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Studies of the Mortality of Atomic Bomb Survivors, Report 14, 1950–2003: An Overview of Cancer and Noncancer Diseases

Ozasa K, Shimizu Y, Suyama A, Kasagi F, Soda M, Grant EJ, Sakata R, Sugiyama H, Kodama K

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[Findings of this study]

We followed the Life Span Study cohort during the period from 1950 through 2003 and elucidated effects of A-bomb radiation on mortality and causes of death using the DS02 dosimetry system. Excess relative risk (ERR) for all solid cancer mortality showed a linear dose-response relationship over the entire dose range, with no threshold observed, with the lowest dose range with significant risk for all solid cancers 0 to 0.20 Gy. The risk of all solid cancer mortality at the age of 70 years after exposure to 1 Gy at age 30 was 42% higher than that for unexposed individuals, increasing by about 29% per decade decrease in age at exposure. With regard to site-specific cancers, significant increase in cancer risk was observed for stomach, lung, liver, colon, breast, gallbladder, esophagus, bladder, and ovary, whereas rectum, pancreas, uterus, prostate, and kidney parenchyma did not have significantly increased risk. Increased risks of non-cancer diseases including those of the circulatory, respiratory and digestive systems were observed, but whether there was a causal relationship with radiation requires further investigation.

[Explanations]

1) This report covers an additional six years of follow-up since the 13th LSS report was published in 2003. This is the first time the DS02 dosimetry system has been used for estimating individual dose and comprehensively analyzing radiation risk by cause of death. The subject population consisted of 86,611 directly exposed A-bomb survivors with individual dose estimates available, from among the LSS cohort of about 120,000 people. During the follow-up period, 50,620 people died, a number representing 58% of the original population, including 10,929 solid cancer deaths.
2) ERR* at the age of 70 years after exposure at age 30 was 0.42/Gy (95% confidence interval [CI]: 0.32, 0.53), while excess absolute risk** was 26.4 persons/Gy /10,000 person-year.

* In this paper, Excess relative risk (ERR) is equivalent to the value of relative risk minus one, indicating radiation exposure-related increase of relative risk. (Relative risk indicates how many times risk increased with radiation exposure, compared to unexposed cases.)

**In this paper, Excess absolute risk (EAR) is mortality in those exposed to radiation minus mortality in unexposed individuals, indicating radiation exposure-related increase in absolute risk.

3) Excess cancer deaths attributable to radiation exposure are estimated to account for more than half of all solid cancer deaths in the dose range of 2 Gy or greater, with the same being the case for about one-fourth in the range of 0.5 Gy-1 Gy and about one-twentieth in the range of 0.1-0.2 Gy.
4) The linear dose-response relationship provided the best fit for the ERR data across the entire dose range, but a concave curve was the best fit for data restricted to dose < 2 Gy. This resulted because risk estimates for exposure to around 0.5 Gy were lower than those in the linear model.

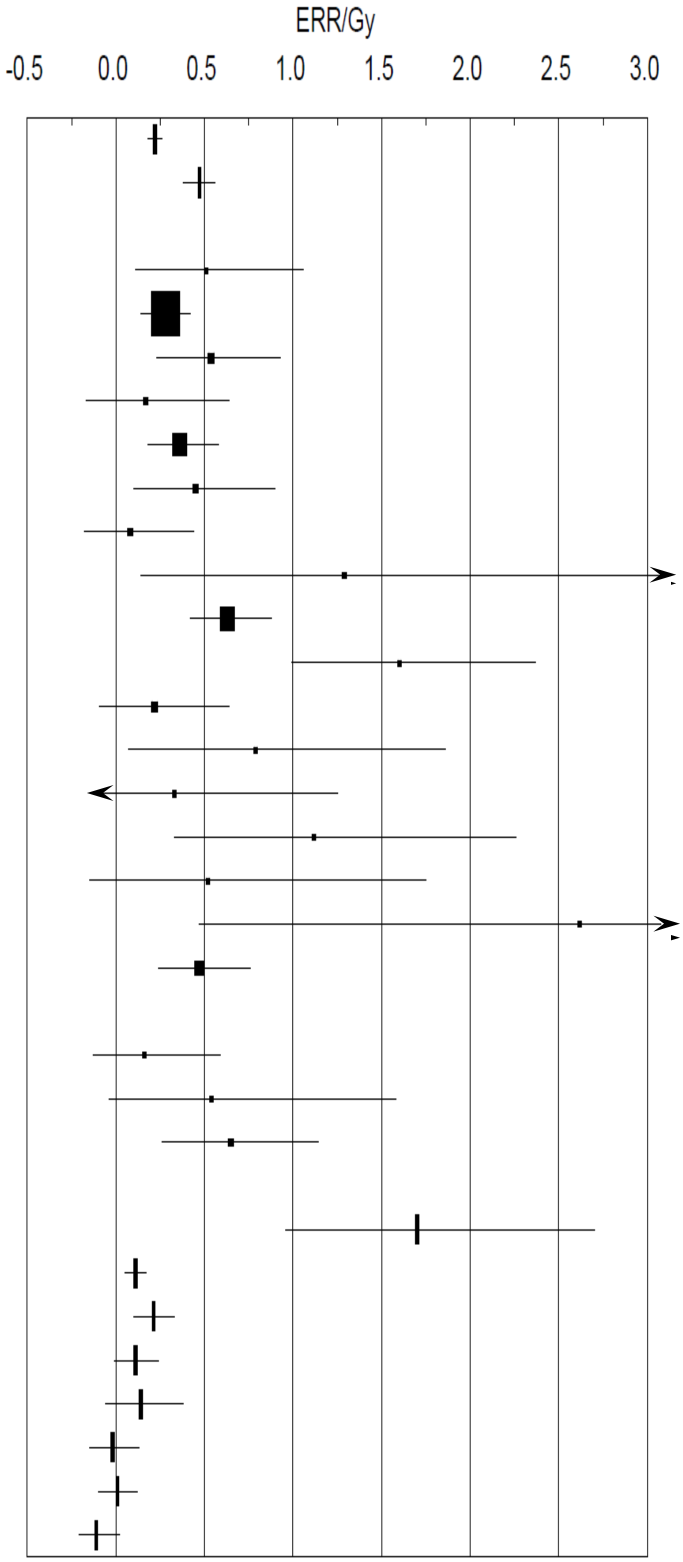
The Radiation Effects Research Foundation has studied A-bomb survivors in Hiroshima and Nagasaki for more than 60 years. RERF's research achievements are considered the principal scientific basis for assessment of radiation risk by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and recommendations regarding radiation protection standards by the International Commission on Radiological Protection (ICRP).

[$]***Radiation Research***, the official monthly journal of the US Radiation Research Society, publishes original and review articles dealing with radiation effects and related subjects in the areas of physics, chemistry, biology and medicine (impact factor in 2010: 2.578).

Figures 1, 2, and 4 were revised, based on the errata (Radiat Res 2013 (April); 179(4):e0040-41), on June 10, 2013.

Figure 1

Cause of death	ERR/Gy [a] (95%CI [b])	Cause
All causes	0.22 (0.18, 0.26)	50,620
All solid cancer	0.47 (0.38, 0.56)	10,929
Cancers of Specific sites [c]		
Esophagus	0.51 (0.11, 1.06)	339
Stomach	0.28 (0.14, 0.42)	3,125
Colon	0.54 (0.23,0.93)	621
Rectum	0.17 (-0.17,0.64)	427
Liver	0.36 (0.18, 0.58)	1,519
Gallbladder	0.45 (0.10, 0.90)	419
Pancreas	0.08 (-0.18, 0.44)	513
Other digestive system	1.29 (0.14, 3.25)	84
Lung	0.63 (0.42, 0.88)	1,558
Breast	1.60 (0.99, 2.37)	330
Uterus	0.22 (-0.09, 0.64)	547
Ovary	0.79 (0.07, 1.86)	157
Prostate	0.33 (NA [e], 1.25)	130
Bladder	1.12 (0.33, 2.26)	183
Kidney parenchyma	0.52 (-0.15, 1.75)	80
Renal pelvis and ureter	2.62 (0.47,7.25)	33
Other solid cancer	0.47 (0.24, 0.76)	864
Lymphoid and hematopoietic malignancies [c, d]		
Malignant lymphoma	0.16 (-0.13,0.59)	284
Multiple myeloma	0.54 (-0.04,1.58)	93
Other neoplasms [c]	0.65 (0.26, 1.14)	518
Non-neoplastic diseases and other causes		
Blood diseases	1.70 (0.96, 2.70)	238
Circulatory diseases	0.11 (0.05, 0.17)	19,054
Respiratory diseases	0.21 (0.10, 0.33)	5,119
Digestive diseases	0.11 (-0.01, 0.24)	3,394
Genitourinary diseases	0.14 (-0.06, 0.38)	1,309
Infectious diseases	-0.02 (-0.15, 0.13)	1,962
Other diseases	0.01 (-0.1, 0.12)	4,847
External causes	-0.11 (-0.21, 0.02)	2,432



a *Excess relative risk (ERR) was estimated using the linear dose model, with adjustments made for city, sex, age at exposure, and attained age.*

b *The horizontal lines show 95% confidence intervals.*

c *The size of the plotted points is proportional to the number of deaths.*

d *ERR of leukemia was 3.1 (95% CI: 1.8, 4.3) at 1 Gy and 0.15 (-0.01, 0.31) at 0.1 Gy based on a linear-quadratic model.*

e *The lower limit of 95% CI was lower than zero, but a specific value could not be calculated.*

Figure 2. Excess relative risk (ERR)

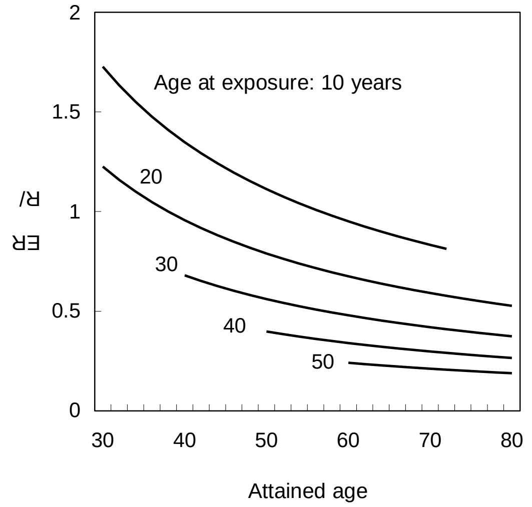
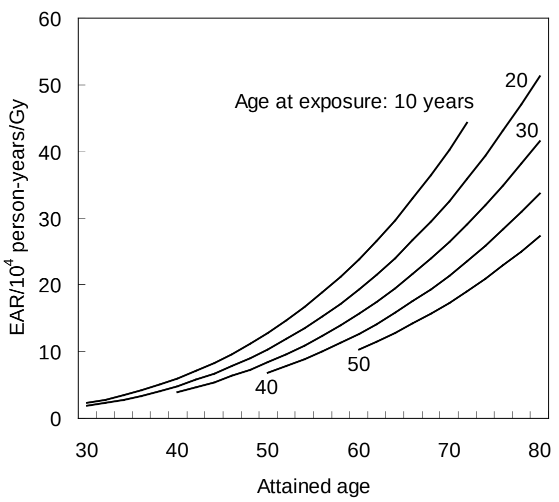


Figure 3. Excess absolute risk (EAR)



Modification of radiation risk for all solid cancer mortality by age at exposure and attained age

ERR/Gy: excess relative risk at 1 Gy

EAR/104 person-year/Gy: excess absolute risk (number of increase for every 10,000 people) at 1 Gy

- Risk increased with decrease in age at exposure. (ERR increased by about 30% per decade decrease in age at exposure.)
- Relative risk declined with increase in number of years after the atomic bombing (with increasing attained age of subjects). (ERR decreased by 10-15% per decade with increase in attained age.)
- On the other hand, since cancer mortality increased with aging of the subjects, excess cancer deaths (EAR) increased.

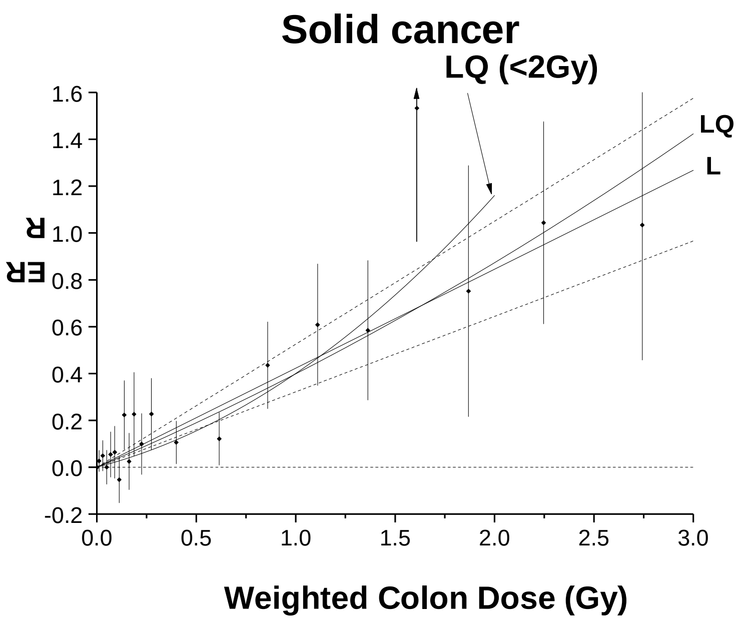


Figure 4. Dose-response relationships of excess relative risk (ERR) with all solid cancer mortality in relation to radiation exposure.

The linear model (L) provided the best fit for ERR dose response across the entire dose range, with the linear-quadratic model (LQ) for the data restricted to dose < 2 Gy. This resulted because risk estimates for exposure to around 0.5 Gy were lower than those in the linear model. In the figure, the dots and vertical bars show point estimates of risk and 95% confidence intervals specific to each dose category. The dotted lines represent 95% CI with the linear model (L), which provided the best fit over the entire dose range.