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Effects of the Miyakejima Volcano Eruption on Public Health

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Abstract

In June 2000, the Miyakejima volcano suddenly erupted, forcing evacuation of all inhabitants. We undertook this study to evaluate the effects on the health of inhabitants after their returning to the island 4 years after the eruption. We examined 269 inhabitants, who visited the Miyakejima Central Clinic, and specifically discussed symptoms related to exposure and anxiety related to the disaster. These data refer to patients who voluntarily visited the health facility, and thus represent the reasons for seeking health care after return to the island. Symptoms related to gas exposure were common, including throat pain (28%) and headache (20%). With a higher concentration of SO_2, the incidence was higher in downwind areas where inhabitants had more symptoms and anxiety. There has been no severe acute attack related to volcanic gas, because detailed SO_2 monitoring and distributing quick information could act effectively. In conclusion, under the threat of imminent gas emission, detailed gas monitoring and care for mental and health condition should be performed according to regional character, which would save the public health and relief inhabitant's anxiety.

Herein, we report practical suggestions for disaster management in large scale volcanic eruption.

Keywords

Miyakejima, Volcanic gas, SO_2 monitoring, Disaster management

Introduction

In June 2000, the Miyakejima volcano eruption with high levels of volcanic activity led to the evacuation of the entire island. For more than four years, the displacement of inhabitants lasted officially at Tokyo 175 km far from Miyakejima. At the beginning of the eruption, the Miyakejima volcano emitted volcanic gas, mainly sulfur dioxide (SO_2), at a rate of 40,000 to 50,000 tons per day. Gradually, the emission decreased to 100~500 tons per day [1].

The Cabinet Office of Japan and the Tokyo Metropolitan Government convened an expert panel to assess the acute and chronic health risks to the respiratory health of Miyakejima inhabitants. This panel proposed that levels of volcanic SO_2 on Miyakejima should be < 0.04 ppm in annual mean measurement and the frequency of > 0.1 ppm levels in a one-hour measurement should be < 10% in order to minimize long term health effects [2].

In Japan, six tourists died due to the inhalation of volcanic gas, including SO_2, at Mt. Aso. Four of the six fatalities had a previous history of bronchial asthma. Forensic autopsy revealed severe pulmonary emphysematous changes and congestion in the lungs due to volcanic gas inhalation [3]. These findings support the idea that individuals with chronic lung disease and severe heart disease are classified at a higher risk of developing health problems after volcanic gas inhalation including the one at Miyakejima.

The Miyakejima volcanic eruption in June 2000 was characterized by the formation of a large collapsed caldera at the summit. The large amount of volcanic gas is supplied as volatile-rich magma from a deep magma chamber by magma convection. The large magma conduit system is likely created as a result of the collapsed caldera formation at Miyakejima [4,5]. The total SO_2 emissions during the first 20 months after the eruption (September 2000 through May 2002) amounted to 15 Mt which is comparable to the SO_2 emitted by the explosive Pinatubo eruption in 1991 during the same time interval [4].

The five-minute average SO_2 concentration often exceeded 5 ppm particularly in the eastern and southwestern areas of the island corresponding to

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Ako and Tsubota, which are on the leeward side of the prevailing winds. Monitoring devices (SO_2 monitors, 100-AH, Rikenkeiki, Tokyo, Japan, or APSA-360, Horiva, Kyoto, Japan) for SO_2 were placed at 16 sampling points on the island [2], which was based on the Mount Aso experience [3].

Some studies investigated the health condition of short-term volunteers or construction workers who came to Miyakejima from other areas [6,7]. Volcanic ash and gas affected a very wide area around the volcano, where the social infrastructure on the island collapsed and severe mental stress occurred at the time between the eruption, the evacuation and the re-entry. We evaluated the inhabitants' anxiety as well as their health condition, during routine treatment at the Miyakejima Central Clinic. This clinic is the sole medical institution on the island This study was performed under a unique situation; on an island, prolonged resident displacement, just after the returning and community recovery complicated by ongoing volcanic activity, where the study includes limitation of population studied and immature questionnaire. This study will be helpful not only for disaster medicine but also for rebuilding the community.

Methods

This survey was conducted in May 2005, about three months after an official proclamation was issued in February 2005 declaring that the environment after the eruption was stable, and that returning to Miyakejima was allowed. A written survey was administered to patients presenting to the outpatient clinic, and thus represents a specific population among inhabitants of the island. Informed consent was obtained from each patient in writing prior to the study, which was designed to analyze serial changes in health conditions after return to the island. Using a questionnaire, 269 patients who visited the Miyakejima central clinic, all over 20-years-old, were asked a number of questions about symptoms related to volcanic gas exposure, stress-related disorders and anxiety in performing activities of daily living, and where they live on the island.

All respondents were questioned in person by one of the authors (MS). Inhabitants who voluntarily visited the clinic were asked to participate in the study, most of whom presented for the treatment of hypertension, back pain, etc. Thus, the presenting problems were not necessarily related to volcanic gas exposure. In this study, the average age was five years older than that of the inhabitants of the island and surveyed only those over age 20. The slightly older age of participants may reflect the fact that people with illnesses are slightly older in general.

Demographic Data

The period between returning to the island and conduct of the survey was from zero to over 100 days. A total of 269 people (137 male, 132 female; mean age; 67.6 ± 14.6 years raging 22-95 years) were surveyed. Overall, 15% of the inhabitants of Miyakejima answered the questionnaire.

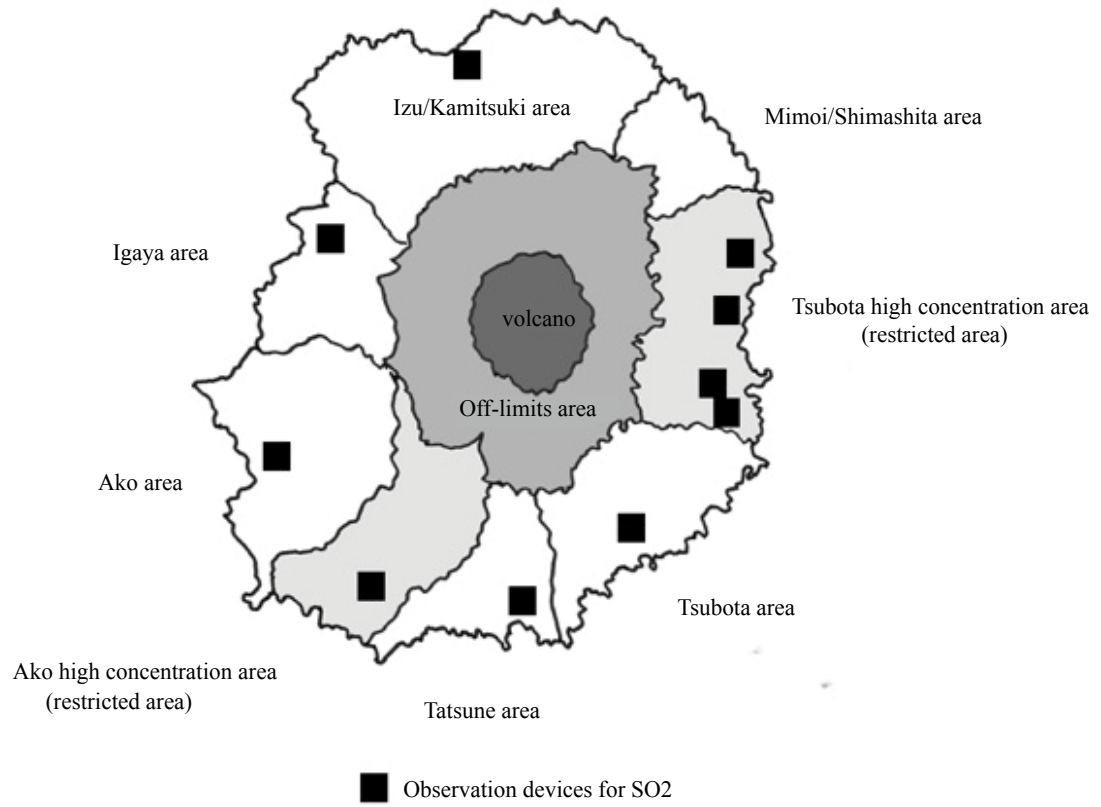

Figure 1: Miyakejima map, showing the area surrounding the volcano, with restricted and residential areas. The devices placed by the government to monitor SO_2 concentration are shown.

Miyakejima was divided into 3 regions based on location relative to the volcano: A hazard area equal to the volcanic vent, an off-limits area around the volcanic vent and further outlying residential areas as shown in Figure 1. In some residential areas, including part of Tsubota and Ako which were high concentration areas, the SO_2 concentration sometimes was so elevated due to being downwind of the volcano that inhabitants were forbidden to live there. Although part of the Ako area and part of the Tsubota area were restricted, the area between was not restricted because of prevailing wind patterns and the distribution of SO_2, as analyzed by the detectors shown in Figure 1. The area between the restricted areas was judged as safe by governmental authorities. One-hundred inhabitants in Ako, 17 in Igaya, 43 in Izu, 54 in Kamitsuki, 55 in Tsubota participated in the survey.

Statistical Analysis

Data management and statistical analyses were performed using Microsoft Excel. Comparison of the theoretical value and frequency of symptoms was evaluated with the χ^2 test. This test was chosen to evaluate the variance of the frequency of symptoms in a population. Age-specific symptoms were evaluated using the unpaired-Student's t-test. A p-value of less than 0.05 was considered statistically significant. This test was chosen to evaluate the null hypothesis among the populations evaluated.

Results

Acute health effects

No one had an acute attack directly attributable to volcanic gas. However, 31.7% of those surveyed had some symptoms. The mean age of inhabitants with symptoms was 60.0 ± 15.5 years old, compared to a mean age of those without symptom at 70.2 ± 13.1 years old. Inhabitants with symptoms were significantly more than 10 years younger than those without symptoms ($P < 0.01$).

Subjective symptoms attributed to volcanic gas exposure included throat irritation 27.5%, headache 20.3%, and eye pain 10.1%. Other symptoms are shown in Table 1. As for headache and throat irritation, we could not rule out the common cold as a cause. It may be difficult to definitely attribute symptoms to specific levels of the gases.

The mean age of those with respiratory symptoms (breathing difficulty 72.4 years old, cough 65.1 years old) was relatively older than those with other symptoms (throat irritation 56.0 years old, headache 59.0 years old, nasal irritation 45.3 years old), as shown in Table 1.

The government issued alerts based on the results of monitoring data. The criteria used for these alerts are shown in Table 2. From February 2005 to June 2005, over 100 volcanic alerts were issued in the Ako (130 times) and Tsubota (176 times) areas, as shown in Figure 2. Compared to those areas, there were about one fourth the number of notices and alerts in Izu (45 times) and Kamitsuki (45 times). Ako and Tsubota were likely to be leeward in prevailing volcanic gases, which caused elevated SO_2 levels in both areas. In analyzing ratio of symptom from each area, 41.9% of Ako and 30.2%

Table 1: Symptoms reported by patients seen in the clinic.

Symptom	People reporting (%)	Mean age (years)
Throat irritation and discomfort	27.5	56.0 ± 17.7
Headache	20.3	59.0 ± 16.7
Dry cough	15.9	65.1 ± 13.1
Breathing difficulty	10.1	72.4 ± 7.4
Tearing	10.1	70.6 ± 6.0
Eye pain	10.1	60.4 ± 16.5
Nasal pain	7.2	45.3 ± 3.1
Sputum	4.3	52.3 ± 15.5
Chest discomfort	2.9	43.5 ± 19.1
Nausea	2.9	60.0 ± 15.6
Running nose	2.9	58.0 ± 9.9
Sneeze	1.4	76
Dry mouth	1.4	36

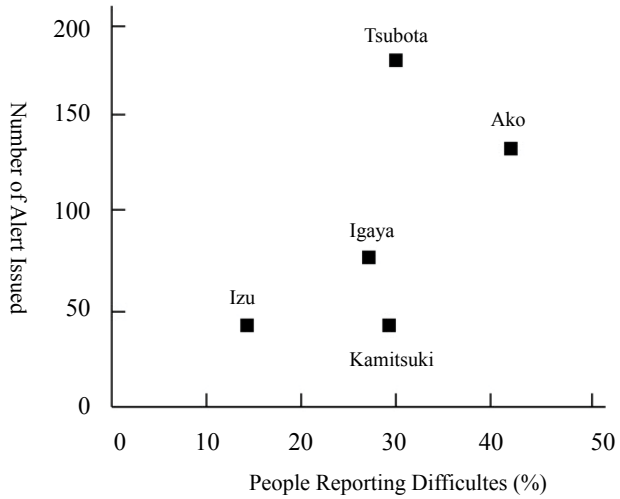

Figure 2: The number of alerts issued by local officials is shown compared to the percentage of people with a variety of health difficulties.

Table 2: Criteria for issuing volcano alerts.

Level	SO_2*	Action for susceptible subjects	Action for healthy subjects
1	> 0.2	Stay inside; If any symptoms are noticed, wear gas mask.	
2	> 0.6	Put gas mask on and leave the facility or go to an area with lower SO_2 levels.	Avoid outdoor exercise
3	> 2.0		Stay inside; If any symptoms are noticed, wear gas mask.
4	> 5.0		Wear gas mask on and leave the facility or go to an area with lower SO_2 levels.

*5 min average SO_2 concentration (ppm).

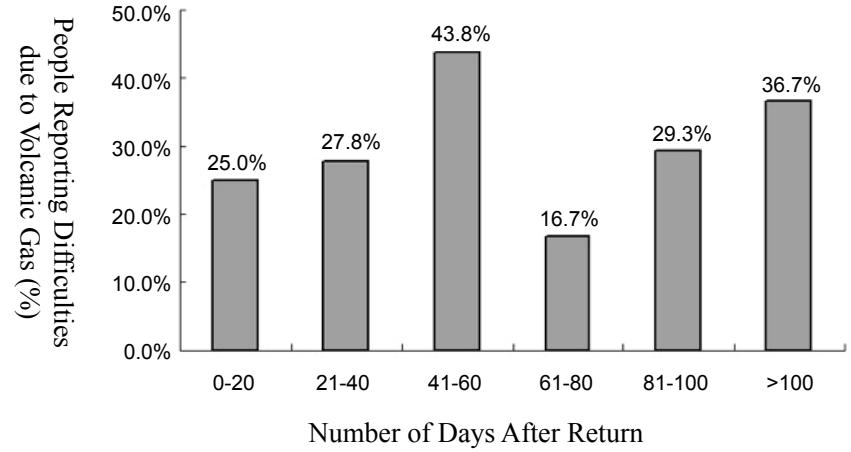

Figure 3a: The percentage of people reporting general health difficulties is shown compared to the number of days after return to the island.

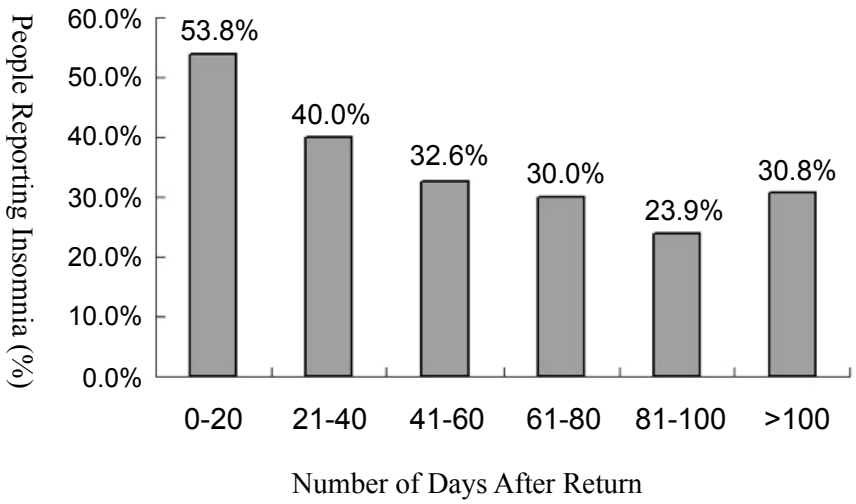

Figure 3b: The percentage of people surveyed who reported insomnia is shown compared to the number of days after return to the island.

of Tsubota inhabitants had some symptoms attributed to exposure to volcanic gas, however fewer people had symptoms in other areas.

Relationship between time and development of symptoms

The development of symptoms was evaluated in relation to the time following return to the island including those related to volcanic gas and stress-related disorders, in particular, insomnia. In this study we regarded insomnia as "being prescribed some sleeping pill already" and "awareness of sleep disorder".

The survey asked patients if they had symptoms that they believe to be attributed to volcanic gas. A comparatively few people (25%) attributed their symptoms to volcanic gas immediately after returning. By days 41 to 60, we found that 43.8% of people reported some symptoms, the highest in the study, which then decreased. However even after 100 days, 36.7% of inhabitants still had some symptoms as shown in Figure 3a. While just after returning to the island, more than half the people (53.8%) reported insomnia, the ratio of people with insomnia decreased to 30.8% by 100 days after their return, as shown in Figure 3b.

Effects on mental health

Prior to the returning the island, inhabitants spent over 4 year as refugees in mainly Tokyo, far from the island and their homes. Respondents were asked to report stress levels while away from their homes on the island. During the evacuation far from the island, stress levels were greater for the inhabitants than after returning to their lives at the site of the volcano. During this long absence, 54.9% of inhabitants felt stress. Some inhabitants could succeed to make small Miyakejima community in Tokyo during evacuation, however, refugee without friends felt more stress significantly than with friends ($p < 0.01$).

Serious damage to homes was reported by 50.0% of inhabitants during the long evacuation. Some inhabitants (15.4%) in high concentration areas could not return their own homes due to high SO_2 levels and were

forced to live in temporary housing in other areas. Some were so shocked to see their deserted home and 27.1% of inhabitants felt that cleanup of the house itself was a heavy burden. Personal and family health problems, caused not only by volcanic gas but also by aging, led to anxiety in 27.1% of those surveyed. As a direct result, 17.4% inhabitants were concerned with the continuing threat of re-eruption and volcanic gas exposure.

Of respondents from the Ako area, 51% reported anxiety and 42% of respondents from the Tsubota area reported anxiety. These values are higher than percentages from the other areas of the island. In both of these areas, inhabitants had more insomnia than other areas, as well.

Overall, inhabitants felt stress from various causes but also reported being generally satisfied with their island life. Most people (87.7%) were satisfied with returning to the island and their previous lives with wild birds and beautiful sea and good friends. Only 6.7% were dissatisfied with their lives because of a monotonous life and fatigue due to the necessary cleanup after the eruption.

Discussion

Characteristics of the eruption and SO_2 monitoring

The gases emitted from Miyakejima contained SO_2, hydrogen sulfide (H_2S), hydrogen fluoride (HF), hydrogen (H_2) and nitrogen (N_2). SO_2 sometimes reached levels causing severe health effects. The effects of the other volcanic gases are considered to be negligible because of the low concentrations observed on the island [2,5]. Monitoring devices for SO_2 were placed at 16 sampling points on the island.

Alert guidelines were additionally recommended by an expert panel for SO_2 levels that cause acute severe effects in different populations, and four levels of alert were defined. These levels are shown in Table 2. Level 1 (0.2 ppm during a 5-minute measurement) and level 2 (0.6 ppm) are set for susceptible populations with existing asthma, obstructive lung disorders, pregnant women, and individuals who need additional care. Level 3 (2 ppm) is set for healthy populations. When the SO_2 exceeds the exposure limits, level 4 (5.0 ppm), which may cause death in individuals with risk factors as chronic lung disease, all inhabitants regardless of health status must evacuate to facilities with desulfurization equipment or move to other lower areas [2].

Exposure and symptoms related to volcanic gas

In the case of Miyakejima, the number of health alerts issued may have a direct proportional relationship with the SO_2 concentration. As shown in Figure 2, the more alerts issued, the more symptoms due to volcanic gas the inhabitants complained of. This suggests a proportional connection between SO_2 concentration and symptoms in this population, as previously reported [8]. These results are quite similar to the study of people exposed to the Kilauea volcano in Hawaii [9]. Increased numbers of people exposed to the Kilauea volcano also reported sputum production, although there was no increased incidence of respiratory or cardiovascular disease compared to non-exposed people in the same study [9]. In comparison, it is noted that after the eruption of Mt. Etna hospital admissions for cardiovascular diseases significantly increased [10].

The magnitude of the symptomatic disorders was reported to differ depending both on SO_2 and fine sulphate particle exposure [11,12]. An epidemiologic investigation around the Sakurajima volcano showed a proportional connection between SO_2 concentration and the incidence of pulmonary disorders [13,14].

Symptoms related to age

In this study, inhabitants with symptoms were more than 10 years younger than those without symptoms. There are a number of possible explanations for this observation. From this data, it is not possible to definitively conclude that younger inhabitants have more susceptibility to volcanic gas compared to older people, because younger people, for example are more likely to work as outdoor workers, thus having a greater chance of exposure to volcanic gas. Another study of the Miyakejima eruption did not demonstrate that younger people have a higher susceptibility to volcanic gas [8]. One report regarding cardiovascular health effects of SO_2 pollution suggested that younger people are more likely to be affected compared to older people [15], but another article suggested the contrary [12]. In this study, older people tended to have respiratory trouble (breathe difficulty, dry cough). Presumably older people are more susceptible to volcanic gas exposure with regard to respiratory disease, because they may have pre-existing respiratory disorders.

The potential for acute adverse health effects of volcanic gas may depend on the level of individual exposure and the susceptibility of exposed organs. Young people did not seem to have the same susceptibility for gas-related disorders when compared to older people. But in the future, they might be at increased at risk of volcanic related disorders, if repeated heavy exposures were to occur over many years.

Short and long-term changes in reported symptoms

The amount of SO_2 emission in Miyakejima volcano was unparalleled in world history. The present investigation is the only survey of original inhabitants at the time of returning to the island for months, so we could grasp dynamic change of gas and stress related symptom immediately. At that time, the concentration of SO_2 was greatly elevated and alerts issued more frequently than subsequently, so a large health survey by volcanic and health experts could not be performed.

Figure 3a shows that over one quarter of the inhabi-

tants reported symptoms associated with volcanic gas exposure soon after the returning to the island. Even more than 100 days later, 36.7% of inhabitants had some physical symptoms. The percent of patients with symptoms remained rather high, possibly due to continuous volcanic emissions in doses high enough to affect general health. On the other hand, Figure 3b shows that the rate of insomnia was at its highest at the time of returning to the island and gradually decreased thereafter.

Probably, gas related symptom would unsteadily change depending on volume of gas emission and mental health disorders might reflect various prospect; anxiety of the re-entry, the threat of re-eruption, the revival of community and so on, which means mental health disorders also require long-term follow-up, but may decrease over time.

Effects on mental health

Miyakejima volcano has erupted 15 times in recorded history, and in the last 100 year-period, people have experienced 4 major eruptions including this one. Social support systems exist, related to the communities, to help cope with the stresses of living near an active volcano. However, this is the first experience with such a large scale and long duration of exposure to volcanic gas with severe damage to much of the island. In Japan, at the disaster area around the volcano of Mt Unzen-Fugen, the proportion of evacuees with psychological distress significantly decreased after 3 years. Investigation showed a progressive improvement over time in anxiety, tension and insomnia [16].

In the present study, isolated refugee significantly felt more stress than those could keep their village community during evacuation ($p < 0.01$). Disaster experts and government of Japan recommend a group refugee by village community unit, which will contribute to relief of anxiety and revive their economy [17]. In recent disaster in Japan, e.g. the Niigataken Chuetsu-oki Earthquake in 2007 and the great east Japan earthquake in 2011, disaster preparedness planners would try to move whole village community to another temporal area to prevent isolated refugee and re-develop the community.

In the Ako area, 51.1% of inhabitants and 41.7% in Tsubota reported anxiety, which is more than that reported in other areas. Additionally, inhabitants in both of these areas reported insomnia more than people in other areas. They not only had the physical disturbance from volcanic gas, but also increased mental stress as evidenced by symptoms such as insomnia. Miyakejima is a small island but has differences among each of the areas.

Practical suggestions

This study was performed by a physician treating inhabitants in sole clinic, not full-time researcher who could come to the island due to ongoing volcanic activity. This study was limited including immature questionnaire and the population studied, however, could start at the beginning of returning to the Miyakjima island, and catch dynamic change of symptoms related to SO_2 and anxiety.

So, we suggest for disaster preparedness planners as next below:

1. Detailed monitoring for SO_2 and fine alert-guidelines (divided into 4 level appropriate to the sensitivity to gas) has seemed to prevent an acute attack to volcanic gas, which system will be effective for other volcanic disaster.
2. SO_2 would elevate on the downwind inhabited areas, which causes the gas related symptoms and anxiety in such specific areas sequentially. Detailed gas monitoring and a follow-up study covering mental and health condition should be continued according to regional character in even small island.
3. In case of prolonged community displacement on large scale disaster, preparedness planners should transfer whole village community, as cooperative aid society, to temporal area, which would prevent isolated refugee and revive the village economy smoothly.
4. It is possible younger people have more susceptibility to volcanic gas more than older people. Continuous investigation should be performed to resolve this question.

Conclusions

The inhabitants of Miyakejima were exposed to significant amounts of SO_2 when they returned home more than four years after the eruption of the volcano. This study has some limitations, most notably that the survey respondents represent a somewhat self-selected population in that they visited the island's health care facility. Thus, these findings may not be representative of the entire population. This study was performed under on-going gas emission at the just returning, yet, the findings are important as they demonstrate the significant number of mental health problems among returnees to the island. These findings emphasize the need to ensure the appropriate management of both physical and mental health symptoms according to regional character in even small island.

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