Association between Occupational Exposure and Lung Function, Respiratory Symptoms, and High-Resolution Computed Tomography Imaging in COPDGene

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Abstract

Rationale: Although occupational exposure to dust and fumes is considered a risk factor for chronic obstructive pulmonary disease, this determination has been limited by reliance on spirometry alone to assess disease severity in predominantly male populations.

Objectives: To determine the effect of occupational exposure on lung function, respiratory symptoms, and findings of emphysema and airway wall thickness measured using quantitative computed tomography in men and women.

Methods: COPDGene is a multicenter study of current and former smokers that underwent standardized volumetric chest computed tomography scans to assess airways, % emphysema, and % gas trapping. Spirometry and a respiratory questionnaire including occupational history were also analyzed in 9,614 subjects (4,496 women). Logistic regression and analysis of covariance was used to assess associations with exposure.

Measurements and Main Results: Occupational exposure to both dust and fumes was reported by 47.9% of men and 20.1% of

women. Adjusting for age, race, body mass index, education, and current and lifetime smoking, the odds ratios for persons with dust and fume exposures for chronic cough, chronic phlegm, persistent wheeze, and Global Initiative for Chronic Obstructive Lung Disease stages 2 and higher chronic obstructive pulmonary disease were significantly elevated and similar for men (1.83, 1.84, 2.0, 1.61, respectively) and women (1.65, 1.82, 1.98, 1.90, respectively). The % predicted FEV₁ was similarly lower in those with exposure in men (70.7 ± 0.8 vs. 76.0 ± 0.9; *P* < 0.001) and women (70.5 ± 0.8 vs. 77.2 ± 0.8; *P* < 0.001). Percent emphysema and gas trapping was greater in those exposed to dust and fumes in men and women. In men, but not in women, persons with exposure had a greater mean square root wall area of 10-mm internal perimeter airways.

Conclusions: Occupational exposure to dust and fumes in men and women is similarly associated with airflow obstruction, respiratory symptoms, more emphysema, and gas trapping in men and women.

Keywords: COPD; occupational exposure; emphysema

Chronic obstructive pulmonary disease (COPD) is a worldwide disease associated with significant morbidity and mortality. Although tobacco smoking is the

most recognized risk factor, occupational exposure (OE) to dust, gases, vapors, and fumes has also been associated with COPD (1–6). It has been suggested

that OEs may account for a substantial population-attributable fraction (~15% of the attributable risk) of COPD (5).

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At a Glance Commentary

Scientific Knowledge on the

Subject: Occupational exposure to dust and fumes has been associated with the development of chronic obstructive pulmonary disease. However, most published studies have focused on men, and have not included an assessment of chronic obstructive pulmonary disease radiographic phenotype defined by quantitative analysis of high-resolution computed tomography imaging.

What This Study Adds to the

Field: We have demonstrated that self-reported exposure to dust and fumes is not only associated with increased Global Initiative for Chronic Obstructive Lung Disease grade chronic obstructive pulmonary disease and respiratory symptoms, but also with more emphysema and gas trapping assessed by computed tomography scan in both men and women. This is the first study that demonstrates an association between occupational exposure to dust and fumes and radiographic phenotype in men and women, and that the effects of exposure on reduced lung function and symptoms in men and women are similar.

The evidence linking OE to COPD is based on epidemiologic studies demonstrating associations between those exposures and a reduction in FEV₁/FVC ratio, and the FEV₁ and increased respiratory symptoms common to COPD, including chronic cough, phlegm, and wheeze (7–11). Many of these epidemiologic studies of large populations were limited because relatively few subjects had significant airflow obstruction (6, 12, 13). Data are also limited linking OE to radiographic abnormalities consistent with either emphysema or small airways disease. Emphysema on high-resolution computed tomography (HRCT) related to exposure have been reported in asbestos-exposed construction workers (14) but not in quartz exposure (15). HRCT could provide a structural correlate to the pulmonary function changes attributable to OE, whereas this previously was available mostly via autopsy studies in gold miners and coal miners (4).

The effect of OE has not been documented as well in women despite the fact that the prevalence of COPD has significantly increased in women (16, 17). Some studies do not report effects separately in women, most likely because few women were included and few had significant exposure (3, 6). Understanding the effects of OE in women is important because women may respond differently compared with men (18). For example, women who smoke may present earlier with more severe disease suggesting that they may be more susceptible to developing COPD (19).

COPDGene is a multicenter study designed to determine the genetics and epidemiology of the clinical and radiographic phenotypes of COPD. The participants are current and former smokers who underwent spirometry; standardized volumetric chest CT scans to assess airway wall thickness, % emphysema, and % gas-trapping; and multiple questionnaires. The COPDGene population provides a unique opportunity to perform a comprehensive evaluation of the effects of OE on pulmonary function, respiratory symptoms, and radiographic phenotype. We sought to determine the effect of OE on lung function, respiratory symptoms, and

findings of emphysema and airway wall thickness measured using quantitative CT in men and women. Some of the results of these studies have been previously reported in the form of an abstract (20).

Methods

The institutional review board at each of the 21 clinical centers approved the study. Subjects were African Americans or non-Hispanic whites who were current or ex-smokers with greater than or equal to 10 pack-year history of smoking and had radiographic and clinical phenotype assessment performed as described (21).

OE History

OE history was ascertained from the questionnaires by using the following questions:

1. "Have you ever worked for a year or more in a dusty job"? (dust exposure)
2. "Have you ever been exposed to gas, smoke, chemicals, or fumes at work"? (fume exposure)

OE was considered in four categories: (1) dust and fumes, (2) only dust, (3) only fumes, and (4) no exposure. Subjects uncertain of OE were considered as not

Figure 1. CONSORT diagram for subjects included in current analysis.

having any significant OE. Those not answering the questions were excluded.

HRCT Imaging

The HRCT imaging protocol has been described (21, 22), but briefly, volumetric chest CT scans were obtained at full inspiration and expiration. Scans were reconstructed with thin-slice collimation with slice thickness and intervals of less than 1 mm for enhanced spatial resolution. Lung densitometry analysis was performed using the SLICER program (<http://www.slicer.org/>). Percentage of emphysema was defined as the percentage of lung less than −950 HU at inspiration and gas trapping was defined as percentage of lung less than −856 HU at end expiration. Airways segmentation and quantitative analysis was performed using Pulmonary Workstation 2 (VIDA Diagnostics, Inc., Coralville, IA). The square root of the airway wall area of a hypothetical 10-mm diameter airway was used as a measure of airway wall thickness (23).

Respiratory Symptoms

Subjects answered questions based on a modified version of the American Thoracic Society respiratory questionnaire (24) where chronic cough was defined as cough on most days for 3 months out of a year and chronic phlegm was similarly defined. Persistent wheeze was defined as wheezing on most days or nights, or if all of the following were present: wheeze with colds, apart from colds, and more than once per week.

Spirometry

All subjects performed spirometry following American Thoracic Society standards (EasyOne spirometer, Zurich, Switzerland) and predicted values were based on the Third National Health and Nutrition Examination Survey reference values (25). Post-bronchodilator values after 180 µg of albuterol were reported.

Data Analysis

Analysis of covariance was used to determine associations between exposures with spirometric measures, % emphysema, % gas trapping, and airway wall thickness, adjusting for multiple comparisons using Tukey method. The natural log (ln) of the % emphysema and % gas trapping were used because these untransformed variables were not normally

distributed. Logistic regression was used to determine associations with the following as outcomes: respiratory symptoms, Global Initiative for Chronic Obstructive Lung Disease (GOLD) grade 2 or higher, greater than 20% gas trapping, and greater than 6% emphysema. The cut-offs for % gas trapping and % emphysema were selected based on the 95th percentile upper limit in 108 nonsmoking subjects with HRCT imaging enrolled in COPDGene (26). All multivariable analyses were adjusted for age, race, body mass index (BMI), pack-years of smoking, education, and current smoking status. We also assessed residual confounding by smoking by comparing smoking adjusted and unadjusted results and assessed effect modification by sex (sex × OE). Analyses were conducted using SAS-PC, version 9.2 (PROC GLM and PROC LOGISTIC, SAS Institute, Inc., Cary, NC).

Results

OE and Demographics

A total of 9,614 subjects were included in the final analysis. There were 5,118 men and 4,496 women who were current or ex-smokers who had complete data out of

10,300 total enrolled subjects in COPDGene (Figure 1). The prevalence of exposure was generally similar across all centers as shown in Tables E1 and E2 in the online supplement. More men than women reported OE (Table 1), but similar numbers of men and women (9.0% and 10.0%, respectively) were uncertain of OE. Men were more likely to be current smokers (54.7% and 50.1%, respectively), have more pack-years of smoking (47.7 ± 26.6 vs. 41.0 ± 22.8 , respectively), and if currently smoking were using more cigarettes (9.8 ± 11.7 vs. 7.9 ± 10.7 , respectively). Level of education was similar between men and women as was mean BMI.

Spirometry, Symptoms, and Radiographic Data

Percent predicted FVC, FEV₁, and FEV₁/FVC and the prevalence of respiratory symptoms was similar between men and women (Table 2). The distribution among GOLD grades was also similar between men and women. Men had slightly more emphysema and gas trapping on CT imaging but there was no difference in airway wall thickness (Table 2).

Table 1. Occupational Exposure and Demographics

	Men (n = 5,118)	Women (n = 4,496)
Occupational exposure history		
No exposure, n (%)	857 (16.7)	1,838 (40.9)
Uncertain, n (%)	460 (9.0)	448 (10.0)
Dust and fume, n (%)	2,450 (47.9)	904 (20.1)
Dust, n (%)	675 (13.2)	688 (15.3)
Fume, n (%)	676 (13.2)	618 (13.7)
Demographics		
Age, yr, mean (SD)	59.7 (9.0)	59.7 (9.0)
Race		
Non-Hispanic white, n (%)	3,393 (66.3%)	3,100 (69.0%)
African American, n (%)	1,725 (33.7%)	1,396 (31.0%)
Body mass index	28.4 (5.6)	29.2 (6.9)
Smoking history		
Smoking burden, pack-years, mean (SD)	47.7 (26.6)	41.0 (22.8)
Current smoker, n (%)	2,800 (54.7)	2,253 (50.1)
Cigarettes/day, mean (SD)	9.8 (11.7)	7.9 (10.7)
Current smoking by cigarettes/day		
0 cigarettes/day, n (%)	2,319 (45.3)	2,243 (49.1)
1–10 cigarettes/day, n (%)	881 (17.2)	930 (20.7)
11–20 cigarettes/day, n (%)	1,257 (24.6)	930 (20.7)
21–30 cigarettes/day, n (%)	444 (8.7)	257 (5.7)
30 cigarettes/day, n (%)	217 (4.2)	136 (3.0)
Level of education		
<High school, n (%)	700 (13.7)	595 (13.2)
High school or GED, n (%)	1,344 (26.3)	1,105 (24.6)
Some college, no degree, n (%)	1,405 (27.4)	1,328 (29.5)
≥College degree, n (%)	1,669 (32.6)	1,468 (32.6)

Table 2. Spirometry and Respiratory Symptoms

	Men	Women
Spirometry		
n	5,118	4,496
FVC, % predicted, mean (SD)	87 (18.6)	87.3 (18.0)
FEV ₁ , % predicted, mean (SD)	76.1 (26.3)	77.1 (24.8)
FEV ₁ /FVC, mean (SD)	0.66 (0.17)	0.68 (0.16)
PRISM, n (%)	548 (10.7)	635 (14.1)
GOLD 0, n (%)	2,198 (43.0)	1,975 (43.9)
GOLD 1, n (%)	435 (8.5)	325 (7.2)
GOLD 2, n (%)	981 (19.2)	853 (19.0)
GOLD 3, n (%)	624 (12.2)	474 (10.5)
GOLD 4, n (%)	332 (6.5)	234 (5.2)
n*	4,570	3,681
GOLD 0–1, n (%)	2,633 (57.6)	2,300 (59.6)
GOLD 2–4, n (%)	1,937 (42.4)	1,561 (40.4)
Respiratory symptoms		
n	5,118	4,496
Chronic cough, n (%)	1,794 (35.0)	1,565 (34.8)
Chronic phlegm, n (%)	1,710 (33.4)	1,256 (27.9)
Persistent wheeze, n (%)	1,049 (20.5)	905 (20.1)
Radiographic measurements		
n	4,781	4,186
% Emphysema, median (IQR)	2.7 (7.2)	1.3 (4.6)
% Emphysema > 6%, n (%)	1,474 (30.8)	944 (22.6)
n	4,293	3,806
% Gas trapping, median (IQR)	17.0 (26.9)	12.3 (23.2)
Gas trapping >20%, n (%)	1,907 (44.4)	1,315 (34.5)
n	4,709	4,088
P ₁₀ , mm, mean (SD)	3.65 (0.14)	3.70 (0.12)

Definition of abbreviations: GOLD = Global Initiative for Chronic Obstructive Lung Disease; IQR = interquartile range; P₁₀ = square root of the airway wall area of a hypothetical 10-mm diameter airway; PRISM = preserved ratio impaired spirometry, which is a group with preserved FEV₁/FVC ratio but a reduced FEV₁.

*The PRISM group was not included in this analysis.

OE and Risk of GOLD Stage and Respiratory Symptoms

The odds ratio (OR) for dust and fume exposure on chronic cough for men and women (1.83 [1.56–2.13] vs. 1.65 [1.40–1.96]), on phlegm (1.84 [1.58–2.15] vs. 1.82 [1.53–2.16]), and on persistent wheeze (2.01 [1.67–2.42] vs. 1.98 [1.64–2.40]) were similar (Figures 2A–2C). The OR for dust and fume exposure for GOLD stage 2 or greater COPD was similar between men and women (Figure 2D) with an OR (95% confidence interval [CI]) of 1.61 (1.36–1.91) for men and 1.90 (1.57–2.29) for women. The effects of OE to dust or fume alone are also shown in Figures 2A–2D. The only evidence of significant effect modification by sex was on chronic cough ($P = 0.02$) (see Table E5). The OR for chronic cough (1.47 [1.22–1.77]) was

elevated solely for women with dust exposure, whereas men had a significant increased OR for chronic cough (1.24 [1.01–1.54]) with OE to fumes alone.

Effect of OE on Spirometry

Men with OE to dust and fumes had a significantly lower FEV₁/FVC (0.63 ± 0.005 vs. 0.67 ± 0.005) and a lower FEV₁ % predicted (70.7 ± 0.8 vs. 76.0 ± 0.9) compared with no exposure (Table 3). Women with OE to dust and fumes also had a lower FEV₁/FVC (0.64 ± 0.006 vs. 0.69 ± 0.005) and % predicted FEV₁ (70.5 ± 1.0 vs. 77.2 ± 0.8) compared with no exposure. Men exposed to either dust or fumes alone did not have significantly lower FEV₁ % predicted or FEV₁/FVC, whereas women with OE to dust alone had a significantly lower FEV₁ % predicted (73.4 ± 1.1 vs. 77.2 ± 0.8) and FEV₁/FVC (0.66 ± 0.006 vs.

0.69 ± 0.005) compared with no OE. Women with OE to fumes alone did have a lower FEV₁/FVC (0.67 ± 0.007 vs. 0.69 ± 0.005) compared with no exposure. However, the effects of OE on FEV₁/FVC and FEV₁ % predicted in men and women were not statistically different (see Table E3).

Effect of OE on HRCT Morphology

Table 3 demonstrates the effect of OE on spirometry and HRCT findings. Men with OE to dust and fumes had significantly more ln(% emphysema) (0.90 ± 0.05 vs. 0.74 ± 0.05) and ln(% gas trapping) (2.80 ± 0.04 vs. 2.69 ± 0.04) compared with no exposure. Compared with no exposure, women with OE to dust and fumes also had increased ln(% emphysema) (0.35 ± 0.07 vs. 0.08 ± 0.05) and ln(% gas trapping) (2.55 ± 0.05 vs. 2.33 ± 0.04). Airway wall thickness (square root of the airway wall area of a hypothetical 10-mm diameter airway) was significantly greater in men with OE to dust and fumes (3.69 ± 0.0065 vs. 3.67 ± 0.006 mm) but there was no difference in women (3.73 ± 0.005 vs. 3.73 ± 0.004 mm) compared with no exposure. There was not significantly more % emphysema or % gas trapping in either men or women with OE to dust or fumes alone compared with no exposure (Table 3). The OR for more than 6% emphysema was increased with OE to dust and fumes with an OR (95% CI) of 1.59 (1.33–1.92) in men and 1.75 (1.40–2.18) in women (Figure 3A). The OR (95% CI) was similar for more than 20% gas trapping in men (1.34 [1.12–1.59]) and in women (1.74 [1.42–2.13]) with OE to dust and fumes (Figure 3A). Men exposed to dust or fumes alone did not have an increased OR for more than 6% emphysema or more than 20% gas trapping (Figure 3). Women exposed to dust alone also had an increased OR (95% CI) for greater than 6% emphysema (1.31 [1.02–1.67]) and greater than 20% gas trapping (1.30 [1.03–1.63]) (Figure 3). Women exposed to fumes alone had increased likelihood of having more than 6% emphysema (1.39 [1.09–1.76]) but not more than 20% gas trapping (Figure 3C). The effects of OE on HRCT morphology were not statistically different in men and women (see Table E5). The effects of OE on respiratory symptoms, spirometry, GOLD grade, and HRCT morphology adjusted for sex, age, race, BMI, pack-years of smoking, education, and current smoking status in men and women combined are presented in Tables E4 and E5.

Figure 2. Effect of occupational exposure on respiratory symptoms and Global Initiative for Chronic Obstructive Lung Disease (GOLD) stage 2–4 disease expressed as odds ratio and 95% confidence intervals. Analyses were adjusted for age, race, pack-years of smoking, education, body mass index, and current smoking status. The odds ratios were similar in men and women for (A) chronic cough, (B) chronic phlegm, (C) persistent wheeze, and (D) GOLD grade 2–4.

Effect of Smoking

The effects of OE on respiratory symptoms, GOLD grade, spirometry, and HRCT morphology outcomes were similar regardless of adjustment for pack-years of smoking and current smoking status (see Tables E6–E9).

Discussion

We have shown that current or ex-smokers with greater than or equal to 10 pack-year smoking history with self-reported OE to dust and fumes are more likely to have GOLD stage 2 or greater COPD and chronic respiratory symptoms, adjusting for age, BMI, race, smoking history, education, and current and lifetime smoking. Additionally, this study is the first to demonstrate a positive association between OE to dust and fumes with quantitative measurement of emphysema and gas trapping on HRCT

imaging. There is also reason to have suspected that women may respond differently than men when exposed to the same COPD risk factors (18). Women seem to present with more severe COPD at an earlier age, suggesting that they could be more susceptible to smoking and other risk factors (19). Therefore, it is reasonable to assume that women with OE should be at least equally affected as men if not more so. Although more men had combined dust and fume exposures than women, other than in the assessment of airway wall thickness, the effects of OE were generally similar for both men and women, particularly for persons with both dust and fume exposures, which represented most persons with OEs in this cohort. Our results highlight the importance of an occupational history in both men and women.

The reason for the lack of an association between airway wall thickness in men but not women is uncertain, but may relate to the

sensitivity of the method used to make the measurement. The measurement of airway wall thickness is a derived number calculated based on the diameter of a theoretical 10-mm airway, whereas the assessment of gas trapping and % emphysema are obtained by direct CT measurement. The greater number of men with occupational dust and fume exposures would provide a more precise measurement of calculated airway wall thickness than in the women and would be more likely to be able to detect the small differences noted (Table 3). Conversely, the relatively small numbers of persons with dust and fume exposure alone most likely contributes to the variation in the significance of the effects of these exposures among the men and women for all outcomes.

Although previous studies on OE and COPD included men and women, most were adjusted for sex rather than providing sex-specific estimates (1, 3, 27–32). In a large population-based study of 8,515 whites, Korn and coworkers (7) found that women did not have increased risk of COPD (defined as FEV_1/FVC ratio <0.60) when exposed to dust or gas and fumes, but did have increased OR for some respiratory symptoms including wheezing and breathlessness. Another population-based study with 1,635 subjects found that men with OE had increased risk of COPD, cough, phlegm, and asthma, but not wheeze or dyspnea. Among women, the OR for dyspnea and asthma was increased, but not for COPD, cough, or phlegm (33). In a Swiss study of 4,267 subjects, OE as measured by a job-exposure matrix increased the risk of GOLD stage 2 or greater COPD in men but not in women (6). However, there were only 57 cases of GOLD stage 2 or greater COPD. It is likely because of our larger sample and the inclusion of persons at risk for significant disease because they were selected on smoking behavior that we were able to study men and women separately.

Data from the Third National Health and Nutrition Examination Survey demonstrated that men and women are at increased risk for COPD if working in certain industries, but unlike our analysis there were no data on respiratory symptoms or CT imaging (12). Furthermore, as in other large general population-based studies (9,823) only 693 subjects (7.1%) had COPD. Although

Table 3. Effect of Occupational Exposure on Spirometry and High-Resolution Computed Tomography Morphology Compared with No Exposure

Variable (Mean ± SE)	No Exposure	Dust and Fume	Dust	Fume
Men				
n = 5,118				
% Predicted FEV ₁	76.0 ± 0.9	70.7 ± 0.8*	74.7 ± 1.1	75.4 ± 0.9
FEV ₁ /FVC	0.67 ± 0.005	0.63 ± 0.005*	0.66 ± 0.007	0.66 ± 0.005
n = 4,709				
P ₁₀ , mm	3.67 ± 0.006	3.69 ± 0.005*	3.69 ± 0.007	3.68 ± 0.007
n = 4,781				
Ln(% emphysema)	0.74 ± 0.05	0.90 ± 0.05*	0.76 ± 0.06	0.77 ± 0.06
Exp(% emphysema)	2.1	2.4	2.1	2.2
n = 4,293				
Ln(% gas trapping)	2.69 ± 0.04	2.80 ± 0.04*	2.73 ± 0.05	2.70 ± 0.05
Exp(% gas trapping)	14.7	16.4	15.4	15.0
Women				
n = 4,496				
% Predicted FEV ₁	77.2 ± 0.8	70.5 ± 1.0*	73.4 ± 1.1*	74.8 ± 1.1
FEV ₁ /FVC	0.69 ± 0.005	0.64 ± 0.006*	0.66 ± 0.006*	0.67 ± 0.007*
n = 4,088				
P ₁₀ , mm	3.73 ± 0.004	3.73 ± 0.005	3.73 ± 0.005	3.73 ± 0.006
n = 4,186				
Ln(% emphysema)	0.08 ± 0.05	0.35 ± 0.07*	0.22 ± 0.07	0.22 ± 0.08
Exp(% emphysema)	1.1	1.4	1.2	1.2
n = 3,806				
Ln(% gas trapping)	2.33 ± 0.04	2.55 ± 0.05*	2.42 ± 0.06	2.36 ± 0.06
Exp(% gas trapping)	10.2	12.8	11.3	10.5

Definition of abbreviations: Exp = exponentiation of natural log; Ln = natural log; P₁₀ = square root of the wall area of a 10-mm diameter airway.

**P* < 0.05 compared with no exposure using analysis of covariance adjusting for multiple comparisons using Tukey method. Outcomes were adjusted for age, race, pack-years of smoking, education, body mass index, and current smoking.

Matheson and coworkers (13) reported that exposure to biologic dust was associated with an increased risk of COPD in women but not mineral dust or gas and fumes, a limitation is that there

were only 42 subjects with COPD out of 1,213. In our study we had a robust population of subjects with COPD, with concurrent CT data, respiratory symptoms, and pulmonary function,

although we lacked information regarding the specific nature of the exposure.

Others have shown that OE has been associated with emphysema on autopsy findings (34–36), and the presence of emphysema on CT imaging has been associated with silicosis, coal workers' pneumoconiosis, and asbestos exposure in small single-center studies (14, 15). Additionally, there are pathologic data to link small airways disease to dust exposure (37). The amount of gas trapping present on expiratory HRCT is thought to be one method of estimating the amount of small airway disease present especially in individuals with minimal emphysema. Our finding of increased gas trapping in men and women with dust and fume exposures is consistent with the pathologic data demonstrating the presence of small airways disease in dusty occupations. To our knowledge this is the first study to examine the effect of OE exposure to dust and fumes on HRCT phenotype and is congruent with the previously limited autopsy findings.

Our analysis also has some limitations. Although we obtained detailed information on respiratory symptoms, pulmonary function, and HRCT-defined phenotype, as noted previously, we lacked information regarding the nature of the exposure. There was no information available regarding the specific exposure, including intensity, duration, calendar year, job title, or industry while exposed. In addition, we lacked detailed occupational histories that would have permitted using a detailed job-exposure matrix to assess lifetime exposures. Despite these limitations, significant effects of exposure were noted. Our approach confirms previous observations that indicate that asking about exposure is comparable with using a job-exposure matrix used to broadly classify OE to dust and fumes (38). In conclusion, our findings confirm that OE to dust and fumes is independently associated with respiratory symptoms, more advanced COPD (≥GOLD grade 2), and a reduction in FEV₁ and FEV₁/FVC. Our findings extend the literature linking OEs to COPD using HRCT to assess evidence of emphysema and small airway disease. We noted findings attributable to OEs in men and women highlighting the importance of taking an occupational history of both sexes. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

Figure 3. Effect of occupational exposure on the presence of gas trapping greater than 20% and emphysema greater than 6% as measured by quantitative computed tomography assessment. Analyses were adjusted for age, race, pack-years of smoking, education, body mass index, and current smoking status. The odds ratios were similar in men and women for (A) % gas trapping and (B) % emphysema.

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