

Effects of SO₂ on Respiratory System of Adult Miyakejima Resident 2 Years after Returning to the Island

Satoko IWASAWA¹, Yuriko KIKUCHI¹, Yuji NISHIWAKI¹, Makiko NAKANO¹, Takehiro MICHIKAWA¹, Tazuru TSUBOI¹, Shigeru TANAKA², Takamoto UEMURA¹, Ai ISHIGAMI¹, Hiroshi NAKASHIMA³, Toru TAKEBAYASHI¹, Mitsuru ADACHI⁴, Akihiro MORIKAWA⁵, Kouichi MARUYAMA⁶, Shoji KUDO⁷, Iwao UCHIYAMA⁸ and Kazuyuki OMAE¹

¹Department of Preventive Medicine and Public Health, School of Medicine, Keio University, ²Department of Public Health, School of Human Life Sciences, Jumonji University, ³Department of Preventive Medicine and Public Health, National Defense Medical College, ⁴First Department of Internal Medicine, Showa University School of Medicine, ⁵Department of Pediatrics and Developmental Medicine, Gunma University Graduate School of Medicine, ⁶Bureaus of Social Welfare and Public Health, Tokyo Metropolitan Government, ⁷Department of Pulmonary Medicine/Infection and Oncology, Nippon Medical School and ⁸Urban and Environmental Engineering, Faculty of Engineering, Kyoto University, Japan

Abstract: Effects of SO₂ on Respiratory System of Adult Miyakejima Resident 2 Years after Returning to the Island: Satoko IWASAWA, *et al.* Department of Preventive Medicine and Public Health, School of Medicine, Keio University—**Background:** Mt. Oyama in Miyakejima Island erupted in June, 2000. All Miyake villagers were forced to evacuate from the island in September, 2000, due to continuous eruptions and emissions of unsafe amounts of volcanic gas, mainly SO₂. From February, 2005, Miyake villagers returned to the island despite volcanic gas still being emitted. **Objectives:** This study examines the 2-yr changes in Miyake residents' respiratory systems from autumn 2004 to November 2006. **Methods:** The study population was 823 Miyake adult residents who participated in the health check-up in 2006. Respiratory effects were evaluated by a questionnaire for respiratory symptoms and spirometry. SO₂ has been continuously monitored at 7 sampling points of the inhabited area. The mean SO₂ concentration from February 2005 to November 2006 was 0.031 ppm. The area was categorized into 4 areas by SO₂ concentration, namely, areas L, H-1, H-2 and H-3, where average SO₂ concentrations were 0.019, 0.026, 0.032, and 0.045 ppm, respectively. **Results:** The

study subjects showed no deterioration in lung function. Prevalence of cough and phlegm among all participants were significantly higher in 2006 than in 2004, and age-, sex- and smoking-adjusted odds ratios of cough and phlegm were 1.75 (95%CI 1.33–2.30) and 1.44 (1.12–1.87). Prevalence of chronic bronchitis-like symptoms among normosusceptible subjects in 2006 was 4.1% which was significantly higher than that of 2.1% in 2004 ($p=0.035$). Compared to area L, the frequencies of phlegm and irritation of the nose were significantly increased in areas H-2 and H-3. **Conclusion:** SO₂ exposure-related respiratory symptoms were observed in adult Miyakejima residents after returning to the island.

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Key words: Volcanic gases, Sulfur Dioxide, Respiratory symptoms, Spirometry

Miyakejima Island is an island volcano 8 km in diameter, located 180 km south-southwest of Tokyo. In the last 500 yr, Mt. Oyama has erupted repeatedly about every fifty years. The last eruption started in June, 2000, and due to continuous eruptions and emissions of lethal/unsafe amounts of volcanic gas, the Miyake village government decided to evacuate all residents from the island in September, 2000. At the time of the evacuation, the amount of sulfur dioxide discharge, the major toxic component of the volcanic gas, was approximately 50,000 tons/day¹⁾. The volcanic activity gradually decreased, but it has not ceased and sulfur dioxide discharges of

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Correspondence to: S. Iwasawa, Department of Preventive Medicine and Public Health, School of Medicine, Keio University, 35 Shinanomachi, Shinjuku, Tokyo 160-8582, Japan (e-mail: di055005@sc.itc.keio.ac.jp)

1,200 – 3,500 tons/day continue to be observed as of July, 2007.

In September 2002, the Tokyo Metropolitan Government and the Cabinet Office of Japan organized a Scientific Committee for Assessment of Health Risk and Volcanic Activity in Miyakejima Island (*Miyakejima kazan gas kentoukai*) and began to discuss requirements for cancellation of the evacuation order and a return to the island. The Committee published the assessment report in March 2003²⁾ and concluded that there remained both acute and chronic health risks induced by volcanic gas inhalation if the villagers returned to the island. However, the report also indicated that the health risks would be kept to a minimum if (1) the annual average SO₂ concentrations in residential areas were 0.04 ppm or below and the percentage of the time of SO₂ concentrations exceeding 0.1 ppm were less than 10%, (2) the village government developed an alert system for high levels of volcanic gas emissions and for evacuating residents away from the gas, and (3) the residents sufficiently understood the acute and chronic health risk induced by volcanic gas inhalation and promised to act under order of evacuation by the village government. The committee also recommended that the village government should perform health check-ups of the respiratory system for all villagers before their return to the island in order to make them aware of their own respiratory sensitivity to SO₂, because asthmatics are particularly susceptible to SO₂, and should continue to do health check-ups every year after returning to the island to detect early effects of SO₂ on the respiratory system, because SO₂ concentrations on the island are high enough to induce acute and chronic effects on the respiratory system.

The village government developed an alert system and finished installing it around the end of 2004. Health risk communication activity was performed approximately 60 times from April 2003 to March 2004 in voluntary cooperation with the authors³⁾, and approximately 1,600 villagers participated in the activity. In July 2004, the village council decided to cancel the evacuation order on February 1st, 2005, and to approve residence in the area designated by the Scientific Committee for villagers who accepted the health risk voluntarily and promised to act under the government order of evacuation. The village government carried out health check-ups in the autumn of 2004. On February 1st, 2005, 1,477 villagers returned and restarted their lives on Miyakejima island.

After returning to the island, the village government annually carried out the health check-ups under the Ordinance of Security for Safety and Health against Volcanic Gas promulgated by the Miyake Village Government.

We analyzed the 2-yr changes in the respiratory system of adult Miyakejima resident villagers using health check-up data from autumn 2004 and November 2006, namely,

before and 2-yr after villagers' returning to the island. We did not use the February 2006 data because we considered that comparability of the data was somewhat heterogeneous since February is in the winter and is a flu season in Japan.

Subjects and Methods

Assessment of SO₂ concentrations

The Tokyo Metropolitan Government has continuously monitored SO₂ levels at 7 sampling points in inhabited areas on the road circling the island using SO₂ monitors (100-AH, Rikenkeiki, Tokyo, Japan, or APSA-360, Horiba, Kyoto, Japan) (Fig. 1.), and has disclosed 5-min SO₂ averages. Based on these values, we categorized the inhabited area into 1 lower-SO₂ area and 3 higher-SO₂ areas, namely, Izu and Kamitsuki districts as Area L, the Igaya district as Area H-1, the Tsubota district as Area H-2, and the Ako district as Area H-3. Table 1 shows the SO₂ concentrations by area from February 2005 to November 2006. The average SO₂ concentration in all areas was 0.031 ppm, and those in areas L, H-1, H-2 and H-3 were 0.019, 0.026, 0.032, and 0.045 ppm, respectively. The rates (%) of SO₂ 1-h averages exceeding 0.1 ppm in Areas L, H-1, H-2 and H-3 were 2.0, 4.4, 6.0, and 7.5%. The maximal 5-min averages in Areas L, H-1, H-2 and H-3 were 4.27, 5.40, 17.25, and 5.52 ppm. The fluctuation of the SO₂ concentration during February 2005 to November 2006 was not significant.

Study population

The study population was registered adult villagers of Miyakejima village. Just before returning to the island in 2004, the number of villagers were 2,983, and 1,909 of these participated in the health check-ups carried out from September to November, 2004. The participation rate was 64.0%.

The 2-yr follow-up health check-up was performed in November 2006. Table 1 shows the characteristics of the participants. The number of registered villagers was 2,669 in 2006, and 823 participated in the health check-up. The overall participation rate was 30.8%. No differences in sex ratio, age, or smoking habit were found among the four SO₂ concentration areas.

Among the participants in the 2006 health check-up, 128 residents were judged by physicians in the village clinic to be hypersusceptible to SO₂ because they had a current or past history of asthma, obstructive lung function, current symptoms of whistling and wheezing, and/or deterioration of pulmonary symptoms. When diagnosis was difficult, specialists of respiratory medicine made the assessment.

Medical examinations

Respiratory symptoms were examined using the Japanese version of the self-administered ATS-DLD

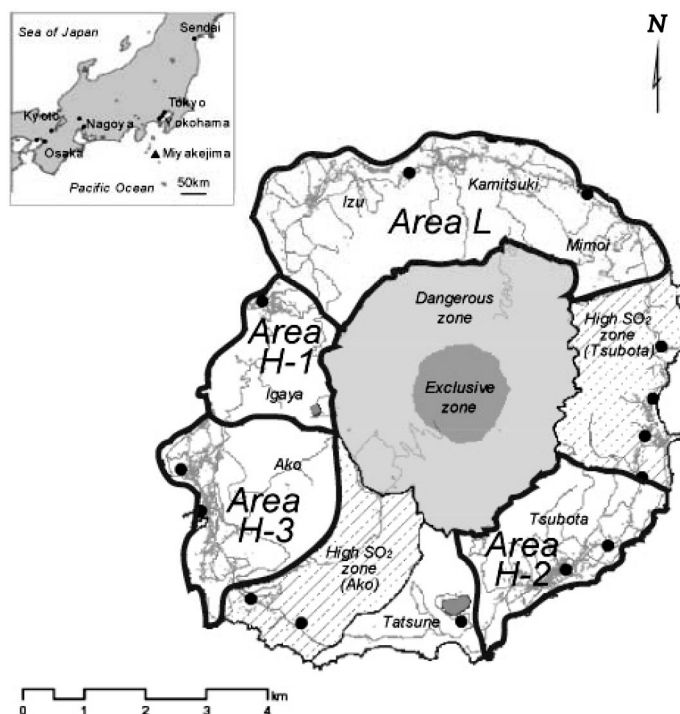


Fig. 1. Miyakejima (Black solid circles indicate fixed monitoring stations).

Table 1. Characteristics of study population and concentrations of SO₂

	All n=823	Area			<i>p</i> *	
		L n=298	H-1 n=76	H-2 n=214		H-3 n=235
Participation rate (%)	30.8	32.7	45.8	31.7	25.6	<0.001
Male (%)	43.3	44.3	46.1	45.1	39.6	0.58
Age (yr)						
mean ± SD	64.1 ± 16.1	64.3 ± 15.0	66.9 ± 14.2	63.3 ± 17.6	63.6 ± 16.5	0.38
range	19–95	20–93	19–95	19–88	20–95	
Smoking (%)						
Current smoker	20.3	20.1	17.1	21.1	20.9	0.40
Past smoker	14.1	17.1	7.9	13.1	13.6	
Non-smoker	65.5	62.8	75.0	65.7	65.5	
Hypersusceptives (%)	15.6	13.4	14.5	16.4	17.9	0.54
Concentration of SO ₂ [#]						
Average (ppm)	0.031	0.019	0.026	0.032	0.045	
Rate of SO ₂ 1-h average exceeding 0.1 ppm (%)	5.0	2.0	4.4	6.0	7.5	
Maximal 5-min average concentration (ppm)	17.25	4.27	5.40	17.25	5.52	

L: Izu, Kamitsuki and Mimi districts. H-1: Igaya district. H-2: Tsubota district. H-3: Ako district. *: *p* by one-way ANOVA or Chi square test. #: 5-min average concentration of SO₂ during February 2005 to November 2006.

Table 2. Two-year changes in pulmonary function in study subjects who participated in both 2004 and 2006 health check-ups

	2004		2006		Two-year change (2006–2004)				
	n		n		All	L	H-1	H-2	H-3
Female									
n	232		232		232	76	21	59	76
FVC	2.32 ± 0.60		2.38 ± 0.53		0.06 ± 0.36*	0.08 ± 0.35*	0.15 ± 0.3*	0.01 ± 0.44	0.08 ± 0.32*
FEV ₁	1.81 ± 0.48		1.84 ± 0.44		0.03 ± 0.25	0.03 ± 0.28	0.04 ± 0.22	0.03 ± 0.28	0.04 ± 0.23
FEV ₁ %	78.12 ± 8.33		77.41 ± 7.23		-0.72 ± 8.88	-1.22 ± 9.09	-3.85 ± 7.80*	0.22 ± 9.18	-0.83 ± 8.51
MEF ₅₀	2.50 ± 1.11		2.50 ± 1.10		0.00 ± 0.96	-0.12 ± 1.07	-0.33 ± 1.15	0.07 ± 0.68	0.12 ± 0.87
MEF ₂₅	0.72 ± 0.48		0.66 ± 0.42		-0.07 ± 0.45	-0.11 ± 0.53	-0.20 ± 0.51	0.01 ± 0.36	-0.06 ± 0.37
%FVC	98.80 ± 20.58		104.12 ± 16.13		5.32 ± 16.67**	5.70 ± 16.4**	10.51 ± 13.43**	3.85 ± 21.24	6.34 ± 14.52**
%FEV ₁	95.18 ± 19.82		101.12 ± 17.18		5.94 ± 14.77**	5.95 ± 16.18**	7.36 ± 13.39*	6.00 ± 18.07*	6.06 ± 13.14**
%MEF ₅₀	88.54 ± 35.81		92.83 ± 38.27		4.29 ± 35.59	-0.07 ± 38.02	-6.78 ± 43.23	6.45 ± 27.06	8.91 ± 34.45*
%MEF ₂₅	72.70 ± 44.28		73.00 ± 44.33		-0.04 ± 48.63	-3.35 ± 58.72	-10.76 ± 53.92	7.11 ± 45.22	-0.65 ± 42.10
Male									
n	175		175		175	57	21	41	56
FVC	3.26 ± 0.79		3.26 ± 0.74		0.00 ± 0.37	-0.02 ± 0.43	-0.06 ± 0.37	-0.02 ± 0.29	0.01 ± 0.36
FEV ₁	2.53 ± 0.71		2.51 ± 0.68		-0.02 ± 0.28	-0.03 ± 0.33	0.01 ± 0.25	-0.03 ± 0.28	-0.01 ± 0.23
FEV ₁ %	77.46 ± 9.38		76.82 ± 8.66		-0.63 ± 5.91	-0.62 ± 6.46	1.37 ± 6.34	-1.07 ± 6.52	-0.92 ± 5.80
MEF ₅₀	3.23 ± 1.43		3.11 ± 1.42		-0.12 ± 0.86	-0.05 ± 0.84	-0.05 ± 0.93	-0.08 ± 0.91	-0.19 ± 0.86
MEF ₂₅	1.00 ± 0.65		0.92 ± 0.59		-0.08 ± 0.41*	-0.07 ± 0.48	0.05 ± 0.45	-0.06 ± 0.46	-0.09 ± 0.33
%FVC	91.14 ± 15.75		93.65 ± 15.34		2.50 ± 12.31*	1.94 ± 14.83	0.85 ± 10.93	0.72 ± 8.76	2.98 ± 12.92
%FEV ₁	85.94 ± 15.93		88.58 ± 16.06		2.64 ± 11.67**	2.19 ± 15.29	3.77 ± 9.91	0.51 ± 10.63	2.76 ± 10.08
%MEF ₅₀	86.27 ± 33.51		86.16 ± 32.62		-0.11 ± 26.43	2.80 ± 26.66	1.74 ± 27.02	0.43 ± 28.04	-3.74 ± 25.67
%MEF ₂₅	72.63 ± 40.82		73.14 ± 37.88		0.97 ± 35.04	3.45 ± 40.67	10.90 ± 38.88	-0.67 ± 36.72	-0.82 ± 30.11

*, **: $p < 0.05$ and 0.01 by paired t -test.

(American Thoracic Society-Division of Lung Disease) questionnaire⁴) with additional questions regarding job histories. All answers to the questionnaire were confirmed and, if necessary, rewritten in more detail based on a doctor's interview or trained interviewer.

According to Fletcher's criteria⁵, we defined symptoms of chronic bronchitis as complaining of "cough and phlegm continuing for at least 3 mo or more every year" for assessing the 2-yr effect of SO₂ on the lungs.

Pulmonary function was assessed by utilizing the forced maximum expiratory flow-volume test (spirometry) using electronic autospirometers (Easy One spirometer, ndd Medical Technologies; Andover, MA) operated by experienced clinical laboratory technicians. Because the reliability and reproducibility of the spirometry measurements depends strongly on the cooperation and efforts of the examinees, the significance of and method for the spirometry were explained to all examinees, who were then trained in mastering the test maneuver. The flow-volume test was repeated at least three times for each subject, and the trial satisfying the criteria recommended by the ATS⁶ was used for statistical analysis. Using prediction equations developed by the Japanese Respiratory Society⁷, %predicted values were calculated.

Statistical analysis

For continuous data, data distribution was examined, and an appropriate transformation was performed to approximate a normal distribution before the analysis. The mean values of the variables were compared by Student's *t*-test, or analysis of variance followed by Dunnett's test for adjusting multiple comparisons. For prevalence data of subjective symptoms and chronic bronchitis-like symptoms, prevalence was compared by the chi-square test, Fisher's exact method, or the McNemar test. Adjusted odds ratios were examined using a logistic regression model considering sex, age, current smoking status, residential area and hypersusceptiveness.

All statistical analysis was performed using SPSS version 15.0 (SPSS Institute Inc.) and Excel 2003 (SP3, Microsoft Co.).

Results

Lung function test

Excluding spirometry with insufficient test maneuvers, pulmonary function at the time of the 2006 health check-up was compared by sex and area, as well as between normosusceptive and hypersusceptive subjects. There was no difference in either sex in lung function among the areas. Hypersusceptive subjects showed lower lung function compared to normosusceptive subjects (data not shown).

Table 2 demonstrates the lung function of 407 residents out of 673 participants in both the 2004 and 2006 health

check-ups. Two-year differences in a few lung function parameters were significantly but sporadically decreased as assessed by the paired *t*-test, but %predicted parameters were significantly increased in both males and females. Hypersusceptive subjects also showed no deterioration of lung function after 2 yr SO₂ exposure (data not shown). In addition, no significant differences in lung function changes were observed among the four areas. When smokers and non-smokers were separately analyzed, only female smokers showed significant decrease of FEV₁ 1.0%.

Subjective symptoms

Table 3 shows the changes in prevalence of respiratory symptoms in those who participated in both the 2004 and 2006 health check-ups. The prevalences of "Do you usually have a cough? (Cough)" and "Do you usually bring up phlegm from your chest? (Phlegm)" were significantly increased in 2006 in all subjects. Age-, sex-, smoking- and residential area-adjusted odds ratios indicated a more than 1.44 times increase in the prevalences. Male smokers showed larger increases in prevalences of Cough and Phlegm than male non-smokers, and age- and residential area-adjusted odds ratios indicated a 3.84 times increase in Cough and a 2.10 times increase in Phlegm. Female smokers also showed larger increases in prevalences of Cough and Phlegm than female non-smokers, but the increases of adjusted odds ratios were not statistically significant, probably due to the small number of female smokers. In addition, no significant differences in prevalence of respiratory symptom changes were observed among the four areas.

Table 4 demonstrates the number of normosusceptive residents with or without chronic bronchitis-like symptoms in 2004 and 2006 who participated in both health check-ups. The prevalence of chronic bronchitis-like symptoms in 2004 was 2.1% (12/555), whereas that in 2006 was 4.1% (23/555). The increase was statistically significant by the McNemar test ($p=0.035$). Although statistically not significant, the increase in the symptoms was higher in Areas H-2 and H-3 than in Area L.

Table 5 compares the differences in the prevalence of symptoms among the four areas. No clear differences were observed among the four areas except for increasing frequencies of phlegm and irritation of the nose in the highest SO₂ concentration areas, H-2 and H-3, after returning to the island. Age-, sex-, smoking-, and hypersensitivity-adjusted odds ratio of the nasal irritation in Area H-2 was 1.63 (95% CI: 1.01–2.62) when subjects in Area L were assigned as a referent population.

Discussion

This is the first follow-up study evaluating the influence of volcanic gas on the health of Miyakejima adult villagers who returned to the island.

The volcanic gases from Mt. Oyama contain not only

Table 3. Changes in prevalence of respiratory symptoms in study subjects who participated in both 2004 and 2006 health check-ups

	n	Prevalence (%)		p*	AOR (95% CI) ^{\$1}	AOR (95% CI) ^{\$2}
		2004	2006			
Do you usually have a cough?						
All subjects	673	16.2	25.4	<0.001	1.75 (1.33–2.30)	
Male						
Non-smokers	179	15.6	19.0	0.405		1.25 (0.71–2.20)
Smokers	88	14.9	39.8	<0.001		3.84 (1.84–8.03)
Female	372	16.0	24.2	0.001		1.64 (1.13–2.36)
Non-smokers						
Smokers	33	25.8	36.4	0.219		1.70 (0.55–5.27)
Do you usually bring up phlegm from your chest?						
All subjects		20.7	27.5	<0.001	1.44 (1.12–1.87)	
Male		25.4	26.8	0.719		1.04 (0.64–1.70)
Non-smokers						
Smokers		32.2	50.0	0.012		2.10 (1.13–3.90)
Female		15.7	21.5	0.005		1.44 (0.99–2.10)
Non-smokers						
Smokers		22.6	39.4	0.031		2.23 (0.74–6.76)
Does your chest ever sound wheezy or whistling?						
All subjects		13.2	15.3	0.230	1.21 (0.89–1.65)	
Male		13.3	12.8	1.000		0.96 (0.51–1.79)
Non-smokers						
Smokers		13.8	18.2	0.508		1.49 (0.64 – 3.45)
Female		13.3	15.1	0.496		1.17 (0.77–1.77)
Non-smokers						
Smokers		9.7	24.2	0.125		3.44 (0.75–15.7)
Have you ever had an attack of wheezing that has made you feel short of breath?						
All subjects		8.2	8.6	0.784	1.13 (0.76–1.67)	
Male		10.4	8.4	0.629		0.84 (0.40–1.74)
Non-smokers						
Smokers		3.4	4.5	1.000		1.68 (0.32–8.70)
Female		7.6	9.2	0.391		1.27 (0.75–2.15)
Non-smokers						
Smokers		16.1	15.2	1.000		0.87 (0.18–4.20)

*: p by McNemar test. ^{\$1}: Age-, sex-, smoking- and residential area-adjusted odds ratio (\$1) or age- and residential area-adjusted odds ratio (\$2) with 95% confidence interval applying logistic regression model. Smoking status of 1 male was unknown.

Table 4. Change of chronic bronchitis-like symptoms in normo-susceptive population

Chronic bronchitis-like symptoms		2006 health check-up									
		All		Area							
				L		H-1		H-2		H-3	
Yes	No	Yes	No	Yes	No	Yes	No	Yes	No		
2004 health check-up	Yes	6	6	2	2	0	1	0	2	4	1
	No	17	526	3	185	0	55	7	132	7	154
	<i>p</i> *	0.035		1.000		1.000		0.180		0.070	

*: *p* value by McNemar test.

SO₂ but also hydrogen sulfide, hydrogen chloride, carbon dioxide, and suspended particulate matters (SPM)². Hydrogen sulfide has been continuously monitored at five sampling sites, and the maximum concentration detected has been 2.9 ppm². Hydrogen chloride and SPM are also discharged, but their concentrations have been negligible². Carbon dioxide is not a respiratory irritant. Thus, volcanic gases other than SO₂ are unlikely to have caused the health effects seen in this study. The Air Quality Standard of SO₂ in Japan is 0.04 ppm or below in the daily average of 1-h SO₂ concentrations and 0.1 ppm or below in the 1-h SO₂ concentration. SO₂ concentrations for the whole island of Miyakejima do not yet meet this standard.

During the 2-yr exposure to SO₂, no deterioration of lung function of 232 female and 175 male residents was detected. Therefore, an average SO₂ exposure of 0.031 ppm for 2 yr may be an acceptable level for both normosusceptive and hypersusceptive adult populations. In women, some spirometric parameters were rather improved, which is an unusual change from a physiological point of view. We have no appropriate interpretation of these changes, but speculate that the changes might be the result of (1) environmental change from life in a small and uncomfortable urban apartment complex during the 4-yr evacuation; (2) moderate activity in agriculture improving physical capacity; and/or (3) subjects' skills in carrying out spirometry improved. Because of the absence of lung function data from 2004 or insufficient spirometric maneuver in either the 2004 or 2006 health check-up, 266 study subjects were excluded from the analysis of lung function changes. Between the 266 subjects and the 407 subjects included in the lung function analysis, no differences in age, smoking habit, living area, and proportion of hypersusceptives were found. Thus, it is unlikely that lung function changes were unfairly estimated.

The prevalences of Cough and Phlegm in the 2006 health check-up were significantly higher than those in the 2004 health check-up. This suggests that the mean

exposure to 0.03 ppm of SO₂ for 2 yr may have played a significant role in the increase of the prevalences of Cough and Phlegm because the study subjects were free from SO₂ exposure in 2004. The larger increases in prevalences of Cough and Phlegm observed in smokers may be interpretable as additive effects of irritation on the airway by coincident exposure to tobacco smoke and SO₂.

The prevalence of chronic bronchitis-like symptoms defined by Fletcher⁵ increased from 2.1% in 2004 to 4.2% in 2006 (*p*=0.035) in normosusceptive residents. The increase is within the range of expectations reported by the Scientific Committee for Assessment of Health Risk and Volcanic Activity in Miyakejima Island⁸.

Uno *et al.* (2005)⁹ carried out a health questionnaire study of 1,260 workers and health check-ups on 100 randomly selected workers in 2003, all of whom were hired by the Tokyo Metropolitan government or by the Miyake Village government and engaged in reconstruction work on the Miyakejima island. Although SO₂ concentrations were higher in 2003 than in 2005–2006, no clear relationships between SO₂ and the incidences of respiratory and cardiovascular effects were discovered. Uno *et al.* concluded that some kind of healthy worker effect might explain the results. Another possible reason may be an information bias, induced by fear of discharge due to health effects of the volcanic gases.

Based on a 10-yr follow-up observation in the Azores, Portugal, Amaral *et al.* (2007)¹⁰ reported a relationship between exposure to volcanic gases and the incidence of chronic bronchitis recorded at local health centers. Relative risks of chronic bronchitis in males and females exposed to volcanic gases were 3.99 (95% CI; 2.98–5.35) and 10.74 (6.55–17.34), respectively, compared to those living in volcanically inactive areas. Mean SO₂ concentrations measured by diffusion tubes placed in a residence area for a 2-wk sampling period were 10 ppb¹¹. Mannino *et al.* (1996)¹² and Michaud *et al.* (2004)¹³ analyzed emergency department visits and Kilauea Volcano fog-related air quality in Hilo, Hawaii, and

Table 5. Prevalence of subjective symptoms in 2006 by area

Area	Prevalence (%)			AOR (95% CI)			
	L n=298	H-1 n=76	H-2 n=214	L	H-1	H-2	H-3
Do you usually have a cough?	25.2	23.7	20.1	30.6	1	0.91 (0.49–1.71)	1.22 (0.82–1.83)
Do you usually bring up phlegm from your chest?	25.5	30.3	25.2	32.3	1	1.28 (0.70–2.34)	1.37 (0.91–2.05)
Does your chest ever sound wheezy or whistling?	13.8	17.1	13.6	16.2	1	1.43 (0.59–3.45)	0.95 (0.52–1.77)
Have you ever had an attack of wheezing that has made you feel short of breath?	7.4	11.8	8.4	10.7	1	2.18 (0.65–7.31)	1.13 (0.50–2.52)
Are you troubled by shortness of breath when hurrying on the level or walking up a slight hill? ^s	13.1	18.4	13.6	17.4	1	1.61 (0.81–3.20)	1.03 (0.61–1.74)
Do you have to walk slower than people of your age on the level because of breathlessness? ^s	5.7	7.9	7.5	4.7	–#	–	–
Do you ever have to stop for breath when walking at your own pace on the level? ^s	3.0	2.7	7.0	3.8	–#	–	–
Do you have a history of asthma diagnosed by a doctor?	6.4	15.8*	8.5	10.6	1	5.28 (1.79–15.6)	1.45 (0.66–3.17)
After you returned to the island, do you feel increase of the frequency of symptoms below?							
Cough	14.6	14.5	16.0	18.7	1	0.96 (0.46–1.99)	1.26 (0.79–2.02)
Phlegm	10.8	13.2	16.4*	16.6*	1	1.25 (0.58–2.72)	1.56 (0.94–2.60)
Wheezy or whistling when breathing	5.1	8.0	5.6	5.5	1	1.83 (0.62–5.39)	0.95 (0.42–2.17)
Irritation and/or pain of the throat	15.5	11.8	17.8	21.0	1	0.72 (0.33–1.59)	1.12 (0.69–1.83)
Irritation, runny nose, and/or sniffles of the nose	13.9	17.6	21.0*	21.3*	1	1.32 (0.66–2.66)	1.63 (1.01–2.62)
Irritation and/or pain of the eyes	21.2	21.1	24.3	26.4	1	0.99 (0.53–1.86)	1.15 (0.75–1.76)
Itchy skin	11.8	13.2	9.9	16.2	1	1.08 (0.51–2.32)	1.45 (0.88–2.40)
Catching a cold	7.2	5.3	10.4	8.1	1	0.70 (0.23–2.15)	1.07 (0.55–2.07)

AOR (95% CI): Odds ratio adjusted by age, sex, smoking and hypersusceptibility with 95% confidence interval applying logistic regression model. ^s: Those who suffered from dysarthrosis of foot/leg, coronary heart diseases, and lung diseases were excluded from statistical analysis. *: $p < 0.05$ compared to Low area by Chi square test of Fisher's exact method. #: Logistic regression model was invalid because it was statistically insignificant.

concluded that asthma/COPD had consistent, positive associations with air quality. The air quality data means from 21 February 1997 to 31 May 2001 were 1.97 ppb (range; 0.0–108.5) for SO₂ and 1.91 µg/m³ (0.0–56.6) for PM₁. These reports indicate that SO₂ is a major causal component of chronic bronchitis in volcanically active areas as seen in this study. However, because the diagnostic criteria for chronic bronchitis and SO₂ exposure duration were different in this study and the other 2 studies, it is difficult to compare exposure-response relationships between SO₂ concentrations and the incidence/prevalence of chronic bronchitis.

Short-term high exposure concentrations rather than average exposure concentrations may contribute to irritative symptoms. The significantly higher prevalence of nasal irritation seen in Areas H-2 and H-3 may be due to their higher maximum 5-min concentrations and/or the higher rates of 5-min averages exceeding 0.1 ppm of SO₂. Ishigami *et al.* (2008)¹⁴ conducted an hour-based follow-up study of 611 healthy volunteers who visited Miyakejima island to provide support to residents, and stayed on the island for a few to 15 days from February to July 2005. The hourly incidence of irritative symptoms showed clear exposure-response relationships with hourly average SO₂ concentrations, and exposure to 0.01–0.2 ppm SO₂ or above increased the rates of irritative symptoms such as throat irritation and cough. This result seems to be consistent with our study.

This study has several advantages over other studies which have investigated exposure to SO₂. The observed health effects could be regarded as being specific to volcanic SO₂, since potential health effects by other pollutants such as volcanic hydrogen sulfide and particles or traffic-related pollutants including volatile organic compounds (VOCs) and fine particles have been negligibly low in Miyakejima. However, this study also has some limitations. First, exposure was not personally monitored but approximated by environmental concentrations at the nearest monitoring station. Second, the participation rate was 30.8%. We have no way to assess the differences in characteristics between participants and non-participant residents which could possibly influence the results of this study. No differences in sex ratio, age, and smoking habit were found between the only 2006 health check-up participants and only 2004 health check-up participants. Thus, comparisons between 2004 and 2006 participants may be negligibly biased. The prevalence of airflow limitation as defined by the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria (FEV₁/FVC < 70%) in the present study population was 6.7% in 50–59 y.o., 10.4% in 60–69 y.o., and 24.3% in > 70 y.o., similar to those of the Nippon COPD Epidemiology (NICE) study¹⁵ conducted in 2,343 representative Japanese. Thus, our study population appears not to have been biased in the sense of COPD

status.

A third limitation is the difference in the frequency of official SO₂ alert notices might influence the prevalence of symptoms. The frequency of official alert announcements in the one year before the health check-up was 73 in Area L, 196 in Area H-1, 460 in Area H-2, and 345 in Area H-3. However, the prevalence of symptoms in Area H-3 was higher than that in Area H-2 where the official alert was most frequently announced. Thus, the possibility of some undue influence due to a recall bias was low.

Finally, the prevalence of symptoms in 2004 might be underestimated because most of the participants had a strong desire to go back to their home island, Miyakejima, and therefore might have tended to state a more healthy physical condition. As a result, differences in prevalence between 2004 and 2006 may have resulted from overestimation.

In conclusion, we observed minor health effects on the respiratory system due to 2-yr exposure to mean concentrations of 0.03 ppm SO₂ on Miyakejima Island. This effect was comparable in magnitude to that expected by the Scientific Committee for Assessment of Health Risk and Volcanic Activity in Miyakejima Island (*Miyakejima kazan gas kentoukai*). However, these results may suggest the early stage of a long-term influence. It is therefore necessary to follow-up the effects on the lungs in the future until the volcanic gas emissions have ceased.

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