Cardiovascular Mortality Caused by Exposure to Radon

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Abstract. Cardiovascular diseases (CVD) are reported as the cause of morbidity and mortality in humans exposed to (high) therapeutic doses of radiation, A-bomb explosions, accidental (Chernobyl liquidators) and occupational levels of radiation while CVD risk does not appear to be elevated in other populations exposed to radiation. CVD mortality also appears to be elevated, proportionally with radon progeny exposure in Newfoundland fluorspar miners. In addition, radiation exposure does not seem to increase, and may indeed decrease CVD mortality or morbidity in mammals exposed to radiation in the laboratory. We have calculated the doses to blood and coronary artery wall from radon and progeny, and have concluded radon exposure may indeed increase the incidence of cardiovascular diseases and that a thorough investigation of that risk is justified, even at environmental and occupational levels. These contradictory observations suggest that radiation may be considered as one of many risk factors for cardiovascular diseases. As such, it may be necessary to reduce not only other risk factors as far as possible, but also to minimize exposures to radiation to further reduce the burden of cardiovascular diseases in the population.

1. Introduction

Cardiovascular diseases (CVD) are mainly "congestive heart failure, arrhythmia, angina pectoris and myocardial infarction" [1]. Darby et al [2] have shown that there is increased mortality from CVD disease more than 10 years after radiotherapy for breast cancer but the study by Villeneuve and Morrison [3] did not find a statistically significant increase in CVD in the Newfoundland fluorspar miners. The presentation by Zielinski [4] showed that mortality from CVD increased with dose at a dose related rate similar to cancer mortality but with a longer latency period. This paper is a review of the risk of CVD from ^{222}Rn exposure and other sources of radiation.

2. Radon and Cardiovascular Disease

2.1 Theory

Radon that enters the blood will be distributed to all tissues and results in an equilibrium concentration. The doses to most human tissues have been calculated by Peterman and Perkins [5], Khursheed [6] and Kendall and Smith [7] and are summarised in Table 1. In addition, Marsh and Birchall [8] have calculated the doses, to tissues other than lung, from inhaled radon progeny that enters the blood.

Table 1. Dose from radon and progeny in tissues

Tissue	Dose (μGy per year^{-1} per Bq m^{-3})
Blood	0.0385
Fat	0.512
RBM	0.233
Bone Surfaces	0.378
Liver	2.60
Breast	0.146
Kidney	1.31
Gonads	0.005
Muscle	0.005

Ionizations results in the formation and accumulation of LDL particles, lipoprotein accumulation, SMC migration to the intima, foam cell formation and fibrous lesion formation. These steps leading to atherosclerosis are shown in Figure 1. One of the results of this damage is the formation of fatty nodules, called artheromas, on the blood vessel walls. The latency period for this development is eighteen to thirty years, Figure 2.

Fig. 1 The role of radiation in atherosclerosis

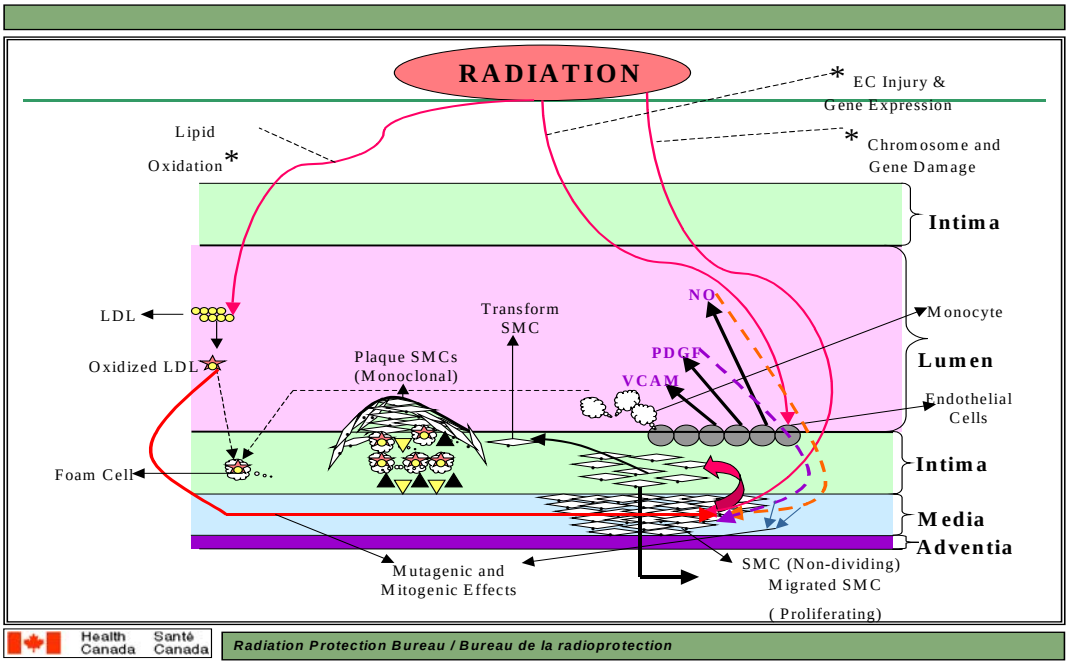
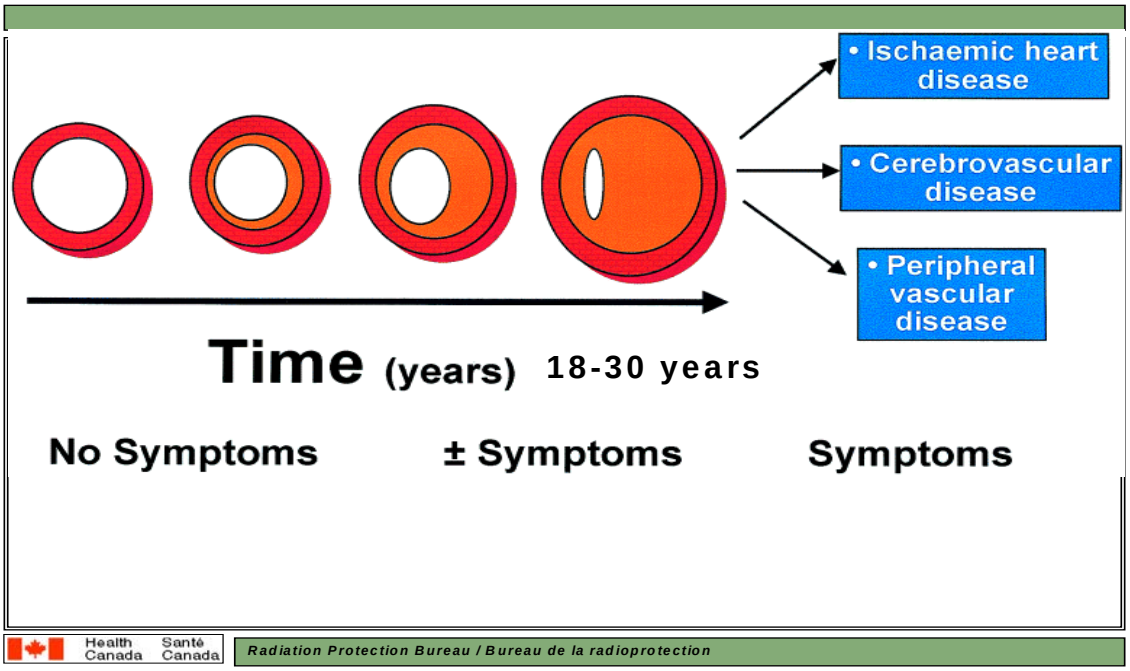


Fig. 2 The evolution of atheroma



2.2 Animals Experiments

2.2.1 CVD Diseases in animals exposed to radiation

The International Centre for Low Dose Radiation Research (ICLDRR) assembled a database on radiation carcinogenesis that contains information on about 85,000 exposed animals and 45,000 corresponding controls. Only nine of over three hundred publications collected by the ICLDRR for cancer data contain information on cardiovascular diseases in animals exposed to relatively low radiation doses and were allowed to live until their natural death. The period of time covered by the ICLDRR database ends in 1996 [9].

The outcomes for which information exist are cardiac diseases (cardiac lesions, cardiac disease with failure, congestive heart failure, auricular thrombosis), atherosclerosis, thrombosis and infarction.

2.2.2 Summary of data for cardiovascular diseases

The terminology used to identify the various cardiac and vascular outcomes found in the literature varies between authors and over time. For example, different specific cardiac diseases or accidents are described by the authors and grouped in tabulated data under the general category “cardiac diseases”, or the authors provide incidence data for the general category “cardiac disease” without detailed explanation.

In this summary, the number of cardiovascular diseases observed in exposed and control animals are compared and the relative risk of each outcome, with corresponding 95% confidence intervals, are calculated using Instat® [1].

2.2.2.1 cardiovascular diseases following exposure to gamma or X-rays

In animals exposed to gamma or X-rays all organs, including cardiovascular tissues, received approximately the same dose of radiation. A total of 170 cases of cardiac diseases, as described by the authors, were observed in the 2445 animals exposed to gamma or X-rays, compared to 126 cases in 1029 controls, with a relative rive risk RR = 0.57 (95% C.I. = 0.46 – 0.71, $p<0.0001$).

2.2.2.2 cardiovascular diseases following intake of alpha or beta emitters

The dose to cardiovascular tissues after intake of alpha or beta emitters is unknown. However, it remains possible to express the relationship observed between the dose (or burden) in organs in which the radionuclides accumulate, without implying a causal relationship between dose and effect. A total of 82 cases of cardiac diseases were observed in 1091 exposed animals, versus 163 in 1157 controls. In these animals, the relative risk of cardiac disease is RR=0.53 (95% C.I.= 0.41 – 0.69, $p<0.0001$).

2.2.2.3 Summary for all types of radiation and all types of cardiovascular diseases

The data in Table 2 gives a total of 251 cases of cardiac or vascular diseases was observed in 3426 exposed animals, compared to 289 cases in 2168 controls, with an overall relative risk RR=0.55 (95% C.I.=0.47 – 0.65, $p<0.0001$), which clearly demonstrates a statistically significant protective effect of radiation exposure against CVD in the mammals used in the experiments.

2.3 Human Experience

Cardiovascular diseases (CVD) have been reported as the cause of morbidity and mortality in humans exposed to (high) therapeutic doses of radiation, A-bomb explosions, accidental (Chernobyl liquidators) and occupational levels of radiation [20]. Other studies include those of Darby et al. [2] mentioned above.

More relevant is the study by Villeneuve and Morrison [3] and Samet et al [21]. Samet et al included "total circulatory" as a cause of death in their review of mortality in New Mexico uranium miners. The SMR was 0.6. Villeneuve and Morrison reported on coronary heart disease (CHD) in the Newfoundland fluorspar miners The source of the radon is water, and therefore uranium ore dust and gamma fields do not complicate the dosimetry. The only dose above background is from radon and progeny. The cohort studied was 1743 underground miners and 321 millers or surface workers. The age of the cohort at first exposure was 28.7 years (SE: 16.1) and the cumulative exposure ranged from zero (some surface workers) to over 1000 WLM (mean: 379 WLM, SE: 799 WLM) for a mean duration of 5.7 years (SE: 5.9). Their analyses gave a non-significant elevated risk of CHD mortality among miners exposed to very high concentrations of radon progeny but they said that workers exposed to high levels of radon progeny have a greater risk of CVD mortally.

[1] GraphPad Software, 5755 Oberlin Dr. #110, San Diego, CA 92121 (www.graphpad.com)

Table 2. Relative risk of cardiovascular disease in mammals exposed to radiation in the laboratory.

			Number of animals		Number of cases			
Cardiovascular disease	Radiation	Species	Controls	Exposed	Controls	Exposed	RR (95% C.I.)	Ref.
Cardiac disease	^{60}Co	Beagle	276	1067	18	59	0.85 (0.51-1.41)	[10]
Thrombosis and infarction	^{60}Co	"	"	"	14	34	0.63 (0.34-1.14)	[10]
All Benjamin 1998 data	^{60}Co	"	"	"	32	94	0.76 (0.52-1.10)	[10]
Auricular thrombosis	X-rays	RF mouse	427	1069	29	40	0.55 (0.35-0.88) p=0.01	[11]
All cardiovascular pathologies	Ext, Th-232	C57 mouse	326	309	79	71	0.95 (0.71-1.25)	[12]
Congestive heart failure	Inject. $^{39}Pu(NO_3)_4$	Beagle dog	20	41	0	1	-	[13]
Atherosclerosis	Inject. $^{90}SrCl_2$	Beagle dog	21	72	1	0	-	[14]
Congestive heart failure	Inject. $^{90}SrCl_2$	"	"	"	2	2	0.30 (0.04-1.95)	[14]
All Gillett 1987 data	Inject. $^{90}SrCl_2$	"	"	"	3	2	0.19 (0.03-1.08)	[14]
Cardiac lesions	Inject. $^{144}CeO_2$	C57 mouse	597	336	42	22	0.93 (0.56-1.53)	[15]
Cardiovascular disease (no details)	Inject. $^{144}CeCl_3$	Beagle dog	15	26	1	1	0.58 (0.03-8.6)	[16]
Cardiac lesions (thrombosis, myocarditis, endocarditis)	Inhal. $^{144}CeO_2$	Syrian hamster	219	349	21	15	0.45 (0.23-0.85) p=0.01	[17]
Cardiac lesions (thrombosis, myocarditis, endocarditis)	Inject. $^{239}PuO_2$	Syrian hamster	267	157	98	42	0.73 (0.53-0.99) p=0.04	[18]
Cardiovascular diseases (includes hemangiosarcoma)	Inject ^{224}Ra	Beagle dog	18	110	0	1	-	[19]
All			2168	3426	289	251	0.55 (0.47-0.65) p<0.0001	

The excess relative risk of CVD in the British radiologists is not due to socio-economic factors since the reference population, for the data from presented by Berrington et al [23] in table 3 is that of all medical practitioners.

The above is summarized in Table 3.

Table 3. Risk of radiation induced cancer and CVD
*Reference population: all male medical practitioners

Study	Excess Relative Risk (ERR) or SMR		Reference
	Cancer	CVD	
Uranium miners	1.90	SMR: 0.60 (95% CI=0.4-0.8)	[21]
A-Bomb survivors	1.70	0.38	[22]
Chernobyl Emergency Workers	2.04	0.79	[23]
British Radiologists* (period 1955-79)	SMR: 0.73	SMR: 0.59 ($p<0.001$)	[24]
Springfield radiation workers	1.41	SMR: 90 ($p<0.001$)	[25]

3. Summary

The apparent protective effect of radiation exposure against CVD in mammals exposed in the laboratory appears to be statistically significant, although these studies were not particularly designed to study these particular effects. However, human data are much more contrasted, with some studies that tend to show an increased risk with radiation exposure, and even a relationship between risk and dose, as in the fluorspar miners, but also with apparently statistically significant protective effects in other populations (for example, British radiologists from 1920 to present [24]).

The risk of CVD may also be influenced by exposure to non-radioactive substances like long-term exposure to fine airborne particulate air pollution [26], a risk factor heavily present in mine atmosphere.

Still, the question remains that radiation (including radon) may cause CVD, but it is not apparent that the risk of CVD from radon exposure is significant compared to the risk of cancer. It is apparently not in uranium mines [for example, 21, 24, 25], but could be in non-uranium mines [3] and in residences.

It needs to be studied to determine if it is significant compared to the lung cancer risk given in ICRP Publication 50 and should be considered in the action level recommended in Section 4.2 of ICRP Publication 65.

The risk from ^{220}Rn (thoron) in blood from in vivo thorium [27] should also be studied in thorotrast patients and considered in calculating the risk to workers.

4. Conclusion

The risk of CVD from radon and other exposures to radiation needs to be evaluated to make certain that a possible risk factor has not been systematically ignored in past and that future risk assessment to workers and the general public are complete.

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