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Original Article

Effects of Mask Fitness and Worker Education on the Prevention of Occupational Dust Exposure

Yoko Takemura[a], Takumi Kishimoto[b], Tomoko Takigawa[a]*, Shinji Kojima[a], Bing-Ling Wang[a], Noriko Sakano[a], Da-Hong Wang[a], Jiro Takaki[a], Tadashi Nishide[c], Kou Ishikawa[c], and Keiki Ogino[a]

[a]*Department of Public Health, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama 700-8558, Japan,*
[b]*Okayama Rosai Hospital, Okayama 702-8055, Japan, and*
[c]*Okayama Occupational Health Promotion Center, Okayama 700-0907, Japan*

To decrease the incidence of pneumoconiosis, we examined dust protective mask performance and its relation to pulmonary function as well as the effects of worker education on the proper wearing of masks. One hundred and seventy-eight workers from 15 factories subject to dust exposure participated in this study. All participants were interviewed to obtain relevant personal information and underwent both a mask leakage and a pulmonary function test. The mask leakage was expressed as a percentage, with under 10% leakage indicating that the dust protective mask worked efficiently. In addition, 23 workers from 2 factories were educated on how to wear masks properly. The average mask leakage was 24.3%, and 58% of workers wore ineffective masks. Though pulmonary function was almost normal, the percent vital capacity (%VC) tended to be lower depending on the mask leakage. Mask education, which was very easy and took only a short time, dramatically decreased average mask leakage from 32.1% to 10.5% ($p < 0.001$). Educating workers to wear masks properly might prevent the worsening of pulmonary function in response to dust exposure. Appropriate mask fitness by education could be useful in preventing the development of pneumoconiosis.

Key words: pulmonary function, education on proper wearing masks, pneumoconiosis, mask leakage, occupational exposure

Pneumoconiosis, one of the oldest occupational diseases in the world [1-6], is defined as a non-neoplastic reaction of the lungs to inhaled mineral or organic dust and the resultant alteration in their structure [7]. Once pulmonary fibrosis occurs it cannot be reversed, and pulmonary function will never return to normal. Occupational dust exposure is inevitable in some industries such as the iron and steel industries as well as shipbuilding. The prevalence of pneumoconiosis in dusty work places has been reported to be 9% [1], and the annual rate of pneumoconiosis as 7.6 per 100,000 foundry workers [8]. The frequent occurrence of pneumoconiosis in dusty work places is therefore an important problem that remains to be addressed.

In Japan, the prevalence of pneumoconiosis is actually decreasing because of early detection resulting from regular health examinations mandated by the

Received August 27, 2007; accepted November 8, 2007.
*Corresponding author. Phone:+81-86-235-7184; Fax:+81-86-226-0715
E-mail:ttomoko@md.okayama-u.ac.jp (T. Takigawa)

pneumoconiosis law. Additionally, there have been improvements in working conditions in response to instituting local exhaust systems and local ventilation, increasing the use of respiratory protection, and providing vocational education. Instituting local exhaust systems reduces the concentrations of dust in which the size of the dust particles and the free silica content are important factors [9]; the concentrations, however, can never be decreased to zero.

The early detection of pneumoconiosis via regular health examinations for workers who are exposed to occupational dust in Japan is effective in preventing pneumoconiosis to a certain extent, but it is not enough. This health examination consists of both a chest X-ray and a pulmonary function test, both of which are highly effective for the control of the pneumoconiosis, but a pulmonary function test is not performed for workers whose chest X-rays show no signs of pneumoconiosis. The chest X-ray can generally predict pulmonary dysfunction, but in a few cases poor pulmonary function is not predicted by the chest X-rays, which indicates that it is possible that the current health examinations alone are not enough to prevent the pneumoconiosis. There are still approximately 1,000 patients newly diagnosed with pneumoconiosis every year, and pneumoconiosis patients comprise 10% of the population suffering from occupational diseases [10], indicating the necessity for further research into the prevention of dust inhalation.

Our previous study revealed that 95% of workers wear masks, an important personal protective tool against dust inhalation. However, some workers still develop pneumoconiosis, and many workers have chest radiographs classified as profusion rate (PR) 0/1 according to the Japanese Classification of Radiographs of Pneumoconiosis [11]. A (PR) 0/1 does not signify pneumoconiosis, but rather denotes a preparatory stage [12]. This finding also suggests that wearing a mask is not an effective means of avoiding dust exposure. However, the effectiveness of masks is well-established [13], and it is rather that the masks are worn incorrectly, resulting in mask leakage, that impacts the effectiveness of the mask as a tool to prevent dust inhalation [14]. There have been no investigations of the relationship between mask fitness and worker pulmonary function, although there are many studies referring to pulmonary function and chest radiographs in workers from dusty work areas [15, 16]. In this study, we attempted to evaluate the relationship between mask leakage and pulmonary function in workers exposed to industrial dust as well as to evaluate the effectiveness of worker education on how to wear masks properly.

Material and Methods

Study population. One hundred and seventy-eight male workers who had worked in 15 dusty factories in Okayama prefecture, Japan, participated in this study, which was conducted during the period 2002-2003. Among the list of dusty factories registered in the Okayama Occupational Heath Promotion Center, these 15 factories agreed to participate in the study. And among the workers in theses factories, workers who provided informed consent and who had enough time to take the pulmonary function test and the mask-fitting test were participated in the study, and there was no control. The relative sizes of the factories and the relevant personal information relating to the workers are shown in Table 1. The subjects were classified into 5 groups based on their occupations: refractory crusher, founder, stonemason, charcoal burner, and shipyard welder. The object and content of the study were explained to the workers. Those who indicated they had adequate understanding of and who agreed to the the terms of the study were retained as study subjects.

Personal interviews. One hundred and sixty-six workers were interviewed during working hours. The interviews were performed by 5 trained co-medical licensed persons (nurses and doctors). The interviewer gathered information such as sex, age, work periods (*i.e.* the time spent working in dusty workplaces), working hours per day, smoking habits, body weight, and height. Work periods included the periods of work not only in their present factory but also in other factories, if the workers had previously worked in a dusty workplace.

Pulmonary function test. One hundred and thirty-seven workers participated in the pulmonary function test. The pulmonary function tests were performed by 2 trained co-medical licensed persons (testing technicians and doctors). Standard pulmonary function parameters were recorded for each subject with a Spiro Meter (Fukuda Denshi, Tokyo, Japan). The test was carried out during working hours in the break room in the factory. Pulmonary function was considered to be abnormal if the tested %VC was below 80%, or if $FEV_{1.0G}$ (percent forced expiration volume in 1st sec) was below 70%; these values are set by the Japanese Pneumoconiosis Law.

Mask-fitting test. To evaluate mask fitness, leakage of the mask was measured. One hundred and seventy-four workers participated. The mask fitness was tested with a mask fitness tester (MT-03, Sibata Scientific Technology Ltd, Tokyo, Japan) in a break room within the factory performed by a trained testing technician. By this procedure, mask fitness was evaluated, and air leakage is expressed as a percentage. There are 2 types of dust particles in the air — very small microscopic particles that can pass through the mask and larger microscopic particles (diameter $> 0.3\ \mu m$) that cannot pass through the mask. If mask fitness is inadequate, larger microscopic particles enter inside the mask. This fitness tester counts the larger microscopic particles inside and outside the mask. The lower the leakage value, the higher the mask fitness. Though a standard for mask leakage has not been established in Japan, we referred to the transmittance of small particles into masks as regulated by Japanese Industrial Safety and Health Law.

In present Japanese Industrial Safety and Health Law (improved in October, 2000 [17]), mask transmittance is standardized using small NaCl particles 0.01–0.1 μm in diameter. Less than 0.1% mask transmittance is the value set for atomic dust or dust containing dioxin, less than 5% mask transmittance is the value set for metallic fumes, and less than 20% mask transmittance is the value set for other dusty workplaces. The present study, however, took place in 2002–2003 and the masks used were suited to the former Japanese Industrial Safety and Health Law for which transmittance was standardized using small silica particles under 0.2 μm in diameter [18]. In the former law, less than 5% mask transmittance was the value set for dusty workplaces. Referring to Japanese Industrial Safety and Health Law, we assumed that less than 5% mask leakage was suitable, but in actuality this 5% value for mask leakage is difficult to achieve. We therefore used a functional limit of less than 10% mask leakage and evaluated the mask leakage by occupation and in relation to the results from the personal interview and the pulmonary function test.

Education regarding how to wear a mask properly. In 2 factories, it was suggested that there was a need for mask education, and therefore workers in these 2 factories were invited to training sessions on how to wear a mask properly, and 23 workers participated. This education study did not

Table 1 Demographics of the interview

Occupation	Refractory crusher	Founder	Stonemason	Charcoal burner	Shipyard welder	Total
Number of factories	9	1	1	1	1	13
Population	104	20	11	9	22	166
Age[a]	48.3 ± 12	39.1 ± 10.6	47.9 ± 13.5	35.2 ± 14.6	38.4 ± 14.1	45.1 ± 13.1
Work period (years)	17 ± 12	11 ± 8	–	17 ± 12	16 ± 12	15 ± 11
Working hours per day (hours/day)	7.7 ± 0.8	–	–	7.3 ± 2	8.0 ± 0	7.7 ± 0.9
Percentage of smokers (%)	73.8	70.0	–	44.4	63.6	70.0
Brinkmann Index of smokers[b]	660 ± 402	318 ± 199	–	243 ± 168	330 ± 197	558 ± 386
Height[c] (cm)	166 ± 6	170 ± 6	170 ± 6	172 ± 6	165 ± 5	167 ± 6
Body weight[d] (kg)	66 ± 9	66 ± 12	67 ± 12	66 ± 10	58 ± 7	65 ± 10
BMI[e]	23.7 ± 2.8	22.6 ± 3.2	23.2 ± 3.5	22.4 ± 2.5	21.4 ± 2.1	23.1 ± 2.9

Stonemasons didn't answer the question related to their smoking habits.
BMI: body mass index
[a]Significant differences were indicated; refractory crusher > founder ($p = 0.002$), refractory crusher > charcoal burner ($p = 0.022$), refractory crusher > shipyard welder ($p = 0.007$)
[b]Significant differences were indicated; refractory crusher > founder ($p = 0.032$), refractory crusher > charcoal burner ($p = 0.030$), refractory crusher > shipyard welder ($p = 0.016$)
[c]Significant differences were indicated; founder > shipyard welder ($p = 0.040$)
[d]Significant differences were indicated; refractory crusher > shipyard welder ($p = 0.016$)
[e]Significant differences were indicated; refractory crusher > shipyard welder ($p = 0.008$)

have a control group.

The education sessions were short and very easy to carry out quickly and on the spot. The content of the training included the basic treatment of maskswith regard to how to choose masks that fit, how to fasten mask strings, and how to change the mask filter when it becomes ineffective. Following this education session, a second pulmonary function test was conducted to evaluate the effects of the education.

Statistical analysis. To assess the differences among occupational groups, analysis of variance and Bonferroni tests were used. To assess the relationships among the factors garnered from the interview, pulmonary function, and mask fitness, a Pearson's correlation coefficient test and partial correlation coefficients test controlling for height, age, and B.I. were performed. To assess the effects of mask education, *t*-tests for independent samples were used. These analyses were processed with SPSS 11.0 for Windows (SPSS Inc., Tokyo, Japan). Differences with $p < 0.05$ were considered statistically significant.

Results

Personal interviews. Of the 178 workers, 166 from a total of 13 factories were interviewed (Table 1). Among the occupational groups, differences in age, Brinkmann Index (B.I.)[19], height, body weight, and body mass index (BMI) were significant ($p < 0.05$).

The total median age was 48 years. Workers with an occupational classification of refractory crusher were significantly older (median age: 50) than workers from the other occupational groups. Seventy percent of the workers were smokers; this percentage is higher than that of the average for Japanese males, which is 48.3% [10]. The highest percentage of smokers was found among workers in the refractory crusher occupational group (73.8%). The B.I. for refractory crusher workers who were also smokers was also significant (B.I.: 660 ± 402, $p = 0.016$). However, the between-group differences in B.I. were not associated with specific occupational characteristics.

Pulmonary function test. Of the 178 workers, 137 from a total of 13 factories participated in the pulmonary function test (Table 2). The test was performed during working hours within the factory. Forty-one workers did not take the test because they did not have time to do so.

Pulmonary function results were mostly within normal limits (mean %VC: 103%, mean $FEV_{1.0G}$: 83 %), although some results were abnormal. Smoking and age decreased pulmonary function (Table 3). The higher the B.I., the worse was the $FEV_{1.0G}$ result ($p = 0.001$, $r = -0.236$). Similarly, the $FEV_{1.0G}$ result ($p = 0.001$, $r = -0.286$) worsened with increasing age.

Mask-fitting test. The interview results showed that 95% of workers wore masks. Of the 178 workers, 174 from a total of 15 factories participated in the mask-fitting test (Table 4). The mean mask leakage was 24.3%.

The majority of leakage values were over 10% (Fig. 1). Fifty-eight percent of workers wore ineffective masks. There were differences in mask leakage among the occupational groups (Fig. 2). The mean

Table 2 Pulmonary function test

Occupation	Number of factories	Participants	%VC (%)	$FEV_{1.0}$ (L)[a]	$FEV_{1.0G}$ (%)
Refractory crusher	9	81	102 ± 17	3.04 ± 0.61	82.8 ± 9.7
Founder	1	20	109 ± 14	3.52 ± 0.52	82.8 ± 7.3
Stonemason	1	11	100 ± 13	2.99 ± 0.64	82.8 ± 8.0
Charcoal burner	1	9	109 ± 8	3.77 ± 0.29	85.8 ± 6.5
Shipyard welder	1	16	96 ± 18	3.05 ± 0.56	83.0 ± 6.9
Total	13	137	103 ± 16	3.16 ± 0.62	83.0 ± 8.7

[a]Significant differences were indicated; founder > refractory crusher ($p = 0.027$)
$FEV_{1.0}$: forced expiration volume in 1st sec
$FEV_{1.0G}$: percent forced expiration volume in 1st sec
%VC: percent vital capacity

mask leakage was highest for shipyard welders, followed by stonemasons (shipyard welder: 39.6%, stonemason: 40.5%). Fig. 3 shows the details regarding mask leakage in each industry. Among shipyard welders and stonemasons, the majority of masks had leakage values greater than 10%.

Mask leakage was highest among shipyard welders (mean: 39.6%). In 24 cases (75.0%), mask leakage values were greater than 10%, and in 14 cases (43.8%) mask leakage was greater than 50%. In 2 cases, mask leakages were even greater than 90% (6.3%). Mask leakages among stonemasons were also high (mean: 40.5%). In 10 cases (90.9%), mask leakage was greater than 10% and in 3 cases (27.3%) greater than 50%; a mask leakage value greater than

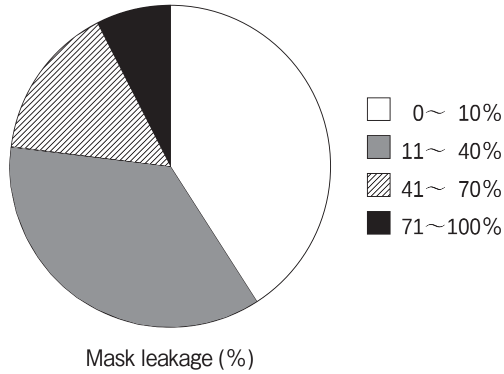

Fig. 1 Mask leakage before education ($n = 174$).
The average mask leakage was 24.3 ± 25.4%. The functional level of mask leakage, defined as less than 10%, was seen in 41.4% of cases.

Table 3 The relationship between factors garnered from the personal interview and pulmonary function ($n = 137$)

Factors	%VC (%)		$FEV_{1.0G}$ (%)	
	r[a]	p	r	p
Age	0.045	0.609	−0.286	0.001
Work period	−0.035	0.710	−0.150	0.113
Working hours per day (hours/day)	−0.065	0.517	0.171	0.091
B.I.	0.017	0.852	−0.236	0.010
Height	0.193	0.025	−0.003	0.969
Body weight	0.099	0.254	0.09	0.312
Mask leakage	−0.191	0.029	0.014	0.872

The relationships between these factors were analyzed using the Pearson's correlation coefficient test.
[a]r indicates the Pearson's correlation coefficient.
B.I.: Brinkmann Index
$FEV_{1.0G}$: percent forced expiration volume in 1st sec
%VC: percent vital capacity

Table 4 Effect of education regarding how to wear masks properly

Occupation	Number of factories	Participants	Mask leakage[a] (%)	
			Before education	After education[b]
Refractory crusher	1	16	16.7 ± 6	5.8 ± 9
Founder	1	7	67.3 ± 21	21.3 ± 24
Total	2	23	32.1 ± 29	10.5 ± 16

Mask leakage was measured in the tearoom of the factory. Of the 176 workers, 23 workers wished to know the correct way to fit their mask, and we instructed them on how to wear the mask properly.
[a]Mask leakage has to be below 10% to protect a worker from dust inhalation.
[b]Education consisted of instructions on how to choose the correct size and form of mask, how to check mask filters, and how to fix a loose mask string.

90% was seen in 1 case (9.0%). Mask leakages among workers from the other industries were lower. Only in 8 cases (40.0%) among foundry workers was mask leakage greater than 10%, and only in 3 cases among charcoal burners were mask leakage values greater than 10% (33.3%).

Shipyard welders and stonemasons showed a tendency towards lower pulmonary function. Although there were no relationships between FVC (forced VC) and mask leakage, %VC had a tendency to be lower if mask leakage was higher ($p = 0.029$, $r = -0.191$, Table 3) and when adjusting for height, the tendency was also significant. However, after adjusting for height, age, B.I., and working period, the tendency existed but lost significance.

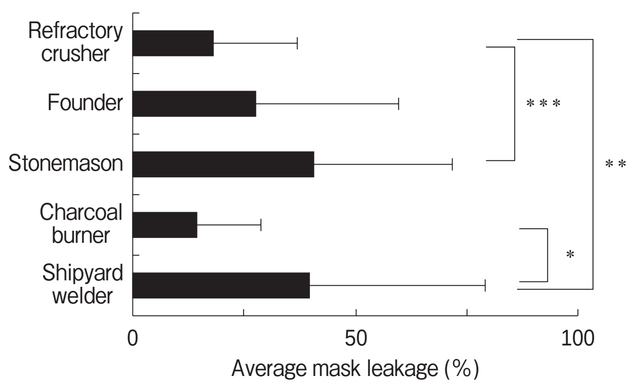

Fig. 2 There were significant differences among the 5 occupational groups in the average values obtained in the mask-fitting test (*$p = 0.046$, **$p < 0.001$, ***$p = 0.028$).

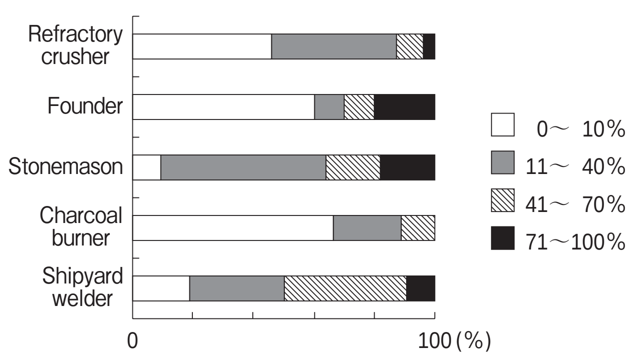

Fig. 3 Details of average mask leakage in each industry obtained from the mask-fitting test. Differences in mask leakage (%) among occupations: stonemason > refractory crusher: $p = 0.028$, shipyard welder > refractory crusher: $p < 0.001$, shipyard welder > charcoal burner: $p = 0.046$.

Education regarding how to wear a mask properly. After an educational session, the mask leakage was measured a second time (Fig. 4). Before education, mask leakage was 32.1 ± 28.0%; after education, mask leakage was reduced to 10.5 ± 15.6% ($p < 0.001$).

Discussion

Pneumoconiosis is one of the most well-known occupational diseases and is caused by dust inhalation. Dust inhalation causes functional changes in the lungs, a loss of lung volume, and obstructive changes. As the dust was responsible for a restrictive type of pulmonary function test, obstructive types of change were also indicated and many studies have revealed the relationship between FEV, dust exposure, and pulmonary functions such as $FEV_{1.0}$ (forced expiratory volume in 1st sec), %VC, and FVC [20-28]. The present study shows that the pulmonary function of most workers exposed to dust and possibly latent pneumoconiosis is within normal limits. This fact resulted in a selection bias, in that all of participants in this study were in active service in dusty working places. The Japanese Industrial Safety and Health Law and Pneumoconiosis Law prescribes that if workers are diagnosed as candidates for pneumoconiosis, measurement of pulmonary function is required and that sometimes work areas will be changed to reduce

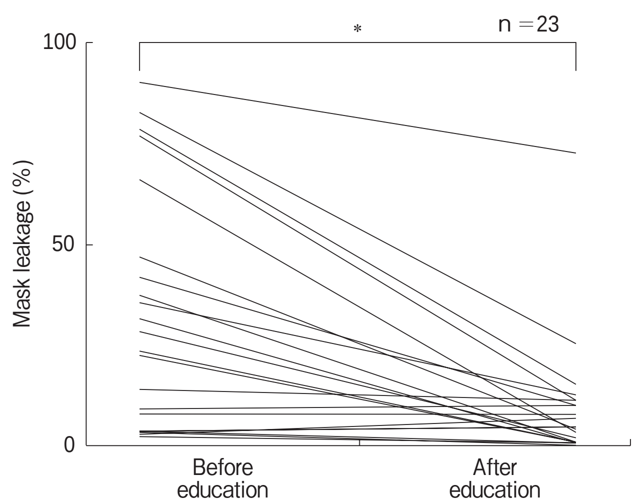

Fig. 4 Differences in mask leakage before and after education (*$p < 0.001$).

dust exposure. Therefore, the pulmonary function of Japanese workers in areas subject to dust exposure is expected to be close to normal. In addition, a selection bias regarding the factories also existed. The factories in this study agreed to participate of their own accord, and that decision to participate was connected with their desire to improve their own surroundings. Therefore, the percentages for wearing masks and mask fitness in the present study may be better than the average of other dusty factories. It is also possible that during the mask-fitting test workers tried to wear masks more properly so that they could avoid being scolded for the loose fit of their masks.

From the present results measuring mask fitness, the average mask leakage was 24.3%, implying poor mask function due to incorrect fitting of the mask. Only 41.4% of workers' masks were effective. In this study, most of the workers had normal pulmonary function, but high levels of mask leakage tended to lower the %VC ($r = -0.195$, $p = 0.027$). However no significant relation was found between $FEV_{1.0G}$ and mask leakage. The pneumoconiosis shows both the restrictive and obstructive type of pulmonary function, and the decline of pulmonary function parameters was variable [20–28], although a study has pointed out that in the PR1 state, the decline of %VC is more distinct than $FEV_{1.0G}$[21]. The participants of this study were in a pre-stage of pneumoconiosis, which may be related to this result. The tendency between %VC and mask leakage might result from the possibility that poor mask fitness induce poor pulmonary function in workers. To the contrary, it also remains possible that workers with poor pulmonary functions tend to wear masks loosely due to feelings of dyspnea, and this hypothesis may also be right in part. However, it has been postulated that wearing an effective mask protects pulmonary function [13], which is in accordance with the former hypothesis. Therefore, the pulmonary function of the participants in the present study who wore ill-fitting and therefore ineffective masks is expected to worsen in the future.

We found that education regarding proper mask fit and usage is very effective for workers because even a very short training period resulted in great improvements in the levels of mean mask leakage, which decreased from 32.1% to 10.5%. Basic education regarding pneumoconiosis and the importance of minimizing dust exposure should be required for persons who work in dusty environments. The prevalence of mask wearing was quite high in this study. However, education is still insufficient. It has been reported that workers only know that they must wear masks as a rule but that they do not understand the reasons for this. Only 19% of workers have adequate knowledge of why masks should be worn [1]. Technical, psychological, and social factors are associated with the reasons why workers do not use their masks correctly [29]. If, however, education of workers is thorough and comprehensive, workers would take mask-wearing more seriously and mask fitness would likely improve.

We found a weak correlation between B.I. and $FEV_{1.0G}$ ($r = -0.236$, $p = 0.010$). In contrast, age and $FEV_{1.0G}$ also had a weak correlation ($r = -0.286$, $p = 0.001$). Therefore, we made an adjustment for age in the statistical relationship between B.I. and $FEV_{1.0G.}$ However, this adjustment resulted in the loss of any significant relationship, likely because the correlation between B.I. and $FEV_{1.0G}$ was weak compared with that between age and $FEV_{1.0G}$. Smoking is well-known to be a factor that leads to chronic obstructive pulmonary disease (COPD) accompanied by lowered lung function [27–28, 30–31]. The OR (confidence interval; CI) for the length of dust exposure among welders was 1.07 (CI: 1.03–1.16). However, the OR (CI) for welders who were also current smokers was 20.2 (CI: 1.27–320.0) and that of refractory workers who were also smokers was 58.9 (CI: 1.83–190) [30]. These results suggest that smoking increases the risk of COPD after dust exposure. Furthermore, in this study, the population of smokers was higher than the national average in Japan, and this prevalence also affected the findings regarding pulmonary function and the prevalence of COPD. It is therefore possible that discontinuation of smoking is more effective in improving pulmonary function than improving mask fitness.

Since pneumoconiosis is a preventable disease, more effort is required to prevent workers from inhaling excessive dust by providing practical knowledge of proper mask-wearing techniques. Our results indicate that low mask fitness has a negative impact on %VC. Therefore, the proper wearing of a mask and worker education are easier, more effective, and less expensive methods than instituting local exhaust systems and local ventilators. Technical, psychological, and social factors are associated with whether or not workers wear masks [1, 29]. Therefore, improvements in mask fitness and worker education addressing these factors are necessary in the future.

In this study, there were some limitations. The sample size was small, and not all workers participated in the study. These limitations originated in the lack of comprehension of the factory managers and the busy work conditions. In addition, the factors affecting pulmonary function in the dusty work places such as the concentrations of dust, the kind of masks, and the kinds of dust were not measured [4, 16, 24]. These factors might have had a negative effect on this study.

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