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abstract

Pulmonary Function and Respiratory Symptoms in Polyvinylchloride Fabrication Workers¹⁻³

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Introduction

In 1978, a union representing employees of a company that fabricates polyvinylchloride (PVC) resins into vinyl sheeting and wallcovering submitted a request to the National Institute of Occupational Safety and Health (NIOSH) for an investigation of complaints concerning respiratory symptoms. The complaints were centered in the calender department, where PVC resins and other items were mixed under heat and pressure to form vinyl sheeting and wallcovering. Other exposures of concern existed in the laminating, color, print and print service, and maintenance departments (table 1). Production line areas were separated by brick walls that largely confined exposures within departments. On the basis of workplace air monitoring by a NIOSH industrial hygienist and interview of employees by a NIOSH physician, further investigation of the pulmonary complaints was recommended.

Pulmonary function abnormalities and dyspnea have been reported in vinyl chloride monomer (VCM) polymerization workers (1-5), who are exposed to VCM and PVC dust. However, area monitoring of workplace air on the floor of the calender department indicated VCM concentrations of 1 ppm or less. Exposure to high PVC dust levels, such as occurs in manual bagging and loading, is associated with radiographic abnormalities (6-11), dyspnea (9) and histopathologic changes (8, 12), although the evidence for pulmonary function impairment is conflicting (9, 11). The PVC dust levels were not measured in the plant under study, but the only sources of PVC dust were fugitive emissions from overhead pneumatic delivery systems, which do not produce dust levels comparable to manual operations.

Because a haze was visible in the calender area in the plant under study, possible exposure to PVC thermal degradation products was assessed. Polyvinylchloride is thermally stable at temperatures below 225° C. Between 225° C and 475° C (the ignition point), hydrochloric acid (HCl) is first released, then, at increasing temperatures, other compounds such as carbon monoxide, carbon dioxide, benzene, and VCM are formed (13). At temperatures in excess of 475° C, phosgene and chlorine are formed. Commercial meat wrappers exposed to fumes from PVC film cut with a hot wire (14, 15) report an increase in respiratory symptoms, although pulmonary function impairment in these workers has not been unequivocally demonstrated (16). Exposure of guinea pigs to sublethal doses of PVC thermal decomposition products produces a depression of the normal ventilatory response to CO₂ (17) and changes in pulmonary function, lung mixed-function oxidase activity, and lung organ to body weight ratio (18). In an industrial accident involving overheating of PVC in a PVC fabrication plant, workers experienced acute upper and lower respiratory irritation; symptoms and abnormal pulmonary function persisted in some workers for several months after the accident (19). However, in the plant under study, the operating temperature of the mixing process in the calender department was 200° C, and airborne concentrations of HCl were below detectable limits. Although historical incidents of PVC overheating were reported by one worker, the frequency and duration of these incidents were not known.

SUMMARY We performed preshift and postshift spirometry and administered a standardized respiratory symptoms questionnaire to 174 white males currently employed in polyvinylchloride (PVC) fabrication to examine the acute and chronic respiratory effects of work exposure. Although there were no significant differences between the in-plant comparison group and any department with potential exposures, there was evidence for respiratory effects in the combined group of comparison and exposed workers. In the combined group, duration of employment was significantly associated with decrements in adjusted cross-shift ratio of forced expiratory volume in one second to forced vital capacity (FEV₁/FVC), preshift FEV₁/FVC, and prevalence of chronic cough and chronic phlegm. In nonsmokers, the prevalences of chronic wheeze and chest tightness were high (36.0 and 50.5%, respectively). The age-adjusted prevalence of chronic wheeze in nonsmokers was also elevated 3.54-fold when compared with that in a community study in the literature. We conclude that the cross-sectional design and in-plant comparison group may mask the effects of exposures on the entire plant population, and that employment in this plant is associated with patterns of obstructive air-flow limitation and respiratory symptoms consistent with exposure to pulmonary irritants. These results suggest that possible agents of pulmonary effects in PVC fabrication are not limited to vinyl chloride monomer, PVC dust, and PVC thermal degradation products.

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Polyvinylchloride fabrication is a widespread process in industry. Because previously reported agents associated with respiratory effects were not present at this plant, we designed this study to determine if work exposure in PVC fabrication under normal operating conditions was associated with acute or chronic pulmonary function impairment or excessive respiratory symptomatology, relative to a comparison group of workers in production line departments subjectively free of fume, dust, and odor.

Methods

The 5 departments with potential exposures and a comparison group of 3 departments subjectively free from fume, dust, and odor were studied (table 1). The comparison group consisted of workers from the shipping, inspection, and receiving and materials depart-

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TABLE 1
PROCESSES AND PRINCIPAL CHEMICALS IN STUDY DEPARTMENTS

Study Departments	Process	Principal Chemicals
Departments with potential exposures		
Calender	Mixing of PVC resins and additional items under heat and pressure to form a soft vinyl dough, which is milled into thin sheets	PVC resin powders Liquid plasticizers Stabilizers Fire retardants Color dispersions
Laminating	Lamination of layers of vinyl sheeting or backing under heat and pressure	Vinyl adhesives 1,1,1 trichloroethane
Print and print service	Mixing of printing inks and decorative printing and embossing of vinyl sheeting	Ink pigment concentrates Solvents*
Color	Mixing of solvent-based inks	Solvents* Lead chromate pigment powders PVC and copolymer resins
Maintenance	Plant clean-up and equipment repair	Dependent on location within plant
Comparison departments		
Shipping Inspection Receiving & materials	Handling of feedstocks or finished product	None

* Solvents include methyl ethyl ketone, methyl isobutyl ketone, toluene, xylene, and cyclohexanone

ments, which handled only finished products (shipping and inspection) or packaged raw materials (receiving and materials). The 201 white males currently employed in these departments were eligible for study. Demographic groups other than white males were not studied because of inadequate representation in the departments under study. Eligible workers were excluded from study if they were unavailable for study ($n = 15$) or if they declined to participate ($n = 12$). The 174 workers studied, representing 86% of the eligible population, were stratified by department and by work shift and were randomly allocated to be tested over the 5 days of the study.

On the day of his test, each worker was administered the American Thoracic Society (ATS) respiratory symptoms questionnaire (20) in a NIOSH trailer adjacent to the plant

by interviewers previously trained in standard technique (21). Trained pulmonary function technicians administered preshift and post-shift spirometry within 90 min of beginning and ending the work shift. Each worker was tested before and after his shift by the same technician. Spirometry was performed in a climate-controlled room in a clean area of the plant and in accordance with the ATS Snowbird conference criteria (22), using Stead-Wells water-filled spirometers (Warren E. Collins, Braintree, MA). Spirometers were calibrated with a stopwatch and a 3-L syringe before testing each shift. Forced vital capacity (FVC) and forced expiratory volumes in one, three, and six seconds (FEV_1 , FEV_3 , and FEV_6) were corrected to BTPS and analyzed. (The ratio of FEV_3 to FEV_6 is an index of flow towards the end of the forced expiration and may re-

flect small airways changes (23)). Work histories indicating the calendar dates and duration of employment in each department were obtained from company records.

The Abbey-Tonascia modification of the Feldstein multiple linear regression technique was used to simultaneously adjust pulmonary function and symptom prevalence for age, height, smoking, shift, day of week, duration of employment, and current department (24). Within each independent variable, comparisons were made to the adjusted function or rate of a reference class. The values for these reference classes were analogous to predicted values, in that they indicate the value that would be expected after adjustment for all independent variables other than the one being tested. Comparisons were made to determine if the adjusted outcome changes over the range of the independent variable under study. For example, the adjusted function of persons in the age classes 30 to 39, 40 to 49, and 50 or more yr was compared with the adjusted function of persons younger than 30 yr of age, the reference class, to determine if age was associated with function. The chi-square test with Yates' continuity correction was used for discrete variables, such as respiratory symptoms, and the two-tailed t test was used for continuous variables, such as pulmonary function (25). Differences that returned p values of less than 0.05 were considered significant.

Results

Age and duration of employment were not significantly different between the 174 eligible workers studied and the 27 eligible workers not studied. Of the 174 eligible workers studied, 170 (98%) had acceptable quality preshift spirometry, 165 (95%) had acceptable quality preshift and postshift spirometry, and 163 (94%) had acceptable quality spirometry plus available work histories.

Demographic characteristics of the 174 workers studied are presented in table 2.

TABLE 2
DEMOGRAPHIC CHARACTERISTICS OF STUDY POPULATION, BY CURRENT DEPARTMENT*

Characteristic	Current Department						Total
	Calender	Laminating	Print and Print Service	Color	Maintenance	Comparison Group	
n	41	23	38	6	25	41	174
Height, inches	70.2 $\pm$ 3.3	70.4 $\pm$ 2.9	69.9 $\pm$ 2.5	69.1 $\pm$ 0.9	70.6 $\pm$ 2.6	69.6 $\pm$ 2.1	70.1 $\pm$ 2.7
Duration of total employment, yr	10.6 $\pm$ 5.2†	15.0 $\pm$ 3.8	11.5 $\pm$ 5.6†	8.2 $\pm$ 5.8†	10.8 $\pm$ 5.8†	14.2 $\pm$ 3.7	12.2 $\pm$ 5.2
Age, yr	37.7 $\pm$ 9.9†	47.3 $\pm$ 9.0	39.8 $\pm$ 9.7	43.7 $\pm$ 18.7	42.2 $\pm$ 7.5	44.0 $\pm$ 10.7	41.8 $\pm$ 10.1
Smoking status, n							
Nonsmoker	18	10	13	2	11	18	75
Ex-smoker	4	4	5	2	3	7	25
Current, < 1 pack/day	4	3	4	1	1	2	15
Current, $\geq$ 1 pack/day	15	6	16	1	10	14	65

* Values are mean $\pm$ SD.

† Two-tailed t test, $p < 0.05$ as compared with that in comparison group.

The mean age of calender workers was significantly less than the comparison group (37.7 yr versus 44.0 yr, respectively, $p < 0.05$). The mean duration of employment of workers in all departments except laminating was significantly less than that of workers in the comparison group. There were no significant differences in mean height or in the distribution of smoking status by department.

Mean adjusted cross-shift changes in pulmonary function are presented in table 3. Cross-shift changes were seldom greater than approximately 1% of preshift values. However, the slight decline (-0.19%) in adjusted FEV_1/FVC over Shift 2 was significantly less ($p < 0.05$) than the 1.30% increase over Shift 1. The 0.24% increase in adjusted cross-shift change in FEV_1/FVC in persons employed for 6 months or more was significantly less ($p < 0.01$) than the 3.22% increase seen in persons employed for less than 6 months.

Aside from the expected changes in adjusted preshift pulmonary function with increasing age and smoking habit, there were no significant differences by shift, day of week, duration of employment, or current department (table 4). However, the duration of employment-related change in the acute response suggested to us that persons whose acute response was greatest might migrate to nonexposed departments, thereby attenuating differences between exposed and comparison departments seen on cross-sectional view. If this were true, total duration of employment in departments, rather than current department membership, would be the most appropriate work history measure to assess employment-associated chronic effects on pulmonary function. When we regressed preshift FEV_1/FVC against total duration of employment in each department (table 5), the slope for each department except maintenance, the smallest group, was significantly less than zero, even after adjustment for age, height, smoking, shift, day of week, and duration of employment in other departments.

Several patterns are apparent in table 6, which presents the mean adjusted prevalences of lower respiratory symptoms. The adjusted prevalences of chronic cough, chronic phlegm, and chronic wheeze were significantly lower ($p < 0.05$) in persons tested on Wednesday than in those tested on Monday. The prevalence of wheeze plus shortness of breath increased daily, from 16.4 to 34.9% over the work week. The adjusted prevalences of chronic cough and chronic

TABLE 3
MEAN ADJUSTED CROSS-SHIFT CHANGE* IN PULMONARY FUNCTION BY CHARACTERISTIC

Characteristic	Class	Mean Cross-shift Change in Adjusted Pulmonary Function (%)		
		FEV_1	FEV_1/FVC	FEV_3/FEV_1
Age	< 30	0.52	0.56	-0.50
	30-39	0.38	0.76	0.08
	40-49	0.32	0.53	0.36
	50+	0.62	0.53	-0.02
Smoking status	Nonsmoker	0.62	1.06	0.29
	Ex-smoker	0.79	0.51	-0.36
	Current smoker	-0.15	0.18	-0.03
Shift	1	0.64	1.30	0.00
	2	-0.52	-0.19†	-0.01
	3	1.33	-0.07	0.30
Day of week	Mon	0.01	1.05	0.08
	Tue	0.62	0.19	0.43
	Wed	-0.14	1.21	0.38
	Thu	-0.47	0.29	-0.53
	Fri	3.44	0.10	-0.20
Duration of employment, yr	< 0.5	2.41	3.22	0.04
	≥ 0.5	0.17	0.24‡	0.06
Current department	Comparison group	1.30	0.69	-0.14
	Calender	0.56	0.89	0.00
	Laminating	-0.15	0.75	-0.20
	Print and print service	1.16	1.01	1.30
	Color	0.99	-0.73	1.17
	Maintenance	-2.09	-0.50	0.07

* (Pre-Post)/Pre $\times 100$.

† Two-tailed t test, $p < 0.05$.

‡ Two-tailed t test, $p < 0.01$.

TABLE 4
MEAN ADJUSTED PRESIFT PULMONARY FUNCTION BY CHARACTERISTIC

Characteristic	Class	Mean Adjusted Preshift Pulmonary Function		
		FEV_1 (L)	FEV_1/FVC (%)	FEV_3/FEV_1 (%)
Age, yr	< 30	4.38	82.0	97.3
	30-39	3.96*	77.6*	94.9†
	40-49	3.62‡	76.1*	94.1‡
	50+	3.04‡	70.8‡	92.2‡
Smoking status	Nonsmoker	3.79	77.5	94.5
	Ex-smoker	3.84	79.1	95.7
	Current smoker	3.50*	73.4†	93.6
Shift	1	3.73	75.7	94.6
	2	3.63	75.6	93.8
	3	3.56	77.0	94.6
Day of week	Mon	3.81	76.1	94.8
	Tue	3.68	74.7	93.5
	Wed	3.54	76.1	93.8
	Thu	3.73	77.2	95.2
	Fri	3.54	75.2	94.0
Duration of employment, yr	< 0.5	3.85	76.0	94.9
	≥ 0.5	3.65	75.9	94.2
Current department	Comparison group	3.64	75.4	94.0
	Calender	3.58	75.3	94.1
	Laminating	3.66	74.7	94.4
	Print and print service	3.76	77.6	94.8
	Color	3.37	71.8	92.0
	Maintenance	3.79	77.3	94.4

* Two-tailed t test, $p < 0.05$.

† Two-tailed t test, $p < 0.01$.

‡ Two-tailed t test, $p < 0.001$.

TABLE 5
REGRESSION OF ADJUSTED* PRESIFT FEV₁/FVC ON
TOTAL DURATION OF EMPLOYMENT IN DEPARTMENTS

Department†	n	Correlation r	Explained Variance r ²	Intercept a (%)	Slope b (% yr)	P
Calender	100	-0.168	0.028	78.13	-0.16	0.047
Laminating	95	-0.426	0.181	78.48	-0.35	< 0.001
Print and print service	88	-0.368	0.135	78.75	-0.29	< 0.001
Color	41	-0.312	0.098	78.43	-0.50	0.023
Maintenance	29	-0.209	0.044	76.26	-0.17	0.139
Comparison group	92	-0.287	0.082	77.87	-0.29	0.003

* Adjusted for age, height, smoking, shift, day of week, and duration of employment in other departments

† The sum of number of individuals in each department does not equal 174 because a person may have been employed in more than one department over his work history. As a result, the departmental groups are not mutually exclusive, and comparison of slopes between departments is not appropriate.

TABLE 6
MEAN ADJUSTED PREVALENCE OF LOWER RESPIRATORY SYMPTOMS BY CHARACTERISTIC

Characteristic	Class	Adjusted prevalence (%)				
		Chronic Cough	Chronic Phlegm	Chronic Wheeze	Wheeze and Short- ness of Breath	Chest Tightness
Age, yr	< 40	21.0	25.9	38.4	23.7	42.4
	≥ 40	18.2	20.8	38.6	24.4	49.7
Smoking status	Nonsmoker	13.9	17.4	36.1	26.7	44.8
	Ex-smoker	6.9	16.1	12.3*	9.0	38.0
	Current smoker	27.6*	30.5	49.3	26.7	51.0
Shift	1	19.3	22.8	44.0	28.0	50.5
	2	17.8	21.0	30.0	11.4	45.4
	3	19.7	26.5	36.4	26.5	37.4
Day of week	Mon	29.3	29.0	48.9	16.2	41.5
	Tue	10.5	18.4	49.8	20.0	62.2
	Wed	10.2*	8.0*	20.7*	23.8	40.6
	Thu	27.5	35.1	43.1	29.2	45.2
	Fri	16.6	25.0	25.4	34.9	40.2
Duration of employment, yr	< 0.5	0.0	2.1	31.9	11.2	40.4
	≥ 0.5	21.8*	25.8*	39.4	25.9	47.4
Current department	Comparison group	10.8	13.6	34.1	13.6	39.0
	Calender	21.2	28.4	42.2	30.6	42.6
	Laminating	26.8	33.6	46.8	31.3	60.4
	Print and print service	15.9	23.0	37.9	28.8	55.1
	Color	41.3	47.9	46.8	18.3	45.8
	Maintenance	20.7	13.6	30.8	18.6	40.0

* Two-tailed *t* test, *p* < 0.05.

phlegm were higher (*p* < 0.05) in persons employed for 6 months or more than in persons employed for less than 6 months. Last, the adjusted prevalences of chronic wheeze and chest tightness in all non-smoking PVC workers (36.0 and 50.5%, respectively), although not significantly different between characteristic categories, were higher than expected when compared with community studies in the literature (26-28).

To explore the latter finding, we compared the age- and smoking-specific prevalences of lower respiratory symptoms in PVC fabrication workers with the prevalences expected if the PVC workers

experienced the same symptom prevalences as a community population, obtained from a published study that used the MRC respiratory symptoms questionnaire (29). The MRC and ATS questionnaires elicit similar prevalences of chronic cough, chronic phlegm, and chronic wheeze, but the ATS questionnaire elicits a higher prevalence of any wheeze than does the MRC questionnaire (28); we therefore excluded wheeze plus shortness of breath from this comparison. As indicated in table 7, compared with expected frequencies, the nonsmoking PVC fabrication workers had a 3.54-fold increase in chronic wheeze (*p* < 0.001). The

PVC workers who were moderate smokers had a 1.64-fold excess of chronic wheeze (*p* < 0.001). Other lower respiratory symptoms, however, were lower than expected in PVC workers who smoked (chronic phlegm in moderate smokers, 0.58-fold, *p* < 0.05; chronic cough in heavy smokers, 0.40-fold, *p* < 0.005).

Discussion

The results of this cross-sectional study indicate that acute and chronic obstructive ventilatory changes and an increased prevalence of lower respiratory symptoms, consistent with the presence of pulmonary irritants, are associated with employment in this PVC fabrication plant. The 3.22% cross-shift increase in FEV₁/FVC in persons employed for less than 6 months may be due to a training effect, which is significantly attenuated in persons employed for more than 6 months by cumulative effects of workplace exposures. The decreased cross-shift change in FEV₁/FVC during Shift 2 relative to Shift 1 may be related to natural circadian rhythm (30). Although adjusted preshift pulmonary function is not significantly different between workers currently employed in departments with potential exposures and the comparison group, adjusted preshift FEV₁/FVC declines significantly with total duration of employment in all but one department, suggesting an employment-associated chronic obstructive effect.

The daily increase over the work week in the prevalence of wheeze plus shortness of breath suggests cumulative exposure to a lower respiratory irritant. The adjusted prevalence of chronic cough and chronic phlegm increases with increasing duration of employment, and the seemingly high overall prevalence of chronic wheeze, as supported by comparisons with a community study, also suggest that employment is associated with an increase in lower respiratory symptoms. The interpretation of the observed variation in prevalence of chronic symptoms by day of week is unclear.

The fact that none of the foregoing conclusions are evident from interdepartmental comparisons is notable, and underscores the limitations of the cross-sectional design and in-plant comparison group. A healthy working population may result from differential initial employment, selective migration within areas of the plant, and employment termination (31). In this study, for example, although persons employed for 6 months or more had a significantly

TABLE 7
OBSERVED AND EXPECTED* LOWER RESPIRATORY SYMPTOMS BY
AGE AND SMOKING STATUS

Smoking Status	Age (yr)	n	Observed and Expected Symptom Frequencies					
			Chronic Cough		Chronic Phlegm		Chronic Wheeze	
			Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
Never	18-44	43	10	6	8	6	27	9
	45+	32	12	7	6	7	19	4
	Total	75	22	13	14	13	46	13
	O/E		1.69		1.08		3.54 [§]	
Previous	18-44	13	6	3	3	3	4	5
	45+	12	2	5	2	5	5	5
	Total	25	8	8	5	8	9	10
	O/E		1.00		0.62		0.90	
Light to moderate	18-44	43	18	14	10	14	38	25
	45+	17	3	10	4	10	13	6
	Total	60	21	24	14	24	51	31
	O/E		0.88		0.58 [†]		1.64 [§]	
Heavy	18-44	10	4	7	6	7	9	8
	45+	10	2	8	3	8	9	15
	Total	20	6	15	9	15	18	13
	O/E		0.40 [‡]		0.60		1.38	

* Expected frequencies derived from reference 30.

† Chi-square test, $p < 0.05$.

‡ Chi-square test, $p < 0.005$.

§ Chi-square test, $p < 0.001$.

smaller cross-shift change in FEV_1/FVC than did persons employed for less than 6 months, in both groups FEV_1/FVC increased over the work shift. We conclude that the cross-sectional design and in-plant control group may mask the effects of exposures on the PVC workers as a whole.

Other explanations exist for these results. The lack of interdepartmental differences may simply indicate that employment in PVC fabrication is not associated with effects on pulmonary function or symptoms. However, the consistent associations of duration of employment with cross-shift change in FEV_1/FVC , preshift FEV_1/FVC , and prevalence of lower respiratory symptoms argue for work-associated effects. In this cross-sectional study design, we cannot differentiate between cohort effects, in which time-dependent effects would be due to high past exposure levels (or to introduction of a toxic agent), and effects caused by longer exposure to a similar dose level. Concern about a possible cohort effect is raised by the anecdotal reports of PVC overheating in the plant under study. Because the calendaring area is enclosed by a brick wall, it is likely that exposure to PVC thermal degradation products would be limited to calendaring department employees. However, the significant declines in adjusted preshift FEV_1/FVC in relation to total duration of employment were not limited to the

calendering department, but existed in all but one department (table 5).

Although this study cannot identify specific agents associated with the observed ventilatory effects, the industrial hygiene results rule out VCM, HCl, and PVC thermal degradation products. The PVC additives that partially volatilize at temperatures of 200° C or less, and chemicals used in noncalendering areas of the plant, might be contributing to the development of respiratory symptoms and functional abnormalities in the work force. For example, the lead chromate in pigments used in the color department is a carcinogen, and chromate dust, when hydrated in the respiratory tract to form chromic acid, would be a pulmonary irritant (32). The large number of chemicals used in this plant alone complicates the search for an agent or agents. However, PVC fabrication is a widespread process in industry, and the consistent evidence from this study of employment-associated pulmonary effects should motivate further research.

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