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Respiratory Disease in Cotton Textile Workers: Epidemiologic Assessment of Small Airway Function

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We performed a cross-sectional study of 705 textile workers in two cotton mills and one silk mill in Shanghai, People's Republic of China, to assess small airway function among cotton textile workers and to compare the FEV_1 to the FEF_{25-75} in detecting airflow obstruction in these workers. All workers had at least 2 years of work experience. Environmental sampling was performed with vertical elutriators and revealed that in the cotton mills mean elutriated dust levels were 1.07 ± 0.23 mg/m^3 in mill 1 and 1.01 mg/m^3 ± 0.24 mg/m^3 in mill 2. Mean endotoxin levels were 332 ± 83 ng/m^3 in mill 1 and 101 ± 46 ng/m^3 in mill 2. No differences were found in preshift FEV_1 or FEF_{25-75} between cotton and silk workers. Cotton workers had significantly greater declines than silk workers in FEV_1 across a workshift, but not in FEF_{25-75}. These acute changes in FEV_1 were noted in both byssinotic and nonbyssinotic workers. Although cotton dust may affect both large and small airways, spirometric measures of small airway function (e.g., FEF_{25-75}) add little to the FEV_1 and FVC in detecting airflow limitation in cotton dust-exposed workers. © 1994 Academic Press, Inc.

INTRODUCTION

The cotton textile industry has been expanding in the industrializing world in the last decade. The acute respiratory effects of cotton dust exposure in workers in this industry have been extensively studied in developed nations such as Sweden (Haglind *et al.*, 1981), the United Kingdom (Berry *et al.*, 1973), and the United States (Martin and Higgins, 1976; Schachter *et al.*, 1984). The syndrome of chest tightness on returning to work with improvement over off-shifts in these workers, termed byssinosis, was described by Shilling over 30 years ago (1956). Byssinosis may or may not be associated with a decline in lung function over the workshift, and exposed nonbyssinotic workers may experience a decline in lung function as well. However, an across-shift decline in airway function, measured as the forced expiratory volume in 1 sec (FEV_1), has been shown to occur more frequently in those workers with byssinosis than in asymptomatic workers with the same exposure (Berry *et al.*, 1974; Merchant *et al.*, 1975). Also, the prevalence of byssinosis and across-shift decline in FEV_1 has been shown to increase with increasing exposure to inhalable dust (Berry *et al.*, 1974).

A variety of pathophysiologic mechanisms have been postulated to account for

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byssinosis, including effects of allergenic cotton proteins, contaminant bacterial proteolytic enzymes, histamine, mechanical effects of inert dusts, and endotoxin contamination (Butcher *et al.*, 1983). Although the precise etiology of the syndrome is still controversial, inhaled endotoxins, alone or in combination with other agents, seem most likely to be responsible for the acute ventilatory response to cotton dust (Castellan *et al.*, 1987; Mundie and Ainsworth, 1986). Moreover, long-term endotoxin exposure may also be associated with symptomatic chronic respiratory disease (Kennedy *et al.*, 1987).

There are a few longitudinal studies which have documented accelerated loss in lung function in cotton workers over time (Glindmeyer *et al.*, 1991; Kamat *et al.*, 1981; Larson and Barman, 1989; Zuskin and Valic, 1975; Zuskin *et al.*, 1991). The higher incidence of symptoms and accompanying spirometric changes in cotton workers with longer work tenures in both cross-sectional and longitudinal studies suggests that long-term cotton dust exposure ultimately results in chronic obstructive lung disease. The effects of cotton dust exposure on the peripheral airways are less clear. Using the slope of phase III and closing volume determinations from single-breath nitrogen washout curves, Haglind *et al.* (1983) found no evidence of small airway dysfunction in a select group of 6 asymptomatic and 16 mild byssinotic cotton textile workers, 10 of whom were smokers. However, very little epidemiologic data regarding small airway-function changes in cotton industry workers exist. Whether such effects can be detected early is of obvious interest to occupational health professionals, as individuals at risk for developing chronic lung disease from this exposure might be identified with screening spirometry before the advent of FEV_1 decrements or symptoms.

We have previously reported the prevalence of respiratory symptoms and their relationship to cotton dust exposure in a cohort of cotton textile workers in Shanghai, China, using silk workers as a comparison group (Christiani *et al.*, 1986). The relationships between symptoms, exposure to cotton dust, and changes in FEV_1 in this cohort have previously been reported as well (Christiani *et al.*, 1986). The latter study found significant across-shift decrements in FEV_1 in both symptomatic and asymptomatic cotton workers but not in silk workers. Byssinotics were found to have significantly greater decrements than nonbyssinotics with comparable work duration, but the prevalence of byssinosis was low.

The present study examines a measure of small airway function in this population. The forced expiratory flow between 25 and 75% of the vital capacity was determined as a parameter of peripheral airway function and was evaluated at baseline and following a workshift. The relationships between pulmonary function tests and symptoms and exposure history in the cohort are also described. Our study represents one of the largest cohort studies of cotton textile workers investigating these relationships reported to date.

MATERIALS AND METHODS

The study design, methods of data collection, and definitions used have been previously described elsewhere (Christiani *et al.*, 1986). A brief description follows.

Study Population

Sampling took place in the fall and winter of 1981–1982. Cotton textile workers rotating on the day shift from two Shanghai mills were selected from the yarn preparation areas (including opening, carding, drawing, combing, and winding and spinning operations). Eligible workers included all those in yarn preparation with 2 or more years in the mill who were beginning the first day of their work week after 2 days off. Moreover, individuals with a history of respiratory disease before entering the mill were excluded. Ninety percent of eligible workers participated in the study.

Silk workers from a nearby factory were selected as a control population, who were identical in every respect except for job. Workers were excluded from study if they had prior work experience in the cotton textile industry or if they had been involved in silk–cotton blending currently or in the past. Those with a history of physician-diagnosed respiratory disease prior to working at the mill were excluded as well. The silk and cotton workers came from one of two similar working-class neighborhoods in the Shanghai area, and individual earnings were identical in both mills.

Pulmonary Function Tests

Spirometry was performed before the subjects entered the work area following a 2-day absence from work and at the end of the same day. Those workers who smoked were required to abstain from smoking for at least 1 hr prior to testing. Forced expiratory maneuvers were obtained by a single technician, using an 8-1 water-seal field spirometer (W. E. Collins Co., Braintree, MA). Three tracings which met the American Thoracic Society's criteria for acceptability were obtained from up to seven trials per worker at each session. The tracings were read manually, with the starting point of exhalation determined by back extrapolation.

Lung-function parameters included forced expiratory volume in 1 sec (FEV_1), forced vital capacity (FVC), and forced expiratory flow between 25 and 75% of vital capacity (FEF_{25-75}). Values of FEF_{25-75} were derived from the volume–time tracing using a computerized digitizing method developed by O'Donnell *et al.* (1987).

Calculation of the percentages of parameter change over a workshift and acceptability criteria was performed using procedures described elsewhere (Christiani *et al.*, 1986). Criteria for reproducibility were a minimum of three acceptable curves, the best two of which vary by no more than 10% or 200-ml difference in FVC. The highest values of FEV_1 and FVC were taken from technically acceptable blows and expressed as a percentage of best FVC (FEV_1/FVC%). The FEF_{25-75} from the curve with the largest sum of FEV_1 and FVC was used in the analysis. To adjust for baseline lung volume, the change in FEV_1 and FEF_{25-75} over a workshift was expressed as a percentage of preshift values as

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

$$\%\ \Delta\ FEV_1 = \Delta\ FEV_1 \times 100/(FEV_1 \text{ before shift})$$

and

$$\Delta\ FEF_{25-75} = FEF_{25-75} \text{ after shift} - FEF_{25-75} \text{ before shift}$$

$$\%\ \Delta\ FEF_{25-75} = \Delta\ FEF_{25-75} \times 100/(FEF_{25-75} \text{ before shift}).$$

Exposure Assessment

Air sampling data for both total dust and endotoxin levels have been previously reported (Olenchock, 1983). Briefly summarized, air sampling was performed with four vertical elutriators using polyvinyl chloride filters (37 mm, 5 μm pore size; Gelman Sciences, Inc., Ann Arbor MI) placed at a height of 1.4 m and operated at a flow of about 7 liters/min. Sampling of each work area was performed for at least 6 hr for a minimum of 2 consecutive days.

Extracts of particulate matter on the filters, as well as bulk samples of cotton obtained from bales, were assayed for gram-negative bacterial endotoxin using a modified *Limulus* amebocyte lysate test (QCL-1000; Whitacker Bioproducts, Walkersville, MD) and the results were expressed as EU/cubic meter of air and EU/mg of bulk material, respectively.

Statistical Analysis

Demographic data and symptom prevalence were compared using contingency tables and the χ-square statistic. Pulmonary function parameters were expressed as mean values and compared using a two-sided Student's *t*-test.

Linear regression was used to model the effects of exposure on baseline pulmonary function (preshift FEV_1 and FEF_{25-75}) and on acute change in function (% Δ FEV_1 and % Δ FEF_{25-75}) over a workshift. Exposure was defined both categorically (exposed or nonexposed) and continuously (actual level of dust or endotoxin). The confounding variables of age, height, gender, and smoking were adjusted for in each model.

Environmental assessment revealed a bimodal dust exposure distribution with a narrow (threefold) range. Workers were arbitrarily divided into high-exposure and low-exposure groups for both total dust and endotoxin levels, depending upon the range recorded in their assigned work area. High-exposure elutriated dust levels ranged from 1.07 to 1.57 mg/m^3 meters of air; the low-exposure level range was 0.45–0.06 mg/m^3. Similarly, the high-exposure level for endotoxin was defined as a concentration greater than 100 ng/m^3 of air.

Using the silk workers as a reference group, prediction equations for preshift FEV_1, FVC, and FEF_{25-75} were generated after adjustment for age, height, and smoking. Percent predicted values were obtained and separate regression models for men and women were estimated using previously reported methods (Christiani *et al.*, 1986). Regression models were estimated using the calculations

Females: $FEV_1\ (l) = -0.024 \times \text{age (years)} + 0.032 \times \text{height (cm)} - 1.729$
$FVC\ (l) = -0.010 \times \text{age (years)} + 0.040 \times \text{height (cm)} - 2.972$
$FEF_{25-75}\ (l/s) = -0.050 \times \text{age (years)} + 0.009 \times \text{height (cm)} + 2.971$

and

Males: FEV_1 (l) = −0.029 × age (years) + 0.055 × height (cm) − 0.008 × smoking (pack-years) −4.800

FVC (l) = −0.017 × age (years) + 0.066 × height (cm) − 0.002 × smoking (pack-years) −6.433

FEF_{25-75} (l) = −0.044 × age (years) + 0.035 × height (cm) − 0.024 × smoking (pack-years).

Since only four women were smokers, the model for female-predicted values was based upon 203 nonsmoking silk workers, coefficient of determination (R^2) = 0.52 for FEV_1 and 0.32 for FEF_{25-75}. The model for the men included a term for smoking and was based on 186 silk workers, R^2 = 0.62 for FEV_1 and 0.39 for FEF_{25-75}.

RESULTS

The cotton- and silk-worker populations were similar demographically and had a similar baseline (preshift) pulmonary function (Table 1). Of the original total

TABLE 1
RAW DATA ON EXPOSED AND CONTROL POPULATIONS

	Cotton workers	Silk workers
Number	355	352
Mean age (years) ± SEM	38.43 (10.40)	37.03 (10.45)
Mean work tenure (years) ± SEM	17.14 (10.32)	17.85 (11.56)
Percentage male	47.3	42.3
Percentage smokers	33.24	23.71
Mean average amount smoked (pack-years) for smokers ± SEM	10.03 (10.38)	11.0 (10.30)
Symptom prevalence (%)		
Chronic cough	18.3	6.8*
Chronic bronchitis	21.7	7.1*
Byssinosis	6.8	0*
Pulmonary function		
Mean FEV_1 (l) ± SEM	2.85 (0.70)	2.79 (0.63)
Mean percentage predicted FEV_1 ± SEM	99.8 (13.60)	99.6 (12.44)
Mean FVC (2) ± SEM	3.51 (0.77)	3.40 (0.74)
Mean percentage predicted FVC ± SEM	100.9 (12.40)	100.2 (10.86)
Mean Δ FVC% ± SEM	−1.51 (5.39)	−0.09 (5.47)
Mean Δ FEV_1% ± SEM	−2.07 (5.22)	−0.11 (4.99)*
Mean FEF_{25-75} (l/s) ± SEM (preshift)	2.64 (1.07)	2.68 (0.95)
Mean percentage predicted FEF_{25-75} (preshift)	102.7 (33.03)	103.16
Mean FEF_{25-75} (l/s) ± SEM (postshift)	2.60 (1.07)	2.70 (0.98)
Mean Δ FEF_{25-75} (l/s) ± SEM	−0.03 (0.35)	0.02 (0.37)**
Mean % Δ FEF_{25-75} ± SEM	−0.49 (15.79)	1.40 (13.97)**

Note. SEM, standard error of the mean; FEV_1, forced expiratory volume in 1 sec; FVC, forced vital capacity; FEF_{25-75} forced expiratory flow rate between 25 and 75% of vital capacity.

* $P < 0.01$.

** $P = 0.06$.

*** $P = 0.1$.

cohort of 912 workers, 705 had complete acceptable pre- and postshift data for analysis as well as other spirometric parameters. Of this group, only those with reproducible spirometry ($n = 676$) were included in the analysis of spirometric parameters and 8 workers were dropped from the study because of missing data. While there were more male smokers among the cotton workers with inadequate data, there were no significant differences in smoking history, gender, age, or symptoms between cotton and silk workers in this small group. The final spirometric data analysis represented 76% of those originally recruited and included 676 persons. There was no excess prevalence of byssinotic or otherwise symptomatic individuals in the excluded group and there was nearly equal number of cotton to silk workers excluded. Consequently, removing these individuals from analysis probably did not alter our results.

There were no significant differences in mean age, gender, or mean work tenure between cotton and silk workers included in the analysis. While there was a higher percentage of smokers among the cotton workers (33.23 versus 23.8%) this difference did not achieve statistical significance. The average amount smoked was similar in the two groups.

Symptoms of byssinosis (all grades) were reported by 6.8% of the cotton workers and were absent in the silk workers. The prevalence of chronic cough was greater among cotton than silk workers (18.3 versus 6.9%, respectively), and chronic bronchitis was also more prevalent in cotton workers (21.7 versus 6.9%). The differences in prevalence of each symptom were statistically significant ($P < 0.01$). Smoking cotton workers reported symptoms of chronic cough and chronic bronchitis significantly more frequently than nonsmoking cotton workers, but byssinosis was not significantly more prevalent in the smokers.

Baseline preshift mean spirometry was similar in both groups. There were no differences between cotton and silk workers in preshift FEV_1, FVC, FEF_{25-75}, or in predicted percentage values for these parameters. However, the cotton workers demonstrated a greater mean decrement in across-shift FEV_1 and FVC than the silk workers (−2.07 versus −0.05%, respectively; $P < 0.01$). The mean cross-shift change in FEF_{25-75} was also greater in the cotton-exposed than in the silk-exposed cohort and achieved statistical significance (−0.03 versus +0.18, respectively; $P = 0.05$).

Mean FEF_{25-75} in cotton dust-exposed individuals with clinical byssinosis was compared with those without symptoms. There were no significant differences between these groups in either mean baseline FEF_{25-75} or in percentage of change in FEF_{25-75} across a workshift.

Regression analysis of the acute change in spirometric parameters across a workshift is shown in Table 2. When the effects of age, smoking, and gender were accounted for, $\% \Delta FEV_1$ was shown to be strongly associated with cotton dust exposure ($P < 0.0001$). By contrast, regression analysis of the percentage of change in FEF_{25-75} ($\% \Delta FEF_{25-75}$) over a workshift when adjusted for covariates did not show as strong a relationship to cotton dust exposure ($P = 0.07$).

We also examined the pattern of lung function change in the subset of workers exhibiting a drop in FEV_1 of at least 5%. There were no significant differences in

TABLE 2
REGRESSION ANALYSIS OF ACROSS-SHIFT CHANGE IN SPIROMETRIC PARAMETERS IN 676 TEXTILE WORKERS

	% Δ FEV_1		% Δ FVC		% Δ FEF_{25-75}	
Variable	Beta	$P < [t]$	Beta	$P < [t]$	Beta	$P < [t]$
Intercept	9.202	0.16	6.178	0.37	−24.479	0.18
Height	−0.055	0.16	−0.039	0.35	0.168	0.13
Age	−0.016	0.44	−0.008	0.72	0.007	0.91
Smoking[a]	0.450	0.45	1.275	0.04	−1.498	0.37
Gender[b]	0.271	0.69	0.099	0.89	−3.179	0.10
Exposure to cotton[c]	−1.793	<0.01	−1.417	<0.01	−2.026	0.07

[a] Smoking: 0 = no, 1 = yes.
[b] Gender: 0 = female; 1 = male.
[c] Exposure: 0 = silk worker, 1 = cotton worker.

the magnitude of change in FVC or FEF_{25-75} compared with workers exhibiting less than 5% cross-shift FEV_1 change.

We then examined the spirometric data as a function of work tenure was performed. Both silk and cotton worker cohorts were uniformly distributed by gender and number of workers in each of four work–tenure categories. There was a relatively large number of workers with greater than 20 years exposure in each group: 149 cotton workers and 147 silk workers. Acute changes in FEV_1 (% Δ FEV_1) over a workshift in cotton workers with different work tenures were greater than in silk workers (Table 3). As shown by our previous study, a decline in FEV_1 was seen even in cotton workers with fewer than 5 years work experience, and those with longer work tenures experienced progressively greater declines in this parameter. A large difference was noted between cotton and silk workers with between 11 and 20 years experience (−2.2 versus −0.76%, respectively; $P = 0.06$) and was highly significant in those with over 20 years in the industry (−2.52% in cotton workers versus +0.18 in silk workers; $P < 0.01$). While cross-shift FVC tended to decline more as a function of work tenure, the differences between cotton and silk workers were significant only in the greater-than-20-year-work-tenure group.

In contrast, acute changes in FEF_{25-75} over a workshift were present but less impressive (Table 3). In both cotton and silk workers with fewer than 20 years experience no significant differences were found nor was a significant trend toward greater magnitude of decline with increasing tenure noted. In those with over 20 years experience, the cotton workers had a significant decline in FEF_{25-75} over a workshift compared with silk workers (−2.59 + 1.12%, respectively; $P = 0.05$).

Regression analysis of the preshift mean FEV_1 revealed no differences between the cotton and silk workers when age, smoking, and gender were accounted for (data not shown). Similarly, no effect of cotton exposure on the baseline mean FEF_{25-75} was seen in the regression model (Table 4). When smoking history and

TABLE 3
ACUTE CHANGE IN PERCENTAGE OF SPIROMETRIC PARAMETERS IN COTTON AND SILK TEXTILE WORKERS WITH VARIOUS WORK TENURES OVER A WORKSHIFT (SEM, STANDARD ERROR OF THE MEAN)

	Cotton			Silk		
Years worked	n	% Δ	SEM	n	% Δ	SEM
			% Δ FEV_1			
2–5	51	−0.98	0.75	70	0.36	0.69
6–10	60	−1.43	0.63	39	−0.44	0.90
11–20	84	−2.20	0.55	80	−0.76	0.53***
>20	142	−2.52	0.45	145	0.018	0.39*
			% Δ FVC			
2–5	51	−0.26	0.64	70	0.22	0.68
6–10	60	−1.04	0.83	39	−0.89	0.57
11–20	83	−1.24	0.49	80	−1.05	0.63
>20	142	−2.02	0.47	145	0.56	0.48*
			% FEF_{25-75}			
2–5	51	0.96	2.61	70	1.13	1.80
6–10	60	1.15	1.40	39	2.69	2.59
11–20	84	−0.23	1.61	80	1.23	1.20
>20	142	−2.59	1.34	145	1.12	1.16**

* $P < 0.01$.
** $P < 0.05$.
*** $P = 0.06$.

exposure to cotton dust were combined as a single term in a regression model to assess an interaction of these variables on pulmonary function, no significant differences in preshift FEV_1, preshift FEF_{25-75}, or cross-shift change in these parameters were found between cotton and silk workers.

When regression analysis was performed on cotton workers alone, examining

TABLE 4
REGRESSION MODEL FOR PRESHIFT-FORCED EXPIRATORY FLOW RATE BETWEEN 25 AND 75% OF VITAL CAPACITY (FEF_{25-75})

Variable	Outcome: Preshift FEF_{25-75}[a] Beta	$P > [t]$
Intercept	−0.36	0.71
Height	+0.031	<0.01
Age	−0.05	<0.01
Smoking[b]	−0.358	<0.01
Gender[c]	+0.43	<0.01
Exposure to cotton[d]	−0.015	0.80

[a] $R^2 = 0.39$, $n = 676$.
[b] Smoker: 0 = no, 1 = yes.
[c] Gender: 0 = female, 1 = male.
[d] Exposure: 0 = silk worker, 1 = cotton worker.

level of exposure to dust and endotoxin, there was no significant exposure–response relationship for across-shift drop in FEV_1 or FEF_{25-75}.

DISCUSSION

This study of a large cohort of cotton textile workers in the People's Republic of China was undertaken to determine the effects of cotton dust exposure on spiromatic measures of the small airways and to compare these findings with standard spirometry (FEV_1 and FVC) in exposed workers.

The cotton workers experienced a significantly higher incidence of chronic bronchitis and chronic cough, despite similar exposure to cigarette smoking. Typically, bronchitis symptoms represent a process which involves predominantly larger airways such as lobar bronchi. Kamat *et al.* (1981) found a significant relationship between dust exposure and both clinical symptoms and decline in FEV_1 over a 5-year period. Others have found a greater incidence of bronchitis in cotton textile workers with longer work tenures, particularly when respirable dust exposure is high (Zuskin and Valic, 1975).

Confirming the findings of multiple other studies, we found a significant decline in FEV_1 over a workshift in cotton workers, but not in silk workers after adjusting for cigarette smoking. This change became more pronounced with longer work tenure, suggesting a greater degree of airway reactivity with prolonged exposure. Rastogi *et al.* (1989) also found that more significant declines in FEV_1 were noted in cotton workers with more than 10 years of work experience, both in those with byssinosis and in asymptomatic individuals. Haglind *et al.* (1983) found increased bronchial reactivity in 8 of 22 cotton workers, including nonsmokers, but not in control synthetic textile workers. In a longitudinal study of Yugoslavian cotton workers, Zuskin and co-workers (1991) found significantly greater across-shift declines in FEV_1 at a follow-up study after 10 years.

We did not find a significant decline in FEF_{25-75} across shift in our population. In those with greater than 20 years of experience in the cotton textile industry, the unadjusted preshift mean FEF_{25-75} was lower than in silk workers with the same work duration, and this difference achieved statistical significance ($P = 0.05$). But even in cotton workers who manifested symptoms of the byssinosis syndrome, we found no differences in either baseline FEF_{25-75} or percentage of change in FEF_{25-75} across a workshift when compared with nonbyssinotic cotton workers.

In the entire cohort, our regression model revealed no differences in either mean baseline FEV_1 or FEF_{25-75} between the cotton and silk workers when adjusted for smoking, age, and gender. The commensurate drop in FEF_{25-75}, whose value is in part dependent on both the FEV_1 and FVC, does not necessarily represent an independent small airway effect of cotton dust exposure in this cohort. If chronic exposure to cotton resulted in dysfunction of the smaller airways, then we would expect to have seen a difference between these groups, given the relatively larger number of workers with long work tenures. In addition, there was no significant decline in FEF_{25-75} in those individuals with the highest dust and endotoxin exposures. Castellan *et al.* (1987) have demonstrated that elutriated dust does not correlate with spirometric changes in FEV_1 as well as with elutriated endotoxin levels. In our cotton group as a whole, significant across-shift declines in FEV_1, but not in FEF_{25-75}, occurred despite elutriated endotoxin levels well above those at which Castellan and co-workers demonstrated significant changes in FEV_1. The fact that such an effect was not seen argues that long-term cotton dust exposure produces mainly chronic bronchitis and, unlike smoking, does not have a profound antecedent effect on small airways.

Similar observations have been described by other investigators performing clinical studies of the acute effects of cotton dust exposure. Merchant and co-workers (1975) studied pulmonary function in 12 cotton workers who demonstrated across-shift declines in FEV_1. They found no consistent decline in $FEF_{50\%}$ or $FEF_{75\%}$ in response to increasing concentrations of inhaled cotton dust. There were no workers with abdominal closing volumes and only three with an abnormal closing capacity as determined by a single-breath nitrogen test compared to standard predicted values at baseline. After cotton dust inhalation there were no significant changes in either of these parameters of small airway function. Haglind *et al.* (1983) evaluated small airway function in 22 cotton workers using single-breath nitrogen washout curve parameters (the slope of phase III of the nitrogen washout curve and the ratio of closing volume to vital capacity, CV/VC) and spirometric measures ($FEF_{50\%}$). There were no significant abnormalities in any of these parameters in either asymptomatic or bissynotic workers with significant across-shift declines in FEV_1.

In contrast to these clinical studies, few epidemiologic investigations have addressed the issue of small airways dysfunction due to cotton dust exposure in cotton industry workers. Beck (1984) performed a cross-sectional analysis of pulmonary function in active and retired cotton textile workers and controls never exposed to cotton dust. FEV_1, FVC, MEF_{50}, and MEF_{25} were affected by both cotton dust exposure and smoking and were often additive. However, when each exposure effect was examined, it was cotton that was associated with greater declines in FEV_1 and FVC and smoking with declines in MEF_{50} and MEF_{25}. This suggests that cotton dust may predominantly affect a different site in the airways than smoking does. Using a parameter of small airway function derived from flow–volume spirometry, Schachter and colleagues (1984) evaluated differences between 477 cotton workers from Columbia, South Carolina, and a demographically similar group of 932 controls. They found no differences between nonsmoking cotton workers and nonsmoking controls, but noted a synergistic effect between cotton dust exposure and smoking in producing an abnormal flow–volume curve. In a 4-year longitudinal follow-up study of 1817 cotton–textile industry workers, Glindmeyer *et al.* (1991) reported a greater annual decline in FEF_{25-75} in synthetic textile workers than in cotton workers, although a significant dose–response relationship was present in the cotton-exposed group. They also found a strong interaction between cotton dust exposure and smoking history in annual declines in lung function. Although our study design was somewhat different, our population's overall smoking prevalence, intensity, and cumulative pack-years were lower and we did not find any interactive effect of smoking on cotton dust exposure resulting in greater change in preshift or across-shift pulmonary function in our cohort.

Support for the conclusion that cotton dust is not identical to cigarette smoke on larger airways is provided by pathologic investigation of the lungs of cotton exposed workers. Edwards and co-workers (1975) performed a pathologic study of the lungs of 43 individuals with a history of byssinosis dying of unspecified causes. A significant increase in smooth-muscle and mucous-gland hypertrophy was noted in upper and lower lobar bronchi, but no significant changes were found in segmental bronchi. Eosinophilic infiltration and fibrosis were absent as well. There are no studies which directly correlate pulmonary function in cotton textile workers with pathologic grading of airway involvement, as is the case for smoking-related bronchiolitis and bronchitis (Cosio, 1984; Mullen *et al.*, 1987). The precise pathophysiology of this effect of cotton dust on the airways is as yet unclear and remains a topic of investigation.

Our study does have some limitations that mandate caution in interpretation of the results. Disease prevalence may be underestimated in cross-sectional studies by a self-selection of the cohort of workers who are more severely affected. While such a "healthy worker" effect may be present to some extent in our population, the low turnover of the workforce in China diminishes this factor to some extent.

The cross-sectional design of this study does not allow for estimation of the incidence of chronic airway obstruction in this population. However, it does permit conclusions about the pattern of lung function abnormality in cotton-exposed workers as determined spirometrically to be made. We found that FEF_{25-75} did not discriminate between cotton-exposed and nonexposed workers. One possible explanation is that cotton dust affects predominantly larger airways, as is suggested by the limited pathologic data available (Edwards, 1984). However, given the fact that a considerable fraction of cotton dust is highly respirable, one would expect a more diffuse distribution of involvement in the airways. Indeed, the significant drops observed in FVC probably reflect premature small airway closure in these workers. The variability of measurements of spirometrically determined small airway parameters such as FEF_{25-75} is considerably greater than that of FEV_1 and FVC and is subject to greater interpretative error (Wright *et al.*, 1992). Even after employing the digitizing method of O'Donnell *et al.* (1987) to increase resolution and accuracy, significant intersubject variation occurs and the parameter is sensitive to changes in lung volume. Spirometric measures of small airway function may not be sufficiently sensitive or specific for the detection of abnormalities in bronchioles in organic dust exposure.

The results of our study have implications for medical surveillance or organic dust-exposed populations. Based on our findings, it appears to be adequate to monitor FEV_1 and FVC alone as spirometric indicators of overall lung function. The absence of an effect of exposure to cotton dust on small airway function makes screening parameters such as FEF_{25-75} unnecessary. Spirometric equipment for measuring flow–volume loops from which these parameters are derived may be more expensive and require more maintenance than simple devices such as volume spirometers. These considerations are particularly of concern in developing countries with limited funding for screening programs and possibly limited access to medical equipment-servicing facilities.

CONCLUSIONS

We conclude that exposure to cotton dust is associated with an acute decline in

FEV_1 and FVC, but not FEF_{25-75}. We believe our results support the conclusion that obtaining the FEV_1 and FVC alone is an adequate and cost-effective approach to monitoring the physiologic status of workers in this industry.

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