Association between Chronic Obstructive Pulmonary Disease and Employment by Industry and Occupation in the US Population: A Study of Data from the Third National Health and Nutrition Examination Survey

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Data from the US population-based Third National Health and Nutrition Examination Survey, conducted from 1988 to 1994, were used to estimate the population prevalence, prevalence odds ratios, and attributable fractions for the association of chronic obstructive pulmonary disease (COPD) with employment by industry and occupation. The aim was to identify industries and occupations at increased risk of COPD. COPD was defined as forced expiratory volume in 1 second (FEV_1)/forced vital capacity <70% and FEV_1 <80% predicted. The authors used SUDAAN software (Research Triangle Institute, Research Triangle Park, North Carolina) to estimate the weighted population prevalence and odds ratios using 9,823 subjects aged 30–75 years who underwent lung function tests. Odds ratios for COPD, adjusted for age, smoking status, pack-years of smoking, body mass index, education, and socioeconomic status, were increased for the following industries: rubber, plastics, and leather manufacturing; utilities; office building services; textile mill products manufacturing; the armed forces; food products manufacturing; repair services and gas stations; agriculture; sales; construction; transportation and trucking; personal services; and health care. Occupations associated with increased odds ratios for COPD were freight, stock, and material handlers; records processing and distribution clerks; sales; transportation-related occupations; machine operators; construction trades; and waitresses. The fraction of COPD attributable to work was estimated as 19.2% overall and 31.1% among never smokers.

airway obstruction; occupational diseases; occupational exposure; prevalence

Abbreviations: CI, confidence interval; COPD, chronic obstructive pulmonary disease; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; NHANES III, Third National Health and Nutrition Examination Survey; OR, odds ratio; RR, relative risk.

Chronic obstructive pulmonary disease (COPD) is the fourth leading cause of death among persons older than 45 years of age in the United States [1]. Occupational exposure is a known risk factor for COPD. Industry-based epidemiologic studies have shown that occupational exposure to inorganic and organic dusts and to chemical agents can increase the risk of COPD [2–4]. In addition, general population-based studies have identified associations between COPD and employment in industrial and job categories or specific occupational exposures [5–16]. However, to our knowledge, the contribution of occupational exposure to COPD morbidity in the general US population has not yet been quantified. The population-based Third National Health and Nutrition Examination Survey (NHANES III) [17, 18] enables estimation of the population prevalence and prevalence odds ratios for COPD and employment by industry as well as evaluation of the magnitude of the effect of occupational exposure on COPD in the US population [19].

The objective of the present study was to analyze the NHANES III survey data to estimate the prevalence, prevalence odds ratios, and attributable fractions for COPD and employment by specific industry sectors (industry) and occupational categories (occupation). The aim was to estimate the magnitude of the effect of occupational exposure on COPD in the US population and to identify industries and

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occupations at increased risk of COPD that can be targeted for etiologic studies or disease prevention programs.

MATERIALS AND METHODS

Study subjects

The NHANES III survey was conducted from 1988 to 1994 by the National Center for Health Statistics in Hyattsville, Maryland, to assess the health and nutritional status of the US population. A multistage, stratified probability sampling design was used to select a representative sample of the US adult population aged 17–90 years (17). African Americans, Mexican Americans, and persons aged 60 years or older were oversampled. Eighty-one counties in the United States were sampled; in each county and selected household, the probability of a person being chosen was based on sex, age, and race/ethnicity. The resulting total sample of 20,050 adult subjects aged 17 years or older included 47 percent females and 53 percent males; 42.3 percent were Caucasian, 27.4 percent were African American, and 26.5 percent were Mexican American. The survey included a questionnaire, a laboratory examination, and lung function testing.

The present study included subjects aged 30–75 years (*n* = 11,447). These age cutoff points were chosen under the assumption that COPD due to occupational exposure would not generally be observed before midlife (20). In addition, many subjects less than age 30 years are still reaching their full lung function potential (21), and many older subjects develop age-related medical conditions that can affect lung function. Furthermore, we excluded 1,009 subjects because of lung function testing problems (missing tests (*n* = 826), unreliable flow volume curves (*n* = 97), or only one reliable maneuver (*n* = 86)), 506 subjects with physician-diagnosed current asthma, and 109 subjects for whom occupational codes were missing, leaving 9,823 subjects for the data analysis.

Definition of COPD

The definition of COPD was based on Global Initiative for Chronic Obstructive Lung Disease (GOLD) working group criteria (20) of forced expiratory volume in 1 second (FEV_1)/ forced vital capacity (FVC) less than 70 percent and FEV_1 less than 80 percent predicted. The FEV_1 percent predicted values were calculated by using sex-specific reference equations for Caucasians, African Americans, and Mexican Americans, estimated from tests of asymptomatic nonsmokers in the NHANES III study (21). Lung function testing methods for the NHANES III study conformed to the 1987 American Thoracic Society acceptability and reproducibility criteria (22).

Cigarette smoking

The NHANES III survey included questions on current smoking status, number of cigarettes smoked, and age at which smoking started and stopped. Two smoking variables were created: smoking status and pack-years. For smoking status, subjects were categorized as never smokers, former smokers, or current smokers. Pack-years were estimated by multiplying the current number of packs of cigarettes smoked (or, for former smokers, the number of packs smoked when they last smoked) by the number of years of smoking. Never smokers were defined as those who smoked fewer than 100 cigarettes during their entire life.

Occupational coding

Occupational coding was based on two items on the NHANES III Adult Survey Questionnaire. That is, study subjects were asked to identify 1) the type of work they performed for the longest period of time (occupation) and 2) for this occupation, the type of business or industry they worked in the longest (industry). In the NHANES III data set, occupation was coded according to the 1990 Occupational Classification System used in the 1990 US Census (23). These codes were derived from the 1980 Standard Occupational Classification codes published by the US Department of Commerce (24). Industry was coded according to the 1990 Industrial Classification System used in the 1990 US Census, a modification of the Standard Industrial Classification codes (25). These detailed industry and occupation codes are collapsed in the NHANES III public use data set.

Industry categories used in the analysis

The NHANES III data set contains 44 industry and 40 occupation codes that include workers with a varied potential for exposure to respiratory hazards. A priori, we grouped industries in which workers had a similar potential for exposure to respiratory hazards believed to cause COPD as follows. We kept the original industry categories, but subjects with office work occupations were excluded from the industrial sectors. Office workers from all industry sectors were combined into a single category that was used as a comparison group. This "office workers" category included managers, secretaries and typists, clerks, and administrative workers as well as teachers, writers and artists, professionals, and workers from such nonmanufacturing sectors as banking, insurance, communications, education, social service, and public administration. We moved laborers, cleaners, material handlers, and maintenance workers from the banking, insurance, communications, education, social service, and public administration sectors into a new industry category called "office building services." Similarly, we moved construction, horticultural, medical, food preparation, and transportation workers from the nonmanufacturing sectors to the appropriate industry category with a similar potential for exposure to respiratory hazards.

This recoding resulted in 26 industry categories. For the final analysis, we combined categories in which odds ratios for COPD were not increased into one category of "other industries," which resulted in 16 final categories for the overall analysis.

Occupation categories used in the analysis

The NHANES III data set includes 40 occupation codes combined across all industries. A priori, we collapsed them into 25 occupational categories believed to have a similar potential for exposure to respiratory hazards and sufficient numbers for analysis. For the final analysis, occupational categories for which there was no evidence of an increased risk of COPD were combined in an "other occupations" category, resulting in 14 final categories.

Statistical data analysis

We used the SUDAAN software program (26) to estimate the weighted population size, prevalence, and prevalence odds ratios for COPD by industry and occupation. This software adjusts for the sampling design in calculating the variance estimates (27) and uses individual sampling weights assigned by the National Center for Health Statistics to adjust for the number of persons in the population that each sampled person represents. The weighted estimates are unbiased estimators of the US population parameters (19).

The SUDAAN logistic program was used to estimate odds ratios for COPD and industry/occupation adjusted for the effect of age, sex, race/ethnic group, body mass index, smoking status, pack-years of cigarette smoking, education, and socioeconomic status (20). Socioeconomic status was adjusted by using the poverty income index, computed as the ratio of the family income and the poverty threshold value specific to the family size. Industry (or occupation) was included in the models as a set of 0 or 1 dummy variables representing each industry (or occupation). Because of large numbers and a low prevalence of COPD, office workers were used as the baseline category against which other occupational groups were compared. Preliminary analyses revealed differences between sexes and among race/ethnic groups in the size of the adjusted odds ratios; therefore, we also conducted sex- and race/ethnic-specific analyses for COPD to better identify subgroups at risk of COPD.

In an unweighted analysis, we examined trends in adjusted odds ratios for COPD and increasing duration of employment in the longest-held occupation (ascertained by asking the following question: Considering all your employers, for how long did you do this kind of work?). For that purpose, occupations were grouped, according to the size of the estimated odds ratio for COPD, into high- and low-risk groups. In these groups, the trend with duration of employment (0, 1–14, ≥15 years) was estimated by using office workers as the "unexposed" comparison group.

The population attributable fraction (AF_p; i.e., the fraction of cases with COPD due to industrial exposure) was calculated according to the following formula (28–30):

$$AF_p = \sum_{i=1}^{k} p_{ci}(OR_i - 1)/OR_i$$

where k = number of industry sectors; p_{ci} = cases$_i$/total cases, where cases$_i$ represents the estimated number of COPD cases in the ith industry and total cases represents the total number of cases summed across industry sectors; and OR_i = the adjusted odds ratio for COPD estimated for the ith industry.

RESULTS

Of the 9,823 subjects aged 30–75 years for whom lung function tests were valid, 693 (7.1 percent) were identified as having COPD. To assess disease severity, we compared mean percent predicted FEV_1, mean percent predicted FVC, and FEV_1/FVC ratio for subjects without COPD, with COPD, and with physician-diagnosed emphysema or chronic bronchitis reported on the NHANES III questionnaire (table 1). In table 1, subjects with COPD defined epidemiologically had lower mean lung function values than those with physician-diagnosed emphysema or those with chronic bronchitis.

Table 2 shows the distribution of all study subjects and never smokers according to nonoccupational risk factors for COPD that were adjusted for in the logistic regression. Table 2 also shows the population prevalence of COPD according to these factors.

COPD by industrial sectors

The overall analysis identified 14 industries with increased adjusted odds ratios for COPD. Table 3 shows the estimated numbers of US workers employed in these industries, the estimated prevalence of COPD, the sample size, the number of observed cases with COPD, and the adjusted odds ratios and 95 percent confidence intervals for COPD for all

TABLE 1. Mean (standard error) FEV$_1$*% predicted, FVC*% predicted, and FEV$_1$/FVC ratio for subjects without COPD,* with COPD, and with physician-diagnosed emphysema and chronic bronchitis, Third National Health and Nutrition Examination Survey subjects aged 30–75 years, United States, 1988–1994

COPD group	No.	FEV$_1$% predicted	FVC% predicted	FEV$_1$/FVC ratio
Without COPD	9,130	98.0 (0.1)	98.9 (0.2)	79.2 (0.1)
With COPD†	693	63.8 (0.5)	83.5 (0.6)	58.7 (0.4)
With physician-diagnosed emphysema‡	156	69.9 (2.0)	87.0 (1.5)	60.2 (1.3)
With physician-diagnosed chronic bronchitis‡	438	87.2 (0.9)	92.7 (0.7)	74.0 (0.6)

* FEV$_1$, forced expiratory volume in 1 second; FVC, forced vital capacity; COPD, chronic obstructive pulmonary disease.

† COPD defined epidemiologically as FEV$_1$/FVC <70% and FEV$_1$ <80% predicted.

‡ Subjects are not mutually exclusive from those in the other groups.

TABLE 2.   Distribution of all study subjects and never smokers by nonoccupational risk factors for COPD* and population prevalence of COPD, Third National Health and Nutrition Examination Survey subjects aged 30–75 years, United States, 1988–1994

Risk factor	All subjects		Never smokers	
	No.	P* (%) (SE*)	No.	P (%) (SE)
Total	9,823	7.0 (0.4)	4,369	2.5 (0.3)
Race				
Caucasian	4,086	7.5 (0.5)	1,658	2.5 (0.5)
African American	2,774	4.9 (0.5)	1,174	1.6 (0.4)
Mexican American	2,568	2.7 (0.4)	1,312	1.7 (0.3)
Other	395	5.9 (1.5)	225	3.8 (1.3)
Age category (years)†				
30–39	4,324	1.9 (0.4)	2,098	1.0 (0.4)
40–49	1,717	6.7 (1.0)	713	1.4 (0.7)
50–59	1,820	13.3 (1.2)	725	5.0 (1.1)
60–75	1,962	17.5 (1.5)	833	6.9 (1.2)
Sex				
Male	4,657	7.8 (0.6)	1,398	2.3 (0.6)
Female	5,166	6.1 (0.4)	2,971	2.5 (0.5)
Smoking status				
Never smoker	4,369	2.5 (0.3)	4,369	2.5 (0.3)
Former smoker	2,735	7.9 (0.7)		
Current smoker	2,719	12.8 (0.7)		
No. of pack-years (mean (standard error))‡		28.7 (0.4)		
Body mass index (kg/m^2)				
<38	9,445	6.9 (0.4)	4,158	2.3 (0.3)
≥38	378	10.1 (3.3)	211	7.3 (3.0)
College education				
Yes	2,973	4.1 (0.4)	1,453	2.2 (0.5)
No	6,850	9.2 (0.4)	2,916	2.7 (0.4)
Poverty index§				
≥5	1,075	4.7 (0.5)	495	2.3 (5.5)
2–4.99	3,833	6.8 (0.6)	1,713	2.1 (0.4)
1–1.99	2,310	9.1 (0.9)	993	3.1 (0.7)
<0.99	2,605	8.1 (0.7)	1,168	3.1 (1.0)

* COPD, chronic obstructive pulmonary disease; P, population prevalence; SE, standard error.
† 5-year age categories were fitted in the logistic model.
‡ Mean and standard error values were averaged over former smokers and current smokers only.
§ Poverty increases with decreasing poverty index value.

subjects and for never smokers. The "other industries" category combines industries for which the overall odds ratios were not increased.

The results for never smokers provided supporting evidence for the overall results. Although the overall odds ratios for some of the industries shown in table 3 were low, results from the sex- and race/ethnic-specific analyses identified subgroups with a higher risk of COPD and provided further supporting evidence for the overall results.

The sex-specific analyses showed that for females, the adjusted odds ratios for COPD (number of cases/number of

subjects exposed) were increased for rubber, plastics, and leather manufacturing overall (8/46; OR = 4.7, 95 percent confidence interval (CI): 2.7, 8.3) and for never smokers in that industry (2/31; OR = 3.8, 95 percent CI: 1.2, 12.3); for the textile mill products manufacturing industry overall (10/99; OR = 2.4, 95 percent CI: 1.2, 4.8) and for never smokers in that industry (3/53; OR = 6.0, 95 percent CI: 0.6, 62); for the agriculture industry overall (13/196; OR = 2.0, 95 percent CI: 0.9, 4.5) and for never smokers in that industry (6/134; OR = 2.3, 95 percent CI: 0.5, 10.4); for sales overall (40/512; OR = 1.6, 95 percent CI: 0.9, 2.9) and for never

TABLE 3. COPD* by industry, Third National Health and Nutrition Examination Survey subjects aged 30–75 years, United States, 1988–1994

Industry	All subjects (n = 9,823)†							Never smokers (n = 4,369)‡						
	N*	P* (%) (SE*)	n*	COPD§	OR*,¶	95% CI*	AC*	N	P (%) (SE)	n	COPD	OR¶	95% CI	AC
Rubber, plastics, leather manufacturing	9.0	14.8 (3.9)	71	9	2.5	1.4, 4.4	0.8	3.1	4.8 (2.4)	39	2	2.5	1.0, 6.4	0.1
Utilities	12.0	16.7 (6.0)	94	12	2.4	0.7, 7.7	1.2	2.2	24.6 (16)	23	2	27.7	3.6, 214	0.5
Office building services (males)	5.4	13.6 (6.6)	84	12	2.4	0.7, 7.8	0.4	1.0	0.0 (0.0)	18	0			
Textile mill products manufacturing	15.4	15.3 (4.6)	163	20	2.2	1.1, 4.2	1.3	6.3	5.2 (4.1)	71	5	3.1	0.4, 28	0.2
Armed forces	14.0	13.3 (3.5)	119	16	2.2	1.2, 3.9	1.0	4.5	11.6 (7.2)	40	2	4.4	0.9, 20	0.4
Food products manufacturing	21.0	13.9 (3.0)	267	27	2.1	1.1, 4.1	1.5	6.9	3.8 (2.8)	119	4	2.1	0.3, 14	0.1
Repair service, gas station	29.6	12.0 (3.0)	256	22	1.5	0.8, 2.9	1.2	8.6	0.0 (0.0)	61	0			
Chemicals, petroleum, coal manufacturing	13.7	11.6 (4.1)	107	10	1.5	0.5, 4.4	0.5	6.1	5.4 (5.6)	44	1	2.6	0.2, 27	0.2
Agriculture	39.0	10.4 (1.9)	598	60	1.5	0.8, 2.7	1.4	17.8	1.8 (1.0)	246	7	0.8	0.2, 2.8	
Sales	136.5	8.3 (1.2)	1,012	83	1.4	0.9, 2.2	3.2	59.9	3.2 (1.3)	441	13	1.9	0.6, 5.5	0.9
Construction	54.3	8.7 (2.0)	493	46	1.3	0.8, 2.3	1.1	12.9	4.9 (2.7)	129	6	3.5	0.9, 14	0.5
Transportation and trucking	35.9	8.9 (2.2)	325	32	1.2	0.8, 2.0	0.5	12.4	2.3 (1.9)	91	4	2.0	0.3, 15	0.1
Personal services	40.3	6.1 (1.6)	543	41	1.1	0.6, 2.0	0.2	21.4	1.5 (0.7)	308	13	0.6	0.2, 2.3	
Health care	74.4	4.4 (1.3)	653	27	1.1	0.6, 2.1	0.3	39.9	2.5 (1.2)	349	7	1.8	0.5, 5.6	0.4
Other industries#	201.5	6.1 (0.8)	2,090	124	0.8	0.6, 1.2		64.7	1.8 (0.7)	844	20	0.9	0.3, 2.5	
Office workers	401.0	4.7 (0.4)	2,653	133	1.0			197	1.8 (0.5)	1,335	20	1.0		
Total working population**	1,103	6.9 (0.4)	9,528	674			14.7	465	2.4 (0.3)	4,158	106			3.5

 * COPD, chronic obstructive pulmonary disease; N, estimated number of US workers in 100,000; P, population prevalence; SE, standard error; n, sample size; OR, odds ratio; CI, confidence interval; AC, number of attributable cases in 100,000.

 † For this model, the model goodness-of-fit Wald $F_{(df = 38)}$ = 297, $p < 0.0001$; for industry, Wald $F_{(df = 16)}$ = 2.7, $p < 0.004$.

 ‡ For this model, the model goodness-of-fit Wald $F_{(df = 28)}$ = 98.3, $p < 0.0001$; for industry, Wald $F_{(df = 16)}$ = 2.5, $p = 0.009$.

 § Number of cases with COPD.

 ¶ Adjusted for age, sex, race/ethnic group, body mass index, smoking status, pack-years of cigarette smoking, education, and socioeconomic status.

 # Includes industries for which the adjusted odds ratios were not increased; refer to the text.

 ** Excluded were 295 subjects who never worked, of whom 211 were never smokers.

smokers in that industry (8/279; OR = 3.0, 95 percent CI: 0.7, 13); for food products manufacturing overall (9/123; OR = 1.5, 95 percent CI: 0.6, 4.0) and for never smokers in that industry (2/77; OR = 3.4, 95 percent CI: 0.3, 44); and for personal services overall (34/470; OR = 1.5, 95 percent CI: 0.7, 3.2). For the rubber, plastics, and leather manufacturing industry, the detailed analysis showed that occupations in this industry contributing the most cases were textile apparel machine operators as well as fabricators and assemblers. For sales, a detailed analysis showed that the adjusted odds ratios were increased for Caucasian females (34/285; OR = 1.9, 95 percent CI: 1.0, 3.5).

Industries presented in table 3 that employed mainly males were utilities, the armed forces, repair services and gas stations, and transportation and trucking. However, use of the male office workers group as a referent resulted in odds ratios for COPD similar to those reported in table 3. The prevalence of COPD among the male referent group was 5.1 percent (standard error, 0.9); for the overall referent group, it was 4.7 percent (standard error, 0.4).

Race/ethnic-specific adjusted odds ratios for COPD for Caucasians were similar to the overall odds ratios shown in table 3. Industries associated with increased adjusted odds ratios for COPD (number of cases/number of subjects exposed) mainly for African Americans and Mexican Americans were office building services, agriculture, and construction (office building services—African Americans: 6/48; OR = 2.9, 95 percent CI: 0.8, 10.6; Mexican Americans: 4/24; OR = 2.1, 95 percent CI: 0.4, 9.9; agriculture—African Americans: 14/76; OR = 2.1, 95 percent CI: 0.9, 5.1; Mexican Americans: 22/339; OR = 1.8, 95 percent CI: 0.7, 4.6; construction—African Americans: 15/140; OR = 1.6, 95 percent CI: 0.7, 3.6; Mexican Americans: 9/160; OR = 1.6, 95 percent CI: 0.5, 5.9). Industries for which the odds ratios were increased mainly for Mexican Americans were personal services (15/161; OR = 2.7, 95 percent CI: 0.8, 9.7) and health care (4/118; OR = 3.7, 95 percent CI: 1.3, 10.7). The personal services industry included hairdressers and cosmetologists.

TABLE 4. COPD* by occupation, Third National Health and Nutrition Examination Survey subjects aged 30–75 years, United States, 1988–1994

Occupation	All subjects†							Never smokers ‡						
	N*	P* (%) (SE*)	n*	COPD§	OR*,¶	95% CI*	AC*	N	P (%) (SE)	n	COPD	OR¶	95% CI	AC§
Freight, stock, material handlers	8.3	8.4 (2.0)	87	8	2.2	1.3, 3.7	0.4	4.8	0.8 (0.7)	36	2	0.8	0.2, 4.0	
Armed forces	14.0	13.4 (3.5)	117	16	2.0	1.1, 3.6	0.9	4.4	11.8 (7.3)	39	2	4.1	0.9, 19.4	0.4
Vehicle mechanics	21.1	12.8 (3.7)	149	15	2.0	0.9, 4.1	1.4	6.4	0.6 (0.0)	40	1	0.4	0.0, 3.4	
Records processing, distribution clerks	43.9	10.4 (2.6)	370	31	1.8	0.8, 3.6	2.0	20.3	5.5 (2.1)	171	8	2.9	1.1, 7.6	0.7
Sales: retail, personal services	82.2	9.1 (1.7)	564	48	1.5	0.8, 2.6	2.5	36.3	3.8 (2.0)	263	8	2.1	0.5, 8.6	0.7
Transportation, material moving	13.8	13.2 (4.5)	146	16	1.4	0.6, 3.0	0.5	3.6	1.1 (1.0)	36	1	0.5	0.1, 5.2	
Other machine operators	49.1	9.8 (2.0)	562	44	1.3	0.7, 2.5	1.1	13.8	6.5 (3.2)	216	9	3.8	0.9, 16.1	0.7
Agriculture	38.9	10.2 (2.1)	592	60	1.3	0.7, 2.5	0.9	16.7	2.3 (1.1)	241	9	1.0	0.3, 3.1	
Construction trades, laborers	50.1	7.5 (2.0)	456	41	1.2	0.6, 2.5	0.6	12.0	4.8 (2.6)	119	6	3.4	1.1, 10.5	0.4
Motor vehicle operators	30.9	11.3 (2.3)	348	34	1.2	0.7, 2.1	0.6	7.1	2.6 (2.5)	83	2	1.8	0.2, 14.3	0.1
Textile, apparel machine operators	25.9	10.4 (2.5)	327	25	1.2	0.7, 1.9	0.5	11.1	1.9 (0.9)	171	6	0.7	0.3, 2.1	
Waitresses	13.5	9.3 (3.4)	105	11	1.1	0.5, 2.5	0.1	3.2	4.8 (4.4)	35	2	2.0	0.3, 15.2	0.1
Other occupations#	365.8	5.6 (0.6)	3,395	204	0.9	0.7, 1.2		153.2	4.5 (0.5)	1,531	31	0.8	0.3, 2.0	
Office workers	342.5	4.9 (0.4)	2,277	118	1.0			169.9	2.0 (0.5)	1,159	19	1.0		
Total working population**	1,100.0	7.0 (0.4)	9,495	671			11.5	462.8	2.5 (0.4)	4,140	106			3.1

* COPD, chronic obstructive pulmonary disease; N, estimated number of US workers in 100,000; P, population prevalence; SE, standard error; n, sample size; OR, odds ratio; CI, confidence interval; AC, number of attributable cases in 100,000.

† For this model, the model goodness-of-fit Wald $F_{(df = 32)}$ = 337, $p < 0.0001$; for occupation, Wald $F_{(df = 14)}$ = 2.3, $p < 0.02$.

‡ For this model, the overall model goodness-of-fit Wald $F_{(df = 28)}$ = 105, $p < 0.0001$; for occupation, Wald $F_{(df = 14)}$ = 2.1, $p = 0.03$.

§ Number of cases with COPD.

¶ Adjusted for age, sex, race/ethnic group, body mass index, smoking status, pack-years of cigarette smoking, education, and socioeconomic status.

\# Includes industries for which the adjusted odds ratios were <1; refer to the text.

** Excluded were 33 subjects whose occupations were unknown and 295 subjects who never worked, of whom 211 were never smokers.

COPD by occupational categories

The overall analysis identified 12 occupational categories with increased odds ratios for COPD. Table 4 shows the estimated number of US workers employed in these occupations, the prevalence of COPD, the sample size, the number of cases with COPD, and the adjusted odds ratios and 95 percent confidence intervals for COPD for all subjects and for never smokers. Occupations for which there was no evidence of increased odds ratios were combined into an "other occupations" category. An occupational category generally included workers from several industries, but some occupational categories were similar to industries (the armed forces and agriculture) and were included for completeness. Occupations that had the highest odds ratios were freight, stock, and material handlers; the armed forces; vehicle mechanics; and records processing and distribution clerks. In addition, among never smokers, the odds ratios were also high for other machine operators and for construction trades and laborers.

Results from the race/ethnic-specific analyses identified subgroups with a higher risk of COPD and, although based on small numbers, showed a degree of consistency. For Caucasians, the odds ratios for COPD (number of cases/number of subjects exposed) were similar to the overall results, but they were specifically increased for the occupations of records processors, schedulers, and distribution clerks (23/180; OR = 1.8, 95 percent CI: 0.8, 4.4); sales: retail and personal services (43/333; OR = 1.7, 95 percent CI: 0.9, 3.1); and other machine operators (25/178; OR = 1.6, 95 percent CI: 0.8, 3.2). For African Americans and Mexican Americans, the odds ratios were higher for agriculture and construction, as reported for the industries. For the armed forces, the odds ratios were increased for all three race/ethnic groups: Caucasians (7/53; OR = 1.5, 95 percent CI: 0.5, 4.3), African Americans (5/42; OR = 2.1, 95 percent CI: 0.7, 6.2), and Mexican Americans (2/12; OR = 1.7, 95 percent CI: 0.1, 20.8). For vehicle mechanics, the odds ratios were also increased for all three race/ethnic groups: Caucasians (9/66; OR = 2.1, 95 percent CI: 0.8, 5.2), African Americans (3/25; OR = 3.8, 95 percent CI: 0.8, 17.3), and Mexican Americans (2/46; OR = 2.0, 95 percent CI: 0.3, 14.5). For transportation and material moving, the increased odds ratios were observed mainly for Caucasians (8/44; OR = 1.6, 95 percent CI: 0.7, 3.9) and African Americans (7/55; OR = 1.7; 0.6, 4.8).

Attributable fraction for COPD

The overall attributable fractions for industry and occupation were calculated from equation 1 by using the estimated population size, prevalence, and adjusted odds ratios provided in table 3 and table 4. No cases were attributed to industries in which $OR_i \leq 1$.

For each industry, table 3 shows the number of attributable cases. The total estimated working population aged 30–75 years was 110,300,000. Of these persons, 7,652,390 (6.9 percent) were estimated to have COPD. The number of cases attributable to employment in industries, after adjustment for confounding, was 1,467,290, resulting in an attributable fraction of 1,467,290/7,652,390 × 100 = 19.2 percent. We also estimated the overall adjusted odds ratio for COPD and the 14 industries with OR > 1 grouped into one category as 1.5 (95 percent CI: 1.1, 2.0). Based on this odds ratio, the attributable fraction was estimated to be 19.6 percent (95 percent CI: 7.0, 28) (31). For never smokers, the estimated working population was 46,490,000, of whom 1,131,840 (2.4 percent) were estimated to have COPD. The number of attributable cases was 352,167, which resulted in an attributable fraction of 31.1 percent. For never smokers, the overall odds ratio for COPD and the industries with OR > 1 grouped into one category was 1.9 (95 percent CI: 0.9, 4.1), and the attributable fraction was estimated as 27.8 percent (95 percent CI: 1.0, 47).

For each occupation, table 4 shows the number of attributable cases. The number of cases of COPD attributable to employment by occupation was 1,150,900 of 7,642,230 total cases, resulting in an attributable fraction of 15.1 percent. (Thirty-three subjects for whom there was no job code were excluded, resulting in a slightly different weighted total number of cases from the industry.) The overall adjusted odds ratio for occupations with OR > 1 grouped into one category was 1.4 (95 percent CI: 1.0, 2.0), and the corresponding attributable fraction was estimated as 15.1 percent (95 percent CI: 3.4, 25.8). For never smokers, the number of attributable cases was 307,299 of 1,123,370 total cases, resulting in an attributable fraction of 27.4 percent. The overall adjusted odds ratio for occupations with OR > 1 grouped into one category was 2.1 (95 percent CI: 0.9, 5.0), and the attributable fraction was 25.6 percent (95 percent CI: 2.3, 28.5). Because the occupations were summed over industries and some of the industries with increased odds ratios were not represented by the occupational categories with increased risk, the attributable fractions for the occupations were lower than those for the industry.

Trends with duration of employment

The average duration of working in the longest-held occupation was 15.9 (standard error, 0.1) years. For the high-risk occupations (for all subjects, $OR \geq 1.5$) shown in table 4, the odds ratios for COPD by duration of employment—0, 1–14, and ≥15 years—were 1.0, 1.4 (95 percent CI: 0.8, 2.6), and 1.7 (95 percent CI: 1.1, 2.5), respectively. The greatest trend was observed among the armed forces, where the respective odds ratios were 1.0, 1.4 (95 percent CI: 0.3, 6.1), and 2.0 (95 percent CI: 1.0, 4.0). For the lower-risk occupations (for

all subjects, 1 < OR < 1.5) shown in table 4, the respective odds ratios were 1.0, 1.4 (95 percent CI: 1.0, 1.9), and 1.5 (95 percent CI: 1.2, 2.0). The results suggest a trend associated with working 15 or more years in risky occupations.

DISCUSSION

A recent study that estimated the cost of occupational COPD in the US population assumed that 15 percent of deaths from COPD is attributable to occupational exposure (32). The overall cost for occupational COPD was estimated to be $5 billion in 1996 (32). The present study estimated that 19 percent (approximate 95 percent CI: 7, 28) of COPD in the US working population aged 30–75 years is attributable to occupational exposure. For never smokers, the attributable fraction was estimated as 31 percent (approximate 95 percent CI: 1, 47).

The present study generated hypotheses aimed at 1) identifying industries associated with an increased risk of COPD that might be targeted for further research and 2) estimating the attributable fraction for occupational COPD. The estimated attributable fraction of 19 percent was based on increased odds ratios for COPD in 14 industries listed in table 3. Additional supporting evidence for an increased risk of COPD in these industries came from increased odds ratios for never smokers, for sex- and race/ethnic-specific subgroups, and by occupational categories. In preliminary analyses in which a less stringent cutoff point of 75 percent was used for the FEV_1/FVC ratio, we observed a higher degree of consistency among the three major race/ethnic groups for the adjusted odds ratios for industries and occupations. Use of Global Initiative for Chronic Obstructive Lung Disease criteria resulted in a reduced number of COPD cases and wider confidence intervals but also in decreased odds ratios for African Americans and, to a lesser degree, Mexican Americans. This result may be related to higher age-related mean FEV_1/FVC values observed for the two race/ethnic groups in the NHANES III study (21).

An increased risk of COPD has been reported for many of the associations observed in the present study. Several general population-based studies reported associations with specific occupational exposures. A study conducted in Tucson, Arizona, found an association between airflow obstruction and self-reported exposure to silica, fiberglass, sawdust, Freon (E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware), automobile exhaust, solvents, and construction work (5). The US Six-City study found associations of chronic respiratory symptoms and COPD with working with dusts, fumes, and gases (6).

In addition, studies in Norway found significant associations between airflow obstruction and occupational exposure to quartz (11–13), ammonia, nitrous gas, sulfur dioxide gas, metal fumes, and anhydrides (13). A study of New Zealand subjects aged 20–44 years found associations between airflow obstruction (FEV_1/FVC <75 percent) and working as cleaners, bakers, spray painters, laboratory technicians, and plastics and rubber workers and in construction and mining. In addition, shortness of breath was reported more frequently by hairdressers and chemical processors. Chronic bronchitis was reported more often in food processors, chemical

processors, and spray painters and in construction and mining. In a large international study of subjects aged 20–44 years, self-reported occupational exposure to vapors, gas, dust, or fumes was associated with chronic bronchitis in agricultural, textile, paper, wood, chemical, and food processing workers (15). In the Netherlands, the Zutphen study found an increased risk of nonspecific lung disease for textile workers and tailors (relative risk (RR) = 2.4), construction and cement workers (RR = 2.3), transportation workers (RR = 2.1), furnace workers (RR = 2.1), wood and paper workers (RR = 1.7), and farmers (RR = 1.6) (33). Industry-based studies of COPD have found an increased risk in textile mills (34), the rubber industry (35), mining, construction, chemical production, food products manufacturing, and agriculture (36–39).

The US Work-Related Lung Disease Surveillance Report lists industries associated with significantly elevated proportional mortality ratios for COPD (40). In support of our findings, the proportional mortality ratios for taxicab services, trucking services, automotive and miscellaneous repair services, construction, gasoline service stations, and the military were among the highest. On the other hand, mining and potteries, which had the highest proportional mortality ratios listed in the Work-Related Lung Disease Surveillance Report, were not identified by the present study primarily because of limitations described in the paragraph that follows.

To our knowledge, previous epidemiologic studies have not reported an increased risk of COPD for industries such as utilities, the armed forces, office building services, sales, and health care and for occupations such as records processing clerks as well as freight, stock, and material handlers. (The records processing clerks category includes mail handlers.) The National Institute for Occupational Safety and Health conducted several Health Hazard Evaluations in mail processing and distribution plants in response to workers' complaints of work-related upper and lower respiratory symptoms and asthma (41). In addition, an epidemiologic study found decrements in lung function associated with more than 10 years of high exposure to paper dust (42).

The strengths of the present study include reliable lung function data, a large sample size that allowed for unbiased estimation of the effect of the confounding factors, and varied industrial and job exposures. Application of the sampling weights resulted in odds ratios that were similar to those obtained from unweighted analyses. The limitations of the study are mainly due to the study design and include the following: 1) the NHANES III survey was not designed to be representative of US employment patterns, thus potentially obscuring the importance of some high-risk work; 2) industry and occupation categories were not always homogenous with respect to exposure to respiratory hazards; 3) lack of detailed industry/occupation codes undoubtedly resulted in some misclassification of exposure; and 4) the cross-sectional study design has limitations for the ascertainment of correct causal exposure.

In conclusion, the results of the present study show that employment in specific industries and occupations is associated with an increased risk of developing COPD, and they add further evidence that occupational exposures contribute significantly to the overall burden of COPD. Part of this burden may be due to the synergistic effect of tobacco smoking and occupational exposure (43). More research is needed to confirm that the newly identified industries and occupations are associated with an increased risk of COPD and to identify causal risk factors. To maximize the impact of this research on reducing the prevalence of COPD in the US population, etiologic research and preventive interventions should focus on industries that have high odds ratios and a large number of cases attributable to workplace exposure.

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