Longitudinal and Cross-sectional Analyses of Lung Function in Steelworkers

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We evaluated associations between dust exposure, demographic factors, and lung function by longitudinal and cross-sectional analyses in 475 steelworkers who participated in at least three spirometry tests over 5 yr between 1982 and 1991. Baseline and follow-up spirometry and changes between baseline and final follow-up assessment attributable to age, height, weight, weight gain, smoking status, pack-years, and years worked in dusty areas were examined using stepwise multiple linear regression techniques. Smoking, aging, being overweight, excessive weight gain, and dust exposure were related to a lower level and a steeper slope of decline of pulmonary function. Cigarette smoking was also an important risk factor. Dust exposure was related to the level of lung function, with a stronger effect at baseline than at follow-up. Estimated loss at baseline of FEV_1, FVC, and FEV_1/FVC% was 9.3, 6.4 ml, and 0.1% per year of employment in a dusty area, respectively, whereas the association between dust exposure and longitudinal decline of lung function was weak. However, a strong relationship between weight gain and longitudinal decline of FEV_1 and FVC was found. Estimated decreases in FEV_1 and FVC attributable to weight gain were 4.7 and 6.3 ml per lb/yr, respectively. This work suggests that weight gain is an important determinant for longitudinal lung function decline. This large impact of weight gain in the decline of lung function in a middle-age and relatively overweight working population has not been previously reported. Additional work needs to be undertaken to show the strength of this relationship in other populations. Wang M-L, McCabe L, Hankinson JL, Shamssain MH, Gunel E, Lapp NL, Banks DE. Longitudinal and cross-sectional analyses of lung function in steelworkers.

AM J RESPIR CRIT CARE MED 1996;153:1907–13.

Steel manufacturing presents some of the most diversified respiratory exposures of any industry. Based on the process location, the major respirable contaminants include iron ore and coal dust, iron oxide, coke oven emissions, silica dust, metal fumes, gases and vapors (CO, SO_2, H_2S, ozone, oxides of nitrogen), and, in some situations, the release of numerous chemicals used to make cores and molds.

There are several reports showing a relationship between the steel manufacturing environment and the lung function of steelworkers. A significant lung function decline, consistent with slight airway obstruction, was observed over the night shift in steelworkers who worked in the strandcasting (continuous casting) department (1). Pulmonary symptoms and function in 272 steelworkers confirmed the influence of smoking on respiratory symptoms and lung function and suggested that nonsmoking steel plant and continuous casting workers had moderate, but detectable, effects from industrial pollution (2). In addition, a study performed in 1,087 Polish steel mill workers indicated a strong relation between the VC and FEV_1 and the degree of obesity (3). In a later report, 642 of these steelworkers without respiratory or circulatory disease were classified according to relative body mass. In workers with more than 124% of optimal body mass, the VC was adversely affected. The FEV_1 was not adversely affected until the body mass reached 135% of optimal. Significantly lower values of VC and FEV_1 were found when comparing obese with nonobese counterparts (4).

A 5-yr longitudinal study of lung symptoms and function in steelworkers compared 196 steelworkers (mostly in foundry and roll sheet works) with 186 unexposed workers of similar age, weight, height, smoking habits, and socioeconomic conditions at baseline (5). Although a significant adverse effect was found to be attributed to industrial pollution, the effects of other demographic factors and smoking habits on lung function were not evaluated.

We have attempted to relate demographic factors, the work environment, and smoking habits to pulmonary function in steel workers through both cross-sectional and longitudinal analyses using a retrospective longitudinal cohort data set obtained from the periodic medical health screening program of a major steel corporation. Unlike the above study, this population did not include foundry workers.

(Received in original form June 12, 1995 and in revised form October 12, 1995)

Supported by Cooperative Agreement No. U60/CCU306149 from the National Institute for Occupational Safety and Health.

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METHODS

Materials and Subjects

The medical records of 1,171 employees who participated in the health surveillance program in a major steel corporation were randomly chosen and reviewed. These workers had participated in yearly spirometry tests from 1980 to 1991 at least once and as many as 12 times. Medical records provided information regarding (*1*) demographic parameters: date of birth, sex, race, height, and body weight for each worker at the time of testing; (*2*) smoking status: smoking category, number of cigarettes smoked per day, years of smoking, and years since quit smoking; (*3*) spirometry indices: FVC, FEV_1, FEF_{25-75}, and PEFR.

Spirometry was performed in the Medical Department of the steel corporation according to the 1979 American Thoracic Society (ATS) recommendations (6) by registered nurses who completed a course on spirometry tests approved by the National Institute for Occupational Safety and Health (NIOSH). From the start of the study in April 1982 to its completion in September 1991, a water-filled survey spirometer with an Eagle One Microprocessor (W. E. Collins, Braintree, MA) was constantly used. Spirometer calibration was performed daily with a 3-L syringe. Volume-time curves accompanied by a computer printout of spirometry test values were available for all tests. A total of 3,587 tests with 10,761 curves were reviewed by at least two physicians for acceptability of effort, satisfactory start of test, the presence of cough, leaking of air flow, and premature termination. Consistent with the ATS guidelines, no subjects were excluded because of a lack of a reproducibility test (7). A total of 152 tests (4.2%) without at least one acceptable curve were excluded.

The subjects included in these data analyses were (*1*) described to be white or black men; (*2*) had at least three valid tests performed between 1982 and 1991; (*3*) had at least a 4-yr follow-up interval. This resulted in a cohort of 475 steel workers (451 white, 24 black) with a total of 2,298 spirometric tests.

Dust Exposure Assessment

The management of the steel corporation provided a detailed work history for each worker. These records included all transfer dates beginning with the date of hire and ending with the date of entry into the most recent job, accompanied by coding of job location and title and the total time employed in each job. In this manner, we were able to determine what job each worker held, how long each job lasted, and periods of unemployment, which were subtracted from the total years of employment. Because of the number of different jobs within the steel corporation and the great variety of dusty and nondusty work areas, we identified and grouped locations within the corporation where there were clearly recognized dust exposures and locations where dust exposure was not recognized. The recognition of dusty levels for each job location was made by the industrial hygienist of this corporation. Using this scheme, each year of employment in the Blast Furnace sites, in the Sinter Plant, in Steelmaking, and in the Continuous Caster Department were considered as a year employed in a dusty area. Each year spent working in Operational Services (i.e., Pipefitters, Riggers, Carpenters, Fire Fighters, *et al.*) were estimated as 50% time worked in a dusty area, whereas each year worked in the Tin Mill, in producing Strip Steel, in the Sheet Mill Department, and in Administration Offices were not added to the sum of the years worked in dusty areas. The expression for dust exposure as the number of years worked in the dusty areas was a combination of duration and the level of exposure. Therefore, the dust exposure assessment for each worker was based on the detailed job history and knowledge of the dust exposure level in the different locations. We calculated the total number of years worked at dusty job locations prior to the date of the first test and added this to the number of years employed in a dusty job location from the baseline to the final follow-up test as a surrogate for cumulative dust exposure.

Data Analysis

Variables of pulmonary function considered in this analysis were the FVC, FEV_1, and the FEV_1/FVC ratio. In some analyses, these parameters were reported as the percent predicted value (8). Predicted values for black men were calculated using the predicted value for white men multiplied by 0.85. Cross-sectional analyses for the baseline and the follow-up used the absolute value of these measurements at the first and last valid spirometric test. The longitudinal analysis of lung function used the change in all spirometry measurements available over time. Changes in these spirometric values over the follow-up period refer to the annual decline (slope) determined for each subject by simple linear regression using all the data points available. Weight gain over the time of follow-up was also calculated individually using the same data points and the same regression method as the calculation of the decline (slope) of pulmonary function indices.

The relationships between pulmonary function and various factors were examined using SAS stepwise multiple linear regression techniques (9). The independent variables examined in the cross-sectional data analysis for the spirometric measurements at both the baseline and the follow-up were age, race, height, weight, smoking status (current, ex-, and never smokers), pack-years, and years worked in the dusty areas measured at or calculated up to the same time of corresponding spirometric tests. The candidate regressors for the longitudinal analysis of changes (slopes) in FEV_1, FVC, and FEV_1/FVC% included the age halfway between the first and last spirometric test, mean of the subjects' recorded heights, body mass index (BMI, kg/m^2), weight gain (lb/yr), five categories of smoking status (continuous smokers or nonsmokers, quitters before baseline, quitters or starters during follow-up), pack-years during the interval, years worked in the dusty areas between the first and last test, and the follow-up interval. The significant level for inclusion was $p < 0.2$. Considering the possibility that the insignificant covariates might be confounding factors, the multiple linear models, including all the candidate regressors, with the smoking status during follow-up as a categorical variable (five levels) were also derived using JMP package (10). We examined the differences of the associations between the changes in weight and the changes in spirometric indices in subgroups stratified by age, height, weight, BMI, and smoking status. The partial correlation coefficient between weight gain and the slopes of FEV_1 and FVC, after adjusting for all other independent variables, was calculated from the residuals obtained from multiple linear regressions listed in Table 5 (11).

The quadratic terms of age, height, weight, and dust years, and also the interaction terms of race and other covariates, age, and weight gain have been examined. The results indicated that these terms were highly insignificant and did not improve the model fit. Therefore, the multiple linear models, not including the polynomial and the interaction terms, are presented to simplify the interpretation of the relations of various factors to the pulmonary function.

RESULTS

Of the 475 workers, there were 97 with three tests, 115 with four, 114 with five, 88 with six, 42 with seven, 16 with eight, and three with nine, respectively. Years of follow-up ranged from 4 to 9, with an average of 6.2 yr. The mean number of tests for each participant in this study was 4.8.

The demographic characteristics and pulmonary function results stratified by the smoking status at follow-up are shown in Table 1. The average age at the midway point approximated 40 yr. The age ranged around 20 to 61 at baseline, and around 25 to 66 at follow-up. The 25th, 50th, and 75th percentiles of the age distribution at the baseline and the follow-up were around 30, 34, 43, and 36, 41, 49, respectively. The population had worked in dusty areas for approximately 11 yr prior to the first test and 16 yr prior to the last test. At the time of the final follow-up test, 37.5% workers were current smokers. The FEV_1 and FVC declined an average of 45 and 52 ml/yr, respectively, for the group as a whole. The FEV_1 and FVC decline was 53 and 56 ml/yr for current smokers, 44 and 53 ml/yr for ex-smokers, and 37 and 44 ml/yr for nonsmokers, respectively. That there was a relatively large proportion of overweight workers; (26 and 33.6% had a BMI $> 30\ kg/m^2$ at baseline and follow-up, respectively) can be seen in Table 2.

The results from the cross-sectional analysis of the multiple linear regression models for pulmonary function indices at baseline and at follow-up are shown in Table 3. Only those regressors with p values less than 0.2 were included in the model. As expected, the adverse effect of age and smoking on all three pul-

TABLE 1

DESCRIPTION OF THE STUDY POPULATION BY SMOKING*

	Whole	Smoking Status at Follow-up		
		Current	Ex	Never
Subjects, n	475	178	158	139
Age at midway, yr	39.8 (7.9)	38.0 (6.9)	41.5 (8.2)	40.1 (8.6)
Race, % white	94.9	93.3	95.6	96.4
Mean height, cm	178.1 (6.9)	177.9 (7.2)	178.1 (7.0)	178.4 (6.3)
Years of dusty area				
Prebaseline	11.5 (9.1)	10.7 (8.4)	12.3 (9.8)	11.8 (9.2)
At follow-up	16.3 (11.0)	15.4 (10.2)	16.9 (11.8)	16.7 (11.0)
Pack-years				
At baseline	14.8 (15.9)	21.2 (14.0)	20.6 (16.5)	0.0 (0.0)
At follow-up	18.5 (18.9)	29.8 (16.7)	22.2 (17.7)	0.0 (0.0)
Body weight				
Baseline, lb	192.0 (32.4)	185.3 (32.3)	194.0 (31.8)	198.2 (32.1)
Follow-up, lb	200.7 (36.8)	192.7 (36.3)	205.5 (38.3)	205.4 (34.3)
Slope, lb/yr†	1.39 (2.66)	1.22 (2.38)	1.94 (2.97)	0.97 (2.54)
Body mass index				
Baseline, kg/m^2	27.5 (4.3)	26.6 (4.0)	27.8 (4.2)	28.3 (4.5)
Follow-up, kg/m^2	28.7 (4.8)	27.6 (4.4)	29.4 (5.1)	29.3 (4.8)
FVC				
Baseline, L	4.96 (0.84)	4.88 (0.81)	4.91 (0.84)	5.11 (0.88)
Baseline, % pred‡	97.2 (13.0)	95.3 (11.6)	97.1 (12.0)	99.7 (15.1)
Follow-up, L	4.60 (0.88)	4.52 (0.87)	4.54 (0.87)	4.78 (0.87)
Follow-up, % pred‡	93.5 (14.0)	91.2 (13.1)	93.2 (13.7)	96.7 (14.8)
Slope, L/yr†	−0.052 (0.057)	−0.056 (0.055)	−0.053 (0.063)	−0.044 (0.050)
FEV_1				
Baseline, L	3.93 (0.72)	3.85 (0.69)	3.93 (0.72)	4.05 (0.74)
Baseline, % pred‡	93.4 (13.9)	90.8 (12.7)	94.3 (13.3)	95.7 (15.6)
Follow-up, L	3.66 (0.75)	3.53 (0.74)	3.67 (0.75)	3.82 (0.73)
Follow-up, % pred‡	90.7 (15.4)	86.7 (14.3)	91.9 (14.7)	94.5 (16.3)
Slope, L/yr†	−0.045 (0.047)	−0.053 (0.044)	−0.044 (0.051)	−0.037 (0.046)
FEV_1/FVC%				
Baseline, %	79.4 (7.0)	78.9 (7.6)	80.2 (7.3)	79.2 (5.9)
Baseline, % pred‡	95.9 (8.3)	95.1 (8.9)	96.9 (8.6)	95.6 (7.0)
Follow-up, %	79.5 (6.9)	78.1 (7.6)	80.8 (6.7)	80.0 (6.0)
Follow-up, % pred‡	96.8 (8.4)	94.8 (9.0)	98.5 (8.0)	97.4 (7.4)
Slope, %/yr†	−0.10 (0.74)	−0.21 (0.68)	−0.04 (0.77)	−0.02 (0.76)

* Values are means with SD shown in parentheses.
† Change per year of weight and spirometry indices, calculated by simple linear regression.
‡ Percent predicted values calculated based on those of Knudson and coworkers (8).

monary indices at baseline and at follow-up was highly significant. Race, height, and body weight are also significantly related to lung function, with the values for blacks being lower than for whites. Dust exposure, expressed as years worked in dusty areas, was also related to the level of lung function, with a stronger effect at baseline than at follow-up. The extent of FEV_1, FVC, and FEV_1/FVC% decline at baseline averaged 9.3, 6.4 ml, and 0.1%, respectively. At follow-up, the exposure-related loss of FEV_1 and FEV_1/FVC% averaged 5.0 ml and 0.1% per year of job in a dusty area, respectively. The exposure-related loss of FVC was not significant (about 1.5 ml/yr, $p > 0.65$, not entered into the model). Models substituting BMI for body weight were also developed. Briefly, BMI, measured at the time of the first and the last spirometry test, adversely affected the FVC and the FEV_1 by 16.2 and 8.8 ml per kg/m^2 at baseline ($p < 0.019$ and 0.142, respectively), and the FVC and the FEV_1 by 26.1 and 16.7 ml per kg/m^2, at follow-up ($p < 0.0001$ and 0.003, respectively).

TABLE 2

DISTRIBUTION OF BODY MASS INDEX (BMI) BY CLASSIFICATION OF OBESITY AT BASELINE AND FOLLOW-UP IN 475 STEELWORKERS

BMI Range (kg/m^2)	Grade of Obesity*	At Baseline		At Follow-up	
		(*n*)	(%)	(*n*)	(%)
< 25.0	0	140	29.5	94	19.8
25.0–29.9	I	212	44.6	221	46.5
30.0–40.0	II	116	24.4	147	30.9
> 40.0	III	7	1.5	13	2.7

* The classification of obesity is based on the Panel Summary Statements on Energy, Obesity, and Body Weight Standards (22).

Linear regression models at the significant level of $p < 0.2$ for inclusion were developed for the longitudinal changes per year in FEV_1, FVC, and FEV_1/FVC ratio (Table 4). As expected, smoking and aging had a negative effect on pulmonary function. Continuous smokers and starters during follow-up had lower predicted FEV_1 and FVC values than did nonsmokers and ex-smokers. Smoking effect expressed as pack-years during follow-up significantly affected the FEV_1/FVC ratio. Importantly, there was a highly significant association between FEV_1 and FVC decline and weight gain ($p = 0.0001$). Of the total variability explained by the models for the changes in FEV_1 and FVC (8.8 and 11.6%, respectively); 6.1 and 7.1% were attributable to weight gain, respectively.

Models for the decline of lung function, including all the independent variables, are also presented in Table 5. Inclusion of all the covariates did not change the major findings of the effect of weight gain on annual decline of FEV_1 and FVC, and the ef-

TABLE 3

MULTIPLE LINEAR REGRESSION MODEL FOR PULMONARY FUNCTION INDICES AT BASELINE AND AT FOLLOW-UP IN 475 STEELWORKERS*

	At Baseline			At Follow-up		
	FEV_1 (*L*)	FVC (*L*)	FEV_1/FVC% (%)	FEV_1 (*L*)	FVC (*L*)	FEV_1/FVC% (%)
r^2	0.4328	0.4566	0.1145	0.4282	0.4628	0.1167
Constant	−4.3930	−6.7924	99.2537	−3.9269	−6.2589	105.2216
	0.7040	0.8093	8.4007	0.7366	0.8335	8.5390
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Age, yr	−0.0202	−0.0169	−0.1389	−0.0267	−0.0305	−0.0844
	0.0044	0.0050	0.0512	0.0041	0.0040	0.0474
	(0.0001)	(0.0008)	(0.0070)	(0.0001)	(0.0001)	(0.0760)
Race†	−0.4426	−0.7504	3.6208	−0.4678	−0.7425	3.0830
	0.1152	0.1324	1.4045	0.1201	0.1367	1.3922
	(0.0001)	(0.0001)	(0.0102)	(0.0001)	(0.0001)	(0.0273)
Height, cm	0.0538	0.0733	−0.0732	0.0533	0.0736	−0.1213
	0.0040	0.0046	0.0450	0.0042	0.0048	0.0487
	(0.0001)	(0.0001)	(0.1040)	(0.0001)	(0.0001)	(0.0132)
Weight, lb	−0.0013	−0.0024	–	−0.0024	−0.0038	0.0122
	0.0008	0.0010	–	0.0008	0.0009	0.0092
	(0.1188)	(0.0177)	–	(0.0023)	(0.0001)	(0.1862)
Smoker‡	−0.1211	−0.1378	–	−0.2177	−0.1614	−2.1054
	0.0600	0.0690	–	0.0651	0.0741	0.7553
	(0.0441)	(0.0464)	–	(0.0009)	(0.0300)	(0.0055)
Pack-years	−0.0043	−0.0032	−0.0491	−0.0042	−0.0037	−0.0334
	0.0019	0.0022	0.0203	0.0017	0.0019	0.0194
	(0.0258)	(0.1540)	(0.0160)	(0.0115)	(0.0544)	(0.0862)
Years of exposure	−0.0093	−0.0064	−0.0987	−0.0050	–	−0.1004
	0.0035	0.0040	0.0426	0.0028	–	0.0329
	(0.0079)	(0.1108)	(0.0209)	(0.0810)	–	(0.0024)

* Values are partial regression coefficients and standard errors, with p values shown in parentheses. Missing values indicate $p > 0.2$.
† 1 = black; 0 = white.
‡ Current smoker at baseline or at follow-up: 1 = yes; 0 = no.

TABLE 4

MULTIPLE LINEAR REGRESSION MODEL FOR LONGITUDINAL DECLINE OF PULMONARY FUNCTION INDICES IN 475 STEELWORKERS*

	ΔFEV_1 (*L*/yr)	ΔFVC (*L*/yr)	ΔFEV_1/FVC% (%/yr)
r^2	0.0875	0.1160	0.0798
Constant	−0.0247	0.0313	−1.0008
	0.0134	0.0158	0.1988
	(0.0661)	(0.0488)	(0.0001)
Age, yr	−0.0005	−0.0011	0.0072
	0.0003	0.0003	0.0042
	(0.0557)	(0.0005)	(0.0919)
Weight gain, lb/yr	−0.0047	−0.0063	–
	0.0008	0.0009	–
	(0.0001)	(0.0001)	–
Interval, yr	0.0020	−0.0039	0.1341
	0.0015	0.0017	0.0250
	(0.1782)	(0.0226)	(0.0001)
Smoker†	−0.0145	−0.0108	–
	0.0044	0.0052	–
	(0.0010)	(0.0368)	–
Interval, pack-years‡	–	–	−0.0188
	–	–	0.0070
	–	–	(0.0071)
Interval, exp§	–	–	−0.0306
	–	–	0.0131
	–	–	(0.0201)

* Values are partial regression coefficients and standard errors, with p values shown in parentheses. Missing values indicate $p > 0.2$.
† Continuous smokers and starter during follow-up: 1 = yes; 0 = no.
‡ Pack-years during follow-up.
§ Years of exposure during follow-up.

fect of dust exposure during the follow-up on the decline of FEV_1/FVC ratio. The predicted FEV_1 and FVC values calculated from the models in Table 5 were the highest in nonsmokers followed by quitters before baseline, quitters during follow-up, starters during follow-up, and continuous smokers. The estimated effects attributed to the weight gain on the longitudinal decline of FEV_1 and FVC after adjusting for all the covariates were −4.6 and −6.4 ml/yr per lb/yr, respectively (Table 5). For showing the effect of weight gain on the longitudinal decline of lung function, the values for changes in FEV_1 and FVC by quintiles of changes in weight are presented in Figures 1 and 2. Results obtained from calculating the partial correlation coefficient indicated that weight gain had its greatest effect on lung function in the following categories: age > 30, mean height > 182 cm, baseline weight > 200 lbs, and baseline body mass index > 30 kg/m² — corresponding to a Grade II or III obesity; but these correlations did not differ apparently by smoking status (Table 6).

The effect of dust exposure on the decline of FEV_1 and FVC we were unable to detect, although there was a statistically significant effect of dust exposure on the change of FEV_1/FVC% of −0.03% per year of job at dusty areas.

Residual plots and collinearity diagnostics were performed to check model normality, linearity, equality of variances, outliers, and multicollinearities. No evidence of systematic poor fit was found.

DISCUSSION

As expected, the cross-sectional analyses revealed the influences of age, race, and height on lung function, and the longitudinal

TABLE 5

MULTIPLE LINEAR REGRESSION MODEL FOR LONGITUDINAL DECLINE OF PULMONARY FUNCTION INDICES IN 475 STEELWORKERS*

	ΔFEV_1 (*L/yr*)	ΔFVC (*L/yr*)	$\Delta FEV_1/FVC\%$ (*%/yr*)
r^2	0.0913	0.1318	0.0888
Constant	−0.0291	0.0188	−0.7352
	0.0194	0.0227	0.3034
	(0.1338)	(0.4071)	(0.0158)
Age, yr	−0.0004	−0.0010	0.0072
	0.0002	0.0003	0.0044
	(0.1141)	(0.0014)	(0.0992)
Weight gain, lb/yr	−0.0046	−0.0064	0.0052
	0.0008	0.0009	0.0126
	(0.0001)	(0.0001)	(0.6670)
BMI, at baseline, kg/m^2	−0.0002	−0.0003	−0.0036
	0.0005	0.0005	0.0078
	(0.6714)	(0.6025)	(0.6444)
Interval, yr	−0.0027	−0.0045	0.1274
	0.0016	0.0019	0.0261
	(0.1037)	(0.0213)	(0.0001)
Smoker†	−0.0035	0.0087	−0.2399
	0.0084	0.0098	0.1320
	(0.6746)	(0.3767)	(0.0699)
Starter‡	−0.0140	−0.0682	0.7266
	0.0261	0.0305	0.4078
	(0.5911)	(0.0258)	(0.0755)
Ex-smoker§	−0.0029	0.0121	−0.1063
	0.0081	0.0095	0.1275
	(0.7216)	(0.2029)	(0.4046)
Quitter‖	0.0092	0.0283	−0.2339
	0.0084	0.0098	0.1312
	(0.2689)	(0.0041)	(0.0753)
Never smoker	0.0054	0.0191	−0.1464
	0.0079	0.0092	0.1239
	(0.4980)	(0.0414)	(0.2380)
Interval, pack-years¶	−0.0007	−0.0002	−0.0097
	0.0008	0.0009	0.0126
	(0.3341)	(0.8172)	(0.4312)
Interval, exp**	−0.0004	0.0007	−0.0284
	0.0008	0.0010	0.0133
	(0.6263)	(0.4880)	(0.0336)

* Values are partial coefficients and standard errors, with p values shown in parentheses.
† Continuous smoker.
‡ Started smoking during follow-up.
§ Quit smoking before baseline.
‖ Quit smoking during follow-up.
¶ Pack-years during follow-up.
** Years of exposure during follow-up.

analyses confirmed an increasing rate of fall in pulmonary function associated with aging and smoking. What was perhaps unexpected was the relatively small effect of dust exposure and the important effect of weight gain on the longitudinal decline of lung function.

The Effect of Industrial Pollutants on Lung Function

We used the years worked in a dusty area as a surrogate for dust exposure. There was no systematic approach to monitoring air quality in this steel manufacturing facility. Historical monitoring data for the many working environments in the steel corporation were not available. We could not determine the cumulative exposure levels of air pollutants for individual workers, although a detailed history of job locations was available for each worker. Because of the great variety of ambient air conditions throughout the plant and the open areas where all workers were likely to be exposed to similar pollutants, it seemed reasonable to use the years of employment in a dusty area as an estimate of dust exposure. In addition, because of the numerous air

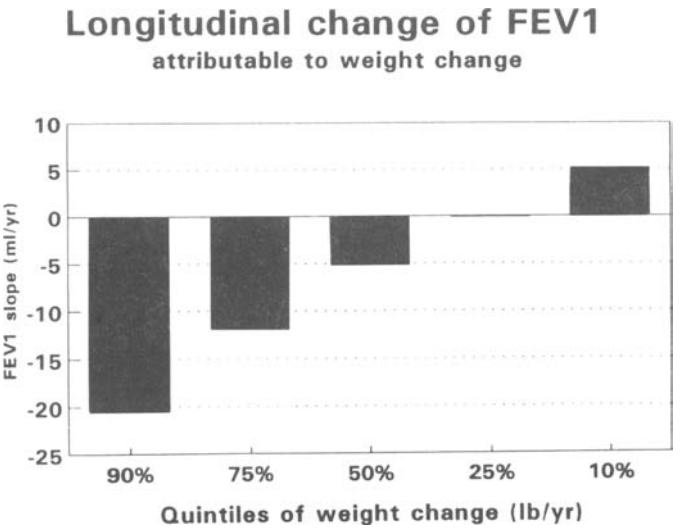

Figure 1. Effect attributed to weight gain on the longitudinal change of FEV_1 by quintiles of changes in weight. Based on the equation in Table 5. The quintiles of changes in weight of 90, 75, 50, 25, and 10% are 4.46, 2.58, 1.12, 0.02, and −1.21 lb/yr, respectively.

pollutants in the workplace, it appeared reasonable to seek a relationship between airborne exposure and lung function in general, rather than a specific industrial pollutant effect.

The results from cross-sectional multiple linear regression analyses of this study suggest that the adverse effect of dust exposure on lung function was stronger at baseline than at follow-up. This is consistent with the recognition that the steel corporation made significant improvements in order to reduce workplace dust exposures. This series of improvements began in the early 1970s and continues to the present. The other possibility is that other factors such as smoking and weight gain increased in relative importance at follow-up survey.

The results show a greater dust effect on the FEV_1 and $FEV_1/FVC\%$ than on the FVC at both baseline and follow-up

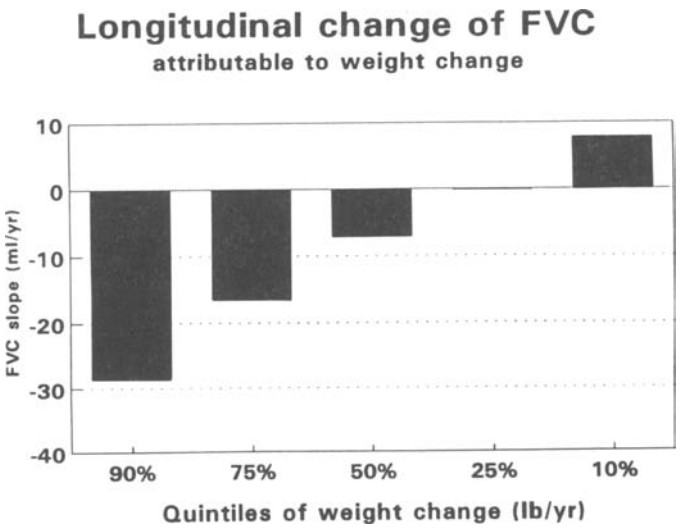

Figure 2. Effect attributed to weight gain on the longitudinal change of FVC by quintiles of changes in weight. Based on the equation in Table 5. The quintiles of changes in weight of 90, 75, 50, 25, and 10% are 4.46, 2.58, 1.12, 0.02, and −1.21 lb/yr, respectively.

TABLE 6

PARTIAL CORRELATION COEFFICIENTS BETWEEN SLOPES OF FEV_1 FVC AND THE SLOPE OF WEIGHT GAIN IN 475 STEELWORKERS, 1982–1991*

	FEV_1 Slope (*L/yr*)	FVC Slope (*L/yr*)
Slope of weight gain, lb/yr		
By baseline age, yr		
< 30 (*n = 101*)	−0.0853	−0.2124
30–40 (*n = 217*)	−0.3080†	−0.3531†
> 40 (*n = 157*)	−0.3152†	−0.3023‡
By smoking status at follow-up		
Current (*n = 178*)	−0.2830‡	−0.2845‡
Never (*n = 139*)	−0.2673§	−0.2676§
Former (*n = 158*)	−0.2078§	−0.3046†
By baseline weight, lb		
< 175 (*n = 147*)	−0.1236	−0.1453
175–200 (*n = 160*)	−0.2757‡	−0.3095†
> 200 (*n = 168*)	−0.2940‡	−0.3731†
By mean height, cm		
< 174 (*n = 122*)	−0.1613	−0.1590
174–182 (*n = 219*)	−0.2262‡	−0.2497‡
> 182 (*n = 134*)	−0.4267†	−0.5242†
By baseline BMI, kg/m^2		
< 25 (*n = 141*)	−0.1972	−0.2003
25–30 (*n = 211*)	−0.1961§	−0.2471‡
> 30 (*n = 123*)	−0.3262‡	−0.4189†

* Values are partial correlation coefficients calculated from the residuals obtained from the multiple regressions in Table 5.
† $p < 0.0001$.
‡ $p < 0.001$.
§ $p < 0.01$.

in the cross-sectional survey. This pattern of effect is consistent with airway obstruction.

In the longitudinal data analysis, no statistically significant associations were found between years worked in a dusty area and the rate of decline in FEV_1 or FVC, although a small but statistically significant decline in the FEV_1/FVC ratio was seen with more years of dust exposure. This may suggest that measuring the rate of decline in the FEV_1/FVC% is a more sensitive index in detecting dust effect. Alternatively, this may reflect the strong influence of smoking and weight gain on the rate of FVC and FEV_1 decline. The influence of these two parameters masked the effect of dust exposure.

The weak association between dust exposure and the decrements in pulmonary function in the longitudinal analysis may also be due to a lack of statistical power. In a study of 418 healthy, nonsmoking adults followed in all seven surveys over 11 yr, Burrows and colleagues (12) reported the mean FEV_1 in different surveys deviated from the predicted values by as much as 30 ml. Such survey biases were not explained by differences in personnel, equipment, or methodology. The standard deviation of the annual decline in our population was 57 ml/yr for FVC and 47 ml/yr for FEV_1. In view of this, the power to detect the dust exposure effect on ΔFEV_1 and ΔFVC of less than 1 ml/yr of employment in a dusty job during follow-up is probably limited in the current longitudinal analysis.

In addition, we recognize that the rate of lung function decline may not be linear in all populations, and it may sometimes show an accelerated decline early and then plateau, so that much of the dust-related decline occurred before the start of the longitudinal study period. For example, Hodous and Hankinson (13) studied 65 new miners with measures of pulmonary function every 6 mo for 2 yr and once more 5 yr later. They reported a rapid decline of FEV_1 during the first 2 yr of mining exposure with a subsequent slowing of the rate of loss over the next 5 yr. Seixas and coworkers (14) also found a significant nonlinear effect of the exposure to dust on pulmonary function in a group of 977 U.S. underground coal miners beginning work in or after 1970. These miners showed a rapid initial loss of FVC and FEV_1, with no additional loss of function related to dust exposure. The pattern of dust-related lung function loss in these two studies may be reflected in the current study.

The Effect of Weight and Weight Gain on Lung Function

Most reference regression equations express the values of FVC and FEV_1 as a function of age and standing height. Body weight has been reported to add little to the prediction (15, 16). Other investigators have concluded that weight should be a part of the prediction equation (17, 18). In a study by Dockery, subjects 30 kg or more above average weight had FVC values of about 200 ml below average (19). Cotes and colleagues (20) showed that coal miners with pneumoconiosis, when submitted to a 3-mo period of inactivity, had an average increase of weight of 4.1 kg, together with a decrease in both the FVC and FEV_{75} of 90 ml. Enright and colleagues (21) showed that waist and hip circumference were strong independent predictors of a decreased FEV_1. Participants with a 115-cm waist circumference (95th percentile) had a mean FEV_1 150 ml lower than participants with a 90-cm waist. They considered this degree of obesity to be unhealthy, and they excluded those participants whose hip or waist size was above the 95th percentile from the healthy subgroup. The mean BMI for the healthy subgroup were 25.4 and 26.0 kg/m^2 for women and men, respectively.

Our data showed that weight contributed a small effect to the FVC ($p < 0.02$) at baseline, but it was importantly related to the FEV_1 and to the FVC at follow-up ($p < 0.002$ and 0.0001, respectively). At baseline, about 30% of the workers were within the normal range of BMI, whereas 44.6, 24.4, and 1.5% workers were defined as Grades I, II, and III obesity (22) (Table 2). By the time of the final follow-up survey, only about 20% of the workers were within the normal range of BMI, and 46.5, 30.9, and 2.7% workers were classified as Grades I, II, and III obesity. The population as a whole gained an average of about 9 lb, and the influence of weight on lung function became more important at follow-up. This weight-related lung function abnormality affected both the FVC and FEV_1, without altering the FEV_1/FVC ratio, suggesting a restrictive effect. The relationship between obesity and the reduction in lung volumes was consistent with other studies (23–25). Bedell and colleagues (25) also observed that when obese patients lost weight, their lung function returned toward normal.

An important finding in this longitudinal analysis is the association between weight gain and FEV_1 and FVC decline. There were a few reports (18, 26) dealing with weight gain and loss of lung function over time, but these were not in cohorts examining occupational relationships. Previous reports of dust exposure and longitudinal decline in FEV_1 in coalminers indicated a large unexplained variation (27, 28). Love and Miller (27) noted that a large part of the total variation of the loss of FEV_1 was unexplained and that even the best fitting statistical model accounted for only about 7% of the variation. The results of our study suggest that weight gain is an important indicator, which explains about 6% of the total variation, and it should be used as an independent variable in longitudinal studies. The longitudinal effect of weight gain on changes of spirometric values over time appears to vary with age, height, weight, and BMI. Our findings are consistent with those of Bande and colleagues (26), although they found the relations between weight gain slope and the slopes of FEV_1 and FVC to be weaker in smokers, especially heavy smokers.

In conclusion, the results of the present study suggest that

smoking, being overweight, excess weight gain over time, and dust exposure in this work environment were related to a lower level (as measured cross-sectionally) and a steeper rate of decline (as measured longitudinally) of pulmonary function. Because it has not been previously well described, the impact of weight gain on FEV_1 and FVC over time is of interest. Gaining one pound per year approximated one-third to one-half of the total estimated FEV_1 or FVC decline caused by cigarette smoking. In those who gain considerable weight, the effect of weight gain could become clinically important and explain an accelerated rate of lung function decline in members of a population. It is most apparent in those who enter the study with a large body habitus.

The influence of weight gain on pulmonary function varied by age, body size, and smoking habits; the interaction between these factors, and whether this is an important feature of the longitudinal assessment of other working populations need to be explored further.

Acknowledgment: The writers are grateful to Drs. Roberto Benzo and Huahao Shen of the West Virginia University School of Medicine for their great assistance in reviewing the acceptability of spirometry tests, and to Drs. Robert Castellan and Paul Henneberger of the National Institute for Occupational Safety and Health for their generous and valuable commentary during the analysis, and also to Mr. Michael Billie and Mrs. Cathy Murphy of the West Virginia University School of Medicine for their efforts in data entry and manuscript preparation.

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