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Original Article

Obstructive Pulmonary Function Impairment among Korean Male Workers Exposed to Organic Solvents, Iron Oxide Dust, and Welding Fumes

Ji Young RYU[1], Sang-Yoon LEE[1] and Dae Hwan KIM[1]*

[1]Department of Occupational and Environmental Medicine, Inje University Haeundae Paik Hospital, Republic of Korea

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Abstract: We evaluated spirometric obstructive pulmonary function impairment among workers who were occupationally exposed to organic solvents, iron oxide dust, or welding fumes. Data were collected from records of periodic health examinations of workers. In total, 448 Korean male workers were enrolled and classified into three exposure groups: exposure to organic solvents, iron oxide dust, or welding fumes. Logistic regression analysis was performed to evaluate the association between occupational exposure and pulmonary function. Compared to exposure to organic solvents, exposure to iron oxide dust was significantly associated with obstructive pulmonary function impairment (odds ratio [OR], 9.61; 95% confidence interval [CI], 2.20–41.97). The group exposed to welding fumes did not show a significantly higher OR compare to those exposed to organic solvents (OR, 2.83; 95% CI, 0.74–10.8). These results suggest that exposure to iron oxide dust has a greater association with obstructive pulmonary function impairment than exposure to organic solvents or welding fumes.

Key words: Organic solvents, Iron oxide dust, Welding fumes, Occupational exposure, Obstructive pulmonary function impairment

Introduction

Workers in many industrial areas are exposed to various inhalable agents including dust, gases, welding fumes, and organic solvents. Occupational exposure to these agents may cause several respiratory diseases such as asthma, interstitial lung diseases, and chronic obstructive pulmonary disease (COPD)[1–3]. Interstitial lung disease reveals restrictive pulmonary function abnormalities, whereas asthma and COPD generally show obstructive abnormalities on the spirometric test.

*To whom correspondence should be addressed.
E-mail: kimdh@paik.ac.kr

Asthma and COPD are major causes of chronic mortality and morbidity worldwide and appropriate therapy with an early diagnosis of these diseases can significantly reduce socioeconomic burden and enhance patient quality of life[4, 5]. Occupational exposure to inhalable deleterious agents can lead to the development of work-related asthma[6]. Recent studies have indicated that 16.3% of all adult-onset asthma is caused by occupational exposure[3]. Although smoking is a representative COPD risk factor, a number of studies have addressed the contribution of occupational exposure to COPD[7–11]. Several studies have shown that the population fraction of COPD attributable to occupational exposure is 15–20%[8, 12, 13]. However, the respective effect of each inhalable agent on airflow obstruction has not been investigated sufficiently in COPD and only a few studies have compared the effect of individual exposure.

Many factors affect pulmonary function such as age, smoking, and socioeconomic status[14–17]. These factors can potentially act as confounders when evaluating the effect of occupational exposure on obstructive pulmonary function impairment (OPFI). Moreover, these factors can interact with each other[18]. Therefore, these factors should be considered when assessing the effects of occupational exposure to noxious agents.

In the present study, we evaluated spirometric OPFI among Korean workers who were exposed to organic solvents, iron oxide dust, or welding fumes considering the effects of age, abdominal obesity, smoking, and duration of exposure.

Subjects and Methods

Subjects

Data were collected from records of periodic health examinations conducted for workers according to the Korean Occupational Safety and Health Law. All health examinations were conducted in the Department of Occupational and Environmental Medicine, Haeundae Paik Hospital, Busan, South Korea, from March to September 2011. In total, 448 Korean male workers who had been exposed to organic solvents, iron oxide dust, or welding fumes were enrolled. Of these, 273 workers were from a shipbuilding company, 102 were from chemical and allied product manufacturers (paint and polyurethane manufacturing), and 73 were from a metal material manufacturing company. The periodic health examinations included a physical examination, chest-radiography, spirometry, and a self-administered questionnaire. The questionnaire was designed to collect relevant information related to work history, smoking habit, and respiratory symptoms. All enrolled workers had been working in the same field for at least 1 year. Workers with old tuberculosis or active lung lesions on chest-radiography were excluded. This study was approved by the institutional review board of Haeundae Paik Hospital (IRB No. 2012-056).

Occupational exposure and study groups

Occupational exposure to inhalable workplace agents was assessed by each company's data on their workers, collected during the first half of 2011. Welders and grinding workers from a shipbuilding company were enrolled in this study. Most welders in the company used CO_2 arc welding with a rod consisting of iron (80–90%), titanium dioxide (4–10%), aluminum oxide (1–3%), and manganese (1–3%). Welding fumes were measured for welders, and the arithmetic mean exposure (± standard deviation, SD) was 2.70 $mg \cdot m^{-3}$ (± 1.35). Iron oxide, titanium dioxide, manganese and its compounds, and aluminum and its compounds were found in the welding fumes in a quantitative analysis by atomic absorption spectroscopy.

Grinding workers were exposed to metallic dust generated from grinding. The major component of metallic dust is iron oxide dust and the arithmetic mean exposure to iron oxide dust was 2.94 (± 1.04) $mg \cdot m^{-3}$. During metal materials manufacturing, the enrolled workers were involved in forging. Similar to grinding workers, forging workers were exposed to metallic dust. Iron oxide dust was also a main component of the metallic dust in the forging workers, and the arithmetic mean exposure was 1.79 (± 0.44) $mg \cdot m^{-3}$. Although metallic dust contains dusts from other metals in addition to iron oxide, the working environmental measurement was only conducted for iron oxide dust. According to the Korean Occupational Safety and Health Law, the working environmental measurement was conducted for metal accounting for >1% of the weight ratio among the total material.

Workers in polyurethane and paint manufacturing were mainly exposed to organic solvents including toluene, ethyl glycol, methylethylketone, methylene bisphenyl diisocyanate, and dimethylformamaide. The concentrations of all organic solvents except toluene were below the detection limits at both companies.

Workers were classified into three groups by type of occupational exposure: those exposed to organic solvents, iron oxide dust, and welding fumes. Welders from the shipbuilding company were exposed to welding fumes (222 workers). Grinding workers from the shipbuilding company and forging workers from metal material manufacturing were classified as the group exposed to iron oxide dust (124 workers). The group of workers exposed to organic solvents was from both the paint and polyurethane manufacturers (102 workers).

Smoking habit

Current smoking status was classified into non-smoker, ex-smoker, and current smoker. Five categories, based on personal pack-years were used in the logistic regression analysis, regardless of current smoking status.

Determining OPFI by spirometry

Spirometric OPFI was determined as the forced expiratory volume in 1 s (FEV_1)/forced vital capacity (FVC)<70% and a FEV_1<80% of the predicted value. Be-

Table 1. Demographic characteristics of the study group stratified by occupational exposure[a]

	Organic solvents (n = 102)	Iron oxide dust (n = 124)	Welding fumes (n = 222)	Total (n = 448)	*p*-value
Age (yr)	40.9 ± 8.6	40.7 ± 11.7	42.7 ± 10.7	41.8 ± 10.6	0.158
Height (cm)*	171.4 ± 6.8 [1]	170.1 ± 7.2 [1,2]	169.2 ± 6.0 [2]	170.0 ± 6.5	0.014
Weight (kg)	69.4 ± 9.7	70.2 ± 11.2	68.8 ± 10.5	69.3 ± 10.5	0.471
WC¶ (cm)	81.3 ± 5.1	81.6 ± 4.9	81.6 ± 5.3	81.5 ± 5.2	0.844
WC¶					0.171
<90 cm	95 (93.1%)	118 (95.2%)	199 (89.6%)	412 (92.0%)	
≥90 cm	7 (6.9%)	6 (4.8%)	23 (10.4%)	36 (8.0%)	
Smoking (pack-yr)	10.3 ± 8.7	10.9 ± 11.0	12.1 ± 11.9	11.4 ± 11.0	0.343
Smoking status*					0.002
Non-smoker	17 (16.7%)	32 (25.8%)	46 (20.7%)	95 (21.2%)	
Ex-smoker	26 (25.5%)	8 (6.5%)	44 (19.8%)	78 (17.4%)	
Current smoker	59 (57.8%)	84 (67.7%)	132 (59.5%)	275 (61.4%)	
Duration of exposure (yr)*	13.6 ± 8.5[1]	7.0 ± 7.2[2]	13.4 ± 9.1 [1]	11.6 ± 8.9	0.000
Duration of exposure*					0.000
<10 yr	35 (34.3%)	93 (75.0%)	87 (39.2%)	215 (48.0%)	
10–19 yr	36 (35.3%)	21 (17.3%)	90 (40.5%)	147 (32.8%)	
≥20 yr	31 (30.4%)	10 (8.1%)	45 (20.3%)	86 (19.2%)	
Industrial classification					na
Chemical industry	102 (100%)	0 (0.0%)	0 (0.0%)	102 (22.8%)	
Metal material industry	0 (0.0%)	73 (58.9%)	0 (0.0%)	73 (16.3%)	
Ship building industry	0 (0.0%)	51 (41.1%)	222 (100%)	273 (60.9%)	

[a]Data are expressed as mean ± SD or *n* (%). *p<0.05, [1, 2]Groups with the same number in the exponent do not differ significantly. ¶Waist circumference, na, not available.

cause bronchodilator testing was not routinely performed during the periodic health examinations, the reversibility of airflow obstruction could not be evaluated.

Spirometric measurements were performed with a portable computerized spirometer (Flowscreen®, Cardinal Health, Tuttlingen, Germany) calibrated daily with a 3 L syringe. We followed the American Thoracic Society (ATS)/ European Respiratory Society (ERS) norm for all measurement procedures[19]. All workers were tested before they started daily work (at least 8 h of leave from work).

Statistical analysis

We used SPSS Statistics ver. 20.0.0.1 (SPSS Inc. Chicago, IL, USA) for the statistical analysis. Demographic differences in each exposure group were analyzed by one-way analysis of variance (ANOVA) and the chi-square test. Spirometric values among the exposure groups were analyzed by one-way ANOVA. Logistic regression analysis was performed to evaluate the effects of independent variables on OPFI. Age, waist circumference, smoking, exposure duration, and occupational exposure were included as independent variables in the logistic regression analysis. Age was divided into two categories: below 40 and 40 or older. Waist circumference was also divided into two categories: below 90 cm and 90 cm or larger. Smoking habit was divided into five categories: less than 1 pack year, 1–9 pack years, 10–19 pack years, 20–29 pack years, 30 pack years and over. Duration of occupational exposure was classified into three categories: less than 10 yr, 10–19 yr, 20 yr and more.

Results

Demographic characteristics

The demographic characteristics of the exposure groups (total, n=448) are listed in Table 1. The mean age (± SD) of the workers and the mean waist circumference were 41.8 (± 10.6) yr and 81.5 (± 5.2) cm, respectively, and no significant differences were observed between the groups. In all, 95 (21.2%) workers were non-smokers who had never smoked and 275 workers were current smokers (61.4%). The mean pack-years was 11.4 (± 11.0) pack-years, and it was not significantly different between the groups. The mean duration of occupational exposure was 11.6 (± 8.9) yr and was significantly shorter in the group exposed to iron oxide dust.

Table 2. Prevalence of spirometric obstructive pulmonary function impairment and spirometric parameters by occupational exposure[a]

	Organic solvents (n=102)	Iron oxide dust (n=124)	Welding fumes (n=222)	*p*-value
Obstructive impairment[b]	3 (2.9%)	13 (10.5%)	15 (6.8%)	0.084
Overall				
FEV_1 (l)*	3.8 ± 0.6[1]	3.7 ± 0.6[1, 2]	3.6 ± 0.6[2]	0.030
FVC (l)	4.7 ± 0.7	4.61 ± 0.7	4.5 ± 0.7	0.177
FEV_1/FVC (%)	80.4 ± 5.9	80.2 ± 7.6	79.1 ± 6.3	0.170
FEV_1% (pred)	101.6 ± 11.3	101.9 ± 12.5	102.6 ± 13.9	0.741
FVC% (pred)	104.9 ± 13.0	106.2 ± 13.4	107.6 ± 14.5	0.239
Smoking status				
Non-smoker (n=95)				
FEV_1 (l)	3.6 ± 0.4	3.4 ± 0.7	3.4 ± 0.6	0.631
FVC (l)	4.5 ± 0.6	4.3 ± 0.7	4.2 ± 0.7	0.710
FEV_1/FVC (%)	80.5 ± 5.7	79.5 ± 7.0	79.4± 6.7	0.831
FEV_1% (pred)	99.1 ± 12.3	103.3 ± 14.0	102.1± 13.3	0.576
FVC% (pred)	102.5 ± 16.3	107.7 ± 15.8	106.6 ± 14.1	0.512
Ex-smoker (n=78)				
FEV_1 (l)	3.8 ± 0.5	3.8 ± 0.6	3.5 ± 0.5	0.116
FVC (l)	4.8 ± 0.7	4.7 ± 0.6	4.4 ± 0.7	0.098
FEV_1/FVC (%)	79.4 ± 5.8	80.4 ± 7.6	80.1 ± 6.4	0.890
FEV_1% (pred)	100.8 ± 9.4	105.6 ± 13.7	106.1 ± 16.9	0.331
FVC% (pred)	104.8 ± 10.0	108.0 ± 13.7	109.8 ± 18.2	0.432
Current smoker (n=275)				
FEV_1 (l)	3.8 ± 0.6	3.8 ± 0.6	3.6 ± 0.6	0.162
FVC (l)	4.7 ± 0.7	4.7 ± 0.7	4.6 ± 0.6	0.593
FEV_1/FVC (%)	80.8 ± 6.1	80.4 ± 8.0	78.7 ± 6.1	0.680
FEV_1% (pred)	102.6 ± 11.9	100.9 ± 11.8	101.7 ± 12.8	0.734
FVC% (pred)	105.6 ± 13.2	105.5 ± 12.5	107.2 ± 13.2	0.564

[a]Data are expressed as mean ± SD or *n* (%). [b]Spirometric obstructive pulmonary function impairment was defined as a forced expiratory volume in 1 s (FEV_1)/forced vital capacity (FVC)<70% and a FEV_1<80% of predicted value. *p<0.05, [1, 2]Groups with the same number in the exponent do not differ significantly.

OPFI and spirometry

The prevalence of OPFI within each exposure group and spirometric parameters by occupational exposure are listed in Table 2. The prevalence of spirometric OPFI tended to be highest in the group exposed to iron oxide dust (10.5%), but the difference was not statistically significant. The FEV_1 was significantly lower in the group exposed to welding fumes than that in the group exposed to organic solvents. However, other spirometric parameters including FVC, FEV_1/FVC, FEV_1% (pred), and FVC% (pred) were not significantly different. In a subgroup analysis by current smoking status, no significant differences in the spirometric parameters were observed between exposure groups.

Logistic regression analysis

The logistic regression analysis results are presented in Table 3. The group aged ≥40 yr had a higher adjusted odds ratio (OR) for OPFI (adjusted OR, 3.30; 95% confidence interval [CI], 1.10–9.88) compared to the group aged <40 yr. Abdominal obesity (waist circumference ≥ 90 cm) had a strong association with airflow obstruction (adjusted OR, 5.62; 95% CI, 1.82–17.37). The adjusted OR for having OPFI in the group with ≥ 30 pack-years of smoking was 4.01 (95% CI, 1.11–14.43). Occupational exposure duration of ≥ 20 years was significantly associated with OPFI (adjusted OR, 3.71; 95% CI, 1.14–12.09) compared to duration<10 years. The group exposed to iron oxide dust was highly associated with OPFI (adjusted OR, 9.61; 95% CI, 2.20–41.97) compared to the group exposed to organic solvents. No significant interactions were observed between independent variables in the logistic regression model, when we applied interaction terms to the model.

Table 3. Logistic regression results for spirometric obstructive pulmonary function impairment

	Crude odds ratio	(95% CI)	Adjusted odds ratio†	(95% CI)
Age (yr)				
<40	1 (reference)	–	1 (reference)	–
≥40	4.93	(1.98–12.27)	3.30	(1.10–9.88)
Waist circumference (cm)				
<90	1 (reference)	–	1 (reference)	–
≥90	3.10	(1.18–8.13)	5.62	(1.82–17.37)
Smoking (pack-yr)				
0	1 (reference)	-	1 (reference)	–
1– 9	0.65	(0.19–2.21)	1.11	(0.29–4.34)
10–19	0.71	(0.22–2.27)	1.23	(0.35–4.31)
20–29	1.64	(0.52–5.11)	1.62	(0.48–5.43)
≥30	5.00	(1.52–16.43)	4.01	(1.11–14.43)
Duration of exposure (yr)				
<10	1 (reference)	–	1 (reference)	–
10–19	1.49	(0.58–3.86)	1.74	(0.59–5.11)
≥20	4.08	(1.67–9.93)	3.71	(1.14–12.09)
Occupational exposure				
Organic solvents	1 (reference)	–	1 (reference)	–
Iron oxide dust	3.87	(1.07–13.96)	9.61	(2.20–41.97)
Welding fumes	2.39	(0.68–8.45)	2.83	(0.74–10.8)

†Adjusted for age, weight circumference, pack-year, duration of exposure, and occupational exposure. CI, confidence interval.

Discussion

We evaluated spirometric OPFI among Korean workers exposed to organic solvents, iron oxide dust, or welding fumes considering the effects of age, abdominal obesity, smoking habit, and exposure duration.

Some previous studies have found that exposure to dust is more relevant than exposure to fumes, gases, or irritants in patients with COPD[20–22]. In contrast, one study found that gases or vapors, sensitizers, or organic solvent composite were more important occupational exposures than dust composition[23]. In a recent cohort study, exposure to biologic dust, mineral dust, gases/fumes, and vapors, gases, dusts, or fumes (VGDF) was associated with increased incidence of COPD[24].

In the present study, the prevalence of spirometric OPFI within exposure groups was highest in the group exposed to iron oxide dust. In the logistic regression analysis, exposure to iron oxide dust was significantly associated with OPFI compared to exposure to organic solvents. Although the OR of exposure to welding fumes was higher than that of exposure to organic solvents, exposure to welding fumes was not significantly associated with airflow obstruction. Because the major component of welding fumes is iron oxide, it is expected that exposure to welding fumes would have similar effects on pulmonary function as exposure to iron oxide dust. However, our results suggest that exposure to iron oxide dust leaves workers more vulnerable to OPFI than exposure to welding fumes. Grinding and forging workers were not only exposed to pure iron oxide dust but also to other types of metallic dust. Although it was assumed that exposure to other metallic dust was insignificant, there is a possibility that exposure to a mixture of metallic dust had an effect on pulmonary function. Different particulate size between iron oxide dust and iron oxide fumes may also have contributed to OPFI. However, the explanation for the positive association between exposure to iron oxide dust and OPFI in this study remains unclear.

We also found that ≥20 yr exposure duration was highly associated with airflow obstruction. It is generally difficult to evaluate the effect of exposure duration, as the exact calculation of exposure duration may be impossible in workers with complex job histories. However, even in workers with simple occupational histories, the effect of exposure duration may be obscured by the effects of aging. The use of personal protective devices can also be quite different over the duration of exposure. At present, all workers who are exposed to toxic inhalable agents wear protective masks by law in Korea. However, in the past, wearing a protective mask was not mandatory in the workplace, and many workers did not wear protective equipment. Therefore, the degree of exposure to toxic agents may not be consistent over the duration of exposure. All of these limitations make it difficult to evaluate and interpret the effect of exposure duration.

We included age, smoking, and abdominal obesity as independent variables in our logistic regression analysis. After reaching peak pulmonary function at approximately 20 yr of age, the physiological changes in lung elasticity, muscle strength, and chest wall stiffness that may cause airflow obstruction tend to increase[25)]. Thus, age is often considered a COPD risk factor. However, it is still unclear whether the general aging process indeed leads to COPD[5)]. Furthermore, it is difficult to evaluate the independent effect of age itself on COPD because age usually shows collinearity with the duration of exposure in occupational environments and may reflect the general exposure that can affect lung function throughout life. We classified workers into two age categories (<40 yr and ≥40 yr) for the logistic regression analysis. Pulmonary changes tend to increase after age 40 and the Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines also suggest that COPD must be considered at >40 yr if there is any implication for COPD such as respiratory symptoms, smoking habit, or occupational exposure[5)]. Our findings showed that the group aged ≥40 yr had a 3.27 times higher adjusted OR for OPFI compared to that of workers aged <40 yr. This result supports the notion that being aged >40 yr is an important factor when considering OPFI.

Obesity can also influence respiratory function. Body mass index (BMI) is a useful indicator to evaluate obesity, and it is correlated with respiratory function[26)]. However, the effect of BMI on respiratory function is limited[27)]. In fact, it seems that abdominal obesity has a more significant effect on pulmonary function than BMI. Abdominal obesity is generally correlated with decreased FEV_1 and FVC[27)]. Therefore, we included abdominal obesity as an independent variable that could affect respiratory function in our analysis. Our results showed that the group with abdominal obesity had a higher OR for OPFI, suggesting that abdominal obesity may have an important role in obstructive pulmonary function and must be considered when evaluating the effect of occupational exposures.

Cigarette smoking is a well-known risk factor for COPD[5)]. In the present study, smoking ≥30 pack-years showed a significant crude OR for airflow limitation. However, when adjusted, the OR in the category of ≥30 pack-years showed no statistical significance but had a tendency for increased airflow obstruction. Although we did not find a significant association with direct smoking exposure as measured by pack-years, the results support the notion that high number of pack-years, such as ≥30 pack-years, may be a risk factor for airflow obstruction. We also found no significant differences in OR when we applied current smoking status to the logistic regression model instead of pack-years.

Several limitations to this study should be noted. First, exposure to metallic dust among grinding and forging workers was not fully assessed. According to Korean Occupational Safety and Health Law, the occupational environmental assessment for those workers only includes iron oxide. Although the majority of metallic dust is iron oxide dust, other metallic dusts can also affect pulmonary function. Second, a postbronchodilator spirometric test is not routinely performed during periodic health examinations for workers; therefore, the reversibility of airflow obstruction could not be evaluated. This may have caused misclassification of OPFI. Third, our study was cross-sectional in design, so casual inferences of association could not be determined. Fourth, we did not include non-exposed workers as a reference because of the limitation of periodic health examination that is confined to exposed workers only. More relevant and clearer data could be obtained using spirometric measurements from workers who are not exposed to inhalable toxic materials as a reference.

In summary, exposure to iron oxide dust in grinding and forging workers was significantly associated with spirometric airflow limitations compared to exposure to organic solvents in polyurethane and paint manufacturer workers. Although exposure to welding fumes also showed a higher OR for OPFI than exposure to organic solvents, it was not significant. Age, abdominal obesity, smoking habit, and exposure duration were also related to spirometric airflow obstruction. These findings suggest that smoking workers who are obese, ≥40 yr, and exposed to occupational inhalable agents need more careful evaluation and management for OPFI.

Further investigations should include spirometric testing on workers who are not exposed to toxic inhalable materials and other occupational exposure to more clearly interpret the present findings.

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