years after first registration when radiation cancers would be most likely to occur. Data were given for 13 types of cancer for all radiologists registered after 1920. Deaths from cancer amounted to 140 with a SMR of 0.91 compared to all men in socio-economic class 1 and 1.17 adjusted for the lower cancer mortality among doctors. When, however the deaths from cancer are divided into two categories, according to whether or not they are related to smoking (using the 1986 classification of the International Agency for Research on Cancer) it is found that the corresponding SMRs for radiologists compared to men in socio-economic class 1 are respectively 0.60 for smoking related cancers and 1.16 for other cancers, which, adjusted for comparison with all doctors, would be 0.77 and 1.58.

I conclude, therefore, that the lower mortality from cancer than would be predicted from their exposures to radiation can reasonably be explained by the radiologists’ life-style, possibly because of seeing so many patients with lung cancer, having given up smoking to a rather greater extent than doctors as a whole.

CONCLUSION

Study of the health of British radiologists, as of radiologists in other developed countries, was crucial in determining the acute effects of ionizing radiation and led to the introduction of stringent precautions which were quickly adopted and successful for their immediate purpose. Large scale epidemiological studies of radiologists as groups have, however, been required to show that the risk of long-term effects, such as the production of cancer, have also been reduced to acceptable levels. With the low levels of exposure to which radiologists are now subject, risks are so small that they cannot be detected from group studies in which the variation in mortality determined by common variations in life style are likely to be greater than the very small risks from ionizing radiation that may be predicted from theoretical considerations.

In such circumstances direct evidence of any effect – or indeed of its absence – can be obtained only by study of a population in which we have reliable estimates of the exposures of individual members, as is being obtained, for example, in the study of radiation workers in the UK\(^3\) or of nuclear energy workers by the International Agency for Research on Cancer.\(^4\) Even, however, with such evidence a level of exposure may be reached such that impossibly large numbers of individuals would be required to detect the effect. In such circumstances, we have to rely on estimates of risk extrapolated from the effect of higher doses, backed up by knowledge of the mechanisms by which the relevant disabilities are produced.

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10. Register General. (1938) Decennial supplement, England and
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