Pulmonary Function Among Cotton Textile Workers*

A Study of Variability in Symptom Reporting, Across-Shift Drop in FEV_1, and Longitudinal Change

David C. Christiani, M.D., M.P.H., M.S., F.C.C.P.; Ting-ting Ye, MD, M.P.H.; David H. Wegman, M.D., M.S.; Ellen A. Eisen, Sc.D.; He-lian Dai, M.D.; and Pei-lian Lu, M.D.

Longitudinal variability in respiratory responses, including symptom reporting and across-shift change in ventilatory function, were examined in relation to long-term loss of ventilatory function in a group of 447 cotton textile workers in Shanghai, China. The study used a standardized respiratory questionnaire and standardized spirometric testing before and after a work shift on the first day of the workweek. Prediction equations for FEV_1 were generated from a group of silk textile workers from the same city. Environmental samples included both vertical elutriated cotton dust and endotoxin levels. There was considerable variability in symptom reporting between the baseline and 5-year follow-up survey for all symptoms. However, subjects who consistently reported symptoms had a significantly accelerated 5-year loss in FEV_1 compared with those who never reported symptoms. Subjects with symptoms of chest tightness or dyspnea at one survey lost FEV_1 at a rate intermediate between the never or both groups. Moreover, subjects with an across-shift change in FEV_1 of more than 5 percent at both surveys had the greatest loss in FEV_1 over 5 years (−267 ml) when compared with one-time responders (−224 ml), and nonresponders (−180 ml), though the differences were not significant. Workers with chest tightness and chronic bronchitis in both surveys were overrepresented in the high dust and endotoxin areas. Our results indicate that even with substantial survey-to-survey variability in responses, there is important information contained in both questionnaires and across-shift spirometry. Among cotton workers, consistent responders to either symptom questionnaire or across-shift FEV_1 decrements of $\geq$5 percent appear to be at increased risk for lung function impairment. *(Chest 1994; 105:1713-21)*

Workers exposed to dust from vegetable fibers such as cotton, flax, and hemp have long been recognized to have respiratory symptoms such as chronic bronchitis and acute chest tightness at work. The term byssinosis was first used in the late 19th century to describe a symptom complex that occurs with predictable periodicity, *ie*, chest tightness occurring at work on the first day of the work week initially and then on other days in more advanced stages. The syndrome occurs with variable latency (years, usually) after first exposure.[1] The chest tightness may be accompanied by shortness of breath, cough, and wheezing. Since the clinical presentation often is imprecise, with nonspecific symptoms occurring in a specific time pattern, byssinosis can be easily overlooked clinically. In earlier studies of byssinosis, ventilatory tests were not used. Later, Schilling et al[1] and others included spirometric testing before and after the work shift in an attempt to better characterize the syndrome. These investigations revealed that acute across-shift airway obstruction occurred in some, but not all, workers with the symptoms of byssinosis.[2] Investigation of workers in ten cotton mills in the United Kingdom showed that almost all of the symptomatic workers were exposed to dust levels above 1 mg/m,[3] while later studies in the United States[4] revealed respiratory symptoms at levels considerably lower than this, and a standard of 0.2 mg/m^3 was adopted in the United States.

Current studies of the possible link between acute symptoms of byssinosis and excess respiratory morbidity and mortality in textile workers build on the early observations of Schilling et al.[1] Research questions asked 30 years ago about the relationship between acute symptoms or across-shift change in lung function and chronic, permanent respiratory impairment remain largely unanswered. Interestingly, cross-sectional epidemiologic studies have shown that an across-shift decline in lung function does not correlate well with byssinosis symptoms. For instance, only 5 to 25 percent of workers with byssinosis will have significant across-shift changes when

*From the Department of Environmental Health, Harvard School of Public Health; Pulmonary and Critical Care Unit, Massachusetts General Hospital, Department of Medicine, Harvard Medical School, Boston; the Work Environment Department, University of Massachusetts at Lowell; the Institute of Preventive Medicine, Shanghai Medical University School of Public Health; and the First Hospital of the Shanghai Textile Bureau, Shanghai, China.

Supported by grant R01OHO2421 from the National Institute for Occupational Safety and Health and grant ES00002 from the National Institute for Environmental Health Sciences.

Manuscript received April 13, 1993; revision accepted October 26.

Reprint requests: Dr. Christiani, 655 Huntington Avenue, I-1405, Boston -02115

examined cross-sectionally. Conversely, only 5 to 15 percent of those with across-shift changes report the byssinosis symptom complex.[5]

It is now apparent on the basis of large population studies of cotton dust-exposed workers that respiratory responses occur that do not fit the definition of byssinosis suggested by Schilling et al.[1] These responses include mill fever, acute bronchoconstriction demonstrated by across-shift decline in FEV_1, chest tightness, and chronic bronchitis.[6]

A number of cross-sectional studies have been performed which examine respiratory disease in cotton textile workers. These surveys have described both the prevalence of byssinosis and nonspecific respiratory symptoms as well as the acute drops in lung function across a work shift that occur among cotton textile workers. However, there are only a few longitudinal studies that examine the development of respiratory symptoms and lung function decline in such workers.

In all studies of textile workers there is the implicit assumption that acute respiratory symptoms are reversible (*ie*, with cessation of exposure) or vary substantially from survey to survey[7-9] while chronic symptoms persist. Studies to date have not examined the significance of symptom incidence or persistence in a longitudinal survey, nor have they addressed the issue of the significance of variability in symptoms and across-shift ventilatory change in relation to chronic lung function loss. The objective of this study was to examine longitudinal variability in symptoms and across-shift change in ventilatory function in cotton textile workers and the relationship between this variability and the 5-year loss of pulmonary function. The extent to which across-shift change in ventilatory function was related to observed differences in environmental exposures, variability in symptom reporting, and longitudinal change in lung function were also assessed.

METHODS

Study Population

This study involved cotton textile workers enrolled in a longitudinal study of respiratory disease among textile workers in Shanghai, China. The baseline study in 1981 included 447 cotton textile workers (52 percent female). These represented 90 percent of workers employed more than 2 years and working in eligible jobs. The follow-up survey was performed 5 years later when all but 62 workers (37 female, 25 male) were restudied. Included in the lost worker category are six deceased workers, none of whom died of respiratory disease, and four others who were too ill to participate in the follow-up survey.

The Cohort

The workers studied were employed in the yarn preparation areas of two cotton textile mills in Shanghai, China. The mills were in the same urban neighborhood, with workers living close by. Both are state-owned and because of the structure of industry in urban China during the time of study (1981 to 1986), worker turnover was low.

Respiratory Symptoms

Respiratory symptoms were recorded by using a modified and translated American Thoracic Society questionnaire[10] with additional questions on acute work-related responses.[6] The questionnaire was administered by a trained interviewer to each worker upon his or her return to work after a 48-h rest period and before entering the production area. All questionnaires were administered by native speakers using the local dialect. The questionnaire used in the follow-up study was identical to the initial survey questionnaire except for minor modifications regarding acute symptom periodicity, which was a necessary amendment to accommodate the respondents' unusual work rotation.[11] The workweek was 8 days long, with a change of shift every 2 days and a 2-day break at the end of 6 days of work. Since workers rotated their shift forward on an 8-day cycle, instead of asking a worker to name the day of the week when symptoms were most likely to occur, he or she was asked orally whether symptoms occurred on the first day back after 48 h off, in the middle of the 8-day work cycle, or at the end of the cycle. This modification was incorporated into the written questionnaire at the time of the second survey. This modification, though minor, may have resulted in noncomparable reports of byssinosis in the first and second surveys.

Symptoms were defined as follows:

Byssinosis (all grades)=chest tightness or shortness of breath at work occurring on the first or other days of the workweek according to criteria of Schilling et al[1]

Chronic bronchitis=sputum production occurring on most ($\geq$5) days of the week for at least 3 months a year for at least 2 consecutive years.

Chronic cough=cough without sputum for $\geq$5 days a week for at least 2 consecutive years.

Dyspnea grade 2+=having to walk slower than persons of the same age at an ordinary pace on level ground because of breathlessness.

Chest tightness at work=tightness or constriction of the chest occurring anytime during the work shift and on any workday. Since the workers in these mills worked continual rotating shifts on an 8-day cycle[11] with a 36-h rest at the end of rotation, we report chest tightness at work separately from the typical symptom periodicity which characterizes byssinosis.

Union of symptoms=presence of any of any of the four symptoms noted previously.

Pulmonary Function

The forced expiratory spirogram on the first day of each new 8-day cycle before and after the 8-hour work shift was recorded at both surveys. Workers were asked to refrain from smoking for at least 1 h before performing the test. Forced expiratory maneuvers were recorded for each worker on one of two 8-L water-sealed field spirometers (W.E. Collins Survey 1) under the direction of a trained technician.

The spirometric curves were read manually with the starting point defined by back extrapolation. Pulmonary function indices included FEV_1, and forced vital capacity. All values were corrected to conditions of body temperature and pressure saturated with water vapor. Each subject was retested on the same spirometer as used in the baseline survey. Each worker performed up to seven trials to produce three acceptable curves.[12] Reproducibility was defined as the best two forced vital capacity values within 10 percent or 200 ml, whichever was greater. The best value of FEV_1 was taken from reproducible tests; otherwise, the FEV_1 was treated as missing.

Preshift values of FEV_1 and forced vital capacity were compared with the expected values derived from a population of silk yarn preparation workers studied simultaneously as a comparison group and previously published.[13] Silk yarn preparation workers rather than synthetic fiber workers were chosen as control subjects because all of the synthetic fiber mills in Shanghai were converted cotton mills. Regression equations from the silk worker population included a smoking term (pack-years) for men only, since there were only six female smokers. The models are described by the following:

Females:

FEV_1 (L)= −0.024 age (years)+0.033 height (cm)−1.729

Males:

FEV_1 (L)=−0.029 age (years)+0.055 height (cm) −0.008 smoking (pack-years)−4.742

Environmental Assessment

Airborne cotton dust was collected using vertical elutriators (General Metal Works, Inc) designed to collect particles less than 15 microns in aerodynamic diameter. Multiple area samples were collected from each of the six different work areas in yarn preparation operations of the two mills. The dust samples were collected throughout the work shift at both surveys—1981 and 1986. The work areas for all phases of yarn preparation included: opening, cleaning, carding, drawing, roving, combing, and spinning. There was no change in the methods of cotton processing during the 5-year period with the exception that mill 1 began to blend Dacron with cotton continuously for 2 years before the follow-up survey. At the first survey, 130 air samples were collected. At the second survey, 192 air samples were collected. Sampling procedures were in accordance with the US National Institute for Occupational Safety and Health (NIOSH) recommended guidelines,[14] with the exception that the height of the elutriators was set at approximately 1.6 m to compensate for the slightly lower average height of the work force. Samples were collected in the same areas on follow-up as in the initial survey, and there was no change in the handling or method of weighing the filters.

Endotoxin analysis was performed on the dust filters using methods previously described.[15] Briefly, filters were received in the laboratory sealed facedown in Parafilm M laboratory film (American Can Co, Greenwich, Conn). Sterile nonpyrogenic plasticware was used throughout these assays. Each filter was extracted separately in 10 ml of sterile, nonpyrogenic water (Travenol Laboratories, Inc, Deerfield Ill) by rocking at room temperature for 60 mins. The extracts were decanted into plastic tubes and centrifuged for 10 min at 1,000 g. The resulting supernatant fluids were assayed in duplicate for the presence of Gram-negative bacterial endotoxins by means of the quantitative chromogenic modification of the Limulus amebocyte lysate test (QCL-100, Whitaker Biproducts, Walkersville Md). Since the distributions for dust and endotoxin were bimodal, both exposures were dichotomized into two groups A and B with cutoffs being 1 mg/m^3 for vertical elutriator (VE) dust and 100 ng/m^3 for elutriator endotoxin.

Statistical Analysis

Characteristics of Airway Responsiveness (Symptoms): Byssinosis, chest tightness, chronic bronchitis, cough, and dyspnea 2+ were the symptoms of primary interest. Consistency of symptom reporting was defined as follows: Subjects were "always" responders if he or she reported the symptom in both surveys; "inconsistent" responders if they reported the symptom on one of the two surveys; and "never" responders if they did not report the symptom on either survey. Inconsistent responders included two potentially distinct groups, those who became symptomatic during the 5-year study and those who became asymptomatic.

Characterization of Across-shift Change in FEV_1 (Δ FEV_1 Percent): Airway responsiveness to cotton dust was characterized according to the subject's across-shift change in FEV_1 (Δ FEV_1 percent) in either survey. In adjusting for differences in lung size, the change in FEV_1 over the work shift was standardized by the average FEV_1 level during the day, *ie*, adjusted day change=(AM FEV_1−PM FEV_1)÷0.5 (AM FEV_1+PM FEV_1). The average level, rather than the initial level, was used to standardize the acute change in order to avoid biases that might arise from measurement error in FEV_1.[16] This potential bias is due to regression to the mean whereby spuriously high preshift measurements would be followed by apparently large negative acute changes, resulting in a spurious negative correlation between initial level and

Table 1—*Cotton Dust and Endotoxin Concentrations in Area Samples***

	Dust (mg/m^3)		Endotoxin ($\mu g/m^3$)	
	Mill 1	Mill 2	Mill 1	Mill 2
Opening	1.69† (0.97-2.36)‡ 20§/A‖	1.27 (0.42-2.89) 23/A	0.33 (0.13-0.80) 16/A	0.22 (0.05-0.45) 11/A
Cleaning	1.17 (0.59-2.32) 17/A	1.73 (1.09-2.93) 8/A	0.36 (0.20-0.92) 11/A	0.58 (0.03-1.34) 7/A
Carding	1.29 (0.65-2.26) 32/A	1.52 (0.48-2.58) 36/A	0.48 (0.17-0.78) 20/A	0.35 (0.04-1.70) 29/A
Drawing	0.69 (0.22-3.75) 31/B	1.52 (0.46-2.32) 24/B	0.43 (0.02-1.46) 19/A	0.75 (0.52-1.20) 16/A
Combing	0.44 (0.12-1.11) 24/B	0.39 (0.09-0.98) 35/B	0.64 (0.27-1.53) 16/A	0.08 (0.07-0.67) 22/B
Roving	0.33 (0.14-0.72) 23/B	0.45 (0.31-0.67) 23/B	0.99 (0.15-1.06) 20/B	0.04 (0.02-0.11) 15/B
Spinning	...¶	0.24 (0.04-0.80) 24/B	...¶	0.004 (0.001-0.14) 24/B

*Collected by vertical elutriator in 1981 and 1986.

†First values in all entries are geometric means.

‡Ranges are closed within parentheses.

§No. of samples collected appears to left of virgule/for all entries.

‖Exposure grouping for stratified analysis (A=>1 mg/m^3 dust, >0.1 $\mu g/m^3$ endotoxin; B=<1 mg/m^3 dust, <0.1 $\mu g/m^3$ endotoxin) appears to right of virgule for all entries.

¶Spinning in mill 1 not measured.

acute change.

Consistency of response was defined as follows: Subjects were "always" responders if the across-shift drop in FEV_1 was 5 percent or greater on both surveys; "inconsistent" responders if the across-shift drop in FEV_1 was 5 percent or greater on one but not both surveys; and "never" responders if the across-shift drop in FEV_1 was less than 5 percent in both surveys. Again, the inconsistent responders were a heterogeneous group of individuals who either gained or lost acute responsiveness.

The relationship between measures of both symptom reporting and across-shift change in FEV_1 was examined in relation to the 5-year decline in lung function. In addition, mean preshift FEV_1 was examined both in relation to consistency of acute change and chronic decline in lung function.

Longitudinal change in FEV_1 was measured by the difference of the second survey preshift FEV_1 and the first survey preshift FEV_1: (FEV_1) 1981−(FEV_1) 1986.

Linear regression models were used to examine the relationship between symptoms and the 5-year decline in FEV_1 while adjusting for appropriate confounders. Cigarette smoking was adjusted for by including both smoking status (yes, no) and cumulative exposure (pack-years) in the same model. The six ex-smokers were excluded from the model.

Results

Environmental Assessment

Cotton dust measurements revealed that most levels in all work areas exceeded the current Occupational Safety and Health Administration permissible exposure limit of 0.2 mg/m^3 8-h time-weighted average dust (Table 1). Median concentrations for dust ranged from 0.24 mg/m^3 in fine spinning to 1.73 mg/m^3 in cleaning. Endotoxin concentrations ranged from 0.004 $\mu g/m^3$ in fine spinning to 0.75 $\mu g/m^3$ in the drawing area. When dichotomized into exposure areas as just described, about half the cotton areas and a third of the endotoxin areas were in the lower category. There was moderately high correlation (Spearman's test) between airborne VE dust and VE endotoxin levels ($r_s=0.66$ for mill 1, $p<0.01$; $r_s=0.79$ for mill 2). Overall, dust levels remained relatively stable over the 5 years between surveys with the exception of the drawing area of one mill which was higher at the second survey. Since workers remained in the same work areas throughout their employment at the mills, there was little change in the personal assignments of dust or endotoxin levels from survey to survey.

Table 2—*Comparison of Symptom Prevalence and Pulmonary Function at Initial Survey in Subjects Seen at Follow-Up and Subjects Unavailable for Follow-Up*

Clinical Data	Follow-Up	Unavailable for Follow-Up
No.	385	62
Age (mean)	36.9*	40.3*
Years worked (mean)	15.8*	19.1*
% male	48.8	40.3
% smoker	34.8	27.4
Pack-years (mean)	8.5	12.8
Symptoms†		
Chronic cough	19.0	22.6
Chronic bronchitis	21.3	22.6
Chest tightness at work	7.5	9.7
Dyspnea 2+	13.5*	24.2*
Byssinosis (all grades)	7.3	9.7
Pulmonary Function‡		
FEV_1 percent predicted (1981)§	99.8±13.4	98.1±15.0
% Δ FEV_1 (1981)‖	−1.90±5.6	−2.78±5.8
FEV_1 % predicted (1986)	97.6±14.8	...
% Δ FEV_1 (1986)	−1.76±6.6	...
FEV_1 5-yr Δ¶	−0.203±0.21	...

*$p<0.05$.
†Expressed as percentages.
‡Values are mean±SD.
§FEV_1 % predicted=(actual÷predicted FEV_1)×100; predicted generated from silk textile workers.
‖% Δ FEV_1=across-shift change in FEV_1×100.
¶FEV_1 5-yr Δ=5-year change in preshift FEV_1.

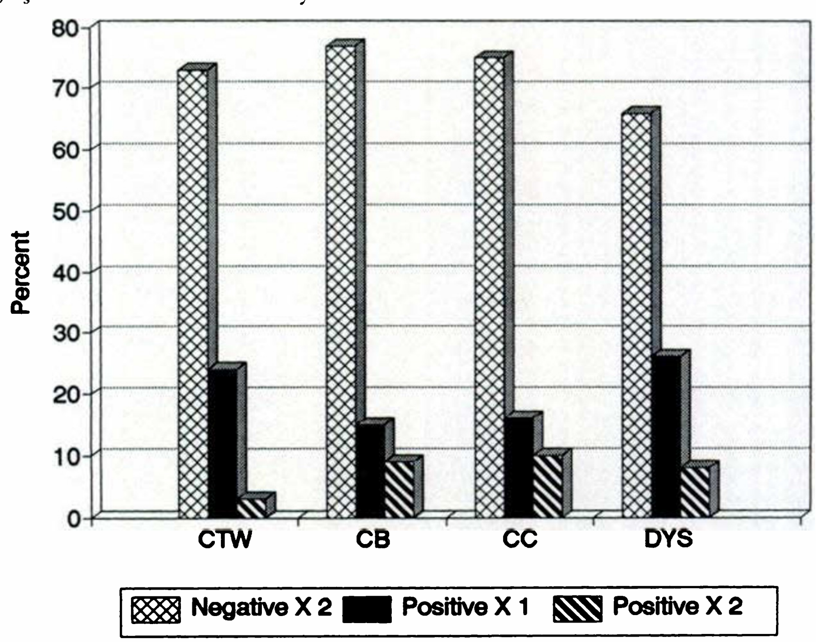

FIGURE 1. Long-term (5-year) consistency of respiratory symptoms. CTW, chest tightness at work; CB, chronic bronchitis; CC, chronic cough; DYS, dyspnea.

Table 3—*Characteristics by Symptom Consistency**

	Chest Tightness			Chronic Bronchitis			Chronic Cough			Dyspnea 2+			Union†		
	N	I	B	N	I	B	N	I	B	N	I	B	N	I	B
No.	281	92	12	296	56	33	288	60	37	256	101	29	180	108	97
Age (mean)	36	38	41	36	40	42	36	38	43	36	39	43	35	37	41
Sex (% male)	51	41	50	43	61	79	44	55	78	52	42	45	50	44	53
Smokers (%)	34	34	58	27	50	76	26	52	73	35	53	38	29	33	46
Work years (1981)	15	17	19	15	17	20	15	16	21	15	17	20	15	16	18
Dustiness‡	47	48	58	43	59	70	42	65	59	46	50	52	41	45	62
FEV_1 % predicted 1981	100	101	91	100	101	94	101	99	95	101	99	93	101	100	97
FEV_1 % predicted 1986	98	98	87	98	100	87	99	97	89	100	96	85	99	99	93
5-year FEV_1 Δ (ℓ)§	−0.189	−0.221	−0.380	−0.191	−0.189	−0.317‖	−0.187	−0.196	−0.331‖	−0.180	−0.228	−0.311‖	−0.183	−0.199	−0.242¶

*N, never; I, inconsistent; B, both.
†Union, affirmative response to any of the four symptoms.
‡Dustiness, proportion of subjects in dust areas ≥1 mg/m^3.
§5-year FEV_1 Δ (L), mean 5-year change in FEV_1.
‖p<0.05, relative to N.
¶p=0.07, relative to N.

Unavailable for Follow-up

The prevalence of respiratory symptoms at first survey (1981) in the 385 cotton workers studied at both surveys and in the 62 workers unavailable for follow-up is shown in Table 2. As expected, age and years worked are greater in the group unavailable for follow-up, since many of these are retirees who did not return for retesting at the time of the second survey. The latter group had lower lung function and more respiratory symptoms at the initial survey. Hence, the resurveyed group did represent healthier individuals.

Respiratory Symptoms

Symptom Prevalence: The prevalence of all chronic respiratory symptoms, except dyspnea which increased, was similar at the time of the second survey. Overall, there was a low prevalence of byssinosis. At most, only 10 percent consistently reported the presence of specific symptoms (Fig 1), while the majority (two thirds) of subjects ever reporting symptoms were inconsistent in their responses.

Symptom Persistence: When symptom consistency was examined in relation to pulmonary function, workers who consistently reported the presence

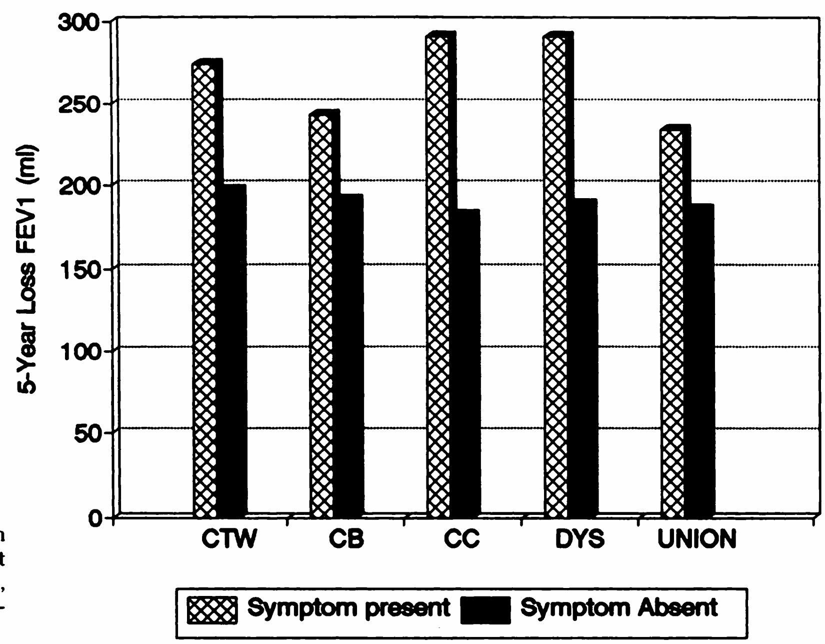

FIGURE 2. Subsequent 5-year loss of lung function in subjects with various respiratory symptoms at initial survey. CTW, chest tightness at work; CB, chronic bronchitis; CC, chronic cough; DYS, dyspnea; UNION, union of symptoms.

of symptoms exhibited an accelerated decline in ventilatory capacity compared with those who never or inconsistently reported these symptoms (Table 3). As a group, those subjects with typical byssinosis, any chest tightness at work and chronic bronchitis, also tended to have more work years, higher dust exposure, and a higher prevalence of smoking. In addition, a high rate of loss (−139 ml/yr) was noted among the four subjects with byssinosis who reported typical byssinosis on both surveys (data not shown).

Symptoms at Initial Survey: When subjects with incident and resolved symptoms were examined separately, there were no statistically significant differences in age or work characteristics. There were significant differences in subjects who report symptoms of chronic cough and dyspnea at the time of the first survey in relation to the 5-year change in pulmonary function (Fig 2). Overall, subjects who reported any of the four respiratory symptoms at the time of the first survey suffered an accelerated loss of lung function over the subsequent 5 years (−234 ml vs −186 ml, p=0.07). The symptoms which were associated with the most significant declines in FEV_1 were chronic cough and dyspnea. When examined in an autoregressive model, after adjustments for baseline FEV_1, age, height, gender, and smoking history, the presence of chest tightness at work, chronic cough, or dyspnea 2+ at the time of initial survey was associated with a significant 5-year loss in FEV_1 (Table 4).

Table 4—***Regression Coefficients for Initial FEV_1, Age, Height, Smoking, and symptoms in Pulmonary Function Models****

Outcome variable=FEV_1 1986 (L) Independent variable	Parameter Estimate	p>|t|	r^2
FEV_1 1981	0.863	<0.01	
Age	−0.005	<0.01	
Height, cm	0.005	<0.01	
Current smoking (0,1)	−0.017	0.47	
Pack-years	−0.003	0.04	
Chronic Cough	−0.068	<0.01	
			0.93
FEV_1 1981	0.863	<0.01	
Age	−0.005	<0.01	
Height, cm	0.005	<0.01	
Current smoking (0,1)	−0.020	0.035	
Pack-years	−0.003	0.02	
Dyspnea 2+	−0.105	<0.01	
			0.93
FEV_1 1981	−0.866	<0.01	
Age	−0.005	<0.01	
Height, cm	0.005	<0.01	
Current smoking (0,1)	−0.022	0.35	
Pack-years	−0.003	0.01	
Chest tightness	−0.082	0.04	
			0.92

*General model: FEV_1 (1986)=$\beta_0+\beta_1$ (FEV_1-1981)+β_2 (age)+β_3 (height)+β_4 (smoking)+β_5 (pack-years)+β_6 (symptom 1981)+ϵ

Acute and Chronic Ventilatory Changes

Acute and chronic changes in ventilatory capacity were examined in the cohort of workers tested at both surveys. The group's across-shift change in FEV_1 was comparable between the two surveys and the mean preshift ventilatory function was 98 percent of predicted at the time of the second survey (Table 2).

No statistically significant differences were detected either in 1981 or 1986 in preshift levels of FEV_1 among subjects stratified by consistency of across-shift change, although there was a trend toward larger loss for workers who were consistently pulmonary function responders (Table 5). Preshift FEV_1, on the resurvey adjusted for age, height, gender, and smoking, decreased similarly. The adjusted preshift FEV_1 for consistently positive responders at 94.4 percent contrasted with consistently negative responders whose adjusted FEV_1 was 98.3 percent. Subjects who responded both times with an across-shift drop of 5 percent or more lost 267 ml over 5 years versus 180 ml (t=1.72, p=0.05) for those who never experienced sharp drops. This effect persisted after adjustments for age, height, gender, and smoking by regression analysis (data not shown).

Analysis of Missing Data

Since assessment of the effect of consistency of across-shift change in FEV_1 requires reproducible spirometric tests at 4 sessions (preshift and postshift in two surveys), we lost 141 subjects (36 percent) in

Table 5—***Cross-Sectional Mean Levels of Pulmonary Function According to Consistency of Across-Shift Drop in FEV_1***

	Consistency of $\Delta FEV_1 \leq -5\%$		
	Never	Inconsistent	Always
No.	143	84	17
First survey % predicted FEV_1*	99.3±12.5	99.6±12.9	98.2±14.7
Second survey % predicted FEV_1	98.3±14.4	96.6±14.0	94.4±19.3
FEV_1 5-year Δ (ml)†	−180±197	−224±249	−267±192‡

*Expressed as percent predicted for preshift FEV_1, adjusted for age, sex, height, and smoking (mean±SD).
†FEV_1 5-year Δ=5-year change in preshift FEV_1 (ml [mean±SD]).
‡t=1.72; p=0.05, one-tailed, Always versus Never.

the analysis. We therefore compared the 244 subjects for whom we had complete data with the 144 subjects for whom we had incomplete data with regard to demographics and symptom status at the time of the first survey. The groups did not differ with respect to age, years worked, gender, smoking, percent predicted FEV_1, or 5-year decline in FEV_1. The group with incomplete data was somewhat more likely to have byssinosis (11 vs 6 percent, p=0.1) and to have accumulated fewer pack-years of smoking at the time of follow-up (11 vs 15, p=0.09).

Discussion

Longitudinal respiratory studies of occupational cohorts are not common. The few such studies on cotton textile workers have not addressed the issues of symptom and acute pulmonary function variability over time and in relation to chronic loss of lung function. In the 1970s, Molyneux and Tombleson[7] and Fox and coworkers[8] reported the results of a 3-year follow-up of cotton textile workers in England. Their studies were short-term follow-up investigations which reported incidence rates of byssinosis and chronic bronchitis, but neither ventilatory tests nor symptoms were found to be of value in predicting the rate of FEV_1 deterioration between surveys. Berry and colleagues[17] examined the data from one of these studies and reported the 3-year changes in pulmonary function in both cotton textile workers and synthetic fiber control workers. Cotton workers had an excess annual loss in lung function (54 ml) versus control workers (32 ml). However, the annual decline in lung function was not related to across-shift change in lung function or to symptoms of byssinosis or bronchitis, and information on symptom variability over time was not reported. Valic and Zuskin[18,19] studied a small group of workers exposed to coarse cotton dust over 10 years and found that the prevalence of both byssinosis and nonspecific respiratory symptoms increased with the duration of exposure to cotton dust. Beck et al[20] studied textile workers prospectively in a community-based study in South Carolina and reported a chronic effect of cotton dust exposure on lung function that was independent of cigarette use. Zuskin et al[21] recently reported a follow-up study of a small group (n=66) of textile workers exposed to high levels of dust and examined over 10 years. This group represented about 57 percent of the original cohort and were found to have an increasing prevalence of respiratory symptoms as well as progressive lung function decline.

Based on the common understanding of respiratory symptoms, we would have expected acute symptoms, such as chest tightness at work, to be variable, while chronic symptoms (*eg*, chronic bronchitis), whether due to cigarette smoking, cotton dust exposure, or a combination of these, would be expected to persist and result in consistent reporting. To the contrary, however, our data demonstrated considerable variation over time in the reporting of "chronic" respiratory symptoms among textile workers. Although not anticipated, this finding is consistent with at least one other published report[22] and that of the US Six-Cities study over a 12-year period of follow-up (unpublished data, Dockery et al). In our study, however, workers who consistently reported symptoms at both surveys tended to lose lung function at a higher rate than workers who never or inconsistently reported them. This suggests that, despite considerable distractions in the collection of symptom data over time, there is useful information regarding markers of developing pulmonary impairment.

In this study, we used across-shift change in FEV_1 as a measure of specific airway responsiveness to cotton dust. This method of defining cotton dust responsiveness has been used in cross-sectional studies of cotton-exposed workers.[23] The sources of variability in such bronchial responsiveness in the mill setting may include recent viral infection, pollen exposures, biologic variation in airway smooth muscle tone, differences in inhalation patterns of workers in various jobs, and varying exposure intensity of different textile jobs. Thus, we expected some variability in the magnitude of across-shift change in FEV_1 among cotton textile workers. Those with consistent acute responses had the most accelerated loss in lung function over the 5-year period of observation.

Acute responses at the two surveys were examined in two groups: those who "recovered" from and those who "developed" excessive across-shift changes in FEV_1. Subjects with large across-shift drops in FEV_1 on survey 2 only had greater 5-year declines in lung function than those who had large across-shift drops in FEV_1 on survey 1 only. Although this may be evidence of regression to the mean in the inconsistent responders, there is a biologically plausible explanation for such a finding. Subjects with acute drops only at survey 2 include a subset who will go on to become persistent responders. In contrast, none of those with excessive drops in survey 1 only are persistent responders. Thus, a drop in preshift levels of FEV_1 would be more substantial for those currently (*ie*, at follow-up survey) developing the acute response, some of whom will go on to experience a persistent acute response. Moreover, since we reduced measurement error by discarding spirograms that did not meet reproducibility criteria at both testing sessions, it is unlikely that spuriously high results would regularly occur at the first session of the first testing day. Thus, regression to the mean is unlikely to explain the accelerated loss in lung function found in the consistent responding group. These data also suggest that although a consistent across-shift drop is associated with the largest 5-year declines, it is not a necessary precursor of chronic lung function loss.

With regard to symptoms, workers with chest tightness, chronic cough, and dyspnea at the time of first survey had the largest 5-year decline in lung function after adjusting for initial FEV_1 and other confounders. The significance of these findings needs further clarification, but suggest that these symptoms may be markers for significant respiratory impairment in textile workers. Interestingly, chronic bronchitis was less predictive of 5-year lung function loss. This may have less to do with the pathophysiologic features of chronic airway disease due to cotton than to the variation in reporting chronic respiratory symptoms in this population.

There is evidence that cotton dust exposure leads to accelerated loss of lung function, though the magnitude of the effect and exposure-response relationships have not been well described.[20,24,25] The essential questions regarding chronic exposure and health remain: (1) Does cotton dust exposure lead to chronic loss of lung function? (2) Do the acute responses to cotton dust predict chronic loss of lung function? These results present no information with respect to question 1. They do, however, provide evidence of an acute-chronic link. It is clear from cross-sectional studies that subjects with byssinosis symptoms have a higher prevalence of chronic bronchitis and lower levels of ventilatory function. It has remained unclear whether cotton textile workers with acute work-related symptoms and lung function drops actually have an accelerated loss of lung function. In contrast to cotton-exposed workers, those exposed to grain dust do exhibit such an acute-chronic link between across-shift drop in FEV_1 and chronic loss of FEV_1.[26-28] In examining acute symptoms and across-shift changes prospectively, we need to examine the stability and reliability of these indicators. For example, symptom responses even on carefully standardized questionnaires are quite variable when asked about over time.[29] Across-day spirometry may be influenced by tobacco smoking, age, initial level of FEV_1,[30] and diurnal variation.[31,32]

Our results indicate that even with substantial survey-to-survey variability in responses, there is important information contained in both questionnaire responses and across-shift spirometry. Subjects with consistently negative or positive responses on the questionnaire sustained smaller or greater losses in baseline FEV_1. Subjects with inconsistent symptom responses, regardless of direction of change, fell intermediately between the negative and positive acute responders. With regard to ventilatory function, subjects who had consistent across-shift drops in FEV_1 exceeding 5 percent had a 5-year loss in lung function greater than those with no response. In contrast to symptoms, inconsistent responders differed in the direction of their change, and this difference may reflect both regression to the mean and pathophysiology. The significantly greater 5-year loss in lung function observed in the group that responded at both surveys suggests that this group is at risk for chronic airflow obstruction. Further study is needed to clarify the quantitative relationship between cotton dust and endotoxin exposure and long-term respiratory effects.

ACKNOWLEDGMENTS: The authors thank the following individuals, who were members of the Shanghai field team: technicians Fan Huang-yin, Lu Wei-wei, Li Meng-yin, and Wang Xiao-ling; physicians from the textile hospital and mills; professor Gu Xue-qi, Drs. Zhuo Xian-min, Jiang Li, and Ren Lu from Shanghai Medical University. Dr. Steven Olenchock, National Institute for Occupational Safety and Health, kindly performed the endotoxin analysis. We also thank the workers and staff of the Shanghai First and Second Cotton Mills, First Silk Mill, First Textile Hospital, and the Shanghai Cotton Textile Scientific Institute. We are also indebted to Ms. Marlys Rogers, Ms. Susan Kang, and Ms. Marcia Chertok for research assistance; Ms. Lucille Pothier and Ms. Janna Frelich for computer programming; Dr. John Bollinger for word processing; and Dr. Xiping Xu for his thoughtful comments.

References

1 Schilling RSF, Vigiliani EC, Lammers B, Valic F, Gilson JC. A report on a conference on byssinosis. Proceedings of the 14th International Congress on Occupational Health, Madrid, Spain, 1963; 137-45

2 McKerrow CB, McDermott M, Gilson JC, Schilling RSF. Respiratory function during the day in cotton workers: a study in byssinosis. Br J Ind Med 1958; 15:75-83

3 Roach SA, Schilling RSF. A clinical and environmental study of byssinosis in the Lancashire cotton industry. Br J Ind Med 1960; 17:1-9

4 Merchant JA, Lumsden JC, Kilburn KH, O'Fallon VM, Ujda JR, Germino VH, et al. Dose-response studies in cotton textile workers. JOM 1973; 15:222-30

5 Imbus HR, Suh MW. Byssinosis. Arch Environ Health 1973; 26:183-91

6 Rylander R, Schilling RSF, Pickering CAC, Rooke GB, Dempsey RJ, Jacobs RR. Effects of acute and chronic exposure to cotton dust: the Manchester criteria. Br J Ind Med 1987; 44:577-79

7 Molyneux MKB, Tombleson JBL. An epidemiological study of respiratory symptoms in Lancashire mills, 1963-66. Br J Ind Med 1970; 27:225-34

8 Fox AJ, Tombleson JBL, Wat A, Wilkie AG. A survey of respiratory disease in cotton operatives: Part I. Symptoms and ventilation results. Br J Ind Med 1973; 30:42-7

9 Fox AJ, Tombleson JBL, Wat A, Wilkie AG. A survey of respiratory disease in cotton operatives: Part II. Symptoms, dust estimations, and the effects of smoking habits. Br J Ind Med 1973; 30:48-53

10 Ferris BG. Epidemiology standardization project. Am Rev Respir Dis 1978; 118(suppl):55-88

11 Christiani DC, Eisen EA, Wegman DA, Ye Tt, Lu Pl, Dai Hl. Respiratory disease in cotton textile workers in the People's Republic of China: I. Respiratory symptoms. Scand J Work Env Health 1986; 12:40-5

12 American Thoracic Society Standardization of Spirometry—1987 update. Am Rev Respir Dis 1987; 136:1285-98
13 Christiani DC, Eisen EA, Wegman DH, Ye Tt, Gong ZC, L Pl. Respiratory disease in cotton textile workers: II. Pulmonary function. Scand J Work Env Health 1986; 12:46-50
14 National Institute for Occupational Safety and Health. Criteria for a recommended standard: occupational exposure to cotton dust. Washington, DC: Government Printing Office, 1975; DHEW (NIOSH) publication no. 75-118
15 Olenchock SA, Christiani DC, Mull JC, Ye Tt, Lu Pl. Endotoxin in baled cottons and airborne dusts in textile mills in the People's Republic of China. Appl Environ Microbiol 1985; 46: 817-20
16 Blomquist N. On the relation between change and initial value. J Am Stat Assoc 1977; 72:746-49
17 Berry G, McKerrow CB, Molyneux MKB, Rossiter CE, Tombleson JBL. A study of the acute and chronic changes in ventilatory capacity of workers in Lancashire cotton mills. Br J Ind Med 1973; 30:25-36
18 Valic F, Zuskin E. Changes in respiratory response to coarse cotton dust over a 10-year period. Am Rev Respir Dis 1975; 112:417-21
19 Valic F, Zuskin E. Byssinosis: a follow-up study of workers exposed to fine grade cotton dust. Thorax 1972; 27:459-62
20 Beck GJ, Schachter EN, Maunder LT, Schilling RSF. A prospective study of chronic lung disease in cotton textile workers. Ann Intern Med 1982; 97:645-51
21 Zuskin E, Ivankovic D, Schachter EN, Witek TJ. A ten-year follow-up study of cotton textile workers. Am Rev Respir Dis 1991; 143:301-05
22 Krzyzanowski M, Camilli AE, Lebovitz MD. Relationships between pulmonary function and changes in chronic respiratory symptoms. Chest 1990; 98:62-70
23 Merchant JA, Halprin GM, Hudson AR, Kilburn KH, McKenzie WN, Hurst DJ. Responses to cotton dust. Arch Environ Health 1975; 30:222-29
24 Diem JE. A statistical assessment of the scientific evidence relating cotton dust exposure to chronic lung disease. Am Statistician 1983; 37:395-403
25 Beck GJ, Schacter EV. The evidence for chronic lung disease in cotton textile workers. Am Statistician 1983; 37:404-12
26 Chan-Yeung M, Schulzer M, MacClean L, Dorken E, Tan E, Enarson D, et al. A follow-up study of the grain elevator workers in the port of Vancouver. Arch Environ Health 1981; 36:75-81
27 Tabona M, Chan-Yeung M, Enarson D, McClean L, Dorken E, Schulzer M. Host factors affecting longitudinal decline in lung spirometry among grain elevator workers. Chest 1984; 85:782-86
28 Enarson DA, Vedal S, Chan-Yeung M. Rapid decline in FEV_1 in grain handlers. Am Rev Respir Dis 1985; 132:814-17
29 Samet JM, Speizer FE, Gaensler EA. Questionnaire reliability and validity in asbestos-exposed workers. Bull Eur Physiopathol Respir 1978; 14:177-88
30 Enarson D, Yeung M. Determinants of changes in FEV_1 over a workshift. Br J Ind Med 1985; 42:202-04
31 Dimich HD, Sterling TD. Ventilatory function changes over a workshift. Br J Ind Med 1978; 38:152-55
32 Guberan E, Williams MK, Walford J, Smith MM. Circadian variation of FEV_1 in shift workers. Br J Ind Med 1969; 26:121-25