Industrial Health 2001, **39**, 211–219 **Original Article**

# Fifteen Year Follow-Up Study of VC and $FEV_1$ in Dust-Exposed Workers

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*Received September 18, 2000 and accepted February 28, 2001*

**Abstract: A baseline survey of 3457 male workers exposed to various forms of dust from 11 medical facilities throughout Japan was carried out in 1978 or 1979. We completed the present follow-up study 15 years later on 693 of the men. Vital capacity (VC) and forced expiratory volume in one second ($FEV_1$) were analyzed as indices of lung function. We examined factors that affected both baseline and interval changes in VC and $FEV_1$ by stepwise multiple regression analysis. In the cross-sectional data analysis of baseline, height, profusion rate (PR) and age were selected as predictor variables for VC and $FEV_1$, additionally duration of working for $FEV_1$. It indicated that baseline VC decreased by 84.0 ml with each increase in PR classification. Similarly, baseline $FEV_1$ decreased by 146.6 ml with increasing PR. Baseline VC and $FEV_1$ were both positively influenced by subject height. In the longitudinal analysis, baseline PR, age and smoking habits were selected for predictor variables for decline of VC and $FEV_1$. It indicated a negative influence of baseline PR classification on VC and $FEV_1$ changes (−5.0 and −7.5 ml/y, respectively). Smoking decreased VC and $FEV_1$ by 6.1 and 5.8 ml/y, respectively.**

**Key words:** Occupational dust exposure, Pneumoconiosis, Vital capacity, Forced expiratory volume in one second, Longitudinal study

## Introduction

In Japan, improvements in the work environment and in protective devices against dust exposure have resulted in a decreased number of new pneumoconiosis cases. Moreover, the prevalence of pneumoconiosis per examinees (a ratio of the number of workers with pneumoconiosis to the number of workers examined) has been decreasing since 1983. However, in 1999, 7.7% of examinees still suffered from pneumoconiosis. The number of pneumoconiosis cases ranks second to accidental lower back injury among compensated occupational diseases[1)].

Numerous studies have investigated the relationship between dust exposure and pneumoconiosis[2–28)]. However, many of the Japanese studies were cross-sectional[2–5)] and only a small number were longitudinal[6–8)]. In other countries, several longitudinal studies focused on individual occupational categories[9–27)] although studies across categories through a study area were rare[28)].

The present study focused on workers exposed to one or more of 17 types of dust categories listed in the Enforcement Ordinance of Pneumoconiosis Law[29)]. The aim of the present study was to identify significant factors associated with decreasing vital capacity (VC) and forced expiratory volume in one second ($FEV_1$) in baseline data collected in 1978 or 1979. We also investigated factors contributing to decreased volume analyzed from follow-up data collected during the next 15 years.

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## Subjects and Methods

The yearly examination for pneumoconiosis required by Pneumoconiosis Law was carried out for about 200,000 dust workers. In 1978 or 1979, the Committee for Health Management of Pneumoconiosis entrusted by Japan Industrial Safety and Health Association collected the results of examinations. Those data that were sent from eleven medical facilities of all over Japan consisted of 3457 male dusty workers who had been or were engaged in one or more of 17 types of dust categories. We established those people as baseline population. At 15-year, 824 people (23.8%) underwent the examinations for pneumoconiosis. Analyzed subjects consisted of 693 male (20.0% of baseline) who underwent 15-year examination of chest radiographs and primary lung function tests. A total of 131 male without complete data were eliminated from this analysis. The number of follow-up data points obtained during 15 years varied from 2 to 16 with 9.30 ± 4.67 of average.

Analyzed data were based on the examinations for pneumoconiosis that consisted of chest radiographs, primary lung function tests (Spirometer and Flow-volume curve) and questionnaires for smoking habits and working history. Depending on the pneumoconiosis handbook, lung function tests was carried out two times. Questionnaires were self-administered, while working category and duration were usually written by industrial hygienist before examination.

A cross-sectional analysis of baseline data was undertaken to examine factors that might affect baseline VC and $FEV_1$. These included duration of working, profusion rate classification on a chest roentogenogram (PR), smoking habits, height and age at the baseline.

In the longitudinal study, yearly declines in VC and $FEV_1$ were estimated as the slope of the fitted least squares linear regression of available data during 15 years for each individual. Subsequently, based on the slopes, stepwise multiple regression analysis was used to examine the same parameters in a cross-sectional analysis. The means of selected variables were compared between baseline data and those after 15 years according to age or PR groups by adjusting other factors.

Variables significantly affecting VC and $FEV_1$ cross-sectionally and longitudinally were identified by stepwise multiple regression analysis. Analysis of covariance and Bonferroni's multiple comparison was used for statistical evaluation of differences among baseline data, 15-year data and declined volume. Paired t-tests was used for evaluation of difference between baseline and 15-year. Statistical significance was indicated if $p<0.05$. Statistical analysis was carried out using the SPSS statistical package (SPSS Inc.).

## Results

*Subject profiles*

The baseline age of follow-up subjects ranged from 22 to 72 years (mean ± SD = 48.0 ± 9.1 yrs) and 83.5% (579 of 693) were 40 years or older. Duration of working ranged from one to 45 years (mean ± SD = 21.3 ± 8.3 ) and 91.3% were employed over 10 years. At the baseline survey all the subjects were employed. Dust exposures were primarily from manufacturing ceramic wares and refractory materials (29.6%), underground work (24.5%), and welding (19.4%). Only 1.4% of the workers was exposed to asbestos. Never-smokers accounted for 8.7% (60) of the subjects, 80.1% (555) were current smokers and 5.5% (38) were ex-smokers. According to the baseline PR, 6.9% (48) of the subjects were classified as $PR_0$, 46.9% (325) as $PR_1$, 24.5% (170) as $PR_2$, 10.2% (71) as $PR_3$ and 11.4% (79) as $PR_4$.

*Comparison of baseline data for the dropouts and follow-up subjects*

The dropouts and follow-up subjects showed no significant differences in mean VC and $FEV_1$ adjusted by height, PR, age and duration of working as shown Table 1. Among the predictor variables, duration of working showed no statistical significance between two groups. However, mean age and height showed statistical significance ($p<0.001$ and $p<0.01$, respectively) as shown in Table 1.

**Table 1. Comparison of variables in dropout with follow-up subjects at the baseline**

| | | mean | SD | p value |
|---|---|---|---|---|
| VC (ml)† | dropout | 3523.6 | 20.5 | 0.715 |
| | follow-up | 3532.0 | 40.1 | |
| $FEV_1$ (ml)† | dropout | 2743.0 | 18.5 | 0.093 |
| | follow-up | 2777.9 | 36.2 | |
| duration of working (year) | dropout | 21.2 | 9.3 | 0.821 |
| | follow-up | 21.3 | 8.3 | |
| age (year) | dropout | 49.6 | 9.4 | <0.001 |
| | follow-up | 47.9 | 9.1 | |
| height (m) | dropout | 1.61 | 0.06 | <0.01 |
| | follow-up | 1.62 | 0.06 | |

number of dropout 2633 and follow-up 693. †: adjusted value by PR, duration of working, age and height.

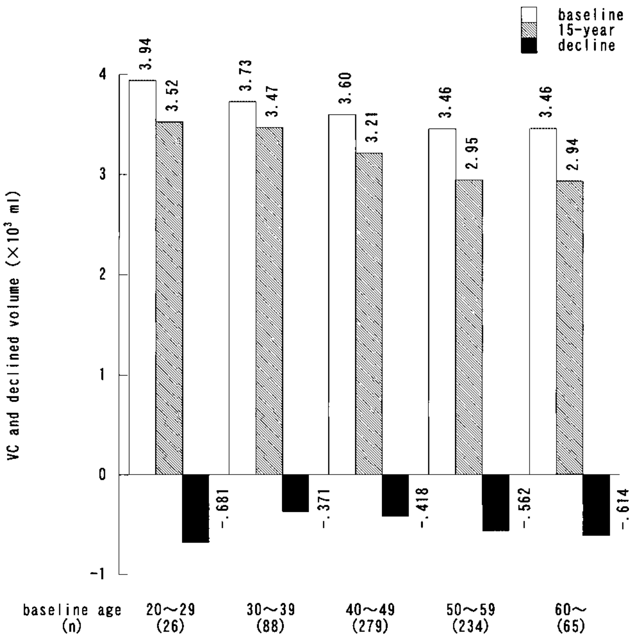


**Fig. 1. Mean VC of baseline (open column), that of 15-year (shadow column) and declined volume during 15-year (closed column) according to the age groups.**

Adjusted mean VC by baseline height, PR and duration of working. VC decreased significantly over the 15 years in all age groups ($p<0.01$).

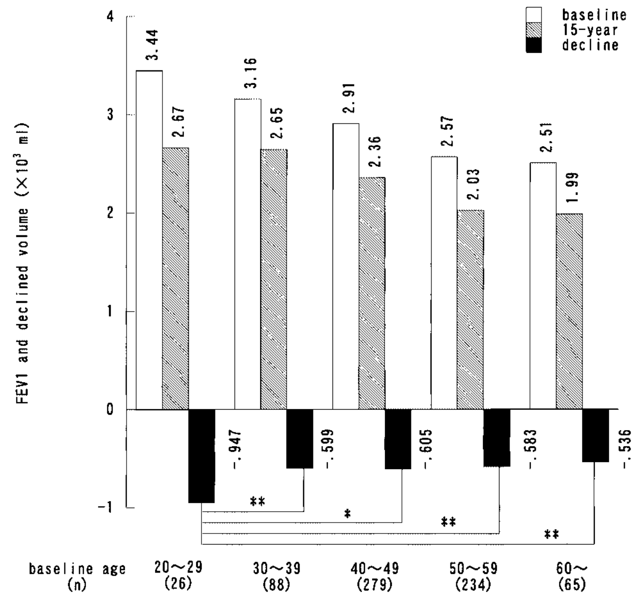


**Fig. 2. Mean $FEV_1$ of baseline (open column), that of 15-year (shadow column) and declined volume during 15-year (closed column) according to the age groups.**

Adjusted mean $FEV_1$ by baseline height, PR and duration of working. $FEV_1$ decreased significantly over the 15 years in all age groups ($p<0.001$). *$p<0.05$, **$p<0.01$.

*Comparisons of means of VC and $FEV_1$ according to age, PR, smoking habits and duration of working*

Mean VC (3567.6 ± 39.3 ml) and $FEV_1$ (2810.4 ± 35.1 ml) at the baseline adjusted by age, height, PR and duration of working were significantly higher than mean VC (3142.3 ± 43.0 ml) and $FEV_1$ (2260.9 ± 38.7 ml) at the 15-year point ($p<0.001$). Over the 15 years, VC and $FEV_1$ declined 488.9 ± 34.9 ml and 603.2 ± 28.1 ml, respectively. Mean annual decline calculated from individual regression equation and adjusted by age, height, PR and duration of working in VC and $FEV_1$ were 32.6 ± 2.3 and 40.2 ± 1.9 ml, respectively.

In all age groups, VC (Fig. 1) and $FEV_1$ (Fig. 2) decreased significantly over the 15 years. The decline in VC over the study interval showed no significance but tended to be more rapid in older age groups except $PR_0$. Conversely, $FEV_1$ declined at a constant rate in all age groups except $PR_0$.

In all baseline PR groups, VC (Fig. 3) and $FEV_1$ (Fig. 4) decreased significantly over the 15 years. The rate of decline in VC and $FEV_1$ over the 15 years increased with a progression of PR, except for $PR_0$. The differences of declined volume between $PR_1$ and other PR groups were significant.

Table 2 shows baseline and 15-year mean VC and $FEV_1$. It indicates their decline in current smokers, ex-smokers and never-smokers over the study interval. The baseline and 15-year mean VC adjusted by baseline height, age, PR and duration of working showed no significance among three groups. However, adjusted mean $FEV_1$ at 15-year in smokers showed significantly lower value than that in never-smokers ($p<0.01$). Furthermore, VC and $FEV_1$ in smokers showed significantly higher decline than that in never-smokers ($p<0.01$).

Table 3 shows baseline and 15-year mean VC and $FEV_1$ indicating their decline according to duration of working. The baseline and 15-year mean VC and $FEV_1$ adjusted by baseline height, age and PR showed no significance among four groups. Only between 1~10 and 11~20 groups, decline of VC showed statistical significance ($p<0.05$).

*Multiple regression analysis of cross-sectional data*

Table 4 shows the results of stepwise multiple regression analysis of the baseline data. For VC, four of five predictor variables were selected, only smoking habits was eliminated. In contrast, three predictor variables were selected for $FEV_1$, duration of working and smoking habits were eliminated. In the predictor variables, only height increased VC and $FEV_1$, other factors reduced those of baseline.

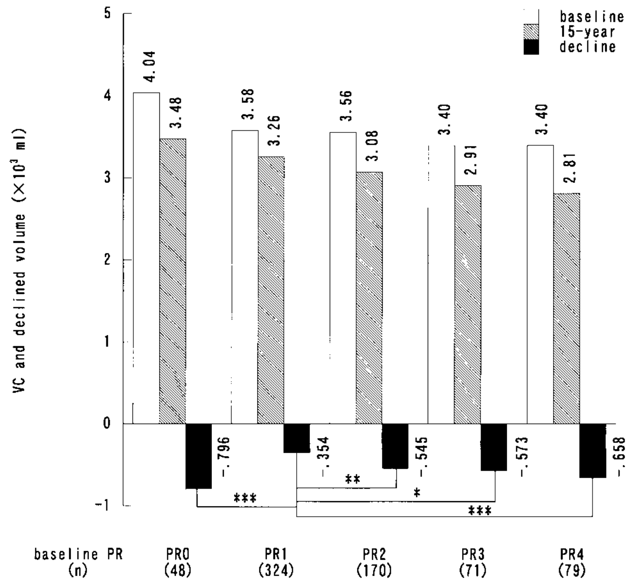


**Fig. 3. Mean VC of baseline (open column), that of 15-year (shadow column) and declined volume during 15-year (closed column) according to the baseline PR groups.**

Adjusted mean VC by baseline height, age and duration of working. VC decreased significantly over the 15 years in all age groups ($p<0.001$). *$p<0.05$, **$p<0.01$, ***$p<0.001$.

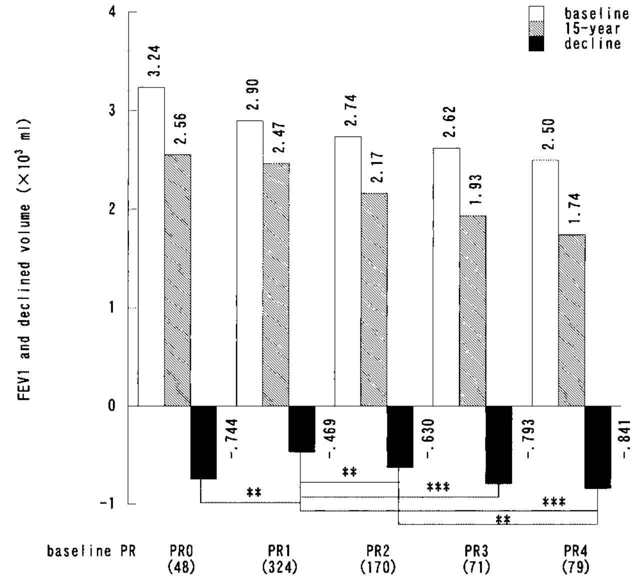


**Fig. 4. Mean $FEV_1$ of baseline (open column), that of 15-year (shadow column) and declined volume during 15-year (closed column) according to the baseline PR groups.**

Adjusted mean $FEV_1$ by baseline height, age and duration of working. $FEV_1$ decreased significantly over the 15 years in all age groups ($p<0.001$). **$p<0.01$, ***$p<0.001$.

**Table 2. Mean decline of VC and $FEV_1$ during 15-year by smoking habits** n=653

| | smoking habits | smokers | ex-smokers | never-smokers |
|---|---|---|---|---|
| | number | 555 | 38 | 60 |
| VC† (ml) | baseline | 3542.3 (43.5) | 3591.2 (168.9) | 3568.9 (132.7) |
| | 15-year | 3112.4 (48.3) | 3142.8 (187.5) | 3258.1 (147.3) |
| | annual decline†† | 33.5[a] (2.6) | 29.4 (10.1) | 20.9[a] (7.9) |
| | 15-year decline†† | 502.5[b] (38.9) | 441.0 (151.1) | 313.5[b] (118.7) |
| $FEV_1$† (ml) | baseline | 2775.3 (39.1) | 2883.7 (151.7) | 2871.9 (119.2) |
| | 15-year | 2208.2[c] (43.0) | 2351.4 (166.8) | 2446.2[c] (131.1) |
| | annual decline†† | 41.7[d] (2.1) | 38.0 (8.2) | 29.6[d] (6.5) |
| | 15-year decline†† | 625.5[e] (31.8) | 570.0 (123.3) | 444.0[e] (96.9) |

a-a, b-b, c-c, d-d, e-e statistically significance ($p<0.01$). † mean (SD) adjusted by height, age, PR and duration of working. †† calculated from regression equation.

*Multiple regression analysis of longitudinal data*

Table 5 shows the results of stepwise multiple regression analysis of the interval changes in VC and $FEV_1$ and their predictors over the 15 years. Baseline PR, age and smoking habits were selected as predictor variables for $\Delta VC$ and $\Delta FEV_1$. However, height and duration of working were eliminated.

In predictor variables, only baseline age reduced annual decline of $FEV_1$ by 0.38 ml/y but other variables increased annual decline.

When the subjects were divided into two groups, $PR_{0+1+2}$ and $PR_{3+4}$, age increased annual decline of $FEV_1$ during 15 years in the former group (coefficient was − 0.016), but decreased in the latter group (coefficient was 1.052).

## Discussion

The present study focused on 693 men who were exposed to at least one of 17 types of dust through their employment. We estimated the loss of VC and $FEV_1$ in the subjects by

**Table 3. Mean decline of VC and $FEV_1$ during 15-year by duration of working** n=692

| | duration of working* (year) | 1~10 | 11~20 | 21~30 | 31~ |
|---|---|---|---|---|---|
| | number | 80 | 237 | 283 | 92 |
| VC† (ml) | baseline | 3686.0 (123.5) | 3546.8 (68.8) | 3566.0 (62.8) | 3523.6 (113.4) |
| | 15-year | 3162.0 (135.3) | 3151.8 (75.4) | 3135.1 (68.7) | 3122.5 (124.2) |
| | annual decline†† | 43.8[a] (7.2) | 28.8[a] (4.0) | 32.1 (3.6) | 34.0 (6.6) |
| | 15-year decline†† | 657.0[b] (107.8) | 432.0[b] (60.0) | 481.8 (54.7) | 510.3 (98.9) |
| $FEV_1$† (ml) | baseline | 2847.8 (110.0) | 2768.4 (61.3) | 2836.4 (55.9) | 2806.3 (100.9) |
| | 15-year | 2233.6 (121.5) | 2242.1 (67.7) | 2277.4 (61.7) | 2282.3 (111.5) |
| | annual decline†† | 45.6 (5.9) | 37.5 (3.3) | 40.9 (3.0) | 40.5 (5.4) |
| | 15-year decline†† | 684.1 (88.0) | 562.0 (49.0) | 613.6 (44.7) | 607.0 (80.7) |

* at the baseline. a-a, b-b statistically significance (p<0.05). † mean (SD) adjusted by height, age and PR. †† calculated from regression equation.

**Table 4. Cross-sectional multiple regression analysis of baseline data**

| | predictor variable | coefficient | p value |
|---|---|---|---|
| VC (ml) | constant | −2893.9 | — |
| | height | 4481.6 | <0.001 |
| | PR | −84.0 | <0.001 |
| | age | −11.6 | <0.001 |
| | duration of working | −5.6 | <0.05 |
| | multiple correlation coefficient (R) 0.596 | | |
| $FEV_1$ (ml) | constant | −751.1 | — |
| | height | 3188.5 | <0.001 |
| | PR | −146.6 | <0.001 |
| | age | −28.5 | <0.001 |
| | multiple correlation coefficient (R) 0.706 | | |

**Table 5. Longitudinal multiple regression analysis for the change of VC and $FEV_1$ during 15-year**

| | predictor variable | coefficient | | p value |
|---|---|---|---|---|
| | | 15-year decline | annual decline | |
| ΔVC (ml) | constant | 184.0 | 12.3 | — |
| | smoking habits† | −91.6 | −6.1 | <0.01 |
| | baseline PR | −75.2 | −5.0 | <0.001 |
| | baseline age | −7.7 | −0.5 | <0.01 |
| | multiple correlation coefficient (R) 0.294 | | | |
| $\Delta FEV_1$ (ml) | constant | −518.3 | −34.6 | — |
| | smoking habits† | −86.7 | −5.8 | <0.001 |
| | baseline PR | −111.9 | −7.5 | <0.001 |
| | baseline age | 5.5 | 0.4 | <0.05 |
| | multiple correlation coefficient (R) 0.307 | | | |

† dummy variable: 0 for never-smokers, 1 for ex-smokers and 2 for smokers.

cross-sectional analysis of the baseline data and by longitudinal analysis over the 15 subsequent years.

Reference values for lung function have been previously reported by Baldwin *et al.*[30] (VC) and Berglund *et al.*[31] ($FEV_1$%). In Japan, several authors reported formulas for estimating the predicted values of lung functions in a normal population[32, 35]. Nakadate[8] reported that the majority of workers exposed to mineral fibers were considered healthy and their average percent vital capacity (%VC) and $FEV_1$% (ratio of $FEV_1$ to forced vital capacity) values were well within the standard range of a healthy Japanese population. Aizawa *et al.*[32] reported that in healthy people whose mean age was 53.8 year-old, mean VC and $FEV_1$ were 3.95 and 3.00 l, respectively. However, in the present study that mean age of the subjects was 47.9 year-old, mean VC and were 3.53 and 2.78 l, respectively. In spite of younger mean age, mean VC and $FEV_1$ showed lower values in the present study. The differences between the two studies can be attributed to the effects of pneumoconiosis in the subjects of the present study.

Several cross-sectional studies have reported data on lung function tests in dust-exposed workers[2–5, 36]. Declines in forced vital capacity (FVC) and $FEV_1$% were observed in gold-miners with silicosis in South Africa[27].

In the cross-sectional analysis of baseline data, height, PR and age were selected as a predictor variable for VC and $FEV_1$, additionally duration of working for $FEV_1$. And cross-sectional stepwise multiple regression analysis of baseline data eliminated smoking habits as significant predictor of VC and $FEV_1$. The results imply that the effects of smoking habits were less than other factors and became obscure by inter-individual variation. However, in the longitudinal study smoking habits was selected as predictor variable. This result confirmed the study of Van der Lende *et al.*[37] who indicated in the cross-sectional analysis, smoking habits was not effective factor while in the longitudinal analysis it was effective. These results suggest that longitudinal analysis is better way to analyze the effects of smoking habits on lung function than cross-sectional analysis.

Hnizdo[38] reported that according to linear regression model it estimates in a 50-year-old current smoker the loss in $FEV_1$ attributable to smoking was 435 ml and an additional loss of 3.85 ml could be attributed to each pack-year history of smoking. Cowie *et al.*[27] reported that the loss in $FEV_1$ attributable to 1 pack year history of smoking was 6.9 ml. The present longitudinal study selected smoking as a predictor of VC and $FEV_1$, which decreased 6.1 and 5.8 ml/y, respectively. Several previous longitudinal studies reported that smoking was strongly related to a decline in lung functions not only in subjects with pneumoconiosis[7, 15, 17, 18, 22, 24, 25], but also in a healthy population[32]. The study by Soutar and Hurley[18] of British coal miners reported that according to the statistical model at age 60 and zero dust exposure, mean $FEV_1$ in ex-smokers and current smokers was 212 ml and 327 ml lower than that of never-smokers, respectively. The study by Krzyzanowski *et al.*[22] of chronic obstructive pulmonary diseases (COPD) reported an annual decline in $FEV_1$ for male never-smokers of 47.3 ml, for ex-smokers 50.4 ml, and for smokers 59.7 ml. In the present study, annual declines in $FEV_1$ were 29.6 ml in never-smokers, 38.0 ml in ex-smokers and 41.7 ml in smokers. Those in never-smokers and smokers differed significantly. Furthermore, several authors reported that the decline in $FEV_1$ was more profound than that in VC[7, 15, 19, 22, 24]. Our observations are in agreement with these previous studies. This observation is a result of smoking-induced obstructive pulmonary changes in addition to the fibrotic and obstructive changes of pneumoconiosis.

Longitudinal stepwise multiple regression using the same baseline variables as predictor variables identified baseline PR, age and smoking habits for estimating ΔVC and $\Delta FEV_1$. Therefore, other factors such as duration of employment and height did not contribute to the volume decline among dust-exposed workers. In $\Delta FEV_1$, PR was found to be the strongest predictor of all. However, in ΔVC smoking habits was stronger than others.

Cowie[23] reported the annual decline in $FEV_1$ for gold miners as 57 ml in $PR_1$, 100 ml in $PR_2$, and 128 ml in $PR_3$ cases. In the present study, the annual decline in $FEV_1$ was 31.5 ml in $PR_1$, 41.6 ml in $PR_2$, and 52.8 ml in $PR_3$. The differences between the two studies may be due to the fact that exposure to dust by the gold miners in Cowie's study could cause more serious impairments of lung function than the exposure to various dust types seen in the present study.

Previous studies have almost all shown age to be a significant factor causing decreases in lung function[2, 6, 7, 9–28, 30–34, 37, 38]. In contrast, in the present longitudinal study, we found that $FEV_1$ increased slightly with age, though only 0.36 ml per year. When we re-analyzed the data by grouping $PR_{0+1+2}$ and $PR_{3+4}$, we found that age was a positive factor only in the latter group. Thus, aging may be an important factor for estimating lung function in a healthy population or mild pneumoconiosis cases[32–35]. The present results showed that the annual declines in $FEV_1$ were constant regardless of baseline age, whereas a greater influence of PR on $FEV_1$ was shown.

Many studies have focused only on $FEV_1$ as an indicator of lung function[10, 12, 16, 17, 19-21, 23, 26], although a number have studied both FVC and $FEV_1$[2, 7–9, 11, 18, 25]. To enable comparison to these previous studies, we did not normalize our VC and $FEV_1$ data to height. However, several studies have analyzed data using values divided by height[2, 6, 7, 34], height squared[8] or height cubed[28], particularly in Japan. In many countries except Japan, it was analyzed by actual values for regression analysis. However, the reference values for pulmonary function in Japanese were also normalized to height[35]. Furthermore, the current Japanese Pneumoconiosis Law[29] requires that expiratory flow rate at 25%VC ($\dot{V}25$) and %VC are normalized to height in health examinations for pneumoconiosis. Nakadate[8] reported that adjustment for body size was unavoidable for nearly all pulmonary function indices, and standing height was usually utilized as an index of body size for that purpose. However, according to Nakamura *et al.*[34], VC, FVC, $FEV_1$ and $\dot{V}25$ should not be normalized to height because they are height-independent. In the present cross-sectional study, both VC and $FEV_1$ were strongly associated with height.

Eisen *et al.*[20] reported that the annual decline in $FEV_1$ of those who remained in his study for the full 5-year term was 44 ml/y and of those who did not have measurement values in the final survey, 69 ml/y. In the present study, only baseline age and height of dropouts were different from those of follow-up. Baseline VC and $FEV_1$ between two groups had no statistical significance. To rule out healthy workers effect, the decline of $FEV_1$ in dropouts should be evaluated.

The worse PR group at the baseline, the larger decreased VC and $FEV_1$ during 15 years. So called, horse-racing effect indicates that the subjects who have lower values at the baseline may show more declined volume than do those having higher values at the baseline. To predict the loss of lung function, multiple regression analysis had better be performed in each PR group.

As conclusion, PR and age were common significant predictor variables for VC and $FEV_1$ both cross-sectional and longitudinal analysis. Height and duration of working were associated with VC and/or $FEV_1$ cross-sectionally and smoking influenced VC and $FEV_1$ longitudinally.

## Acknowledgements

The present study analyzed the results of examinations conducted by Japan Industrial Safety and Health Association entrusted by the Ministry of Labor. The raw data were originally reported in 1985, 1990 and 1995 as part of the "Assessment of pulmonary function tests for the examination of pneumoconiosis" reports. The authors wish to thank the authorities involved and the associated personnel at the following medical facilities; Iwamizawa-Rosai Hospital, Keihai-Rosai Hospital, Kitasato University, The Kanagawa Health Service Association, Fujita Health University, Kyoto Industrial Health Association, Kinki Chuo Hospital, Okayama-Rosai Hospital, Junpukai Asahigaoka Hospital, Hiroshima University and Nishinihon Occupational Health Service Center.

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