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Chronic Respiratory Disease Mortality in the Vicinity of Mt. Sakurajima

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Abstract

(Objective) The volcanic activities of Mt. Sakurajima releases various air pollutants. For example, volcanic ash from Mt. Sakurajima contains up to 7 wt. % of cristobalite. Outdoor radon levels were also reported to be relatively high in the area near the volcano. The present study examined the association of chronic respiratory disease mortality with the volcanic activities of Mt. Sakurajima in Kagoshima Prefecture, Japan. (Methods) Standardized mortality ratios (SMRs) and their 95% confidence intervals (95% CIs) during the period 1965-2006 were calculated, using the entire Kagoshima Prefecture as the reference population. In addition, the relative risks (RRs) and their 95% CIs among residents aged 50-84 years in Tarumizu and in eight other cities with similar population sizes in Kagoshima Prefecture for the period 1975-1995 were calculated, using Poisson regression analysis of grouped data. The frequency of explosions, the amount of ashfall, and the outdoor concentrations of SPM and SO_2 were obtained from local authorities. (Results) The volcanic activities of Mt. Sakurajima has been most active in the 1980s in the second half of the 20th century or later. The SMRs of lung cancer for males and females in Tarumizu for the period between 1965 and 2006 were 1.61 (95% CI: 1.44-1.78) and 1.68 (95% CI: 1.40-1.97), respectively. No evident time trend was observed. The SMRs of all respiratory diseases other than cancer for males and females for the period between 1965 and 2006 were 1.38 (95% CI: 1.28-1.48) and 1.21 (95% CI: 1.11-1.31), respectively. The SMRs showed a peak in the period of 2003-2006. The SMRs of COPDs for males and females for the period of 2003-2006 were 2.75 (95% CI: 1.81-3.69) and 1.90 (95% CI: 0.72-3.08), respectively. The RRs of lung cancer mortality among residents in Tarumizu, compared with those in other cities, was 1.18 (95% CI: 1.01-1.39) for males and 1.35 (95% CI: 1.03-1.76) for females. The RR of all non-malignant respiratory disease mortality in Tarumizu with those in other cities was 1.16 (95%CI=1.03-1.30) for males and 0.92 (95%CI=0.78-1.08) for females; When men and women were combined, all non-malignant respiratory disease mortality in Tarumizu was not elevated. The RR of pneumoconioses in Tarumizu was relatively high only among men but not among women. The continuous measurement of outdoor radon concentrations, conducted by our study group in the 2000s, showed relatively high outdoor radon concentrations, exceeding 20 Bqm^{-3} in the study areas even though the volcano was not very active at the time of radon assay. (Conclusions) The present study showed that residents in Tarumizu, located near Mt. Sakurajima, experienced relatively high mortality rates of lung cancer. The mortality of COPDs and pneumoconioses may also be increased. It is suspected that cristobalite contained in the asfall of the volcano increases the mortality of those respiratory diseases. Further studies on the health effects of Mt. Sakurajima's volcanic activities seem warranted.

Key words: Sakurajima, lung cancer, volcano, radon

Introduction

Mt. Sakurajima in Kagoshima, Japan is one of the world's most active volcano located near metropolitan areas (Fig. 1). At the time of a large eruption in 1914, lava discharged by the volcano connected the Island of Mt. Sakurajima to the Ohsumi peninsula. Since then, the volcano has become active every 10-30 years. Relatively active periods were around 1935, 1946, 1956-67, and the period between 1972 and 2001 with its peak in 1985.

The volcanic ashes of Mt. Sakurajima have been reported to contain SiO_2 (58-59%), Al_2O_3 (17%), CaO (6%),

FeO (4-6%), Fe_2O_3 (3%), Na_2O (3-3.5%), MgO (2.5-3.0%), K_2O (1.4%), TiO_2 (1%), MnO (0.15%), and P_2O_5 (0.1%)[1–2]. However, the volcanic activities of Mt. Sakurajima have been considered to result in no significant increase of crystalline silica deposition in the lung compared with background levels[3–5]. Indeed, a study that investigated the average amounts of intrapulmonary particulate deposits in abandoned or stray dogs in Tarumizu and Sakurajima area (N=25) and a control area (Miyanojo, N=13), which is 40 km from Mt. Sakurajima, did not find any significant differences of intrapulmonary particulate deposits in the two areas[4]. Furthermore, Kitajima et al. examined autopsied lungs of patients in Kanoya, a neighboring city of Tarumizu with heavy ashfall, and those in Oku town in Okayama Prefecture, and reported that the proportion of silica in the dust deposited in the lungs in Kanoya was lower than that in Oku town[3]. In the above mentioned canine and human studies, histopathological evaluation of the lungs found no silicotic nodules[3–5]. Recently, Hillman reported that the Sakurajima ash in general contains up to 7wt % of cristobalite but no other silica polymorph[6].

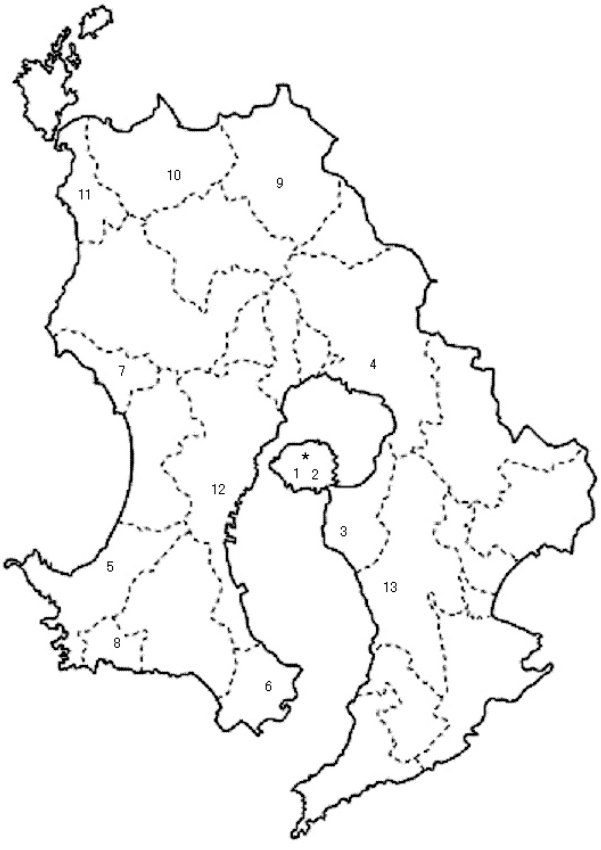

Fig. 1 Map of Mt. Sakurajima and the study areas .
* Mt. Sakurajima

1 Akamizu in Sakurajima	8 Makurazaki
2 Arimura in Sakurajima	9 Ohkuchi
3 Tarumizu	10 Izumi
4 Kokubu	11 Akune
5 Kaseda	12 Kagoshima University Sakuragaoka campus
6 Ibusuki	
7 Kushikino	13 Kanoya

Suspended particulate matter (SPM) in ambient air is a complex, multi-phase system consisting of a spectrum of aerodynamic particle sizes. PM2.5, which has the size of <2.5 μm, have direct health effects since those particles small can deposit in the respiratory system. Laden et al. reported that PM2.5 exposure was associated with lung cancer risk (RR, 1.27; 95% CI, 0.96-1.69)[7]. In 2009, the Ministry of the Environment Government of Japan (MOE) reported that the lung cancer increased by 13% with the SPM increase of 10μgm^{-3} [8]. In Tarumizu, the nearest city from Mt. Sakurajima, the annual average concentration of SPM during the period 1979-1993 was 0.025-0.035 mg m^{-3}, which was lower than the action level established by the MOE (<0.10 mg m^{-3} per day or 0.20 mg m^{-3} per hour) in 1973. In the Arimura observatory station, which is situated in the midpoint between Mt. Sakurajima and Tarumizu city, the annual average concentrations of SPM during the period 1990-2007 were 0.022-0.044 mg m^{-3}, which are below the action level. Nishii et al. reported that there is no correlation between SPM concentrations and the amount of ashfall[9]. With regard to exposure to ashes discharged from Mt. Sakurajima, Yano et al. conducted cross-sectional epidemiological studies in the 1980s, and concluded that the exposure did not have serious effects on the human respiratory system because ash particles are 1) usually too large to be inhaled into the lung, 2) too heavy to drift with the air current, and 3) not hard enough to damage the airway membrane[10–12].

The concentrations of radon were 740-2960 mBq m^{-3} at the altitude of 1,800m above Mt. Sakurajima[13]. Komura el al. compared outdoor radon progeny levels in the areas around Mt. Sakurajima with those in Tatsunokuchi town in Ishikawa Prefecture, which was an area without the influence of Mt. Sakurajima, the outdoor concentrations[13]. In the vicinity of Mt. Sakurajima, the outdoor concentrations of Pb-210 (RaD) and Po-210 (RaF) were 0.155-6.18 mBq m^{-3} and 0.00925-4.74 mBq m^{-3}, respectively, and the annual discharge of Po-210 from the volcano was estimated to be in the range of 10-100×10^{12} Bq y^{-1} [13]. On the other hand, Tatsunokuchi, outdoor concentrations of Pb-210 (RaD) and Po-210 (RaF)

were 0.0456-1.29 mBq m^{-3} and 0.0174-0.154 mBq m^{-3}, respectively. The release of radioactive materials from volcanoes was observed in other volcanoes. For example, Lambert et al. reported that a large quantity of radon and its progeny, including lead (Pb)-210 and polonium (Po)-210, were discharged from Mt. Etna, an active volcano in Italy[14].

Although many studies examined the health effects of Mt. Sakurajima's volcanic activity among the residents in the neighborhood of this active volcano, no evident chronic health effects have been reported[10,11,15]. In the present study, we examined the chronic health effects of the volcanic activities of Mt. Sakurajima by investigating the mortality rates of chronic respiratory diseases in Tarumizu. This city was selected to examine the health effects caused by volcanic activities since this is the nearest city from Mt. Sakurajima, does not have serious air pollution from traffic exhaustion, and has a large enough population size to evaluate chronic respiratory disease mortality. Radon levels in Tarumizu were also examined, since we suspected that the exposure of radon radiation would be a risk factor of lung cancer.

Methods

2.1 Statistical methods

Standardized mortality ratio: Standardized mortality ratios (SMRs) of respiratory diseases in Tarumizu and other cities were calculated for the period 1965-2006, using the sex and age specific mortality rates in Kagoshima Prefecture as the reference. The data were obtained from the annual Vital Statistics Report published by the Kagoshima Prefecture Government.

Relative risk: The mortality rates of various causes of death in Tarumizu were compared with those in eight other cities in Kagoshima Prefecture, except for remote islands, with population sizes of 15,000-50,000. The cities used for analysis were Kokubu, Kaseda, Ibusuki, Kushikino, Makurazaki, Ohkuchi, Izumi, and Akune. The other three cities in the mainland part of Kagoshima Prefecture, Kagoshima, Sendai, and Kanoya were excluded from analysis because those cities have population sizes much larger than that of Tarumizu. Data on mortality for the period 1975-1995 were obtained from the annual Vital Statistics Report. For our analysis, those younger than 50 years or older than 84 years were excluded because of the following reasons: i) the mortality rates of cancer or non-cancer diseases in younger people are low, ii) younger people often migrate because of economical problems, and iii) people 85 years or older are less likely to seek medical care for malignancy. Relative risks (RRs) and 95% confidence intervals (95% CIs) were obtained from Poisson regression analysis of grouped survival data, cross-classified by attained age (5-year category), sex, calendar year and city. DATAB and AMFIT procedures of the EPICURE program[16] were used for analysis. The maximum likelihood estimates of βi, for example, is a log RR for the indicator variable Ri, when compared to the reference category of R_1, adjusting for other variables such as age, sex, and calendar year. A heterogeneity test was based on a global P value for a set of indicator variables. For the analysis of the association of cancer risk with the indicator variables for nine cities, the following model was used to estimate the RRs of a city (represented by C1-C9): H_0 (age, sex, calendar year) exp $(\beta_2C_2+\beta_3C_3+\beta_4C_4+\beta_5C_5+\beta_6C_6+\beta_7C_7+\beta_8C_8+\beta_9C_9)$. Where H_0 represents the baseline lung cancer mortality for cross-classified strata crated by sex, attained age and calendar year. This type of model is commonly used in the risk analysis of radiation-related risk[17,18].

Population data: The population for each year was estimated by Dr. Ohtaki of Hiroshima University by vital statistics provided from a national census performed every 5 years. The population of each city for the period 1975-1977 was estimated using the national census of 1975. We similarly estimated the population of each city for the periods 1978-1982, 1983-1987, 1988-1992 and 1993-1995, based on each national census of 1980, 1985, 1990 and 1995, respectively.

2.2 Exposure data

Radon dosimetry: The outdoor and indoor radioactive radon levels were measured in Tarumizu. The outdoor radon level was consecutively monitored every hour using a radon progeny nuclides monitor (S-2336; Ohyo Koken Kogyo Co., Ltd., Tokyo)[19] in Kagoshima. Continuous air samples were drawn and the air samples were adsorbed on the roll-type membrane filter by a sampling suction pump. For the atmospheric concentration of radon progenies of RaA (^{218}Po), RaB (^{214}Pb) and RaC (^{214}Bi), their discharged alpha activities were measured by a silicon semiconductor detector. Because the filter accommodation including the detector is maintained at a low-pressure (1/10 atmospheres or less) while α activities

are measured, it has excellent energy resolution ability. This device can carry out an automatic consecutive measurement of 1 month or less (in one measurement an hour) because a roll type membrane-filter is used. The indoor radon level was measured using a Radopot radon monitor (Radosys Co. Budapest)[20] in the houses of lung cancer patients (cases) and healthy patients (controls) in Tarumizu. The radon level within living spaces, such as the living room, was measured for 6 months as a single measurement period. The 6-month measurement was continuously performed twice in each house for a year in total, but measurements were completed after a single 6-month period in some cases for specific reasons. The RADPOT radon monitor is a plastic track detector using Columbia Resin 39 (CR39), which is allyl-diglycol-carbonate to detect the tracks created by alpha decay products. Tracks on the CR39 element created by radon progenies attached to this element is chemically etched with potassium hydroxide. We calculated radon concentrations (Bq m^{-3}) from this α track concentration (tracks mm^{-2})[20,21]. The present study was approved by the ethical committee of Kagoshima University Graduate School of Medical and Dental Sciences.

Other exposure data: Data of the frequency of explosion and the amount of ashfall were obtained from records kept at the Kagoshima Local Meteorological Observatory and the prefectural authority.

Results

Volcanic activities: Year-specific explosion frequencies and the amount of ashfall from Mt. Sakurajima from 1955-2006, published by Kagoshima City Meteorological Observatory, are shown in Table 1. Table 2 summarizes the amount of ashfall in Tarumizu and eight other cities with similar population sizes similar to that of Tarumizu. Since there was no monitoring station in five of the cities, the amounts of ashfall measured in neighboring towns were used. The annual amount of ashfall in Tarumizu was larger than that of the other eight cities. The amount of ashfall was significantly related to the distance from Mt. Sakurajima (correlation coefficient=–0.677, P=0.045).

Table 1. The frequency of explosions and the amount of fallout from Sakurajima according to year (data from Kagoshima City Meteorological Observatory).

Year	Number of explosions	Amount of ashfall (g/㎡)	Year	Number of explosions	Amount of ashfall (g/㎡)
1955*	6	—	1982	233	2125
1956	115	—	1983	413	1912
1957	57	—	1984	332	3491
1958	83	—	1985	474	15908
1959	109	—	1986	216	4194
1960	414	—	1987	106	3276
1961	196	—	1988	155	6503
1962	89	—	1989	44	2352
1963	136	—	1990	119	5610
1964	88	—	1991	295	1852
1965	29	—	1992	165	2945
1966	44	—	1993	91	424
1967	127	—	1994	148	1067
1968	37	—	1995	226	268
1969	22	—	1996	171	124
1970	19	271	1997	35	44
1971	10	—	1998	103	243
1972	108	67	1999	237	821
1973	144	1439	2000	169	337
1974	362	1038	2001	110	94
1975	199	1157	2002	59	60
1976	176	1577	2003	17	3
1977	223	2757	2004	11	13
1978	231	4502	2005	12	15
1979	149	1537	2006	15	17
1980	277	1355	2007	10	22
1981	233	2129	2008	28	25

*1955 October-December

Table 2. The amount of ashfall in Tarumizu and eight other cities in Kagoshima Prefecture.

City	Distance from Mt. Sakurajima (km)	Ashfall (g/ m^2/year) from 1979-90	Person-years of observation (age 50 +) in mortality analysis
Tarumizu	10.5	6207	168,116
Kokubu	20.5	634	199,595
Kaseda	36.4	65 (Kinpo)*	173,231
Ibusuki	36.5	61 (Yamagawa)*	198,817
Kushikino	39.3	113	165,322
Makurazaki	48.3	15	177,351
Ohkuchi	52.9	88 (Kurino)*	189,607
Izumi	63.4	94 (Togo)*	228,324
Akune	65.1	94 (Togo)*	197,844

* The amounts of ash-fall were measured in neighboring towns in parenthesis since there was no monitoring station in five cities.

SMR analysis: SMR analysis showed that lung cancer mortality in Tarumizu was significantly higher than that in the entire Kagoshima prefecture during the period between 1965-2006 (Table 3). The SMRs of lung cancer (ICD 9th: 162) for males and females were 1.61 (95% CI: 1.44-1.78) and 1.68 (95% CI: 1.40-1.97), respectively. No evident time trend was observed during the study period.

The SMR analysis showed that COPD (ICD 9th: 490-496) mortality in Tarumizu was significantly higher than that in the entire Kagoshima prefecture (Table 4). The SMRs of COPDs for males and females were 1.88 (95% CI: 1.65-2.12) and 1.70 (95% CI: 1.41-1.99), respectively. When males and females were combined, the SMR was 1.82 (95% CI: 1.63-2.00). The SMRs of COPDs during the periods of 1973-1982 and 2003-2006 were higher than those of other periods.

Acute respiratory disease (ICD 9th: 460-466, 480-487) mortality in Tarumizu was significantly higher than that

Table 3. SMR of lung cancer (ICD 9th: 162) in Tarumizu.

Period	Males			Females			Total		
	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI
1965-1967	8	1.31	0.40-2.21	1	0.34	0.03-1.01	9	0.99	0.34-1.64
1968-1972	17	1.34	0.70-1.97	7	1.61	0.42-2.81	24	1.41	0.84-1.97
1973-1977	26	1.56	0.96-2.16	11	1.89	0.77-3.01	37	1.64	1.11-2.17
1978-1982	35	1.60	1.07-2.13	15	1.98	0.98-2.98	50	1.70	1.23-2.17
1983-1987	34	1.30	0.87-1.70	18	1.90	1.04-2.80	52	1.47	1.07-1.87
1988-1992	55	1.80	1.32-2.27	17	1.51	0.79-2.22	72	1.72	1.32-2.12
1993-1997	66	1.96	1.49-2.43	23	1.74	1.03-2.45	89	1.90	1.50-2.29
1998-2002	58	1.66	1.23-2.08	25	1.69	1.03-2.35	83	1.66	1.31-2.02
2003-2006	42	1.43	1.00-1.87	20	1.66	0.93-2.39	62	1.50	1.13-1.87
1965-2006	**341**	**1.61**	**1.44-1.78**	**137**	**1.68**	**1.40-1.97**	**478**	**1.63**	**1.48-1.78**

Table 4. SMR of chronic obstructive pulmonary disease (COPD) and allied conditions (ICD 9th: 490–496) in Tarumizu.

Period	Males			Females			Total		
	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI
1965–1967	7	0.89	0.23–1.55	5	0.81	0.10–1.53	12	0.86	0.37–1.34
1968–1972	28	1.38	0.87–1.89	21	1.66	0.95–2.37	49	1.49	1.07–1.90
1973–1977	37	2.01	1.36–2.66	22	2.15	1.25–3.05	59	2.06	1.54–2.59
1978–1982	37	2.52	1.71–3.33	18	1.88	1.01–2.75	55	2.27	1.67–2.87
1983–1987	29	1.89	1.20–2.58	16	1.82	0.93–2.71	45	1.87	1.32–2.41
1988–1992	27	1.91	1.19–2.63	10	1.24	0.47–2.02	37	1.67	1.13–2.21
1993–1997	28	1.80	1.13–2.46	15	1.75	0.86–2.63	43	1.78	1.25–2.31
1998–2002	23	1.64	0.97–2.31	13	1.81	0.83–2.80	36	1.70	1.14–2.25
2003–2006	33	2.75	1.81–3.69	10	1.90	0.72–3.08	43	2.49	1.75–3.24
1965-2006	**249**	**1.88**	**1.65-2.12**	**130**	**1.70**	**1.41-1.99**	**379**	**1.82**	**1.63-2.00**

Table 5. SMR of acute respiratory infections (ICD 9th: 460-466), and pneumonia and influeuza (ICD 9th: 480-487) in Tarumizu.

Period	Males			Females			Total		
	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI
1965-1967	-	-	-	-	-	-	-	-	-
1968-1972	27	1.02	0.63-1.40	16	0.66	0.33-0.98	43	0.84	0.59-1.09
1973-1977	25	0.96	0.58-1.34	32	1.27	0.83-1.71	57	1.11	0.83-1.40
1978-1982	30	1.20	0.77-1.64	18	0.74	0.40-1.09	48	0.97	0.70-1.25
1983-1987	42	1.20	0.83-1.60	31	0.90	0.60-1.30	73	1.06	0.82-1.30
1988-1992	74	1.52	1.17-1.87	44	0.97	0.68-1.25	118	1.24	1.02-1.47
1993-1997	53	1.01	0.74-1.28	54	1.03	0.75-1.30	107	1.02	0.83-1.21
1998-2002	58	1.10	0.82-1.38	62	1.18	0.89-1.48	120	1.14	0.94-1.35
2003-2006	70	1.62	1.24-2.00	67	1.53	1.16-1.89	137	1.57	1.31-1.84
1965-2006	**379**	**1.22**	**1.10-1.35**	**324**	**1.07**	**0.96-1.19**	**703**	**1.15**	**1.06-1.23**

Table 6. SMR of all non-malignant respiratory diseases except tuberculosis (ICD 9th: 460-519) in Tarumizu.

Period	Males			Females			Total		
	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI
1965-1967	17	0.68	0.36-1.01	11	0.52	0.21-0.83	28	0.61	0.38-0.84
1968-1972	55	1.17	0.86-1.49	37	1.00	0.68-1.32	92	1.10	0.87-1.32
1973-1977	62	1.40	1.05-1.74	54	1.52	1.12-1.93	116	1.45	1.19-1.72
1978-1982	67	1.69	1.29-2.10	36	1.07	0.72-1.41	103	1.40	1.13-1.68
1983-1987	71	1.40	1.08-1.73	47	1.10	0.79-1.43	118	1.27	1.04-1.50
1988-1992	101	1.61	1.29-1.92	54	1.01	0.74-1.28	155	1.33	1.12-1.54
1993-1997	93	1.20	0.96-1.45	79	1.18	0.92-1.44	172	1.19	1.01-1.37
1998-2002	114	1.35	1.10-1.60	100	1.32	1.06-1.58	214	1.34	1.16-1.52
2003-2006	134	1.89	1.57-2.21	102	1.60	1.29-1.91	236	1.75	1.53-1.98
1965-2006	**714**	**1.38**	**1.28-1.48**	**520**	**1.21**	**1.11-1.31**	**1234**	**1.32**	**1.25-1.40**

Table 7. SMR of asthma (ICD 9th: 493) in Tarumizu.

Period	Males			Females			Total		
	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI
1965-1967	-	-	-	-	-	-	-	-	-
1968-1972	22	1.66	0.96-2.35	15	1.84	0.91-2.77	37	1.73	1.17-2.28
1973-1977	27	2.47	1.54-3.40	18	3.06	1.64-4.47	45	2.67	1.89-3.45
1978-1982	25	2.97	1.81-4.14	14	2.71	1.29-4.13	39	2.87	1.97-3.45
1983-1987	22	2.80	1.63-3.97	12	2.44	1.06-3.82	34	2.66	1.77-3.56
1988-1992	18	3.00	1.62-4.39	4	0.94	0.02-1.86	22	2.15	1.25-3.04
1993-1997	9	1.49	0.52-2.47	8	1.73	0.53-2.92	17	1.59	0.84-2.35
1998-2002	1	0.29	-0.27-0.84	4	1.23	-0.20-3.17	5	0.74	0.09-1.39
2003-2006	4	2.05	0.04-4.06	3	1.49	-0.20-3.17	7	1.76	0.46-3.07
1965-2006	**128**	**2.21**	**1.83-2.59**	**78**	**2.04**	**1.59-2.49**	**206**	**2.14**	**1.85-2.43**

in the entire Kagoshima prefecture (Table 5). The SMRs of acute respiratory diseases among males and females were only elevated during the period 2003-2006. When males and females were combined, the SMR was 1.57 (95% CI: 1.31-1.84).

All non-malignant respiratory diseases (ICD 9th: 460-519) mortality in Tarumizu was significantly higher than that in the entire Kagoshima prefecture (Table 6).

Asthma (ICD 9th: 493) mortality in Tarumizu was also significantly higher than that in the entire Kagoshima prefecture (Table 7).

Tables 8 and 9 shows SMRs of respiratory diseases among males and females in Tarumizu and the other eight cities. The mortality rates for lung cancer and

Table 8. SMR of respiratory diseases among males.

City	Lung cancer (ICD 9th: 162)			COPD and allied conditions (ICD 9th: 490-496)			Acute respiratory infections (ICD 9th: 460-466), and pneumonia and influenza (ICD 9th: 480-487)			All non-malignant respiratory diseases (ICD 9th: 460-519)		
	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI
Tarumizu	341	1.61	1.44-1.78	249	1.88	1.65-2.12	379	1.22	1.10-1.35	714	1.38	1.28-1.48
Kokubu	447	0.92	0.84-1.01	214	0.81	0.70-0.92	598	0.83	0.77-0.90	959	0.85	0.80-0.91
Kaseda	297	1.28	1.13-1.42	168	1.19	1.01-1.37	575	1.69	1.55-1.82	826	1.51	1.40-1.61
Ibusuki	390	1.29	1.17-1.42	187	1.03	0.89-1.18	425	0.96	0.87-1.05	685	0.97	0.90-1.04
Kushikino	335	1.20	1.07-1.33	169	0.99	0.84-1.14	438	1.07	0.97-1.17	714	1.42	1.32-1.53
Makurazaki	334	1.23	1.10-1.37	159	0.96	0.81-1.11	414	1.04	0.94-1.14	645	1.01	0.93-1.09
Ohkuchi	279	1.14	1.01-1.27	195	1.27	1.10-1.45	482	1.35	1.23-1.47	773	1.54	1.43-1.65
Izumi	346	0.89	0.80-0.99	190	0.83	0.71-0.95	627	1.11	1.02-1.19	923	1.84	1.72-1.96
Akune	304	1.12	1.00-1.25	178	1.06	0.91-1.22	498	1.26	1.15-1.37	803	1.25	1.17-1.34

Table 9. SMR of respiratory diseases among females.

City	Lung cancer (ICD 9th: 162)			COPD and allied conditions (ICD 9th: 490-496)			Acute respiratory infections (ICD 9th: 460-466), and pneumonia and influenza (ICD 9th: 480-487)			All non-malignant respiratory diseases (ICD 9th: 460-519)		
	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI	Deaths	SMR	95%CI
Tarumizu	137	1.68	1.40-1.97	130	1.70	1.41-1.99	324	1.07	0.96-1.19	520	1.21	1.11-1.31
Kokubu	169	1.06	0.90-1.22	108	0.86	0.69-1.02	548	0.92	0.85-1.00	769	0.93	0.86-1.00
Kaseda	122	1.29	1.06-1.52	76	0.90	0.69-1.10	557	1.59	1.46-1.72	717	1.45	1.34-1.55
Ibusuki	125	1.06	0.87-1.24	114	1.08	0.88-1.27	401	0.91	0.82-1.00	582	0.94	0.86-1.01
Kushikino	153	1.45	1.22-1.68	126	1.31	1.08-1.54	464	1.18	1.07-1.29	676	1.22	1.13-1.31
Makurazaki	103	0.99	0.80-1.18	76	0.80	0.62-0.98	413	1.07	0.96-1.17	574	1.05	0.96-1.14
Ohkuchi	124	1.30	1.07-1.53	99	1.11	0.89-1.33	388	1.10	0.99-1.21	561	1.11	1.02-1.21
Izumi	153	1.05	0.88-1.22	114	0.89	0.72-1.05	707	1.30	1.21-1.40	896	1.17	1.10-1.25
Akune	118	1.14	0.93-1.34	115	1.20	0.98-1.41	456	1.19	1.08-1.29	681	1.24	1.15-1.34

COPDs in Tarumizu were higher than the other eight cities. However, the SMRs of all non-malignant respiratory diseases in Tarumizu were not higher than those in other eight cities with similar population sizes.

RR analysis of cancer among males: Table 10 shows the results of RR analysis on cancer mortality among males age 50-84. The RR of lung cancer in Tarumizu was 1.18 (95% CI: 1.01-1.39, P=0.043) when the lung cancer mortality of the other eight cities combined were used as the reference category. When RRs for those eight cities were calculated using Tarumizu as the reference, RRs of lung cancer mortality decreased as the distance from Mt. Sakurajima increased (P=0.004). The mortality rates of other smoking-related cancers showed no difference between the inhabitants of Tarumizu and those of the other cities. Smoking-related cancers in our analysis consisted of cancer of the oropharynx (ICD 9th: 140-149), esophagus (ICD 9th: 150), stomach (ICD 9th: 151), rectum (ICD 9th: 154), liver (ICD 9th: 155), pancreas (ICD 9th: 157), larynx (ICD 9th: 161), uterus, part unspecified (ICD 9th: 179), cervix uterine (ICD 9th: 180), body of uterus (ICD 9th: 182), bladder (ICD 9th: 188), and kidney (ICD 9th: 189). The mortality rates for leukemia (ICD 9th: 204-208) and lymphoma (ICD 9th: 200-202) in Tarumizu was higher than those in all of the other cities except for Izumi. The differences among 9 cities, including Tarumizu, were not statistically significant. The mortality rate for other types of cancer in Tarumizu was not different from that in the other cities (data not shown).

RR analysis of cancer among females: Table 11 shows cancer mortality rates among females aged 50-84 for the period 1975-1995. The RR of lung cancer in Tarumizu was 1.35 (95% CI: 1.03-1.76, P=0.028) when other eight cities combined were used as the reference category;

Table 10. Relative risks of lung cancer, smoking-related cancer other than lung cancer and leukemia mortality among males aged 50-84 years old during the period 1975 -1995.

City	Lung cancer (ICD 9th: 162)			Smoking- related cancers* excluding lung cancer			Leukemia (ICD 9th:204-208) and lymphoma (ICD 9th:200-202)		
	Deaths	RR	95%CI	Deaths	RR	95%CI	Deaths	RR	95%CI
Tarumizu	167	1	Reference	325	1	Reference	52	1	Reference
Kokubu	180	0.92	0.75-1.14	423	1.09	0.95-1.26	52	0.82	0.56-1.20
Kaseda	117	0.70	0.55-0.88	304	0.94	0.80-1.10	46	0.88	0.59-1.31
Ibusuki	197	1.04	0.85-1.28	416	1.13	0.97-1.30	32	0.53	0.34-0.83
Kushikino	150	0.97	0.78-1.21	302	0.98	0.84-1.15	44	0.85	0.57-1.28
Makurazaki	156	0.97	0.78-1.21	333	1.04	0.89-1.21	39	0.73	0.48-1.10
Ohkuchi	147	0.79	0.63-0.98	340	0.93	0.80-1.08	54	0.91	0.62-1.33
Izumi	147	0.66	0.53-0.83	482	1.10	0.96-1.27	78	1.07	0.76-1.53
Akune	144	0.77	0.61-0.96	399	1.08	0.93-1.25	57	0.93	0.64-1.36
P for trend (1/km)		0.004			> 0.5			> 0.5	
Tarumizu vs others									
RR		1.18			0.96			1.18	
95%CI		1.01-1.39			0.86-1.08			0.88-1.58	
P value		0.043			0.497			0.263	

* Smoking- related cancers excluding lung cancer=ICD 9th: 140-9,150-1,154-5, 157, 161,179,180,182,188,189

Table 11. Relative risks of lung cancer, smoking-related cancer other than lung cancer, and leukemia mortality among females aged 50-84 years old during the period 1975 -1995.

City	Lung cancer (ICD 9th: 162)			Smoking- related cancers* excluding lung cancer			Leukemia (ICD 9th:204-208) and lymphoma (ICD 9th:200-202)		
	Deaths	RR	95%CI	Deaths	RR	95%CI	Deaths	RR	95%CI
Tarumizu	62	1	Reference	191	1	Reference	38	1	Reference
Kokubu	52	0.71	0.49-1.03	239	1.08	0.89-1.31	36	0.80	0.51-1.26
Kaseda	59	0.88	0.62-1.26	207	1.01	0.83-1.23	18	0.44	0.25-0.78
Ibusuki	44	0.58	0.39-0.85	242	1.04	0.86-1.26	34	0.73	0.46-1.16
Kushikino	64	1.04	0.74-1.48	183	0.98	0.80-1.20	34	0.89	0.56-1.42
Makurazaki	50	0.75	0.51-1.08	213	1.05	0.86-1.28	25	0.60	0.36-1.00
Ohkuchi	51	0.74	0.51-1.08	243	1.16	0.96-1.40	39	0.92	0.59-1.44
Izumi	56	0.67	0.47-0.97	300	1.18	0.99-1.42	59	1.14	0.76-1.71
Akune	46	0.63	0.43-0.92	221	0.99	0.82-1.20	43	0.95	0.61-1.47
P for trend (1/km)		0.031			0.367			> 0.5	
Tarumizu vs others									
RR		1.35			0.94			1.22	
95%CI		1.03-1.76			0.81-1.09			0.87-1.71	
P value		0.028			0.411			0.248	

* Smoking- related cancers excluding lung cancer=ICD 9th: 140-9,150-1,154-5, 157, 161,179,180,182,188,189

the lung cancer mortality among female residents in Tarumizu was higher than the rates in any of the other eight cities examined. When RRs for those eight cities were calculated using Tarumizu as the reference, RRs of lung cancer mortality decreased as the distance from Mt. Sakurajima increased (P=0.031). The rates of mortality from other smoking-related cancers including cancer of the oropharynx, esophagus, stomach, rectum, liver, pancreas, larynx, cervix uterine, uterus, bladder and kidney, among the inhabitants of Tarumizu were

Table 12. Relative risks of non-malignant respiratory disease mortality among males aged 50-84 years old from 1975 to 1995.

City	All non-malignant respiratory diseases (ICD 9th: 460-519)			Acute respiratory infections (ICD 9th: 460-466), and pneumonia and influenza (ICD 9th: 480-487)			COPD and allied conditions (ICD 9th: 490-496)			Pneumoconioses and other lung diseases due to external agents (ICD 9th: 500-508)			Other diseases of respiratory system (ICD 9th: 510-519)		
	Deaths	RR	95%CI	Deaths	RR	95%CI	Deaths	RR	95%CI	Deaths	RR	95%CI	Deaths	RR	95%CI
Tarumizu	305	1	reference	145	1	reference	100	1	reference	20	1	reference	38	1	reference
Kokubu	259	0.73	0.62-0.87	146	0.87	0.69-1.09	77	0.68	0.50-0.91	12	0.49	0.24-1.01	21	0.47	0.28-0.80
Kaseda	318	1.05	0.89-1.22	218	1.50	1.22-1.85	64	0.65	0.47-0.89	12	0.59	0.29-1.21	18	0.48	0.27-0.83
Ibusuki	268	0.78	0.66-0.91	147	0.89	0.71-1.12	88	0.79	0.59-1.05	7	0.30	0.13-0.71	26	0.60	0.36-0.99
Kushikino	270	0.99	0.84-1.17	154	1.19	0.95-1.50	54	0.62	0.44-0.86	5	1.32	0.73-2.38	37	1.07	0.68-1.68
Makurazaki	243	0.86	0.73-1.02	137	1.03	0.81-1.30	56	0.62	0.44-0.85	11	0.56	0.27-1.18	33	0.92	0.58-1.46
Ohkuchi	266	0.79	0.67-0.93	162	1.01	0.81-1.26	62	0.57	0.41-0.78	22	0.97	0.53-1.77	16	0.38	0.21-0.68
Izumi	366	0.93	0.80-1.08	230	1.23	1.00-1.51	87	0.69	0.52-0.92	11	0.41	0.19-0.85	36	0.72	0.46-1.14
Akune	279	0.83	0.70-0.97	178	1.11	0.89-1.38	74	0.68	0.50-0.92	10	0.43	0.20-0.92	17	0.40	0.23-0.71
P for trend (1/km)		0.176			0.045			< 0.001			0.088			0.026	
Tarumizu vs others															
RR		1.16			0.91			1.51			1.63			1.63	
95%CI		1.03-1.30			0.77-1.08			1.22-1.87			1.01-2.63			1.15-2.30	
P value		0.017			0.288			< 0.001			0.044			0.006	

Table 13. Relative risks of non-malignant respiratory disease mortality among females aged 50-84 years old from 1975 to 1995.

City	All non-malignant respiratory diseases (ICD 9th: 460-519)			Acute respiratory infections (ICD 9th: 460-466), and pneumonia and influenza (ICD 9th: 480-487)			COPD and allied conditions (ICD 9th: 490-496)			Pneumoconioses and other lung diseases due to external agents (ICD 9th: 500-508)			Other respiratory diseases (ICD 9th: 510-519)		
	Deaths	RR	95%CI	Deaths	RR	95%CI	Deaths	RR	95%CI	Deaths	RR	95%CI	Deaths	RR	95%CI
Tarumizu	153	1	reference	83	1	reference	47	1	reference	1	1	reference	18	1	reference
Kokubu	176	1.00	0.80-1.24	117	1.22	0.92-1.62	34	0.63	0.41-0.99	6	5.01	0.61-42.2	17	0.81	0.42-1.57
Kaseda	195	1.17	0.95-1.45	146	1.61	1.23-2.11	27	0.53	0.33-0.86	4	3.62	0.40-32.4	3	0.66	0.33-1.36
Ibusuki	161	0.85	0.68-1.07	99	0.96	0.72-1.29	39	0.68	0.44-1.04	0	0.00	0.00-ND	20	0.90	0.48-1.70
Kushikino	209	1.43	1.16-1.76	143	1.80	1.37-2.36	39	0.88	0.58-1.35	9	9.51	1.21-75.1	18	1.02	0.53-1.96
Makurazaki	140	0.88	0.70-1.11	101	1.17	0.87-1.56	23	0.48	0.29-0.78	2	1.93	0.17-21.2	13	0.68	0.33-1.38
Ohkuchi	167	1.00	0.80-1.24	110	1.21	0.91-1.61	34	0.66	0.43-1.03	2	1.84	0.17-20.3	20	1.00	0.53-1.89
Izumi	259	1.29	1.06-1.58	207	1.91	1.48-2.46	34	0.56	0.36-0.87	1	0.76	0.05-12.2	16	0.67	0.34-1.31
Akune	203	1.14	0.92-1.40	135	1.39	1.06-1.83	50	0.92	0.62-1.37	5	4.27	0.50-36.5	13	0.61	0.30-1.25
P for trend (1/km)		0.103			<0.001			0.031			> 0.5			0.287	
Tarumizu vs others															
RR		0.92			0.71			1.5			0.31			1.27	
95%CI		0.78-1.08			0.57-0.89			1.10-2.05			0.04-2.30			0.78-2.08	
P value		0.304			0.003			0.01			0.255			0.343	

not different from those among the females in the other cities. The mortality rate from leukemia and lymphoma in Tarumizu was higher than that in all of the other cities except for Izumi although there was no statistical significance.

RR analysis of non-malignant respiratory disease mortality among males: Table 12 shows relative risks (RRs) of non-malignant respiratory disease among males aged 50-84 for the period 1975-1995. When RRs in Tarumizu were calculated using the other eight cities combined were used as the reference category, mortality rates of a few chronic diseases were significantly increased; the RR of COPDs, pneumoconioses (ICD 9th: 500-508) and other diseases of respiratory system

Table 14. Time trend of relative risks assessed by comparing lung cancer mortality in Tarumizu with that in eight other cities .

Period	Male			Female			Total		
	RR*	95%CI	P value	RR*	95%CI	P value	RR*	95%CI	P value
1975-1977	1.09	0.66-1.82	>0.5	2.06	0.90-4.70	0.087	1.27	0.82-1.95	0.280
1978-1982	1.17	0.80-1.71	0.411	1.24	0.69-2.21	0.476	1.19	0.87-1.63	0.282
1983-1987	0.95	0.66-1.35	>0.5	1.60	0.95-2.68	0.075	1.10	0.82-1.47	>0.5
1988-1992	1.18	0.89-1.62	0.243	1.33	0.80-2.21	0.269	1.23	0.95-1.60	0.118
1993-1995	1.56	1.11-2.20	0.011	0.93	0.45-1.92	>0.5	1.40	1.02-1.90	0.035
1975-1995	**1.18**	**1.01-1.39**	**0.043**	**1.35**	**1.03-1.76**	**0.028**	**1.22**	**1.07-1.40**	**0.004**

* RR: relative risk comparing lung cancer mortality in Tarumizu with that of the eight other cities described in the manuscript

Table 15. Time trend of relative risks assessed by comparing mortality of COPD and allied conditions in Tarumizu with that in eight other cities.

Period	Male			Female			Total		
	RR*	95%CI	P value	RR*	95%CI	P value	RR*	95%CI	P value
1975-1977	1.34	0.78-2.28	0.282	1.76	0.78-3.96	0.175	1.44	0.93-2.25	0.105
1978-1982	1.68	1.12-2.52	0.013	1.89	1.10-3.25	0.021	1.75	1.26-2.42	<0.001
1983-1987	1.70	1.10-2.60	0.016	1.15	0.59-2.21	>0.5	1.49	1.04-2.13	0.029
1988-1992	1.43	0.89-2.29	0.138	1.23	0.56-2.71	>0.5	1.37	0.92-2.06	0.126
1993-1995	1.24	0.66-2.32	>0.5	1.60	0.72-3.56	0.249	1.36	0.83-2.23	0.226
1975-1995	**1.51**	**1.22-1.87**	**<0.001**	**1.50**	**1.10-2.05**	**0.010**	**1.51**	**1.26-1.80**	**<0.001**

*Relative risk comparing COPD and allied conditions (ICD 9th: 490-496) mortality in Tarumizu with that of the eight other cities described in the manuscript

Table 16. Time trend of relative risks assessed by comparing mortality of pneumoconiosis in Tarumizu with that in eight other cities.

Period	Male			Female			Total		
	RR*	95%CI	P value	RR*	95%CI	P value	RR*	95%CI	P value
1975-1977†	-	-	-	-	-	-	-	-	-
1978-1982	2.58	0.84-7.91	0.098	-	-	-	1.98	0.67-5.89	0.219
1983-1987	1.84	0.70-4.82	0.216	-	-	-	1.53	0.59-3.95	0.380
1988-1992	1.96	0.95-4.03	0.067	-	-	-	1.69	0.86-3.32	0.129
1993-1995	0.59	0.14-2.47	0.471	-	-	-	0.47	0.11-1.96	0.303
1975-1995	**1.63**	**1.01-2.63**	**0.044**	**0.31**	**0.04-2.30**	**0.255**	**1.36**	**0.86-2.15**	**0.19**

*Relative risk comparing pneumoconiosis mortality in Tarumizu with that of the eight other cities described in the manuscript

† No death from pneumoconiosis was reported in 1975-77

(ICD 9th: 510-519) in Tarumizu were 1.51 (95% CI: 1.22-1.87, P<0.001), 1.63 (95% CI: 1.01-2.63, P=0.044) and 1.63 (95% CI: 1.15-2.30, P=0.006), respectively. However, RR of all non-malignant respiratory disease mortality in Tarumizu was 1.16 (95% CI: 1.03-1.30 P=0.017), and was not significantly increased. The mortality rates for non respiratory diseases in Tarumizu were not different from those in the other cities (data not shown). When RRs of eight cities were calculated, using Tarumizu as the reference, the RRs of acute respiratory diseases in Tarumizu were the second lowest among all the cities.

RR analysis of non-malignant respiratory disease mortality among females: Table 13 shows mortality rates of non-malignant respiratory diseases among females aged 50-84 for the period 1975-1995. When a RR of all non-malignant respiratory diseases in Tarumizu was calculated using the other eight cities combined as the

Table 17. Time trend of relative risks assessed by comparing mortality of acute respiratory diseases in Tarumizu with that in eight other cities.

Period	Male			Female			Total		
	RR*	95%CI	P value	RR*	95%CI	P value	RR*	95%CI	P value
1975-1977	0.60	0.33-1.11	0.103	0.95	0.76-1.19	>0.5	0.72	0.47-1.12	0.142
1978-1982	1.09	0.74-1.60	>0.5	0.96	0.87-1.05	0.359	0.92	0.68-1.25	>0.5
1983-1987	0.76	0.53-1.10	0.151	0.99	0.91-1.08	>0.5	0.76	0.57-1.01	0.060
1988-1992	1.20	0.90-1.60	0.217	0.96	0.89-1.04	0.342	1.00	0.79-1.26	>0.5
1993-1995	0.72	0.46-1.12	0.143	1.08	0.91-1.27	0.392	0.62	0.43-0.90	0.010
1975-1995	**0.91**	**0.77-1.08**	**0.288**	**0.71**	**0.57-0.89**	**0.003**	**0.83**	**0.72-0.95**	**0.006**

*Relative risk comparing acute respiratory diseases (ICD 9th: 460-466, 480-487) mortality in Tarumizu with that of the eight other cities described in the manuscript

Table 18. Time trend of relative risks assessed by comparing mortality of chronic non-malignant respiratory diseases in Tarumizu with that in eight other cities.

Period	Male			Female			Total		
	RR*	95%CI	P value	RR*	95%CI	P value	RR*	95%CI	P value
1975-1977	1.33	0.82-2.16	0.250	1.59	0.75-3.38	0.230	1.40	0.93-2.10	0.108
1978-1982	1.56	1.09-2.23	0.014	1.49	0.91-2.46	0.116	1.54	1.15-2.06	0.004
1983-1987	1.60	1.12-2.28	0.010	1.17	0.67-2.03	>0.5	1.45	1.07-1.95	0.015
1988-1992	1.80	1.31-2.48	<0.001	1.19	0.68-2.08	>0.5	1.60	1.22-2.12	<0.001
1993-1995	1.28	0.82-2.00	>0.275	1.55	0.84-2.84	0.161	1.37	0.95-1.96	0.090
1975-1995	**1.55**	**1.31-1.84**	**<0.001**	**1.36**	**1.05-1.76**	**0.02**	**1.49**	**1.29-1.71**	**<0.001**

*Relative risk comparing chronic non-malignan respiratory diseases (ICD 9th: 490-519) mortality in Tarumizu with that of the eight other cities described in the manuscript

Table 19. Time trend of relative risks assessed by comparing mortality of all non-malignant respiratory diseases in Tarumizu with that in eight other cities.

Period	Male			Female			Total		
	RR*	95%CI	P value	RR*	95%CI	P value	RR*	95%CI	P value
1975-1977	0.93	0.65-1.34	>0.5	1.24	0.80-1.92	0.333	1.04	0.79-1.38	>0.5
1978-1982	1.29	0.99-1.67	0.059	0.99	0.69-1.41	>0.5	1.17	0.94-1.44	0.153
1983-1987	1.06	0.82-1.37	>0.5	0.88	0.62-1.25	0.478	0.99	0.81-1.22	>0.5
1988-1992	0.35	1.14-1.75	0.001	0.85	0.61-1.19	0.345	1.19	1.00-1.42	0.055
1993-1995	0.93	0.68-1.27	>0.5	0.77	0.50-1.19	0.237	0.87	0.67-1.12	0.268
1975-1995	**1.16**	**1.03-1.30**	**0.017**	**0.92**	**0.78-1.08**	**0.304**	**1.06**	**0.96-1.17**	**0.216**

*Relative risk comparing all non-malignant respiratory diseases (ICD 9th: 460-519) mortality in Tarumizu with that of the eight other cities described in the manuscript

reference category, it was 0.92 (95%CI=0.78-1.08). On the other hand, the RR of COPD mortality rate among females in Tarumizu was 1.50 (95% CI, range: 1.10-2.05, P=0.010). When RRs of other eight cities were calculated using Tarumizu as the reference, the RRs of acute respiratory diseases in Tarumizu was the second lowest (P=0.003) among the nine cities. There was only one death from pneumoconioses or other lung diseases due to external agents, in Tarumizu, and its mortality was not different from that in the other cities.

Period-specific RR analysis: The observation period for RR analysis was divided into the following five periods: 1975-1977, 1978-1982, 1983-1987, 1988-1992, and 1993-1995. The RRs of lung cancer, acute respiratory diseases, chronic non-malignant respiratory diseases and all non-malignant respiratory diseases were calculated for each of the five intervals. There was no significant difference of RRs among those time intervals (Tables 14-19).

Radon exposure: The outdoor concentrations of radon (Rn) progeny were measured in Kagoshima and

Table20. Outdoor concentrations of radon progeny in Kagoshima and Tarumizu during the period between March 2001 and September 2004.

	Kagoshima City *				Tarumizu City*				P value for difference
Variable	Mean†	SE‡	95%CI	Max	Mean†	SE‡	95%CI	Max	between the two cities
RaA(^{218}Po) [Bqm^{-3}]	3.027	0.0255	2.977-3.077	13.81	4.138	0.0260	4.087-4.189	49.86	<0.001
RaB(^{214}Pb) [Bqm^{-3}]	2.326	0.0178	2.291-2.361	9.177	2.525	0.0127	2.500-2.550	19.40	<0.001
RaC(^{214}Bi) [Bqm^{-3}]	2.444	0.0180	2.409-2.480	8.980	2.579	0.0180	2.556-2.602	14.98	<0.001

*The outdoor radon progeny concentrations in Kagoshima and Tarumizu city was monitored at Kagoshima University Sakuragaoka campus and Ichiki district, respectively.
† Means in Kagoshima City were calculated using 5,955 measurements during the period between Mar. 2001 and Jan. 2002. Means in Tarumizu City were calculated using 12,893 measurements during the period between Jan. 2002 and Sep. 2004.
‡ SE: standard error of mean

Table 21. Indoor radon concentration in the houses of lung cancer cases and controls in Tarumizu during the period between October 2001 and December 2006.

	Type of Radioactive Nuclide	N	Arithmetic mean [Bq m^{-3}]	SE*	Geometric mean [Bq m^{-3}]	Median [Bq m^{-3}]
Case	Radon	17	11.0	8.9	8.6	8
Control	Radon	17	9.1	7.6	7.5	6

*SE: standard error of mean

Tarumizu (Table 20). The outdoor levels of all radon progenies in Tarumizu were significantly higher than those in Kagoshima city (P<0.001). We also conducted similar dosimetry study in Tarumizu during the period between 2001 and 2006 to compare indoor radon concentrations in the houses where lung cancer patients and control subjects lived although the number of cases was small (Table 21). There was no significant difference between patients and controls with respect to indoor concentrations of those nuclides. The indoor radon level in the houses of cases and controls in Tarumizu was lower than the global average (40 Bq m^{-3}) presented in the 1993 United Nations Scientific Committee Report[22], and lower than the arithmetic and geometric means (15.5 and 12.7 Bq m^{-3}, respectively) in Japan[23].

Discussion

The present study showed that residents in Tarumizu, located near Mt. Sakurajima, experienced relatively high mortality of respiratory diseases, including lung cancer. The mortality of COPDs and pneumoconioses may also be increased. Since the mortality rates of other smoking-related cancers in that city did not show any marked differences from those of the other cities (Tables 10 and 11), the observed increase is unlikely to be explained by smoking. In addition, a survey conducted by Kagoshima Prefecture showed that the proportions of male and female smokers in Tarumizu were similar to those of other cities in Kagoshima[15]. The consistently high SMR of lung cancer in Tarumizu during the entire period of our statistical analysis (1965-2006) suggests long-term effects of Mt. Sakurajima, which has become active every 10-30 years over the last 100 years.

This is not the first study to examine the lung cancer risk in relation to the volcanic activities of Mt. Sakurajima. Wakisaka examined the mortality in 67 cities, towns and villages of Kagoshima Prefecture within a radius of 50km around Mt. Sakurajima south, and reported that the SMR of lung cancer in that 50 km radius area was elevated when the compared to national mortality[24]. However, they observed no consistent declining gradient in the SMR of lung cancer with increasing distance from Mt. Sakurajima among the regional groups. They concluded that the volcanic activity was unlikely to affect the mortality for lung cancer.

In the RR analysis, in which the mortality rates in Tarumizu were compared with those in eight cities with similar population sizes, Tarumizu had an increased mortality of chronic non-malignant respiratory diseases, including COPDs. However, this city had a decreased mortality of acute respiratory diseases. When acute respiratory diseases and chronic non-malignant respiratory diseases were combined, the RR of all non-malignant respiratory diseases in Tarumizu became close to the unity; 1.16 (95%CI=1.03-1.30) for males and 0.92 (95%CI=0.78-1.08) for females when the other eight cities combined were used as the reference category. An explanation for those RR observations was a possibility that physicians tended to diagnose COPDs as a cause of death for people living near Mt. Sakurajima even if the patients had acute respiratory diseases. On the other hand, the SMR of all respiratory diseases in Tarumizu was significantly elevated. It should be noted here that the SMR analysis compares the mortality in Tarumizu with that in the entire Kagoshima Prefecture. When the SMRs of all non-malignant respiratory diseases were also calculated for eight other cities used in the RR analysis, three of them had larger SMRs than that in Tarumizu. Taken together, there was no convincing evidence indicating the increased mortality of non-malignant respiratory diseases other than lung cancer in Tarumizu.

If the volcanic activities of Mt. Sakurajima are associated only with lung cancer but not with other chronic respiratory disease mortality, a possible factors involved is radiation exposure. Indeed, we first suspected that radon and its progeny released from Mt. Sakurajima may be related to the increased lung cancer mortality among Tarumizu residents since i) there is no convincing evidence to indicate the increase of mortality due to respiratory diseases other than lung cancer; and ii) Komura et al. reported in 1988 that the concentrations of Pb-210 (RaD) and Po-210 (RaF) in the surface of the atmosphere around the area of Mt. Sakurajima were elevated[13]. We measured indoor and outdoor radon levels in Tarumizu. The continuous measurement of outdoor radon concentrations, conducted by our study group in the 2000s, showed relatively high outdoor radon concentrations, exceeding 20 Bq m^{-3} in the study areas even though the volcano was not very active at the time of radon assay. The outdoor concentrations of all radon progenies in Tarumizu were significantly higher than those in Kagoshima city ($P<0.001$).

Pooled analyses of North American and European data reported that an indoor radon concentrations as high as 100 Bq m^{-3} for about recent 30-35 years increased lung cancer risk by 16%[25,26]. Since the RR of lung cancer in Tarumizu was much higher than 16%, radon and its progeny concentrations in Tarumizu should have been higher than 100 Bq m^{-3} if the observed increase of lung cancer mortality in Tarumizu was caused by radon and radon progenies. In other words, radon exposure alone cannot explain the observed increase of lung cancer in Tarumizu.

Crystalline silica is known to cause pneumoconioses[27]. Therefore, if a significant amount of crystalline silica is released from Mt. Sakurajima, pneumoconioses are expected to increase among residents. In order to address this question, Wakisaka et al. examined health insurance claims and reported a 59-year-old man diagnosed with pneumoconioses after living in Sakurajima for more than 20 years even though he did not have a history of occupational dust exposure[28]. In a similar study, a few patients were diagnosed as having pneumoconioses in the Ushine and Kaigata districts of Tarumizu, which is a heavy ashfall area[29]. Unfortunately, however, the occupational history of those cases was not available. In the present study, the RR of pneumoconioses was increased but only among males. The RR of pneumoconioses was not increased among females. The mortality of pneumoconioses did not decrease with the distance from Mt. Sakurajima. Those findings support what was reported by pathological studies reviewed in the introduction section.

As discussed above, in the vicinity of Mt. Sakurajima, silicosis may not be markedly increased. If so, we have to assume that cristobalite in Sakurajima ash increases lung cancer not through silicosis. Whether excessive lung cancer occurs exclusively among subjects with silicosis remains uncertain[30]. The association between silica and lung cancer is generally, but not uniformly, stronger among silicotics than non-silicotics. The notion was supported by the meta-analysis conducted by Kurihara and Wada, who reviewed 6 cohort studies and 2 case-control studies[31]. The estimated common risk from silica exposure among non-silicotic subjects was 0.96 (95% CI, 0.81-1.15). However, there are a couple of studies that showed an increase of risk among non-silicotic subjects[32,33]. Checkoway and Franzblau concluded that population-based or individually-based risk assessments

should treat silicosis and lung cancer as distinct entities whose cause/effect relations are not necessarily linked until more conclusive epidemiologic findings become available[30]. What was reported in the present study supports the notion.

In Tarumizu, lung cancer risk increased 1.18 fold among men and 1.35 folds among women. On the basis of what was reported by Steenland et al.[34], we estimated that the cumulative exposure of 400 mg m^{-3}-years increases lung cancer risk by 1.2 folds. In Tarumizu, the cumulative amount of ashfall during the period 1979-90 was 74,484 g m^{-2}. Since the ash of Sakurajima contains approximately 7% of crystalline silica, and its 10% is assumed to be respirable material (<10um) based on the finding of Hillman[6], cumulative exposure during that 12 year period could be as high as 521 g m^{-3}-years. Even if residents are exposed to its 1.6%, lung cancer risk is expected to increase 1.7 folds.

Conclusions

The present study showed that residents in Tarumizu, located near Mt. Sakurajima, experienced relatively high mortality rates of lung cancer. The mortality of COPDs and pneumoconioses may also be increased. It is suspected that cristobalite contained in the asfall of the volcano increases the mortality of those respiratory diseases. Further studies on the health effects of Mt. Sakurajima's volcanic activities seem warranted.

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桜島近郊における慢性呼吸器疾患による死亡

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【目的】

活火山である桜島は様々な大気汚染物質を放出している。例えば，火山灰に７％程度含まれるクリストバライトがある。また，桜島近郊では比較的高い屋外ラドン濃度が報告されている。本研究は，桜島の火山活動が慢性呼吸器疾患による死亡に与える影響について調査した。

【方法】

垂水市の住民について標準化死亡比（SMR）を求めた。調査期間は1965－2006年で鹿児島県を基準とした。さらに，50－84歳の垂水市と同規模の人口をもつ県内８市の相対リスク（RR）について，ポアソン回帰分析を用いて算出した。桜島の爆発回数と降灰量については鹿児島地方気象台，SPMとSO_2については鹿児島県環境生活部から入手したデータを用いた。

【結果】

桜島は20世紀後半以降の1980年代に最も活発であった。1965－2006年における垂水市におけるSMRは，男性の肺がんが1.61［95％信頼区間（95% CI）: 1.44-1.78］，女性は1.68（95% CI: 1.40-1.97）と他の都市に比べ最も有意に高く，明らかな経年変化はなかった。がんを除いた全呼吸器疾患のSMRは男性が1.38（95% CI: 1.28-1.48），女性は1.21（95% CI: 1.11-1.31）と有意に高かった。そのSMRは，2003－2006年の期間にピークを示した。2003－2006年のCOPDのSMRは男性が2.75（95% CI: 1.81-3.69），女性は1.90（95% CI: 0.72-3.08）であった。垂水における肺がんのRRは他の都市と比べ男性で1.18（95% CI: 1.01-1.39），女性は1.35（95% CI: 1.03-1.76）であった。がんを除いた全呼吸器疾患のRRは男性で1.16（95% CI: 1.03-1.30），女性で0.92（95% CI: 0.78-1.08）と，垂水における全呼吸器疾患は上昇していなかった。垂水において，塵肺による死亡は男性だけが有意に高く，女性では高い結果は得られなかった。2000年代に桜島近郊の屋外ラドン濃度を連続測定した結果，20 Bqm^{-3}を超える高いラドン濃度を頻回に記録した。

【結論】

本研究により，桜島近郊に位置する垂水市の住民において，肺がんによる死亡が高いことが明らかになった。また，COPDや塵肺による死亡も増えている可能性がある。その原因は桜島の火山灰に含まれるクリストバライトによる可能性が疑われた。今後，桜島の火山活動による健康影響について，さらなる研究が必要である。