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Tsunami Damage Associated with a Decline in Respiratory Function among Victims of the Great East Japan Earthquake in Iwate Prefecture: The RIAS Study

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Abstract

A few studies have investigated the long-term impact of tsunami damage on victims' respiratory function. This study aimed to analyze the association between the extent of tsunami damage and the respiratory function of victims 2 years after the Great East Japan Earthquake and Tsunami in tsunami-stricken areas of Iwate Prefecture. Data on 6,608 victims who underwent health checkups in the coastal regions of Iwate Prefecture in 2011 and 2013 were utilized. The association between respiratory function (percentage vital capacity, forced expiratory volume in one second, and forced expiratory volume percentage in one second) in 2013 and tsunami damage was then determined by analysis of covariance, adjusting for age, sex, medical history (hypertension, diabetes, dyslipidemia, and respiratory disease), smoking status (never smoked, former smoker, or current smoker), physical activity level, obesity, and respiratory function at the time of the 2011 survey. Furthermore, multiple linear regression analysis was performed with changes in percentage vital capacity, forced expiratory volume in one second, percentage of the predicted forced expiratory volume in one second, and forced expiratory volume percentage in one second from 2011 to 2013 as dependent variables, and the extent of tsunami damage, sex, age, past medical history, smoking status, physical activity levels, and obesity as independent variables. Two years after the Great East Japan Earthquake and Tsunami, the percentage of the predicted forced expiratory volume in one second in tsunami victims significantly decreased compared with that of non-tsunami victims. Moreover, in tsunami victims, the percentage vital capacity, forced expiratory volume in one second, and the predicted forced expiratory volume in one second inversely correlated with the extent of tsunami damage. In conclusion, two years after the GEJET, tsunami victims showed declines in forced expiratory volume in one second, and the predicted forced expiratory volume in one second compared with non-tsunami victims. Also, tsunami could not be denied as the factor which obstructed impairment of percentage vital capacity.

Keywords: Respiratory function; Earthquake; Tsunami

Introduction

The Great East Japan Earthquake and Tsunami (GEJET) occurred at 14:46 on Friday, March 11, 2011; it had a magnitude of 9.0 and its epicenter was located off the coast of Sanriku. The earthquake struck the entire northeastern coastal region of Japan with strong tremors, while the northern part of Miyagi Prefecture registered the highest seismic intensity of 7 on the Japanese scale. After several tens of minutes, massive tsunamis struck this coastal region, including Iwate Prefecture. They devastated the Fukushima Daiichi Nuclear Power Plant of Tokyo Electric Power Company. These events caused a catastrophe resulting in 15,894 deaths and 2,558 missing people [1]. More than 390,000 buildings were completely or partially destroyed, while more than 470,000 people were evacuated during its peak [2]. In Iwate Prefecture, there were 4,673 deaths and 1,123 missing people [1]. The coastal regions saw destruction of the infrastructure for essential services such as electricity, water, and gas, interruption of cellular and Internet services, and stoppage of supplies of food and energy [3].

There are some reports on respiratory system-related conditions observed immediately after tsunamis, such as tsunami lung [4,5]. Tsunami lung is a condition representing a combination of chemical-induced pneumonia and bacterial pneumonia affecting the entire lung [5]. Furthermore, inspiration of sludge dust delivered by a tsunami may have a long-term impact on respiratory function [6]. It has been reported that sludge accumulated on the seabed may easily break down into dust when it is brought to land by a tsunami and dried, and as the tsunami travels across land, this sludge picks up various materials and may also contribute to dispersion of organic dust. It is thought that the potential inspiration of organic dust during the cleaning of flooded buildings and debris can cause allergic reactions in the alveoli, which may lead to development of hypersensitivity pneumonitis.

However, there are few studies examining the impact of tsunami damage on respiratory function, in particular with long-term follow-up data. Therefore, in the present study, to validate the hypothesis that tsunami damage is associated with a decline in respiratory function, we assessed the association between the extent of tsunami damage and the respiratory function of tsunami victims 2 years after the GEJET in tsunami-stricken regions of Iwate Prefecture.

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Materials and Methods

Study population

At Iwate Medical University, the RIAS (Research Project for Prospective Investigation of Health Problems Among Survivors of Great East Japan Earthquake and Tsunami Disaster) has been conducted to establish systems that enable provision of adequate support to victims and the assessment of health problems caused by the GEJET. The RIAS protocol has previously been reported [7,8]. In 2011, among the residents aged 18 years or older living in parts of the tsunami-stricken region, namely Otsuchi Town, Yamada Town, Rikuzentakata City, and Simoheita district of Kamaishi City in Iwate Prefecture who underwent health check-ups (Figure 1), 10,475 people consented to participate in this study. Consent was informed by verbal and written, and obtained by written. Of these, we excluded 3,867 for the following reasons: 3,639 did not attend health check-ups in 2013, and 228 had no respiratory function test data or incomplete data. Consequently, data from 6,608 people were analyzed in the present study (Figure 2).

Survey items

Extent of tsunami damage: The extent of tsunami damage was determined by comparing the map of tsunami-stricken areas issued by the Association of Japanese Geographers [9] with the boundaries of administrative districts. The extent was classified into three levels: the Non-Flooded Group (including districts not flooded by tsunamis), Partial Flooded Group (including districts partially flooded by tsunamis), and All Flooded Group (including districts completely flooded by tsunamis).

Respiratory function

Respiratory function was tested with an HI-801 spirometer (Chest Corporation, Tokyo, Japan). Percentage vital capacity (%VC) was calculated as a percentage of the standard value expected in Japanese people with normal pulmonary function, proposed by the Special Committee of Pulmonary Physiology of the Japanese Respiratory Society, and used for analyses. The standard value was determined using the following formula based on sex, age, and height of Japanese people [10]: %VC=measured value/standard value; standard value, y=a × height (cm) + b × age + constant; men, a=0.045, b= -0.023, constant= -2.258; women, a=0.032, b= -0.018, constant= -1.178. Measured values were divided by the standard value calculated using the formula described above to determine the %VC. We calculated %FEV1 (forced expiratory volume in one second/forced expiratory volume in one second predicted) × 100) as a percentage of the standard value expected in Japanese people with normal pulmonary function, proposed by the Special Committee of Pulmonary Physiology of the Japanese Respiratory Society, and used for analyses. The standard value was determined using the following formula based on sex, age, and height of Japanese people [10]: %FEV1=measured value/standard value; standard value, y=a × height (cm) + b × age + constant; men, a=0.036, b= −0.028, constant= −1.178; women, a=0.022, b= −0.022, constant= −0.005. Then, measured values were divided by the standard value calculated by using the formula that determined the %FEV1. The forced expiratory volume percentage in one second was calculated as follows: FEV1% = (FEV1/FVC) × 100 = forced expiratory volume in one second (FEV1)/forced VC (FVC) × 100 (%).

Other measurements

A self-administered questionnaire was used to collect data on sex, age, medical history (hypertension, dyslipidemia, diabetes mellitus, and respiratory disease), smoking status, and physical activity. Smoking status was classified into three categories: never smoked, former smoker, and current smoker. Physical activity levels (metabolic equivalents × hours) were calculated based on responses to questions regarding physical activities, and low physical activity level was defined as less than 23 metabolic equivalents × hours/week [11]. Body mass index was calculated from height and weight measured in the survey in 2011, and obesity was defined as a body mass index of 25 kg/m^2 or higher.

Statistical analysis

Baseline characteristics of subjects were presented in three groups classified by the extent of tsunami damage. Comparison across the groups was conducted using the chi-squared test. For comparison of %VC, FEV1, %FEV1, and (FEV1/FVC)%, and for comparison of change in %VC, FEV1, %FEV1, and (FEV1/FVC)% among groups according to the extent of tsunami damage (with the Non-Flooded group as the reference group), multivariate-adjusted means (95% confidence internals [CIs]) were also estimated using ANCOVA after adjusting

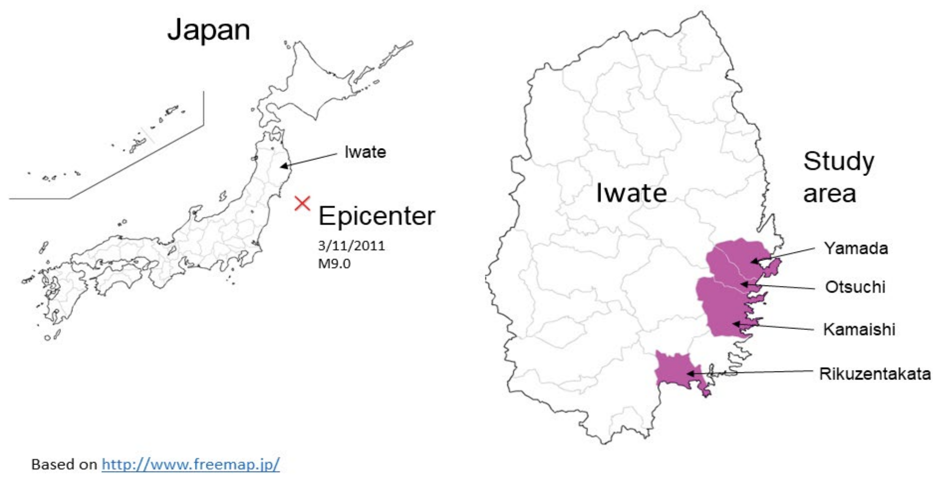

Figure 1: Map of the study.

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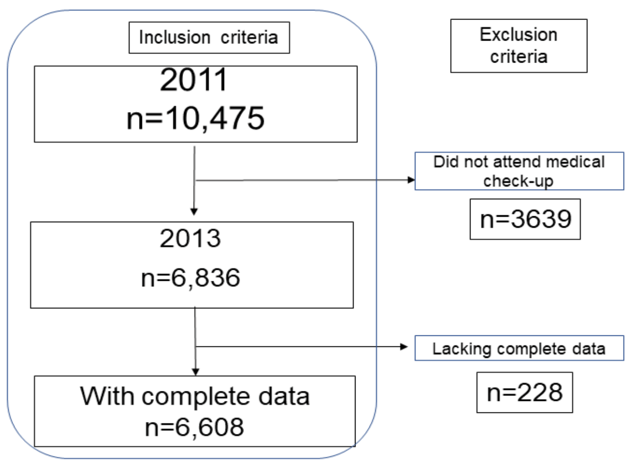

Figure 2: Flowchart of the study.

for sex, age, presence or absence of medical history (hypertension, dyslipidemia, diabetes mellitus, and respiratory disease), smoking status (never smoked, former smoker, or current smoker), low physical activity level, obesity, and respiratory function (%VC, FEV1, %FEV1, and (FEV1/FVC)%) at the time of the 2011 survey. Adjustment for multiple comparisons was performed using the Bonferroni correction. In addition, multiple linear regression analysis was performed with changes in %VC, FEV1, %FEV1, and (FEV1/FVC)%. from 2011 to 2013 (differences in the values between 2011 and 2013) as dependent variables, and sex, age, medical history, smoking status, physical activity, obesity, and extent of tsunami damage as independent variables. Statistical analyses were performed with SPSS Statistics version 23.0 (IBM, Armonk, NY, USA). In all analyses, two-sided P-values <0.05 were considered statistically significant.

Results

Table 1 shows the characteristics of participants in the 2011 survey according to the extent of tsunami damage: sex; age group (i.e., 20–29, 30–39, 40–49, 50–59, 60–69, 70–79, and ≥ 80 years); prevalence of hypertension, dyslipidemia, diabetes mellitus, respiratory disease, and obesity; smoking status, and proportion of participants with a low physical activity level. The proportions of current smokers and participants with a low physical activity level were significantly higher in the All Flooded Group than in the Non-Flooded Group (P=0.036 and P<0.001, respectively). None of the other variables were significantly associated with the extent of tsunami damage (Figures 1 and 2).

Table 2 shows the multivariate-adjusted means (95% CIs) of %VC, FEV1, %FEV1, and (FEV1/FVC)% in 2013, and presents the multivariate-adjusted changes (95% CIs) in %VC, FEV1, %FEV1, and (FEV1/FVC)%. The multivariate-adjusted change in FEV1 in the Partial Flooded Group was significantly higher than those in the Non-Flooded Group (P=0.033). The multivariate-adjusted mean in FEV1 in the Partial Flooded group had a similar tendency (P=0.051). The multivariate-adjusted mean in %FEV1 was significantly lower in the All Flooded Group than those in the Non-Flooded group (P=0.01). The multivariate-adjusted mean in %VC in All and Partial Flooded Group were lower than in the Non- Flooded Group although they were not significant statistically.

Table 3 shows the results of the multiple linear regression analysis performed with changes in %VC, FEV1, %FEV1, and (FEV1/FVC)% from 2011 to 2013. Compared with the Non-Flooded Group, the changes in %VC was significantly larger in the Partial Flooded Group (P=0.023). A similar tendency was observed in the All Flooded Group (P=0.079). For change in FEV1 and %FEV1, the All and Partial Flooded Groups showed significant decreases compared with that of the Non-Flooded Group (P=0.039, P=0.011, P=0.007, and P=0.038, respectively). There was no significant association between change in (FEV1/FVC)% and the extent of tsunami damage.

Discussion

This study analyzed the association between the extent of tsunami damage and the respiratory function of victims 2 years after the GEJET in the tsunami-stricken areas of Iwate Prefecture. Findings show %FEV1 was significantly lower in the All Flooded group compared to those in the Non-Flooded group. FEV1 in the Partial Flooded group was lower than the Non-Flooded group although it was statistically insignificant. %VC in All and Partial Flooded Group were lower than in the Non- Flooded Group although they were not significant statistically. The change in FEV1 in the Partial Flooded Group was significantly higher than those in the Non-Flooded group. Compared to the Non-Flooded group, changes in %VC, FEV1, and %FEV1 in the Partial Flooded Group inversely correlated with the extent of tsunami damage. In addition, FEV1 and %FEV1 in the All Flooded Group were associated with the extent of tsunami damage.

This study also revealed that the proportions of current smokers and participants with a low physical activity level were significantly higher among residents living in the all-flooded area. According to multiple linear regression analysis, the proportions of current smokers and participants with a low physical activity level were inversely associated with a change in FEV1. One of the factors causing cardiopulmonary insufficiency is disuse syndrome [12]. The results of this study, showing an association between a low physical activity level and a decline in respiratory function, were consistent with previously reported results [12]. Thus, decreased physical activity may also partially account for the results of this study.

Exposure to sludge dust left by tsunami, particularly during the cleaning of collapsed houses and debris post-disaster, may be the potential mechanism behind the impairment of respiratory function in tsunami victims. When sludge accumulated on the seabed is brought to land by tsunami and dried, it easily breaks down into dust, and inspiration of this dust may have a long-term impact on respiratory function [6]. A previous study followed-up 27,449 workers involved in rescue and recovery operations after the terrorist attacks of September 11, 2001, in the United States for 9 years [13]. The FVC was found to be reduced in 3/4 of the workers due to inspiration of dust during the operations. In a study including 12,781 New York City firefighters involved in rescue and recovery operations after the terrorist attacks, Both FEV1 and %FEV dramatically decreased within 1 year in proportion to dust exposure, and remained reduced for 6 years [14]. Furthermore, another study, in which exposure levels and annual rates of decline in pulmonary function were assessed in 2,620 workers with occupational exposure to dust, revealed a steep decline in FEV1 in workers with high exposure to dust [15]. In Japan, there is a report of a case in which a worker involved in the clearance of debris in an area stricken by the GEJET developed acute interstitial pneumonia and died approximately 6 months later. Inspiration of sawdust from wooden debris was regarded as the cause [16]. It has also been reported that residents in tsunami-stricken areas developed organizing pneumonia a few months after the disaster [17]. The results of these previous studies

Tsunami disaster group		Non-Flooded n=3401		Partial Flooded n=258		All Flooded n=3401		P-value	
		n	%	n	%	n	%	All vs. Non	Partial vs. Non
Sex	Male	1231	36.2	107	41.5	1107	37.5	1.000	1.000
	Female	2170	68.3	151	58.5	1842	62.5		
Age	20	56	1.6	5	1.9	49	1.7	0.078	1.000
	30	156	4.6	11	4.3	170	5.8		
	40	303	8.9	22	8.5	292	9.9		
	50	525	15.4	30	11.6	455	15.4		
	60	1188	34.9	98	38	1036	35.1		
	70	994	29.2	77	29.8	798	27.1		
	80	179	5.3	15	5.8	149	5.1		
Hypertension		1125	33.1	88	34.1	983	33.3	1.000	0.342
Diabetes		206	6.1	23	8.9	195	6.6	1.000	0.543
Dyslipidemia		326	9.6	26	10.1	289	9.8	1.000	1.000
Respiratory disease		79	2.3	4	1.6	77	2.6	1.000	1.000
Smoking status	Never	2516	74.0	184	71.3	2083	70.6	0.036*	1.000
	Former	477	14.0	45	17.4	437	14.7		
	Current	408	12.0	29	11.2	429	14.5		
Physical activity	<23 METS hour/week	2113	62.1	178	69	2055	69.7	<0.001*	0.426
Obesity	BMI ≥ 25 kg/m^2	1089	32.3	88	34.1	934	31.7	1.000	1.000

Note: METS, metabolic equivalents; BMI, body mass index. P-values were estimated by the chi-squared test, and adjustment for multiple comparisons was performed using the Bonferroni correction. *P<0.05

Table 1: Characteristics of participants in the 2011 survey (n=6,608).

Tsunami disaster group	Non-Flooded	Partial Flooded	All Flooded	*P*	
	(*n*=3401)	(*n*=258)	(*n*=2949)	All vs. Non	Partial vs. Non
%VC					
Multivariate-adjusted mean (95% CI)	103.8 (103.6 - 104.1)	102.7 (101.7 - 103.7)	103.4 (103.1 - 103.7)	0.072	0.097
Change in %VC					
Multivariate-adjusted mean (95% CI)	2.0 (1.7 - 2.3)	0.8 (–0.3 - 1.8)	1.6 (1.3 - 1.9)	0.238	0.070
FEV1					
Multivariate-adjusted mean (95% CI)	2.38 (2.37 - 2.39)	2.35 (2.33 - 2.37)	2.37 (2.36 - 2.38)	0.121	0.051
Change in FEV1					
Multivariate-adjusted mean (95% CI)	–0.01 (–0.0 - 0.00)	–0.04 (–0.06 - –0.02)	–0.02 (–0.03 - –0.01)	0.117	0.033*
%FEV1					
Multivariate-adjusted mean (95% CI)	106.1 (105.8 - 106.4)	105.0 (103.9 - 106.0)	105.5 (105.1 - 105.8)	0.010*	0.136
Change in %FEV1					
Multivariate-adjusted mean (95% CI)	1.8 (1.5 - 2.1)	0.6 (–0.5 - 1.7)	1.2 (0.9 - 1.5)	0.021*	0.114
(FEV1/FVC)%					
Multivariate-adjusted mean (95% CI)	78.8 (78.6 - 78.9)	79.0 (78.5 - 79.5)	78.8 (78.6 - 78.9)	1.000	1.000
Change in (FEV1/FVC)%					
Multivariate-adjusted mean (95% CI)	–0.9 (–1.1 - –0.7)	–0.6 (–1.1 - 0.0)	–0.9 (–1.1 - –0.8)	1.000	0.887

Note: %VC, percentage vital capacity; FEV1, forced expiratory volume in 1.0 second; %FEV1, (FEV1/FEV predicted) × 100; (FEV1/FVC)%, (FEV1/forced vital capacity) × 100; CI, confidence interval. P values were estimated by ANCOVA, and adjustment for multiple comparisons was performed using the Bonferroni correction. Multivariate-adjusted means (95% CIs) were adjusted for age, sex, medical history (hypertension, diabetes, dyslipidemia, and respiratory disease), smoking status (never smoked, former smoker, and current smoker), physical activity level, obesity, and respiratory function (%VC, FEV1, %FEV1 and (FEV1/FVC)%) at the time of the 2011 survey. *P<0.05.

Table 2: The multivariate-adjusted mean (95% confidence intervals) of %VC, FEV1, %FEV1, and (FEV1/FVC)% in 2013, and multivariate-adjusted changes (95% confidence intervals) in %VC, FEV1, %FEV1, and (FEV1/FVC)% according to the extent of tsunami damage.

appear to support those of the present study regarding the impairment of respiratory function (especially, FEV and %FEV) in tsunami victims, persisting even 2 years after the tsunami.

Pathological conditions caused by exposure to dust and presenting a decrease in FEV1 include not only fibrosis of bronchiole walls, alveolar walls, and interstitium, but also occlusion of the peripheral airways [18,19]. This mechanism may account for the results of this study regarding the lower FEV1 and %FEV1 in tsunami victims than in non-tsunami victims. This may also suggest that tsunami may be a factor that causes impairment of the %VC.

This study had several limitations. First, because the extent of tsunami damage was classified by the proportion of flooded areas in the residential areas at the time of the disaster instead of the exposure level of individual participants, some participants may have been misclassified in terms of the extent of tsunami damage. However, even if those who were not actually affected by the tsunamis had been

	%VC			FEV1			%FEV1			(FEV/FVC)%		
	Coefficient	SE	P-values	Coefficient	SE	P-values	Coefficient	SE	P-values	Coefficient	SE	P-values
Tsunami disaster (vs. Non-Flooded group)												
Partial Flooded Group	-1.233	0.543	0.023*	-0.031	0.012	0.011*	-1.181	0.569	0.038*	0.306	0.293	0.296
All Flooded Group	-0.373	0.212	0.079	-0.010	0.005	0.039*	-0.602	0.223	0.007*	-0.045	0.114	0.696
Male (vs. female)	0.100	0.271	0.714	0.011	0.006	0.065	-0.079	0.284	0.782	0.162	0.146	0.267
Age (per 1-year increase)	-0.040	0.009	<0.001*	-0.002	0.000	<0.001*	-0.031	0.009	0.001*	-0.002	0.005	0.630
Medical history (vs. absence)												
Hypertension	-0.472	0.239	0.048*	-0.009	0.005	0.095	-0.405	0.251	0.106	0.068	0.129	0.599
Diabetes	0.025	0.428	0.953	-0.007	0.010	0.486	-0.125	0.449	0.781	-0.104	0.231	0.653
Dyslipidemia	0.062	0.355	0.861	0.008	0.008	0.327	0.313	0.372	0.401	0.169	0.192	0.379
Respiratory disease	-1.063	0.673	0.114	-0.018	0.015	0.237	-0.862	0.705	0.222	0.215	0.363	0.554
Smoking status (vs. never smoked)												
Former smoker	0.004	0.349	0.991	-0.002	0.008	0.752	-0.117	0.366	0.750	-0.078	0.188	0.677
Current smoker	0.284	0.354	0.423	-0.019	0.008	0.015*	-0.678	0.371	0.068	-0.636	0.191	0.001*
Physical activity ≥ 23 METS*hr/wk (vs. <23 METS*hr/wk)	0.324	0.220	0.141	0.010	0.005	0.048*	0.438	0.230	0.057	0.082	0.118	0.490
BMI ≥ 25 kg/m^2 (vs. <25 kg/m^2)	-0.123	0.226	0.588	0.001	0.005	0.873	-0.056	0.237	0.814	0.076	0.122	0.533

Note: %VC, percentage vital capacity; FEV1.0, forced expiratory volume in 1.0 second; %FEV1, (FEV1/FEV predicted) × 100; (FEV1/FVC)%, (FEV1/forced vital capacity) × 100; SE, standard error; METS, metabolic equivalents; BMI, body mass index. *P<0.05

Table 3: Results of multiple linear regression for variables associated with changes in %VC, FEV1, %FEV1, and (FEV1/FVC)%.

classified into the All or Partial Flooded Group, it is plausible that they might have commuted between their shelters and resident areas for clearance of debris and other works after the disaster. On the other hand, if those who were actually affected by tsunamis had been classified into the Non-Flooded Group, the impact of tsunami damage on their respiratory dysfunction might have been underestimated. Second, the subjects included in the analyses were those who participated in both the 2011 and 2013 surveys. Compared to those who participated in only 2011 survey, the respiratory function was not necessarily lower in our subjects. Although our subjects were older, the proportion of males and current smokers was significantly lower in our subjects than in those who participated in only 2011 survey (data not shown). In general, people who regularly undergo medical check-ups are known to be highly health-conscious. Therefore, our results might have been underestimated. However, although the %VC, FEV1, and %FEV1 in the tsunami victims were lower than those in the non-tsunami victims, the differences in these values may not be clinically meaningful because they were within the normal range. However, it has been reported that a much lower FEV1 may lead to death from diseases other than respiratory disease [20], and can be associated with increased risk of cardiovascular or all-cause mortality [21]. Therefore, fluctuations in health status should carefully be monitored in tsunami victims of the GEJET. When physicians, such as emergency physicians, provide aid to victims in tsunami areas, precautions such as dust masks should be utilized.

Conclusion

Two years after the GEJET, tsunami victims showed declines in respiratory function (FEV1, and %FEV) compared with non-tsunami victims. Tsunami victims also trended to have a decrease in %VC compared to non-tsunami victims. The results of this study suggest that, in the event of a large-scale natural disaster accompanied by a tsunami, declines in respiratory function may be associated with not only inspiration of seawater and sludge carried by a tsunami during the disaster, but also subsequent exposure to dust. Therefore, health management programs including regular respiratory function testing should be developed and implemented post-tsunami. Further, when physicians, such as emergency physicians, provide aid to victims in tsunami areas, precautions (e.g. dust masks) may be needed.

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