

Original Article
Preventive & Social Medicine



Comparison of Proportional Mortality Between Korean Atomic Bomb Survivors and the General Population During 1992–2019

Ansun Jeong ,¹ Seong-geun Moon ,² Yunji Han ,³ Jin-Wu Nam ,^{4,6}
Mi Kyung Kim ,² Inah Kim ,⁵ Yu-Mi Kim ,² and Boyoung Park ^{2,6}

¹Department of Health Sciences, Hanyang University, Seoul, Korea

²Department of Preventive Medicine, Hanyang University College of Medicine, Seoul, Korea

³Institute for Health and Society, Hanyang University, Seoul, Korea

⁴Department of Life Science, Hanyang University College of Natural Sciences, Seoul, Korea

⁵Department of Occupational and Environmental Medicine, Hanyang University College of Medicine, Seoul, Korea

⁶Hanyang Institute of Bioscience and Biotechnology, Hanyang University, Seoul, Korea



Received: Jul 26, 2022

Accepted: Dec 28, 2022

Published online: Mar 28, 2023

Address for Correspondence:

Boyoung Park, MD, PhD

Department of Preventive Medicine,
Hanyang University College of Medicine, 222
Wangsimni-ro, Seongdong-gu, Seoul 04763,
Korea.

Email: hayejine@hanmail.net

© 2023 The Korean Academy of Medical
Sciences.

This is an Open Access article distributed
under the terms of the Creative Commons
Attribution Non-Commercial License ([https://
creativecommons.org/licenses/by-nc/4.0/](https://creativecommons.org/licenses/by-nc/4.0/))
which permits unrestricted non-commercial
use, distribution, and reproduction in any
medium, provided the original work is properly
cited.

ORCID iDs

Ansun Jeong

<https://orcid.org/0000-0002-1973-0009>

Seong-geun Moon

<https://orcid.org/0000-0002-5019-3483>

Yunji Han

<https://orcid.org/0000-0003-2351-5456>

Jin-Wu Nam

<https://orcid.org/0000-0003-0047-3687>

Mi Kyung Kim

<https://orcid.org/0000-0001-8503-2631>

ABSTRACT

Background: Atomic bombs dropped on Hiroshima and Nagasaki in Japan in August 1945 were estimated to have killed approximately 70,000 Koreans. In Japan, studies on the health status and mortality of atomic bomb survivors compared with the non-exposed population have been conducted. However, there have been no studies related to the mortality of Korean atomic bomb survivors. Therefore, we aimed to study the cause of death of atomic bomb survivors compared to that of the general population.

Methods: Of 2,299 atomic bomb survivors registered with the Korean Red Cross, 2,176 were included in the study. In the general population, the number of deaths by age group was calculated from 1992 to 2019, and 6,377,781 individuals were assessed. Causes of death were categorized according to the Korean Standard Classification of Diseases. To compare the proportional mortality between the two groups, the *P* value for the ratio test was confirmed, and the Cochran-Armitage trend test and χ^2 test were performed to determine the cause of death according to the distance from the hypocenter.

Results: Diseases of the circulatory system were the most common cause of death (25.4%), followed by neoplasms (25.1%) and diseases of the respiratory system (10.6%) in atomic bomb survivors who died between 1992 and 2019. The proportional mortality associated with respiratory diseases, nervous system diseases, and other diseases among atomic bomb survivors was higher than that of the general population. Of the dead people between 1992 and 2019, the age at death of survivors who were exposed at a close distance was younger than those who were exposed at a greater distance.

Conclusion: Overall, proportional mortality of respiratory diseases and nervous system diseases was high in atomic bomb survivors, compared with the general population. Further studies on the health status of Korean atomic bomb survivors are needed.

Keywords: Atomic Bomb Survivors; Proportional Mortality; Radiation

Inah Kim <https://orcid.org/0000-0001-9221-5831>Yu-Mi Kim <https://orcid.org/0000-0003-1123-8690>Boyoung Park <https://orcid.org/0000-0003-1902-3184>**Funding**

This study was supported by a grant of Division of Disease Control Policy, Ministry of Health and Welfare, Republic of Korea (grant No. 11-1352000-003427-12).

Disclosure

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Jeong A, Park B. Data curation: Jeong A, Moon SG. Formal analysis: Jeong A, Park B. Funding acquisition: Park B. Investigation: Moon SG, Han Y. Methodology: Jeong A, Han Y, Park B. Software: Jeong A, Park B. Validation: Nam JW, Kim MK, Kim I, Kim YM, Park B. Supervision: Nam JW, Kim MK, Kim I, Kim YM, Park B. Visualization: Jeong A. Writing - original draft: Jeong A, Moon SG, Han Y, Nam JW, Kim MK, Kim I, Kim YM, Park B. Writing - review & editing: Jeong A, Moon SG, Han Y, Nam JW, Kim MK, Kim I, Kim YM, Park B.

INTRODUCTION

Atomic bombs were dropped on Hiroshima and Nagasaki, Japan, on August 6 and 9, 1945, respectively.¹ It has been estimated that approximately 440,000 people in Hiroshima and 271,500 in Nagasaki had atomic bomb exposure, of whom 300,000 died in that year.¹ Of these 230,000 people, nearly 50,000 Koreans in Hiroshima and 20,000 Koreans in Nagasaki are estimated to be dead, and approximately 40,000 people died shortly after being exposed to the atomic bomb explosion.¹ After the Korean liberation in 1945, a total of 23,000 people were estimated to have returned to Korea.¹ However, the estimated number is not accurate owing to limited investigation and information.² The Korean atomic bomb survivors had not received attention until the Japanese government tracked Korean atomic bomb survivors in the early 1990s, and only those atomic bomb survivors who had survived until the 1990s were identified. According to the Special Act on Korean Atomic Bomb Survivors implemented in 2017,³ as of July 2021, 2,040 atomic bomb victims were still alive, and the average age was 81.6 years,⁴ suggesting that most of the atomic bomb survivors had already died.

In Japan, to investigate the health effects of atomic bomb radiation, cohorts of atomic bomb survivors, in utero survivors, and offspring of survivors have been constructed and observed through follow-ups since 1950. The results revealed an increased risk of the incidence of or mortality due to thyroid diseases, chronic liver diseases, liver cirrhosis, uterine myoma, and cataract, with a linear dose-response relationship between the exposed radiation dose and disease risk.⁵ In addition, the risks of heart diseases; stroke; digestive diseases; respiratory diseases; cancers including stomach cancer, colon cancer, lung cancer, breast cancer, ovarian cancer, bladder cancer, and thyroid cancer; and death were increased in atomic bomb survivors.^{6,7} Mortality due to gastric, lung, liver, colon, breast, gallbladder, bladder, ovarian, and esophageal cancers was also increased.⁸

Atomic bomb radiation exposure is associated with non-specific inflammatory reactions that cause genome instability⁹ or chronic inflammation through the disruption of T-cell immunity.¹⁰ In a cohort study of nuclear workers in France, the United Kingdom, and the United States, low-dose radiation exposure was associated with increased mortality due to heart diseases and cerebrovascular diseases¹¹ and increased risk of cancer.¹²

Only a few studies of atomic bomb survivors have been conducted in Korea. The medical usage for atomic bomb survivors was 1.4–5 times higher than that of the general population of the same age group, and approximately 67% of atomic bomb survivors reported long-term health problems.¹³ The prevalence of rare diseases, hypertension, chronic liver disease, and hyperlipidemia is higher in atomic bomb survivors in Korea than in the general population.^{2,14} However, studies on atomic bomb survivors in Korea have been limited to small sample sizes and focus over a specific region. This study therefore aimed to investigate the causes of death among atomic bomb survivors in Korea based on the total records registered in the Korean Red Cross and compare the causes of death in the general population using proportional mortality.

METHODS

Study population

Since 1990, Japan has entrusted medical support for atomic bomb survivors to the Korean Red Cross, and atomic bomb survivors have been registered to receive support. Atomic bomb survivors in Korea who registered at the Korean Red Cross are classified into three groups: individuals with proof of being an atomic bomb survivor issued by the Japanese government, individuals with proof of being an atomic bomb survivor in Hiroshima or Nagasaki on the date of atomic bomb explosion, and individuals with proof of being an atomic bomb survivor verified by the Korea Atomic Bomb Casualty Association.²

Since 1992, atomic bomb survivors have been registered in the Korean Red Cross. The total number of registered atomic bomb survivors from 1992 to 2019 was 4,472 and the number of deaths was also recorded annually. In 2019, the number of registered alive individuals was 2,173. A total of 2,299 deaths of atomic bomb survivors have been reported and the year of death ranged from 1901 to 2020. Because the registration of atomic bomb survivors by the Korean Red Cross started in 1992, we did not consider 51 deaths before 1992 because of possibly inaccurate information. In addition, because the most recently available death registration data at the time of analysis was up to 2019, we further excluded the 72 deaths in 2020 and later.

A total of 2,176 deaths were linked to the Causes of Death Statistics of Statistics Korea, and the causes of death were linked for 2,054 deaths using the resident registration number. Information on the situation of the atomic bomb explosion (distance from the hypocenter, location of exposure) and age at death was extracted from the Korean Red Cross. Only information on deaths was provided; thus, the requirement for written informed consent of the study subjects was waived. All personal identifiable information data were deleted after linking the Korean Red Cross data to Statistics Korea data. Mortality data, including the cause and date of death, were obtained by linking the National Health Insurance Service and National Health Insurance Database with the nationwide Death Registration Database provided by the Korea National Statistical Office. From 1992 to 2019, a total of 6,377,781 deaths were reported in the general population.

Variables

In our data, information on age at death, distance from the hypocenter (from the Korean Red Cross), date of death, and cause of death (by linkage to the Causes of Death Statistics of Statistics Korea) was available. Age at death for atomic bomb survivors and the general population was categorized as 45–64, 65–69, 70–74, 75–79, and ≥ 80 years. Distance from the hypocenter was categorized as 0–1 km, 2–3 km, 3–4 km, and ≥ 4 km. Causes of death were classified according to the Korean Standard Classification of Diseases, version 8). Because there were no deaths caused by congenital malformations, deformations and chromosomal abnormalities (Q00–Q99); diseases of the eye and adnexa (H00–H57); diseases of the ear and mastoid process (H60–H93); pregnancy, childbirth, and puerperium (O00–O99); and certain conditions originating in the perinatal period (P00–P96) among atomic bomb survivors, these diseases were excluded from the analysis.

Statistical analysis

Proportional mortality refers to the proportion of deaths attributable to different causes in a specific population over time. Proportional mortality was calculated as the observed number

of deaths due to certain causes over the total number of deaths in the same population.¹⁵ If d be the death count in the study population and i be a specific disease, the proportional mortality is calculated using the following equation¹⁶:

$$PMR_i = \frac{d_i}{d_{total}}$$

Proportional mortality among atomic bomb survivors and the general population was then compared. Considering the different distribution of age at death of atomic bomb survivors compared with the general population and changes in cause of death during the study period, the proportional mortality in atomic bomb survivors and the general population was further compared according to age at death (45–64, 65–69, 70–74, 75–79, and ≥ 80 years) and year of death (1992–1999, 2000–2009, 2010–2019). In addition, in atomic bomb survivors, proportional mortality according to the distance from the hypocenter was compared and we performed the χ^2 test and the Cochran-Armitage trend test to identify the trends in differences in proportional mortality according to the distance from the hypocenter. Statistical analyses were performed using SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA) and two-sided tests, and a significance level of $P < 0.05$ was used.

Ethics statement

This study was approved by the Institutional Review Board (IRB) of Hanyang University (IRB number: HYUIRB-202007-014-15). Informed consent was waived by the board.

RESULTS

Table 1 shows the age at death and the distance from the hypocenter for atomic bomb survivors who died during 1992–2019. The mean age of the atomic bomb survivor at the time of death was 78.8 years. Age at death, the minimum age was 49 and the maximum age was 118. Among a total of 2,176 deaths, proportional mortality for age at death of ≥ 80 years was the highest (1,078, 49.5%), followed by those for 75–79 years (448, 20.6%), 70–74 years (333, 15.3%), 45–64 years (164, 7.5%), and 65–69 years (153, 7.0%). Data of approximately half of the deaths among atomic bomb survivors and distance from the hypocenter were not available (1,101, 50.6%). A distance of 2–3 km from the hypocenter was observed in 648 cases (29.8%), that of 0–1 km was seen in 324 cases (14.9%), and that of ≥ 4 km was seen in 103 cases (4.7%).

Table 1. Baseline characteristics of death among atomic bomb survivors (1992–2019)

Characteristics	Atomic bomb survivors
Mean age at death, yr	78.8 \pm 9.25 (49–118)
Five-year age group for age at death, yr	
45–64	164 (7.5)
65–69	153 (7.0)
70–74	333 (15.3)
75–79	448 (20.6)
≥ 80	1,078 (49.5)
Exposure distance, km	
0–1	324 (14.9)
2–3	648 (29.8)
≥ 4	103 (4.7)
Unknown ^a	1,101 (50.6)

Values are presented as number (%) or mean \pm standard deviation (minimum–maximum).

^aSurvivors whose information on location is insufficient to assess the exposure distance.

Table 2 shows the proportion of each cause of death among atomic bomb survivors. Diseases of the circulatory system were the most common cause of death (553 cases, 25.4%), followed by neoplasms (546 cases, 25.1%) and diseases of the respiratory system (231 cases, 10.6%). Among neoplasms, malignant neoplasms of the digestive organs were the most common cause of death (287 cases, 13.2%), followed by malignant neoplasms of the respiratory and intrathoracic organs (143 cases, 6.6%). Compared with the general population, proportional mortality was significantly higher for diseases of the respiratory system (10.6%, $P < 0.001$), diseases of the nervous system (2.9%, $P = 0.018$), and diseases due to other causes (5.6%, $P < 0.001$) in atomic bomb survivors. Proportional mortality due to malignant neoplasms of digestive organs (14.7%, $P = 0.047$); symptoms, signs, and abnormal clinical and laboratory findings (13.0%, $P < 0.001$); and external causes of morbidity and mortality (8.2%, $P < 0.001$) were significantly higher in the general population than in atomic bomb survivors. No significant differences were found for other causes of death (**Table 2**). When proportional mortality was analyzed by dividing by the three time periods (1992–1999, 2000–2009, 2010–2019), deaths due to respiratory system diseases were high in both 2000–2009 and 2010–2019 (**Appendix 1**).

Table 2. Proportional mortality among atomic bomb survivors and the general population

Causes of death ^a	Atomic bomb survivors	General population	P value
Diseases of the circulatory system	553 (25.4)	1,588,501 (24.9)	0.580
Neoplasms	546 (25.1)	1,704,994 (26.7)	0.090
Malignant neoplasms of digestive organs	287 (13.2)	939,628 (14.7)	0.047
Malignant neoplasms of respiratory and intrathoracic organs	143 (6.6)	389,849 (6.1)	0.358
Malignant neoplasms of lymphoid, hematopoietic, and related tissue	26 (1.2)	76,082 (1.2)	0.982
Malignant neoplasms of the urinary tract	17 (0.8)	50,240 (0.8)	0.922
In situ benign neoplasms and neoplasms of uncertain or unknown behavior	14 (0.6)	23,849 (0.4)	0.072
Malignant neoplasms of male genital organs	13 (0.6)	28,622 (0.4)	0.145
Malignant neoplasms of female genital organs	12 (0.6)	52,602 (0.8)	0.193
Malignant neoplasms of ill-defined, secondary and unspecified sites	8 (0.4)	26,405 (0.4)	0.811
Malignant neoplasm of the breast	6 (0.3)	36,600 (0.6)	0.050
Malignant neoplasms of eye, brain, and other parts of the central nervous system	6 (0.3)	23,487 (0.4)	0.358
Melanoma and other malignant neoplasms of the skin	4 (0.2)	9,312 (0.1)	0.216
Malignant neoplasms of the lip, oral cavity, and pharynx	3 (0.1)	22,485 (0.4)	0.053
Malignant neoplasms of independent (primary) multiple sites	3 (0.1)	4,969 (0.1)	0.576
Malignant neoplasm of the thyroid gland	2 (0.1)	8,005 (0.1)	0.905
Malignant neoplasms of the bone and articular cartilage	1 (0.0)	3,647 (0.1)	0.425
Malignant neoplasms of mesothelial and soft tissue	1 (0.0)	9,212 (0.1)	0.425
Diseases of the respiratory system	231 (10.6)	502,525 (7.9)	< 0.001
Symptoms, signs, and abnormal clinical and laboratory findings	178 (8.2)	828,051 (13.0)	< 0.001
External causes of morbidity and mortality	118 (5.4)	521,956 (8.2)	< 0.001
Diseases of the digestive system	92 (4.2)	322,352 (5.1)	0.064
Endocrine, nutritional, and metabolic diseases	84 (3.9)	290,330 (4.6)	0.100
Diseases of the nervous system	64 (2.9)	140,550 (2.2)	0.018
Certain infectious and parasitic diseases	61 (2.8)	155,452 (2.4)	0.219
Diseases of the genitourinary system	48 (2.2)	113,177 (1.8)	0.154
Mental and behavioral disorders	47 (2.2)	134,686 (2.1)	0.845
Diseases of the musculoskeletal system and connective tissue	23 (1.1)	48,818 (0.8)	0.178
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	6 (0.3)	11,963 (0.2)	0.429
Diseases of the skin and subcutaneous tissue	3 (0.1)	10,806 (0.2)	0.517
Other causes ^{b,c}	122 (5.6)	3,620 (0.1)	< 0.001
Total	2,176 (100.0)	6,377,781 (100.0)	

Values are presented as number (%).

^aCauses of death were classified according to the Korean Standard Classification of Diseases.

^bOther causes refer to people whose cause of death is unknown.

^cOther causes of death were classified as “Other causes,” which apply to the general population, but not to death among atomic bomb survivors (congenital malformations, deformations and chromosomal abnormalities [Q00–Q99], diseases of the eye and adnexa [H00–H57], diseases of the ear and mastoid process [H60–H93], pregnancy, childbirth, and puerperium [O00–O99], and certain conditions originating in the perinatal period [P00–P96]).

The proportional mortality in atomic bomb survivors and the general population by age group is shown in **Table 3**. Among the age categories, the proportional mortality due to neoplasms was highest in atomic bomb survivors until the age of 80 years (45–64 years: 42.7%, 65–69 years: 37.3%, 70–74 years: 33.9%, 75–79 years: 28.8%). In the age group 75–79 years, proportional mortality from diseases of blood and blood-forming organs and certain disorders involving the immune mechanism (0.7% vs. 0.2%, $P = 0.026$) was significantly higher in atomic bomb survivors than in the general population. In the age group ≥ 80 years, proportional mortality from neoplasms (16.4% vs. 14.1%, $P = 0.029$), diseases of the digestive system (4.1% vs. 2.9%, $P = 0.021$), diseases of the nervous system (4.5% vs. 3.2%, $P = 0.019$), and other causes (5.6% vs. 0.0%, $P < 0.001$) was significantly higher in atomic bomb survivors than in the general population. In the age group 45–64 years, proportional mortality due to symptoms, signs, and abnormal clinical and laboratory findings was significantly higher in the general population than in atomic bomb survivors (atomic bomb survivors, 0.6% vs. general population, 4.1%, $P = 0.024$).

Proportional mortality was compared by age group (< 75 , 75–79, ≥ 80 years) at the three different periods (1992–1999, 2000–2009, 2010–2019) (**Appendix 2**). In 2000–2009, the number of atomic bomb survivors who died from a nervous system disorder was higher than that of the general population (3.5% vs. 1.8% and $P = 0.014$). In 2010–2019, proportional mortality from digestive system diseases was high in both the 75–79 years and ≥ 80 years age groups (7.2% vs. 3.2%, $P = 0.002$; 4.6% vs. 2.9%, $P = 0.011$, respectively). Proportional mortality according to the distance from the hypocenter is shown in **Table 4**. The mean age at death of each distance group from the hypocenter was 81.4 years for the 0–1 km group, 80.9 years for the 2–3 km group, 84.8 years for the ≥ 4 km group (**Table 4**), and 76.2 years for the unknown group (data not shown). The post hoc analysis showed that the order of age at death in people within 0–1 km of the hypocenter was equal to that in people within 2–3 km; However, the age at death in people ≥ 4 km away from the hypocenter was greater than both. There was no significant difference in the proportional mortality across the distance groups for other diseases.

DISCUSSION

This study compared the proportional mortality between atomic bomb survivors and the general population to determine the main causes of death in atomic bomb survivors and how these causes differed from those in the general population. Among atomic bomb survivors, deaths due to circulatory diseases were the highest, followed by deaths due to cancer and respiratory diseases. In the general population, the causes of death were highest for cancer, circulatory diseases, and symptoms, signs, and abnormal clinical and laboratory findings, demonstrating different orders between atomic bomb survivors and the general population. The proportional mortality rates for cancer, non-cancer diseases, and other diseases in atomic bomb survivors in Korea were 25.1%, 69.3%, and 5.6%, respectively, which were similar to those in atomic bomb survivors in Japan (23.4% for cancer, 71% for non-cancer diseases, and 5% for other causes).⁸

In previous studies of atomic bomb survivors in Japan, radiation exposure was associated with an increased risk of chronic vascular disease related to hypertension.¹⁷ A cohort study of cleanup workers in Baltic Chernobyl showed a higher prevalence of nervous and digestive diseases.¹⁸ In a study of atomic bomb survivors in Hapcheon, a city in Korea, the prevalence of hypertension, chronic liver disease, and hypercholesterolemia was significantly higher

Table 3. Proportional mortality among atomic bomb survivors and the general population by age group

Causes of death ^a	45-64 yr			65-69 yr			70-74 yr			75-79 yr			≥ 80 yr		
	Atomic bomb survivors	General population	P value	Atomic bomb survivors	General population	P value	Atomic bomb survivors	General population	P value	Atomic bomb survivors	General population	P value	Atomic bomb survivors	General population	P value
Diseases of the circulatory system	32 (19.5)	315,641 (19.1)	0.893	29 (19.0)	162,097 (24.7)	0.099	77 (23.1)	225,356 (27.1)	0.103	123 (27.5)	280,328 (28.4)	0.657	292 (27.1)	605,079 (26.8)	0.831
Neoplasms	70 (42.7)	602,088 (36.5)	0.100	57 (37.3)	248,550 (37.9)	0.869	113 (33.9)	274,878 (33.1)	0.746	129 (28.8)	261,173 (26.5)	0.271	177 (16.4)	318,305 (14.1)	0.029
Diseases of the respiratory system	4 (2.4)	49,948 (3.0)	0.674	10 (6.5)	35,943 (5.5)	0.574	25 (7.5)	60,095 (7.2)	0.828	47 (10.5)	91,192 (9.2)	0.344	145 (13.5)	265,347 (11.8)	0.093
Symptoms, signs, and abnormalities in clinical and laboratory findings	1 (0.6)	67,831 (4.1)	0.024	3 (2.0)	32,027 (4.9)	0.092	23 (6.9)	62,215 (7.5)	0.681	31 (6.9)	114,619 (11.6)	0.002	120 (11.1)	551,359 (24.5)	< 0.001
External causes of morbidity and mortality	19 (11.6)	264,717 (16.0)	0.123	15 (9.8)	57,277 (8.7)	0.628	20 (6.0)	57,497 (6.9)	0.520	16 (3.6)	54,286 (5.5)	0.073	48 (4.5)	88,179 (3.9)	0.349
Diseases of the digestive system	10 (6.1)	158,219 (9.6)	0.128	7 (4.6)	32,163 (4.9)	0.852	11 (3.3)	32,674 (3.9)	0.574	20 (4.5)	33,489 (3.4)	0.214	44 (4.1)	65,807 (2.9)	0.021
Endocrine, nutritional, and metabolic diseases	4 (2.4)	71,430 (4.3)	0.240	5 (3.3)	37,584 (5.7)	0.194	18 (5.4)	48,268 (5.8)	0.758	18 (4.0)	52,425 (5.3)	0.226	39 (3.6)	80,623 (3.6)	0.975
Diseases of the nervous system	1 (0.6)	20,308 (1.2)	0.488	5 (3.3)	9,999 (1.5)	0.072	3 (0.9)	15,971 (1.8)	0.217	7 (1.6)	23,100 (2.3)	0.298	48 (4.5)	71,872 (3.2)	0.019
Certain infectious and parasitic diseases	3 (1.8)	42,785 (2.6)	0.535	7 (4.6)	14,939 (2.3)	0.060	12 (3.6)	19,238 (2.3)	0.113	12 (2.7)	24,306 (2.5)	0.809	27 (2.5)	54,184 (2.4)	0.822
Diseases of the genitourinary system	2 (1.2)	22,402 (1.4)	0.844	4 (2.6)	11,498 (1.8)	0.449	5 (1.5)	15,190 (1.8)	0.682	8 (1.8)	19,334 (2.0)	0.746	29 (2.7)	44,753 (2.0)	0.106
Mental and behavioral disorders	4 (2.4)	22,107 (1.3)	0.198	1 (0.7)	6,636 (1.0)	0.667	4 (1.2)	11,166 (1.3)	0.874	5 (1.1)	19,157 (1.9)	0.224	33 (3.1)	75,620 (3.4)	0.539
Diseases of the musculoskeletal system and connective tissue	1 (0.6)	6,676 (0.4)	0.670	0 (0.0)	4,019 (0.6)	-	3 (0.9)	6,553 (0.8)	0.836	7 (1.6)	9,232 (0.9)	0.138	12 (1.1)	22,338 (1.0)	0.709
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	0 (0.0)	2,800 (0.2)	-	0 (0.0)	1,195 (0.2)	-	0 (0.0)	1,471 (0.2)	-	3 (0.7)	1,865 (0.2)	0.026	3 (0.3)	4,632 (0.2)	0.565
Diseases of the skin and subcutaneous tissue	0 (0.0)	1,044 (0.1)	-	0 (0.0)	661 (0.1)	-	0 (0.0)	1,064 (0.1)	-	2 (0.4)	1,791 (0.2)	0.243	1 (0.1)	6,246 (0.3)	0.213
Other causes ^{b,c}	13 (7.9)	1,726 (0.1)	< 0.001	10 (6.5)	447 (0.1)	< 0.001	19 (5.7)	442 (0.1)	< 0.001	20 (4.5)	416 (0.0)	< 0.001	60 (5.6)	589 (0.0)	< 0.001
Total	164 (100.0)	1,649,722 (100.0)	-	153 (100.0)	655,035 (100.0)	-	333 (100.0)	831,378 (100.0)	-	448 (100.0)	986,713 (100.0)	-	1,078 (100.0)	2,254,933 (100.0)	-

Values are presented as number (%).

^aCauses of death were classified according to the Korean Standard Classification of Diseases.

^bOther causes of death among atomic bomb survivors include those whose cause of death is unknown.

^cOther causes of death were classified as "other causes," which apply to the general population but not to death among atomic bomb survivors (congenital malformations, deformations, and chromosomal abnormalities [Q00-Q99], diseases of the eye and adnexa [H00-H57], diseases of the ear and mastoid process [H60-H93], pregnancy, childbirth, and puerperium [O00-O99], and certain conditions originating in the perinatal period [P00-P96]).

Table 4. Proportional mortality to atomic bomb survivors' radiation exposure distance from the hypocenter (not including the unknown group)

Causes of death ^a	Distance from the hypocenter, km				
	0–1 (n = 324)	2–3 (n = 648)	≥ 4 (n = 103)	P value ^d	P trend ^e
Death at age	81.4 ± 7.5	80.9 ± 7.9	84.8 ± 6.9	< 0.001	-
Certain infectious and parasitic diseases	17 (5.2)	19 (2.9)	2 (1.9)	0.120	0.052
Neoplasms	93 (28.7)	173 (26.7)	22 (21.4)	0.340	0.184
Malignant neoplasms of digestive organs	36 (11.1)	91 (14.0)	12 (11.7)	0.404	0.493
Malignant neoplasms of respiratory and intrathoracic organs	24 (7.4)	43 (6.6)	4 (3.9)	0.455	0.303
Malignant neoplasm of the breast	4 (1.2)	2 (0.3)	0 (0.0)	0.176	0.084
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	2 (0.6)	1 (0.2)	1 (1.0)	0.130	1.000
Endocrine, nutritional, and metabolic diseases	10 (3.1)	33 (5.1)	2 (1.9)	0.166	0.798
Mental and behavioral disorders	4 (1.2)	10 (1.5)	2 (1.9)	0.741	0.672
Diseases of the nervous system	15 (4.6)	21 (3.2)	7 (6.8)	0.182	0.896
Diseases of the circulatory system	83 (25.6)	163 (25.2)	29 (28.2)	0.810	0.770
Diseases of the respiratory system	40 (12.3)	80 (12.3)	8 (7.8)	0.394	0.385
Diseases of the digestive system	10 (3.1)	34 (5.2)	3 (2.9)	0.224	0.532
Diseases of the skin and subcutaneous tissue	1 (0.3)	1 (0.2)	1 (1.0)	0.288	0.645
Diseases of the musculoskeletal system and connective tissue	1 (0.3)	6 (0.9)	2 (1.9)	0.194	0.157
Diseases of the genitourinary system	13 (4.0)	19 (2.9)	5 (4.9)	0.486	1.000
Symptoms, signs, and abnormalities in clinical and laboratory findings	17 (5.2)	46 (7.1)	10 (9.7)	0.259	0.105
External causes of morbidity and mortality	14 (4.3)	34 (5.2)	8 (7.8)	0.390	0.207
Other causes ^c	4 (1.2)	8 (1.2)	1 (1.0)	1.000	1.000
Total	324 (100)	648 (100)	103 (100)		

Values are presented as mean ± standard deviation or number (%).

^aCauses of death were classified according to the Korean Standard Classification of Diseases.

^bAtomic bomb survivors with an unknown exposure distance do not have sufficient information on location for reliable estimation.

^cOther causes of death among atomic bomb survivors include people whose cause of death is not known.

^dP value was calculated using analysis of variance for continuous variables and using χ^2 test for categorical variables.

^eP for trend was calculated the Cochran-Armitage trend test for categorical variables.

than that in sex- and age-matched controls from the Korean National Health and Nutrition Survey.¹⁴ In this study, the higher proportion of cause of death from neoplasm, digestive diseases, or nervous disease was confirmed only in atomic survivors whose age at death was ≥ 80 years, and not in other age groups. In this study, higher proportional mortality rates for some causes of death were observed in the older age group. Several reasons may explain the differences in proportional mortality rates among the age groups. First, cardiovascular system, cancer, respiratory system, nervous system, and digestive system diseases are the common causes of death in Korean aged ≥ 80 years in general.¹⁹ In addition, a study of atomic bomb survivors in Japan found that the risk of cancer begins to increase 10 years after exposure, and the risk of cancer continues to increase with increasing age.²⁰

In Japan, the location and shielding status of atomic bomb survivors were measured in the 1950s, and a dosimetry system was developed in cooperation with the United States. Thus, the exposed radiation dose among atomic bomb survivors was estimated for approximately 92% of the participants in the cohort. Based on the radiation dose estimate with the dosimetry system, it was identified that as the radiation exposure dose increased, the excess relative risk due to diseases related to the circulatory system, respiratory system, and blood significantly increased.⁸ However, the radiation exposure dose in atomic bomb survivors in Korea has never been estimated. Because atomic bomb survivors in Korea were identified and registered after 1990, many atomic bomb survivors who survived up to 1990 were young in 1945 and had passed more than 45 years since the atomic bomb explosion. Thus, they did not remember the location or shielding status. In this study, data of distances from the hypocenter were not available for more than 50% of the deaths among atomic bomb survivors. Therefore, the differences in the cause of death according to the distance from

the hypocenter (surrogate for radiation exposure dose) were limited. In this study, when comparing the proportion of deaths by distance from the hypocenter, statistically significant differences were observed for a few diseases. However, the lower age at death of atomic bomb survivors who were exposed at a close distance from the hypocenter compared with those exposed at a distance would suggest possible health effects of atomic bomb exposure.

Among cancer-related deaths among atomic bomb survivors, the proportion of deaths due to malignant neoplasms of the digestive, respiratory, and intrathoracic organs was the highest. In a cohort study of Japanese atomic bomb survivors, gastric cancer was the most common (29.5%), followed by lung cancer (13.8%). The proportion of cancers in the digestive and respiratory systems was 56.1% and 12.2%, respectively.²¹ A recent study on the Chernobyl accident found that people living in areas contaminated with radioactive material had a 20% higher incidence of cancer.²² In a study analyzing health insurance claims data of atomic bomb victims in Korea from 2002 to 2017, the prevalence of cancer in most of the atomic bomb survivors was higher than that in the general elderly population.² Although it is difficult to directly compare the proportional mortality of this study with that of previous studies that focused on disease incidence, it was confirmed that the high burden of digestive and respiratory cancers is commonly observed in atomic bomb survivors exposed to radiation.

The limitations of this study are as follows: first, to analyze the risk of death within the population, it would be more appropriate to compare the mortality rates between the two groups. However, not all atomic bomb survivors in Korea were available, and we could not completely compare the data with those of the general population. The government and the Korean Red Cross have identified atomic bomb survivors since the 1990s, but because of possible social discrimination, some of the atomic bomb survivors in Korea might not have revealed their damage due to atomic bomb exposure and might not have registered as atomic bomb survivors.²³ Proportional mortality could be calculated without information on the total population as a denominator, which is affected by the total number of deaths (or mortality rate) of the population, and we could not estimate the risk of death from a specific cause. Second, when calculating proportional mortality, deaths that occurred before 1992 could not be included owing to the lack of data. Because we could not consider the deaths before 1992 and the age of death started from 49 years, there was a discrepancy in the age at death of atomic bomb survivors (age at death was ≥ 49 years) and the general population (age at death is distributed across all ages). Due to this issue, the standardized mortality ratio could not be applied. In addition, selection bias due to the incompleteness of the registry data for Korean atomic bomb survivors could have affected the results. The registered Korean atomic bomb survivors were those who survived for at least ≥ 45 years after the atomic bomb exposure. Thus, atomic bomb survivors who were registered with Korean Red Cross would be those who were less affected by exposure and healthier than overall people who were exposed to the atomic bombs. Considering that 42% of people exposed to the atomic bombs died in that year (300,000 died of 440,000 people in Hiroshima and 271,500 in Nagasaki), this selection bias would exist even in the atomic bomb survivors cohort in Japan which was constructed in the late 1940s.^{1,4,24} In studies of atomic bomb survivors in Korea, the selection bias may be more pronounced. Despite the selection bias due to the identification of healthy and less affected Korean atomic bomb survivors, previous studies have shown that Korean atomic bomb survivors have more health problems than the general population.^{2,13,14} Considering that many atomic bomb survivors died immediately after exposure to the atomic bomb,²⁵ the inability to include people who died from the acute effects of the atomic bomb explosion would be a limitation of this study. However, this is a similar limitation

to that reported in the atomic bomb cohort study in Japan. Rather, bias with information of the exposure status due to declining memory was a limitation of this study. Third, as described above, the radiation dose exposure among the atomic bomb survivors could not be estimated, and the distance from the hypocenter was available only in < 50% of the subjects; therefore, the dose-response relationship between the exposure dose and causes of death could be accessed only in a limited manner. Fourth, although the risk of cancer from radiation exposure was higher in women than in men,^{8,26} and exposure to radiation at an early age is known to cause more susceptibility to disease risk,^{8,22} sex, age at the time of exposure, and prenatal exposure were not considered in this study. Fifth, we only considered age and could not consider other important epidemiological risk factors associated with mortality because this was the only available information.

Despite these limitations, this is the first study on atomic bomb survivors in Korea known to identify the proportional mortality of all deaths and compare the data with those of the general population. Most of the studies on atomic bomb survivors have been conducted in Japan, and there have been no studies on the cause of death or long-term health effects of atomic bomb survivors in Korea. More than 90% of atomic bomb survivors are estimated to have died by 2021.⁴ More studies on the health status of Korean atomic bomb survivors and their offspring are needed.

ACKNOWLEDGMENTS

The authors thank the Korean Red Cross for providing the data.

REFERENCES

1. Korea Atomic Bombs Victim Association. What is an atomic bomb victim? <http://wonpok.or.kr/doc/abomb1.html>. Updated 2022. Accessed September 18, 2022.
2. Jung Y. *A Survey on the Status of Atomic Bomb Survivors and Their Healthy Life*. Sejong, Korea: Korea Institute for Health and Social Affairs; 2018.
3. Korea Law Information Center. Special Act on the Support for Korean Atomic Bomb Victims (Act 2016. 5. 29; Amended by Act No. 16409, Apr. 30. 2019). <https://www.law.go.kr/>. Updated 2019. Accessed September 19, 2022.
4. Korean Red Cross. Support for atomic bomb survivors. https://www.redcross.or.kr/business/atomicbomb_support.do. Updated 2022. Accessed September 18, 2022.
5. Yamada M, Wong FL, Fujiwara S, Akahoshi M, Suzuki G. Noncancer disease incidence in atomic bomb survivors, 1958-1998. *Radiat Res* 2004;161(6):622-32.
[PUBMED](#) | [CROSSREF](#)
6. Preston DL, Shimizu Y, Pierce DA, Suyama A, Mabuchi K. Studies of mortality of atomic bomb survivors. Report 13: solid cancer and noncancer disease mortality: 1950-1997. *Radiat Res* 2003;160(4):381-407.
[PUBMED](#) | [CROSSREF](#)
7. Thompson DE, Mabuchi K, Ron E, Soda M, Tokunaga M, Ochikubo S, et al. Cancer incidence in atomic bomb survivors. Part II: Solid tumors, 1958-1987. *Radiat Res* 1994;137(2 Suppl):S17-67.
[PUBMED](#) | [CROSSREF](#)
8. Ozasa K, Shimizu Y, Suyama A, Kasagi F, Soda M, Grant EJ, et al. Studies of the mortality of atomic bomb survivors, Report 14, 1950-2003: an overview of cancer and noncancer diseases. *Radiat Res* 2012;177(3):229-43.
[PUBMED](#) | [CROSSREF](#)
9. Lorimore SA, Coates PJ, Wright EG. Radiation-induced genomic instability and bystander effects: inter-related nontargeted effects of exposure to ionizing radiation. *Oncogene* 2003;22(45):7058-69.
[PUBMED](#) | [CROSSREF](#)

10. Kusunoki Y, Hayashi T. Long-lasting alterations of the immune system by ionizing radiation exposure: implications for disease development among atomic bomb survivors. *Int J Radiat Biol* 2008;84(1):1-14.
[PUBMED](#) | [CROSSREF](#)
11. Gillies M, Richardson DB, Cardis E, Daniels RD, O'Hagan JA, Haylock R, et al. Mortality from circulatory diseases and other non-cancer outcomes among nuclear workers in France, the United Kingdom and the United States (INWORKS). *Radiat Res* 2017;188(3):276-90.
[PUBMED](#) | [CROSSREF](#)
12. Richardson DB, Cardis E, Daniels RD, Gillies M, Haylock R, Leuraud K, et al. Site-specific solid cancer mortality after exposure to ionizing radiation: a cohort study of workers (INWORKS). *Epidemiology* 2018;29(1):31-40.
[PUBMED](#) | [CROSSREF](#)
13. Song KY, Kim YI, Kim TJ. *National Survey on Atomic Bomb Survivors*. Sejong, Korea: Korea Institute for Health and Social Affairs; 1991.
14. Ju YS, Jhun HJ, Kim JB, Kim JK. Non-cancer diseases of Korean atomic bomb survivors in residence at Hapcheon, Republic of Korea. *J Korean Med Sci* 2006;21(3):385-90.
[PUBMED](#) | [CROSSREF](#)
15. Aveyard P. A fresh look at proportional mortality ratios. *Public Health* 1998;112(2):77-80.
[PUBMED](#) | [CROSSREF](#)
16. Kupper LL, McMichael AJ, Symons MJ, Most BM. On the utility of proportional mortality analysis. *J Chronic Dis* 1978;31(1):15-22.
[PUBMED](#) | [CROSSREF](#)
17. Ozasa K, Takahashi I, Grant EJ, Kodama K. Cardiovascular disease among atomic bomb survivors. *Int J Radiat Biol* 2017;93(10):1145-50.
[PUBMED](#) | [CROSSREF](#)
18. Rahu K. *Morbidity and Mortality Among Baltic Chernobyl Cleanup Workers: a Register-Based Cohort Study*. Tartu, Estonia: University of Tartu Press; 2014.
19. Oh HJ, Yang DM, Kim CH, Jeon JG, Jung NH, Kim CY, et al. Exploring mortality rates for major causes of death in Korea. *Open Public Health J* 2019;12(1):16-25.
[CROSSREF](#)
20. Preston DL, Ron E, Tokuoka S, Funamoto S, Nishi N, Soda M, et al. Solid cancer incidence in atomic bomb survivors: 1958-1998. *Radiat Res* 2007;168(1):1-64.
[PUBMED](#) | [CROSSREF](#)
21. Grant EJ, Brenner A, Sugiyama H, Sakata R, Sadakane A, Utada M, et al. Solid cancer incidence among the life span study of atomic bomb survivors: 1958-2009. *Radiat Res* 2017;187(5):513-37.
[PUBMED](#) | [CROSSREF](#)
22. Sumner D. Health effects resulting from the Chernobyl accident. *Med Confl Surviv* 2007;23(1):31-45.
[PUBMED](#) | [CROSSREF](#)
23. Lee EJ. Bodies exposed to atomic bomb and pains - focusing on Korean atomic bomb victims. *Minjok Yeonku* 2019;(73):165-85.
[CROSSREF](#)
24. Ozasa K, Grant EJ, Kodama K. Japanese legacy cohorts: the life span study atomic bomb survivor cohort and survivors' offspring. *J Epidemiol* 2018;28(4):162-9.
[PUBMED](#) | [CROSSREF](#)
25. Fujita S, Kato H, Schull WJ. The LD50 associated with exposure to the atomic bombing of Hiroshima and Nagasaki. *J Radiat Res* 1991;32 Suppl:154-61.
[PUBMED](#) | [CROSSREF](#)
26. Sugiyama H, Misumi M, Sakata R, Brenner AV, Utada M, Ozasa K. Mortality among individuals exposed to atomic bomb radiation in utero: 1950-2012. *Eur J Epidemiol* 2021;36(4):415-28.
[PUBMED](#) | [CROSSREF](#)

Appendix 1. Proportional mortality among atomic bomb survivors and the general population according to the year at death

Causes of death ^a	1992–1999			2000–2009			2010–2019		
	Atomic bomb survivors	General population	P value	Atomic bomb survivors	General population	P value	Atomic bomb survivors	General population	P value
Diseases of the circulatory system	117 (23.7)	459,906 (28.7)	0.014	210 (27.6)	553,034 (25.2)	0.123	226 (24.5)	575,562 (22.3)	0.107
Neoplasms	119 (24.1)	356,047 (22.2)	0.312	196 (25.8)	604,842 (27.6)	0.264	231 (25.1)	744,105 (28.9)	0.010
Malignant neoplasms of digestive organs	76 (15.4)	218,212 (13.6)	0.247	100 (13.2)	339,263 (15.5)	0.074	111 (12.0)	382,153 (14.8)	0.018
Malignant neoplasms of respiratory and intrathoracic organs	28 (5.7)	73,475 (4.6)	0.257	55 (7.2)	139,149 (6.3)	0.288	60 (6.5)	177,225 (6.9)	0.638
Malignant neoplasms of lymphoid, hematopoietic, and related tissue	4 (0.8)	11,831 (0.7)	0.770	7 (0.9)	24,682 (1.1)	0.636	15 (1.6)	39,569 (1.5)	0.751
Malignant neoplasms of the urinary tract	1 (0.2)	7,098 (0.4)	0.487	8 (1.1)	16,632 (0.8)	0.434	8 (0.9)	26,510 (1.0)	0.686
In situ benign neoplasms and neoplasms of uncertain or unknown behavior	1 (0.2)	7,410 (0.5)	0.348	4 (0.5)	8,417 (0.4)	0.581	9 (1.0)	10,578 (0.4)	0.006
Malignant neoplasms of male genital organs	1 (0.2)	2,295 (0.1)	0.471	1 (0.1)	9,313 (0.4)	0.241	11 (1.2)	17,014 (0.7)	0.073
Malignant neoplasms of female genital organs	3 (0.6)	11,968 (0.7)	0.805	6 (0.8)	18,389 (0.8)	0.974	3 (0.3)	22,245 (0.9)	0.065
Malignant neoplasms of ill-defined, secondary and unspecified sites	1 (0.2)	3,778 (0.2)	0.990	4 (0.5)	7,171 (0.3)	0.254	3 (0.3)	12,900 (0.5)	0.452
Malignant neoplasm of the breast	0 (0.0)	5,304 (0.3)	-	2 (0.3)	11,728 (0.5)	0.355	4 (0.4)	19,568 (0.8)	0.212
Malignant neoplasms of eye, brain, and other parts of the central nervous system	2 (0.4)	4,987 (0.3)	0.670	2 (0.3)	8,068 (0.4)	0.550	2 (0.2)	10,432 (0.4)	0.378
Melanoma and other malignant neoplasms of the skin	2 (0.4)	1,700 (0.1)	0.032	1 (0.1)	3,086 (0.1)	0.783	1 (0.1)	4,526 (0.2)	0.534
Other neoplasms	0 (0.0)	7,989 (0.5)	0.764	6 (0.8)	18,944 (0.9)	0.063	4 (0.4)	21,385 (0.8)	0.212
Diseases of the respiratory system	33 (6.7)	83,311 (5.2)	0.138	70 (9.2)	149,595 (6.8)	0.008	128 (13.9)	269,619 (10.5)	0.001
Symptoms, signs, and abnormal clinical and laboratory findings	56 (11.3)	301,278 (18.8)	< 0.001	63 (8.3)	281,030 (12.8)	< 0.001	59 (6.4)	245,743 (9.5)	0.001
External causes of morbidity and mortality	30 (6.1)	112,438 (7.0)	0.419	43 (5.7)	191,114 (8.7)	0.003	45 (4.9)	218,404 (8.5)	< 0.001
Diseases of the digestive system	21 (4.3)	108,692 (6.8)	0.024	25 (3.3)	105,507 (4.8)	0.051	46 (5.0)	108,153 (4.2)	0.232
Endocrine, nutritional, and metabolic diseases	10 (2.0)	65,288 (4.1)	0.020	38 (5.0)	115,735 (5.3)	0.712	36 (3.9)	109,307 (4.2)	0.655
Diseases of the nervous system	4 (0.8)	10,492 (0.7)	0.770	19 (2.5)	35,483 (1.6)	0.048	41 (4.4)	94,575 (3.7)	0.230
Certain infectious and parasitic diseases	9 (1.8)	34,268 (2.1)	0.666	14 (1.8)	49,283 (2.2)	0.501	38 (4.1)	71,901 (2.8)	0.015
Diseases of the genitourinary system	0 (0.0)	16,566 (1.0)	-	17 (2.2)	32,926 (1.5)	0.095	31 (3.4)	63,685 (2.5)	0.094
Mental and behavioral disorders	12 (2.4)	36,576 (2.3)	0.848	19 (2.5)	48,105 (2.2)	0.573	16 (1.7)	50,005 (1.9)	0.714
Diseases of the musculoskeletal system and connective tissue	1 (0.2)	15,696 (1.0)	0.075	15 (2.0)	17,912 (0.8)	< 0.001	7 (0.8)	15,210 (0.6)	0.531
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	1 (0.2)	2,033 (0.1)	0.471	0 (0.0)	3,598 (0.2)	-	5 (0.5)	6,332 (0.2)	0.020
Diseases of the skin and subcutaneous tissue	0 (0.0)	1,614 (0.1)	-	0 (0.0)	4,116 (0.2)	-	3 (0.3)	5,076 (0.2)	0.394
Other causes ^{b,c}	81 (16.4)	857 (0.1)	< 0.001	31 (4.1)	1,242 (0.1)	< 0.001	10 (1.1)	1,520 (0.1)	< 0.001
Total	494 (100.0)	1,605,062 (100.0)		760 (100.0)	2,193,522 (100.0)		922 (100.0)	2,579,197 (100.0)	

Values are presented as number (%).

^aCauses of death were classified according to the Korean Standard Classification of Diseases.

^bOther causes of death among atomic bomb survivors include those whose cause of death is unknown.

^cOther causes of death were classified as “other causes,” which apply to the general population but not to death among atomic bomb survivors (congenital malformations, deformations, and chromosomal abnormalities [Q00–Q99], diseases of the eye and adnexa [H00–H57], diseases of the ear and mastoid process [H60–H93], pregnancy, childbirth, and puerperium [O00–O99], and certain conditions originating in the perinatal period [P00–P96]).

Proportional Mortality in Korean Atomic Bomb Survivors

Appendix 2. Proportional mortality among atomic bomb survivors and the general population by age group and year at death

Causes of death ^a	< 75 yr			75–79 yr			≥ 80 yr		
	Atomic bomb survivor (n = 280), %	General population (n = 941,970), %	P value	Atomic bomb survivor (n = 113), %	General population (n = 237,305), %	P value	Atomic bomb survivor (n = 101), %	General population (n = 425,787), %	P value
1992–1999									
Diseases of the circulatory system	22.9	27.9	0.060	26.6	33.6	0.113	22.8	27.7	0.268
Neoplasms	32.5	30.4	0.445	16.8	16.6	0.951	8.9	7.1	0.479
Diseases of the respiratory system	5.4	4.1	0.289	8.9	6.7	0.361	7.9	6.7	0.624
Symptoms, signs, and abnormalities in clinical and laboratory findings	7.1	6.9	0.873	18.6	23.3	0.236	14.9	42.5	< 0.001
External causes of morbidity and mortality	7.9	10.1	0.213	5.3	3.6	0.329	2.0	2.1	0.933
Diseases of the digestive system	5.4	8.9	0.037	1.8	4.2	0.198	4.0	3.4	0.756
Endocrine, nutritional, and metabolic diseases	1.8	4.8	0.018	3.5	4.2	0.726	1.0	2.3	0.380
Diseases of the nervous system	0.7	0.8	0.872	1.8	0.6	0.107	0.0	0.5	-
Certain infectious and parasitic diseases	2.9	2.5	0.702	0.9	1.9	0.429	0.0	1.3	-
Mental and behavioral disorders	2.1	1.5	0.376	1.8	2.5	0.619	4.0	3.9	0.975
Other causes ^{b,c}	11.4	2.1	< 0.001	14.2	2.7	< 0.001	36.6	2.6	< 0.001
Total	100.0	100.0	-	100.0	100.0	-	100.0	100.0	-
2000–2009									
Diseases of the circulatory system	19.7	22.6	0.297	33.1	30.5	0.481	30.3	26.9	0.139
Neoplasms	41.2	36.8	0.164	29.9	26.6	0.358	14.5	13.3	0.503
Diseases of the respiratory system	6.4	4.4	0.129	7.8	8.7	0.689	11.5	9.8	0.262
Symptoms, signs, and abnormalities in clinical and laboratory findings	1.7	3.7	0.109	3.9	9.6	0.016	14.2	28.8	< 0.001
External causes of morbidity and mortality	10.3	12.3	0.353	2.6	5.7	0.097	4.0	4.4	0.721
Diseases of the digestive system	3.4	6.7	0.046	3.3	3.1	0.916	3.2	2.6	0.454
Endocrine, nutritional, and metabolic diseases	4.3	5.9	0.298	5.8	6.3	0.816	5.1	3.7	0.154
Diseases of the nervous system	2.2	1.4	0.332	0.7	2.0	0.212	3.5	1.8	0.014
Certain infectious and parasitic diseases	2.2	2.4	0.800	2.0	2.3	0.771	1.6	1.9	0.680
Mental and behavioral disorders	0.9	1.3	0.552	1.3	2.2	0.446	4.0	3.7	0.742
Other causes ^{b,c}	7.7	2.4	< 0.001	9.7	3.1	< 0.001	8.0	3.0	< 0.001
Total	100.0	100.0	-	100.0	100.0	-	100.0	100.0	-
2010–2019									
Diseases of the circulatory system	20.4	17.4	0.348	23.2	23.7	0.875	25.8	26.5	0.708
Neoplasms	38.7	39.8	0.790	35.4	32.0	0.333	18.9	17.3	0.306
Diseases of the respiratory system	6.6	5.4	0.545	13.8	11.2	0.265	15.6	15.0	0.698
Symptoms, signs, and abnormalities in clinical and laboratory findings	2.2	5.2	0.113	2.2	6.5	0.019	8.6	14.7	< 0.001
External causes of morbidity and mortality	5.8	13.7	0.007	3.3	6.4	0.090	5.1	4.3	0.313
Diseases of the digestive system	3.7	5.9	0.264	7.2	3.2	0.002	4.6	2.9	0.011
Endocrine, nutritional, and metabolic diseases	8.8	4.2	0.008	2.8	5.1	0.153	3.2	4.0	0.284
Diseases of the nervous system	1.5	2.2	0.555	2.2	3.7	0.288	5.8	5.1	0.438
Certain infectious and parasitic diseases	6.6	2.4	0.001	4.4	2.9	0.233	3.5	3.1	0.593
Mental and behavioral disorders	0.7	1.1	0.678	0.6	1.4	0.332	2.3	3.0	< 0.001
Other causes ^{b,c}	5.1	2.8	0.101	5.0	3.9	0.456	6.6	4.1	0.002
Total	100.0	100.0	-	100.0	100.0	-	100.0	100.0	-

^aCauses of death were classified according to the Korean Standard Classification of Diseases.

^bOther causes of death among atomic bomb survivors include those whose cause of death is unknown.

^cOther causes of death were classified as “other causes,” which apply to the general population but not to death among atomic bomb survivors (congenital malformations, deformations, and chromosomal abnormalities [Q00–Q99], diseases of the eye and adnexa [H00–H57], diseases of the ear and mastoid process [H60–H93], pregnancy, childbirth, and puerperium [O00–O99], and certain conditions originating in the perinatal period [P00–P96]).