Cotton Dust Exposure, Across-Shift Drop in FEV_1, and Five-Year Change in Lung Function

DAVID C. CHRISTIANI, TING-TING YE, DAVID H. WEGMAN, ELLEN A. EISEN, HE-LIAN DAI, PEI-LIAN LU

Department of Environmental Health (Occupational Health Program), Harvard School of Public Health, Boston, Massachusetts; Pulmonary and Critical Care Unit, Massachusetts General Hospital, Department of Medicine, Harvard Medical School, Boston, Massachusetts; Institute of Preventive Medicine, School of Public Health, Shanghai Medical University, Shanghai, People's Republic of China; Department of Work Environment, University of Massachusetts, Lowell, Massachusetts, and the First Hospital of the Shanghai Textile Bureau, Shanghai, People's Republic of China

To evaluate chronic loss of lung function in cotton dust-exposed workers, a 5-yr follow-up study was performed in Shanghai, China from 1981 to 1986. Workers at a nearby silk thread manufacturing mill were used as a control population. There were 384 cotton textile workers restudied from an original group of 446, and 403 silk workers restudied from the original 468. The presence of byssinosis among retested cotton workers at the time of first survey was 7.3%. The prevalence of byssinosis was 9.7% at the initial survey among those lost to follow-up. No byssinosis was found among control subjects. The mean annual decline in FEV_1 was 39.5 ml among cotton workers and 30.6 ml for silk workers ($p < 0.05$). The greatest annual decrements were found among smoking cotton workers, but nonsmoking cotton workers also lost lung function at a faster rate than silk nonsmokers (annual loss = 33.3 ml versus 24.4 ml, respectively). Autoregressive modeling revealed that after adjustments for age, sex, height, and smoking, cotton dust exposure was significantly associated with decline in FEV_1. Moreover, across-shift drop of 5% or more at the time of first survey was predictive of 5-yr decline in FEV_1. Cotton workers who had an acute response (5% or greater drop in FEV_1 at the time of first survey) suffered a 57.0 ml/yr FEV_1 drop compared with a 35.1-ml drop among cotton workers with less acute response at baseline ($p < 0.01$). Silk workers with or without 5% across-shift drops had similar annual rates of decline (−33.8 ml and −36.1 ml, respectively). After adjusting for appropriate confounders, we found that continued exposure to cotton dust in the cotton textile industry is associated with progressive impairment of lung function and that modest across-shift decrements in FEV_1 are strongly predictive of long term impairment of lung function. Workers chronically exposed to cotton dust are at risk of developing chronic airflow obstruction. **Christiani DC, Ye T-T, Wegman DH, Eisen EA, Dai H-L, Lu P-L. Cotton dust exposure, across-shift drop in FEV_1 and five-year change in lung function. Am J Respir Crit Care Med 1994;150:1250-5.**

Exposure to cotton dust has been shown to provoke several pulmonary responses including bronchoconstriction with or without acute chest tightness (1). The syndrome known as byssinosis is characterized by chest tightness, shortness of breath, or cough after an absence from exposure of usually 36 to 48 h upon return to work (2). The disease may progress to a point where the symptoms persist throughout the work week. An excess of chronic bronchitis has been observed among cotton textile workers when compared with synthetic textile workers (3) or community control subjects (4). Pathologic evidence (5) has shown that bronchitis, characterized by an increase in the mucus-secreting elements of the airways, occurs in nonsmoking cotton textile workers. However, the link between the acute airways response and the development of chronic disabling lung disease among cotton-exposed workers remain a matter of controversy.

Numerous cross-sectional studies have evaluated the respiratory health of currently employed cotton textile workers. These studies may have underestimated the true prevalence of pulmonary disease because they have not included workers who left the mills prematurely, or those who develop symptoms and impairment after retirement. In an attempt to account for such biases, a cohort of active and retired South Carolina workers with varying exposures to cotton dust was studied by Beck and colleagues over 6 yr and compared with a community population in Connecticut (6). Cotton workers were found to have a larger loss of lung function than did control subjects, but the appropriateness of the control group, recruited from Connecticut, has been questioned. Valic and Zuskin reported acute and chronic changes in respiratory function in workers exposed to both fine and coarse grade cotton over 9 to 10 yr, respectively (7, 8). In addition, a re-

(Received in original form December 7, 1993 and in revised form May 2, 1994)

Supported by Grant No. R01OH02421 from the National Institute for Occupational Safety and Health, Grant No. ES00002 from the National Institute for Environmental Health Sciences and the Committee for Scholarly Communication, People's Republic of China.

This study was presented in part at the annual American Thoracic Society Meeting in Boston, 1990.

During a portion of this work, Dr. Christiani was a National Program Scholar with the Committee for Scholarly Communication, People's Republic of China.

Correspondence and requests for reprints should be addressed to Dr. David Christiani, Harvard School of Public Health, 665 Huntington Avenue, I-1405, Boston, MA 02115.

cent 10-yr follow-up study from Yugoslavia demonstrated an accelerated loss of lung function among a small cohort of 66 remaining active workers of an original group of 116 (9). None of these epidemiologic studies evaluated the significance of across-shift change in FEV_1 as a predictor of long-term lung function loss.

This study was designed to examine respiratory symptoms, across-shift change in FEV_1, and pulmonary function in a large, stable group of cotton textile workers prospectively over 5 yr, including active and retiring workers. The same outcome measures were also collected in a group of silk textile workers in the same city who were not previously exposed to cotton dust. Results of the pulmonary function surveys were reported here. Findings for the respiratory symptoms are the subject of a separate report (11).

METHODS

The methods used in the resurvey of this population were similar to those used in the initial survey (10). The following is a summary of those methods.

Study Population

The initial study population consisted of all workers in the yarn preparation areas (opening, cleaning, carding, drawing, combing, roving, and fine spinning) of two cotton textile mills in Shanghai, China. Simultaneously, a comparison population was studied consisting of workers from a silk thread processing mill in the same industrial sector of Shanghai. The first survey was performed in 1981 and included 446 cotton and 468 silk textile workers with a minimum of 2 yr employment in the industry. The participants represented 90% of eligible workers in the yarn preparation areas of the three mills. Subjects were excluded from eligibility if they had a history of active tuberculosis or a history of asthma preceding entry into the textile workforce.

The follow-up survey was performed 5 yr later, in 1986, with eligibility for retesting defined as membership in the original cohort.

Questionnaire

A modified version of the ATS standardized respiratory symptom questionnaire was administered by a trained interviewer (12). Questions included smoking history, byssinosis symptoms, and complete work history.

Pulmonary Function Tests

At both surveys, pulmonary function tests were performed before the subjects entered the work area on the first day of work after a 2-d rest. Forced expiratory maneuvers were recorded for each worker on an 8-L water-sealed field spirometer (W. E. Collins Co., Braintree, MA) under the direction of a trained technician. Workers were asked to refrain from smoking for at least 1 h before performing the test. Each worker performed up to seven trials to produce three acceptable curves. Calibration of the two field spirometers was done twice a day with a 3-L syringe. Workers performed their pre- and postshift tests on the same machine.

The spirometric curves were read manually with the starting point defined by back extrapolation. The lung function indices included forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC). Acceptable FEV_1 tracings were allowed to vary by no more than 5% or 100 ml, whichever was greater, and the best FEV_1 and FVC were used regardless of whether they were on the same tracing. All values were corrected to conditions of body temperature and pressure saturated with water vapor (BTPS). The highest values for FEV_1 and FVC were used for subsequent analyses, provided that these values came from technically acceptable tests. These preshift measurements were adjusted for age, height, gender, and smoking (as pack-years) using a prediction equation based on the silk workers' measurements in 1981. One set (25 subjects) of silk workers' records identified subsequent to the earlier publication (10) was included in a new regression analysis of silk workers (see footnote in Table 1). When the FEV_1/FVC ratio was calculated the best FEV_1 was expressed as the percentage of the best FVC.

Change in pulmonary function was measured for each subject over the survey day in 1981 and 1986. In addition, change was measured over the 5 yr using preshift values from each survey. Change in FEV_1 occurring over the workshift was expressed as a percentage as follows:

$$\Delta FEV_1 = FEV_1 \text{ after shift} - FEV_1 \text{ before shift}$$

$$\Delta FEV_1, \% = \Delta FEV_1 \times 100/FEV_1 \text{ before shift.}$$

Longitudinal change in lung function was expressed as annual change: FEV_1 (second survey) − FEV_1 (first survey) divided by 5, in ml. Because lung growth may occur up to age 25 (13), longitudinal change in FEV_1 was evaluated in workers who were age 25 or older at the time of first survey.

Exposure Assessment

Cotton dust and gram-negative bacterial endotoxins were measured using methods previously described (14). Briefly, area samples were taken using vertical elutriators in the various work areas. Samples and sampler locations were identical for both surveys, as were measurements and handling technique. Endotoxin assays were performed on the dust samples using the Limulus amoebocyte lysate assay, chromogenic method, as previously described by Olenchock and coworkers (14). A total of 320 samples were collected in the yarn preparation areas of the two mills during the two surveys to characterize dust and airborne endotoxin levels. No measurements were performed in the interval between the first and second survey, and only minor changes in cotton processing occurred over the 5-yr period. We examined the data for possible exposure-response relationships in several ways. We developed a cumulative index of exposure for each person using (geometric) mean levels of dust and endotoxin exposure from the two samplings multiplied by years of work in the various work areas. Cumulative exposure was examined for both the interstudy period and for working lifetime. We also examined current levels of exposure and 5-yr change in lung function. Finally, we stratified the population into several dust and endotoxin exposure groups and examined longitudinal change in FEV_1 after adjustments for appropriate confounders.

Statistical Analysis

Lung function change over 5 yr was examined using an autoregressive model (15). The effects of interest (e.g., cotton dust exposures, smoking, etc.) are estimated with adjustment for several variables (e.g., age, height). In these models, FEV_1 at 5 yr (second survey) was regressed on FEV_1 at baseline (initial survey); age in yr at second survey; sex (1 = male, zero =

TABLE 1

DEMOGRAPHIC AND PULMONARY FUNCTION CHARACTERISTICS OF COTTON AND SILK TEXTILE WORKERS TESTED AT BOH SURVEYS*

	Cotton	Silk
Number	384	403
Age, yr (1986)	42.0 ± 10.6	41.0 ± 10.4
Height, cm	164.1 ± 7.5§	162.6 ± 7.2‡
% Male subjects	48.4	43.2
Current Smokers, % (1986)	35.7	30.0
Average smoked (1986) for Smokers (pk-yr)	3.3 ± 13.4	12.1 ± 13.0
Yr Employed (1986)	20.5 ± 10.1	21.4 ± 11.5
Pulmonary Function		
FEV_1, L (1986)	2.74 ± 0.71	2.73 ± 0.65
FEV_1, % predicted (1986)	97.78 ± 14.77	98.93 ± 12.83
FVC, L (1986)	3.39 ± 0.77	3.33 ± 0.74
FVC, % predicted (1986)	97.66 ± 12.70	98.18 ± 11.33
FEV_1/FVC % (1986)	80.4 ± 8.3§	82.1 ± 8.5§
Δ FEV_1, % (1981)	−1.90 ± 5.6§	−0.10 ± 4.9§
Δ FEV_1, % (1986)	−1.77 ± 6.6†	−0.87 ± 4.2†
Annual FEV_1 Decline, L	−0.040 ± 0.041§	−0.031 ± 0.039§

* Values are mean ± SD unless otherwise indicated. Prediction equations based on 492 silk workers pre-shift spirometry done at time of first survey (1981) and adjusted for age, height, gender, and smoking.

Δ FEV_1, % = across-shift change in FEV_1.

† $p = 0.05$, cotton versus silk.

‡ $p < 0.05$, cotton versus silk.

§ $p < 0.01$, cotton versus silk.

TABLE 2

BASELINE CHARACTERISTICS OF TEXTILE WORKERS RETESTED VERSUS LOST TO FOLLOW-UP

	Cotton		Silk	
	Retested	Lost to Follow-up	Retested	Lost to Follow-up
Number	384	62	403	65
Age, yr (1981)	36.9 ± 10.6†	40.3 ± 10.6†	35.9 ± 10.4	37.3 ± 12.3
Male subjects	48.4	40.3	43.2	38.5
Current Smokers %	34.6	27.4	23.9	21.9
Chronic cough*	18.8	22.6	6.5	9.2
Chronic bronchitis	21.1	22.6	7.2	7.7
Byssinosis	7.3	9.7	0.0	0.0
Dyspnea 2+	13.5†	24.2†	3.5	7.7
FEV_1 % Predicted‡ (1981)	100.08 ± 13.04	97.23 ± 15.72	99.85 ± 11.45	100.70 ± 14.62
FVC % Predicted‡ (1981)	100.71 ± 11.95	98.33 ± 14.27	100.08 ± 10.50	99.28 ± 12.50
Δ FEV_1, % (1981)	−1.90 ± 5.6	−2.78 ± 5.3	−0.10 ± 4.86	+1.13 ± 5.1

* Symptom prevalence expressed as percentage.
† < 0.05, retest versus nonretest group.
‡ Percent predicted after adjustment for age, sex, height, and smoking.

female); height (cm); personal smoking status (1 = current, zero = never, as well as pack-years); and exposure status (1 = cotton, zero = silk). Because there were so few exsmokers (n = 18), they were excluded from these models. Departures from underlying assumptions of normality and linearity were assessed by examination of the distribution of residuals (observed minus predicted values) in relation to height, age, FEV_1, and predicted values. The r^2 statistic measured goodness of fit.

The relationship between acute, across-shift change in FEV_1 at the time of first survey and annual decline in FEV_1 was also examined in a linear regression model, adjusting for the covariates described above.

RESULTS

All members of the initial cohort who were still employed were identified along with retirees who were still in the area. A total of 90% of the original cohort were contacted and invited to participate again. Of these, 86% (384 cotton and 403 silk workers) participated and were able to provide completed questionnaires. Acceptable spirometric curves were obtained on 361 of the cotton and 373 of the silk workers and used in the subsequent analyses.

Demographic characteristics are shown in Table 1 and reveal that cotton and silk workers were similar in age, smoking prevalence, yr worked, and proportion of male workers. As a group, retested cotton workers were taller than their silk-worker counterparts. Cotton textile workers had larger cross-shift decrements in FEV_1 as well as steeper 5-yr decline in FEV_1.

A total of 127 cotton and silk workers in the initial cohort were not retested (lost to follow-up). These included 30 retirees, 62 active workers on leave including temporary illness leave, 27 who were working outside of Shanghai, two deaths (cotton cohort) from cancer, and six others permanently disabled with nonrespiratory cancer. No interval deaths were reported to be from respiratory disease.

When analyzed considering their characteristics at the time of first survey (Table 2), cotton workers who were lost to follow-up had somewhat lower adjusted preshift FEV_1 whereas silk workers not retested had somewhat larger values for FEV_1. This same pattern was repeated when cross-shift change in FEV_1 was examined. None of these differences was significant.

There was one difference in the two cohorts, however, when examined by symptom status at the initial survey. Cotton workers lost to follow-up reported significantly more dyspnea than those retested while similar differences were not observed among silk workers.

Overall, the differences between retested and nonretested workers from both cohorts were small. The direction of the small differences noted, however, would tend to suggest greater likelihood of attrition for workers in poorer health from the cotton cohort. If cotton dust causes adverse respiratory effects, our incomplete follow-up would likely result in a small bias towards the null hypothesis.

TABLE 3

PULMONARY FUNCTION BY SMOKING STATUS AND DEMOGRAPHIC CHARACTERISTICS FOR COTTON AND SILK TEXTILE WORKERS

	Cotton		Silk	
	Smokers	Nonsmokers	Smokers	Nonsmokers
Number	137	247	121	282
Age, yr (1986)	42.5 ± 11.0	41.8 ± 10.4*	43.2 ± 11.3	40.0 ± 9.9*
Height, cm	169.4 ± 6.4	161.2 ± 6.3*	168.7 ± 5.8	160.0 ± 6.1*
% Male subjects	96.4	21.9	100	18.8
Average smoked, pack-yr	13.3 ± 13.4	–	12.2 ± 13.1	–
FEV_1, L (1986)	3.06 ± 0.85	2.56 ± 0.54	3.10 ± 0.74	2.56 ± 0.52
FEV_1, % predicted (1986)†	95.5 ± 17.2	99.0 ± 13.2	97.5 ± 14.3	99.6 ± 12.1
Δ FEV_1, % (1981)	−1.89 ± 5.9	−1.90 ± 5.4‡	+0.22 ± 4.6	−0.25 ± 5.0‡
Δ FEV_1, % (1986)	−2.14 ± 6.7	−1.56 ± 6.6	−0.16 ± 4.0	−1.21 ± 4.3
Annual FEV_1 decline, L	−0.051 ± 0.049	−0.033 ± 0.035‡	−0.044 ± 0.040	−0.024 ± 0.036‡

* $p < 0.05$ comparing cotton and silk nonsmokers.
† Percent predicted after adjustment for age, sex, height, and smoking.
‡ $p < 0.01$ comparing cotton and silk nonsmokers.

Smoking characteristics in the second survey were found similar (Table 3) to those found at time of initial survey. The majority of smokers were men, 96 and 100% of smokers in the cotton and silk populations, respectively. There were 13 exsmokers in the cotton population (one woman, 12 men) and nine new smokers (eight men, one woman) during the 5 yr between surveys. Among silk workers, there were five exsmokers and 30 new smokers (all male) for the same period.

Pulmonary function was examined according to smoking status and showed that, despite adjusting for pack-years of smoking, smokers from both cohorts and slightly lower percent predicted FEV_1. Smokers also showed greater annual decrements in FEV_1. It is notable that within the nonsmoking category, cotton workers experienced a significantly larger annual decrement compared with silk workers (0.033 L versus 0.024 L, $p < 0.01$).

To examine the overall impact of work in cotton textile environments adjusting for smoking and other subject characteristics, the level of FEV_1 at second survey in function was examined in an autoregressive model. Results of this analysis revealed a significant effect of work in cotton dust environments after adjustments for age, gender, height, and smoking status. When partial coefficients of variation were examined, the prior FEV_1 explained the majority of the observed variation (Partial $r^2 = 0.91$), with all remaining variables accounting for the remainder (Partial $r^2 < 0.01$). It is worth noting that the apparent gender effect (and lack of smoking effect) is probably because smoking was so highly correlated with gender: virtually all smokers are male and almost no females smoke (smoke regularly and gender, $r = 0.73$). Therefore, the model was refit with gender removed. In that model (Table 4) the smoking coefficient became significant ($\beta = -0.05$, $p < 0.01$), whereas there was no change in the exposure coefficient ($\beta = -0.03$, $p < 0.05$).

Relationship between Acute and Chronic Change in Lung Function

The relationship between an acute response to cotton dust exposure at the time of initial survey and subsequent annual change in pulmonary function was examined (Table 5). A ΔFEV_1 of 5% was defined as positive acute response. Cotton workers with no response (i.e., $> -5\%$ cross-shift change) at the time of initial survey had an annual loss in FEV_1 of 35.1 ml, and silk workers 33.8 ml ($p = 0.71$). When those with a cross-shift change of greater than -5% were examined, silk workers' annual loss of FEV_1 was no different from those with $\leq -5\%$ change in 1981 (36.1 ml). However, the cotton workers with a similar acute change in 1981 of $\leq -5\%$ had a significantly larger annual loss in FEV_1 (-57.0 ml) compared with either cotton workers with $> -5\%$ change in 1981 or with either of the silk worker groups. Given the potential confounding due to smoking, a linear regression model was run with 5-yr change in FEV_1 as the dependent variable and cross-shift change in FEV_1, age, height, and smoking status as independent variables. Results show that cross-shift change is strongly predictive of 5-yr change after the adjustments (Table 6). As with the previous model, gender and smoking status are highly correlated and are therefore not simultaneously entered. When gender and smoking status are entered simultaneously, the smoking coefficient drops to -0.11 ($p = 0.09$) and the gender coefficient rises to -3.81 ($p = < 0.01$). The coefficient for across-shift change in FEV_1 remains the same, $\beta = 0.53$, $p = 0.0001$.

TABLE 5

LONG-TERM CHANGE IN PULMONARY FUNCTION AND ACUTE PULMONARY FUNCTION RESPONSE AT TIME OF FIRST SURVEY

Across-shift change in FEV_1 at first survey	Annual Change in FEV_1 (L)	
	Cotton	Silk
$> -5\%$	-0.035	-0.034
	(236)	(243)
$\leq -5\%$	-0.057	-0.036
	(73)	(37)
p-Value† (2-tailed)	< 0.001	0.72

* Across shift loss in FEV_1 at time of first survey:

$$\%\ \Delta\ FEV_1 = \frac{[\text{pre-shift } FEV_1 - \text{post-shift } FEV_1]}{\text{Preshift } FEV_1} \times 100, \text{ at time of first survey}$$

† *t* test comparing five-year FEV_1 change within each category.
n = 307 of 385 with acceptable spirometry on both surveys.

Environmental Measurements

The mean (geometric) area elutriated cotton dust concentrations for the six areas from which the examined workers came ranged from 0.33 to 1.69 for Mill I and 0.24 to 1.73 for Mill II. Endotoxin concentrations ranged from 990 EU/m³ to 6,390 EU/m³ in Mill I and 40 EU/m³ to 7,460 EU/m³ in Mill II. The mean (geometric) area endotoxin concentrations of work areas of both mills from the second survey showed that, in general, endotoxin levels tended to rise despite unchanged or reduced gravimetric dust levels (14).

Samples were taken from the silk mill, which revealed the presence of elutriated dust (geometric) mean 0.2 mg/m³, and nondetectable endotoxin levels (< 1 EU/m³), confirming the absence, in silk mills, of organic dust biologically similar to cotton.

When exposure-response analysis was performed internal to

TABLE 4

REGRESSION MODEL* FOR FEV_1 LEVEL IN SECOND SURVEY

Outcome Variable:	FEV_1 (L) (1986) Regression coefficient	Dependent Variables: Standard Error	p-Value (2-tailed)
Intercept	-0.373	0.23	0.11
1981 FEV_1, L	$+0.876$	0.019	< 0.01
Age, yr	-0.006	0.001	< 0.01
Height, cm	$+0.005$	0.002	< 0.01
Smoking status†	-0.051	0.019	< 0.01
Exposure status‡	-0.030	0.015	< 0.05

$r^2 = 0.92$.
* Based on 594 observations of subjects with acceptable spirometry on two surveys over 5 yr.
† Smoking Status: 1 = smoker, 0 = non-smoker.
‡ Exposure Status: 1 = cotton, 0 = silk.

TABLE 6

REGRESSION MODEL FOR FIVE-YEAR CHANGE IN FEV_1 (L)*

	Regression Coefficient	SE†	p-Value (2-tailed)
Dependent Variables			
Age, Year	-0.21	0.04	< 0.01
Height, cm	0.13	0.07	0.06
Smoking Status (1 = smoker)	-3.00	1.05	< 0.01
$\Delta\ FEV_1$, %‡	0.53	0.08	< 0.01

* Based on 308 observations; cotton workers only. Dependent variable = percent change in FEV_1.
$r^2 = 0.23$.
† Standard error.
‡ Across-shift change in FEV_1 at first survey. Mean value negative, i.e., in same direction as FEV_1 five-year difference.

the cotton group, we were unable to determine any exposure-related variation in symptoms, level of lung function, or longitudinal change in lung function. However, such an analysis was limited by the reliance on area samplers (unavailability of personal samples for cotton dust) and significant job-area changes over the 5-yr interval.

DISCUSSION

Appropriateness of Control Group

Silk yarn workers were selected instead of synthetic fiber mill workers because at the time of these studies, all synthetic fiber mills in Shanghai were converted cotton mills. After excluding silk-worm handlers and silk workers who had previously been cotton textile workers, the silk-yarn preparation workers constituted the best available control group for this study. Moreover, the silk workers were identical to the cotton group in every socioeconomic respect (urban environment, job selection criteria, etc.).

Cotton Dust Exposure and Chronic Airflow Limitation

Respiratory disease associated with exposure to textile dusts was recognized centuries ago by Ramazzini who described such problems among flax- and soft hemp workers (16). Later, Kay described an asthma-like syndrome among cotton spinners in England (17). In Lancashire, England, 19th-century physicians were concerned about the high death rates from respiratory disease among residents of this textile city. The asthma-like syndrome became known as byssinosis and is defined clinically as chest tightness and/or shortness of breath on the first workday of the week after exposure to the dust of cotton, flax, soft hemp, or sisal. In later stages, these acute symptoms are evident on other workdays as well. Byssinosis prevalence has been reported to be lower in countries such as U.S.A. or U.K. where considerable progress has been made in controlling cotton dust exposures (18). However, some important questions remain unanswered, such as: (*1*) What is the relationship between exposure to cotton dust and development of chronic airflow obstruction? and (2) What is the relationship between the acute response to cotton dust and the development of chronic airflow obstruction?

Most of the epidemiologic studies addressing chronic lung disease in cotton textile workers are cross-sectional investigations and cohort mortality studies. The major limitations of cross-sectional designs is that workers developing symptoms are more likely to leave the industry, resulting in underestimation of chronic disease prevalence. Likewise, mortality studies are less effective for identifying increased risk for chronic diseases, which cause prolonged morbidity but are less often the primary cause of death. This is particularly true because treatment for airways disease has become more effective in the late 20th century. Thus, only longitudinal studies are more likely to clarify the remaining questions concerning the risk of chronic obstructive lung disease induced by exposure to cotton dust.

The most widely accepted predictor of the eventual development of chronic obstructive pulmonary disease (COPD) is an accelerated decline in expiratory flow rates, particularly FEV_1 (19). Several longitudinal studies of cotton textile workers have been reported, and in most, the outcome of interest has been change in FEV_1 (6, 9, 20–24). Berry and associates (20) measured lung function in 595 cotton subjects and a comparison group of 81 workers from two synthetic fiber mills up to six times over a 3-yr period. Cotton workers had a mean annual FEV_1 loss of 54 ml, compared with 32 ml among workers from the two synthetic fiber mills. However, workers from the two synthetic fiber mills also differed substantially from each other: 52 ml versus 14 ml. The study, though suggestive, did not make a persuasive case for excess risk of COPD. Moreover, they found that annual decline in FEV_1 was not significantly related to dust levels or to Monday across-shift decline in FEV_1.

Fox and colleagues (21) studied 866 cleaning and cardroom workers 2 yr apart and found a 23 ml/yr loss of FEV_1, no greater than that expected due to age alone. Exposure levels ranged from 1.15 mg/m^3 to 4.8 mg/m^3 (excluding fly). This study was limited by the absence of a control group and the short follow-up interval.

Merchant and colleagues (22) studied 199 subjects in an investigation of cotton-steaming effects. The study had a short follow-up period—10 mo—from which annual FEV_1 declines were calculated. They estimated a mean loss in FEV_1 of 192 ml in 43 nonbyssinotic early yarn preparation area workers. Declines in FEV_1 were less in workers in the spinning and winding areas.

Kamat and colleagues (23) studied Indian cotton textile workers longitudinally and found an accelerated loss of lung function. But, their controls also sustained great losses which were unexplainable, and methodologic problems (e.g., changing spirometers) may have influenced the results.

Beck and associates (6) have published results from a community-based study of active and retired cotton textile workers in South Carolina. Both active and retired cotton workers had significantly greater annual losses in FEV_1 compared with control subjects from Lebanon, CT. This study suggested that in an older, largely retired group of cotton workers, additional loss of lung function occurred after removal from exposure. Although criticized for choice of control subjects and differences in recruitment between the two community surveys, this study raised serious concerns about adverse effects of exposure in both smokers and nonsmokers years after leaving the cotton mills.

Zuskin and coworkers (9) recently published the results of a small longitudinal study of 66 cotton textile workers in a mill in Yugoslavia. The mean annual decline in FEV_1 was 59 ml/yr for female and 68 ml/yr for male workers with average respirable dust concentration of 0.97 mg/m^3. Initial survey across-shift changes in FEV_1 were significantly greater in the 50 workers lost to follow-up than in the 66 workers surveyed twice over the 10-yr period. The association between across-shift change and 10-yr loss was not reported.

Glindmeyer and associates (24) reported 5-yr annual declines in FEV_1, FVC, and FEF_{25-75}, which were steeper in cotton yarn preparation workers than slashing and weaving. These declines were associated with cotton dust exposure in yarn preparation and occurred at levels even as low as 0.2 mg/m^3. However, their synthetic fiber control group exhibited greater ventilatory declines than did the cotton workers, findings not explained by smoking or work tenure.

Our study confirms and extends the findings of Beck and associates and Zuskin and coworkers. Using identical methods of recruitment in cotton and silk workers and choosing both populations from the same districts of a large industrial city, and adjusting for smoking, we have found that cotton textile workers suffer an accelerated loss of lung function over 5 yr compared with silk workers. The annual unadjusted change in FEV_1 for all cotton workers is calculated at 39.5 ml/yr versus 30.6 ml/yr for silk workers. Cotton exposure may have a substantial impact on the lung function of these workers, placing them at considerable lifetime risk of developing chronic obstructive pulmonary disease.

Relationship between Acute Loss in FEV_1 and Chronic Airflow Limitation

Our results indicate that across-shift change in FEV_1 was predic-

tive of chronic, 5-yr loss in FEV_1. This effect was not explained by factors such as smoking, age, gender, or height, or regression to the mean.

Our data suggest that across-shift drop in FEV_1 is predictive of longitudinal loss of lung function. Moreover, even relatively small across-shift changes (i.e., $\leq -5\%$) in FEV_1 in cotton-exposed workers are associated with an excessive loss of FEV_1 as contrasted with workers who do not suffer this acute drop: estimated annual loss of 57.0 ml versus 35.1 ml, respectively. Because this magnitude of effect was not observed in silk workers with a 5% drop on initial survey, we conclude that cotton dust exposure is responsible for the accelerated loss and that cotton exposed workers who exhibit a 5% or greater across-shift decrement in lung function, with or without symptoms, are at the greatest risk for developing chronic airflow limitations. The absence of an association between acute and chronic change in FEV_1 in the control group suggests that the observed association among cotton textile workers was not due to regression to the mean alone.

Previous reports of the relationship between airway responsiveness and longitudinal change in lung function are few and have focused on patients in clinic or on children and young adults. For example, Kanner reported that airway responsiveness, as measured by response to inhaled bronchodilator, was predictive of annual rate of change of FEV_1 and FVC in 84 subjects with varying degrees of chronic airflow limitation, and independent of baseline pulmonary function values (25). He postulated that the responsiveness *per se* was unlikely to be causally related to the decline in spirometric function, but rather both airway responsiveness and accelerated loss of lung function were both the results of inhaled toxins (i.e., tobacco, other pollutants).

Our investigation was not limited by methodologic issues related to the longitudinal community-based studies. For example, we included a control group tested at the same time using identical procedures, ensuring specificity of response to cotton dust and not other, more general, air pollutants. We also had a high participation rate (90%) in both surveys.

Another interesting difference between our study and those described above is that we examined specific airway responsiveness to a workplace contaminant, i.e., airway responses to cotton dust, rather than nonspecific reactivity. In the other published epidemiologic study that examined across-shift drop in FEV_1 and longitudinal change in FEV_1 in cotton workers, by Berry and associates (20), workers were examined over a 3-yr period. There was no relationship between the rate of annual decline in FEV_1 and across-shift change in FEV_1. Their negative result may have been the consequence of a short follow-up period and lower exposure levels than in our study.

In summary, these data suggest that cotton dust-exposed workers have an accelerated loss of lung function compared with silk workers and after adjusting for smoking effects. Moreover, these results further demonstrate that cotton workers, regardless of smoking habit, who exhibit acute, across-shift drops in FEV_1 of 5% or greater are at higher risk of developing chronic airflow limitation. Further research efforts should focus on exposure-response relationships for cotton dust and associated endotoxins so that appropriate controls may be developed to prevent acute and chronic environmental respiratory disorders in exposed workers.

Acknowledgment: The authors thank the following individuals who were members of the Shanghai field team: technicians Wang Xiao-ling, Fan Huang-yin, Lu Wei-wei and Li Meng-yin; physicians from the textile hospital and mills; Professors Gu Xue-qi and Lu Pei-lian, Drs. Zhuo Xian-min, Jiang Li, and Ren Lu from Shanghai Medical University. Dr. Stephen Olenchock of NIOSH kindly performed the endotoxin analysis. The authors 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. They 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. Richard Monson for his thoughtful comments.

References

1. Merchant JA. Byssinosis. In: Occupational Respiratory Diseases DHHS (NIOSH) Pub. no. 86-102, 1986.
2. Schilling RSF, Hughes JPW, Dingwall-Fordyce I, Gilson JC. An epidemiological study of byssinosis among Lancashire cotton workers. Br J Ind Med 1955;12:217–27.
3. Berry G, Molyneux MKB, Tombleson SBL. Relationships between dust level and byssinosis and bronchitis in Lancashire cotton mills. Br J Ind Med 1974;31:18–27.
4. Bouhouys A, Schoenberg IB, Beck GJ, Schilling RSF. Epidemiology of chronic lung disease in a cotton mill community. Lung 1977;154:167–86.
5. Pratt PC, Vollmer RT, Miller JA. Epidemiology of pulmonary lesions in non-textile and cotton textile workers: a retrospective autopsy analysis. Arch Environ Health 1980;35:133–8.
6. 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.
7. Valic F, Zuskin E. Byssinosis: a follow-up study of workers exposed to fine grade cotton dust. Thorax 1972;27:459–62.
8. Valic F, Zuskin E. Changes in respiratory response to coarse cotton dust over a ten-year period. Am Rev Respir Dis 1975;112:417–21.
9. Zuskin E, Ivankovic D, Schachter EN, Witek TJ. A ten-year follow-up study of cotton textile workers. Am Rev Respir Dis 1991;143:301–5.
10. Christiani DC, Eisen EA, Wegman DH, Ye TT, Gong ZC, Lu PL, Dai HL. Respiratory disease in cotton textile workers in the People's Republic of China. II. Pulmonary function results. Scand J Work Environ Health 1986;12:46–50.
11. Christiani DC, Ye TT, Wegman DH, Eisen EA, Dai HL, Lu PL. Variability in symptom reporting, across-shift drop in FEV_1 and longitudinal change in pulmonary function among cotton textile workers. Chest 1994; 105:1713–23.
12. Ferris BG. Epidemiology standardization project. Am Rev Respir Dis 1978;118(Suppl):55–88.
13. Wang XB, Dockery DW, Wypij D, Gold DR, Speizer FE, Ware JH, Ferris BG. Pulmonary function growth velocity in children 6 to 18 years. Am Rev Respir Dis 1993;148:1502–8.
14. Olenchock SA, Christiani DC, Mull JC, Ye T-T, Lu PL. Airborne endotoxin concentrations in various work areas within two cotton mills in the People's Republic of China. Biomedical and Env Sci 1990;3:443–51.
15. Rosner B, Muñoz A, Tager I, Speizer F, Weiss S. The use of an autoregressive model for the analysis of longitudinal in epidemiologic studies. Stat Med 1985;4:457–67.
16. Raffle PAB, Lee WR, McCullum RI, Murray R, eds. Hunter's Diseases of Occupations. Boston: Little, Brown and Company, 1987;690.
17. Kay JP. Observations and experiments concerning molecular irritation of the lungs as one source of tubercular consumption; and on spinner's phthisis. North Engl Med Surg J 1831;1:348–63.
18. Morgan WKC, Vesterlund J, Burnell R, Gee JBC, Willoughby WF. Byssinosis: some unanswered questions. Am Rev Respir Dis 1982;126: 354–57.
19. Fletcher C, Peto R, Tinker C, Speizer FE. The natural history of chronic bronchitis and emphysema. Oxford: Oxford University Press, 1976.
20. Berry G, McKerrow C, Molyneux M, Rossiter C, Tombleson J. 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.
21. Fox AJ, Tombleson JBL, Watt A, Wilkie AG. A survey of respiratory disease in cotton operatives. Br J Ind Med 1973;30:42–7.
22. Merchant JA, Lumsden JC, Kilburn KH, O'Fallon WM, Copeland K, Germino VH, McKenzie WN, Baucom D, Currin P, Stilman J. Intervention studies of cotton steaming to reduce biological effects of cotton dust. Br J Ind Med 1974;31:261–74.
23. Kamat SR, Kamat GR, Salpekar VY, Lobo E. Distinguishing byssinosis from chronic obstructive pulmonary disease. Am Rev Respir Dis 1981;124:31–40.
24. Glindmeyer HW, LeFante JJ, Jones RN, Rando RJ, Abdel-Kader HM, Weill H. Exposure-related declines in lung function of cotton textile workers. Am Rev Respir Dis 1991;144:675–83.
25. Kanner RE. The relationship between airways responsiveness and chronic airflow limitation. Chest 1984;86:54–7.