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Medical and Industrial Hygiene Characterization of the Cotton Waste Utilization Industry

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We studied 260 workers in the cotton waste utilization industry and 310 "blue-collar" control workers from nondusty industries in the same geographic area of the United States by respiratory symptom questionnaire and by pre- and postshift spirometry. We excluded 75 cotton workers and 75 control workers from statistical analysis because of prior hazardous occupational exposures. Plant-wide, 8-hour time-weighted average exposures ranged from 0.28 mg/m^3 to 7.80 mg/m^3. The overall prevalence of symptoms compatible with byssinosis was 5.9% in cotton workers and 4.7% in the controls. Cotton workers with less than 2 years of employment had a significantly greater prevalence of bronchitis than their control counterparts. The cotton workers with 2 years or more of employment had significantly greater prevalences of bronchitis, shift decrement in forced expiratory volume in 1 second (FEV_1) of $\geqslant$ 10%, and FEV_1/FEV_1-predicted $<$ 80%, than their control counterparts. Regression analysis showed that for matched cotton and control workers, the percentage decrement in FEV_1 over the shift was significantly greater for cotton workers; and that in all cotton workers, longevity in industry had a negative effect on the before-shift forced vital capacity (FVC). This study suggests that there are both acute and chronic effects of cotton exposure in the cotton waste utilization industry.

Key words: cotton dust, byssinosis, cotton waste utilization industry, pulmonary disease, bronchitis, nontextile cotton industry, bract

INTRODUCTION

Byssinosis is a pulmonary disease with a unique clinical progression that has been found in workers occupationally exposed to certain organic dusts. Originally

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described by Ramazzini in flax workers [Wright, 1964], it has been characterized in hemp and cotton workers as well. The natural progression of the disease was described by Schilling [Schilling, 1950; Schilling et al, 1963].

Most studies of byssinosis in more recent times have been done in textile mills. The studies by Schilling and his coworkers in the past 30 years were done almost exclusively in textile mills in England [Schilling, 1950; Roach and Schilling, 1960; Schilling, 1956; Schilling et al, 1955]. In this country the major investigations have been in textile mills in the southern states. The studies in the United States generally confirm the British findings that the prevalence of byssinosis is higher in the early stages of textile manufacturing (such as carding) than in later stages (such as spinning) [Zuskin et al, 1969; Schrag and Gullett, 1970; Imbus and Suh, 1973; Merchant et al, 1972, 1973]. Since the dust generated in the early stages comes from cotton that has not been thoroughly "cleaned" of its nonfibrous components, the question has been raised as to the prevalence of byssinosis and other pulmonary abnormalities in nontextile sectors of the cotton industry, in which nonfibrous materials constitute a significant portion of the cotton raw material. One such sector is the waste utilization industry, where waste cotton from textile mills and other sources is cleaned and processed for further use. The National Institute for Occupational Safety and Health (NIOSH) conducted a cross-sectional morbidity and industrial hygiene study of this industry. Its purpose was to assess the prevalence of byssinosis, bronchitis, and lung function impairment, and to measure qualitatively and quantitatively dust exposure, and to determine dose–response relationships.

Description of the Cotton Waste Utilization Industry

Cotton waste processing establishments use fibrous waste from various sources, and, thus, do not have a uniform raw material. Some of the sources of material include gin motes, oil mill motes, linters, and soft cotton mill wastes from textile mills. Soft cotton mill wastes refer to a variety of cotton materials obtained from textile mills processing raw cotton, including mill motes, strips, sweeps, card fly, and filter waste. Also mixed in are fragments of cotton plant parts (bract, stem, leaf, seed, etc.) as well as dirt and, in some instances, rocks and large objects like cans and disposable respirators.

The process of utilizing waste begins with the opening of bales of waste. Many plants have a manual processing area where employees sort out large objects such as bottles, rocks, and oily material. Smaller objects, such as pebbles and stems, bracts, leaves, and capsule components, are removed by machine cleaning. Willow machines open clumps of material and blending machines mix different grades of material to produce a relatively uniform product, which is then sold for making other products, such as mattress pads, automobile upholstery pads, mop yarn, rope, medicinal cotton, sanitary napkins, diesel locomotive filters, air filters, and coarse yarn.

Typical job categories include bale press operators, hand sorters, openers and feeders, sweepers, fork-lift operators, maintenance workers, supervisors, and managerial and office staff. Some workers, such as bale press operators and hand sorters, generally stay at their positions during a working day. Others, such as openers, are semimobile, and may occasionally move around to clean and sweep up. Maintenance workers, fork-lift operators and supervisors are highly mobile and may work in several different areas during a shift.

Morey [1979] examined the composition of materials used in the garnetting and waste utilization industries. Type of material analyzed included first cut linters from cottonseed oil mills and picker (a baled waste fiber obtained after opening) from textile mills. The amount of bract in the linters was minimal. However bract constituted a significant proportion of the trash in picker and other raw materials used in the garnetting and waste utilization industries. Other studies have shown an adverse pulmonary function effect of cotton dust generated during garnetting of waste cotton [Simpson, 1970; Holness et al, 1983]. Thus similar adverse effects may occur in the waste utilization industry.

MATERIALS AND METHODS

Selection of Cotton Waste Utilization Workers

We indentified 19 waste utilization plants as members of a trade association of waste processors. Six of these processed waste from synthetic textile mills exclusively, and therefore these plants were not studied. A significant portion of the raw material for the remaining 13 plants was cotton waste. However, because the proportion of synthetic material varied considerably within each plant over time, all 13 plants were treated equally as potential sites of cotton dust exposure. NIOSH visited each plant to determine who among the employees were exposed to dust from the waste utilization process. Participation in this study was completely voluntary. The goal was to study 100% of the "at risk" persons identified.

In total, we studied 260 workers in these 13 plants. Although accurate records of nonrespondents were not kept, the participation rate was estimated to be well over 90% at each plant. Generally those who did not participate were off work on the day of the study. Only two persons who were present refused to participate.

Medical Survey Methods

The cotton waste utilization workers were examined on the first day back, which in this industry was always Monday. We visited eight of the plants between mid-May and the end of July in 1978; we visited the remaining five between early February and mid-March, 1979. Each worker was examined initially before he or she began working and was reexamined 6–8 hours later. At the before-shift examination, trained NIOSH interviewers administered to each subject a standardized questionnaire for respiratory symptoms based upon the British Medical Research Council (MRC) Questionnaire on respiratory symptoms, modified for byssinosis. Each subject, while standing, attempted at least five forced expiratory maneuvers into an Ohio 840 waterless electronic spirometer. The postshift spirometric procedures were identical to the preshift. An oscilloscope instantaneously produced a record of each flow-volume curve, giving the technician an immediate check on each subject's effort and performance. The spirometry data were corrected for body temperature, pressure saturated with vapor (BTPS), and were stored directly on tape. For each individual the largest forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1) at each session were used in the analysis.

Definitions of Symptoms and Methodologic Problems

The grading scheme of Schilling [Schilling et al, 1963] was used as the basis for the definition of byssinosis, and the definition of bronchitis was persistent cough or phlegm on most days for as much as 3 months each year. The workers were divided into smoker, nonsmoker and exsmoker categories.

In some plants the questions designed to elicit periodic cough were inadvertently not asked. It was decided to grade byssinosis for each person with missing periodic cough data according to his or her responses to the questions on chest tightness and dyspnea. Previous experience has shown that few workers presented with byssinosis only with the symptom of periodic "Monday" cough [Merchant et al, 1973]. In the first nine plants the questions on present chest tightness were worded in such a way to force a subject to respond positively only if he/she experienced chest tightness after a week or 10 days away from the job. Since we were clearly interested in documenting chest tightness after only 2 days off from work, the wording of the question was corrected, but only in the last four plants. For analysis purposes we incorporated the positive answers in the first nine plants with the positive answers in the last four plants, despite the differences in the questions that were asked. The overall effect of this error would be to diminish the sensitivity of our questions to elicit the symptoms of byssinosis, and thus potentially to underreport the true prevalence of this condition.

Environmental Sampling Procedure

The environmental sampling procedure is described in detail in Zey et al [1984]. To provide exposure data for comparison with the data from the medical evaluations, sampling commenced when preshift pulmonary function testing was initiated and was stopped after postshift medical tests were completed. Because many waste cotton workers worked only intermittently in any given work station, several vertical elutriators were located strategically to collect samples that would reflect worker exposure during the work shift. At a minimum, two vertical elutriators were positioned in each distinct operational area of the plant where workers normally worked. Additionally, at least one vertical elutriator was placed in each distinct nonwork area, such as the lunch room, in which the workers entered for significant periods.

The work patterns and movements of each medical test participant were observed and recorded by the industrial hygiene personnel. Each employee was assigned the average dust concentration as measured by the vertical elutriators located in that area of the plant where the employee had spent some time. The interval exposures were then cumulated for the entire survey period and a time-weighted average (TWA) exposure of each worker determined.

Selection of Control Subjects

"Blue collar" workers not exposed to dusts or chemicals known to have adverse effects on pulmonary function served as a comparison group for NIOSH's study of five nontextile cotton industries, including the waste utilization industry. All the cotton waste utilization plants included in this study were in the Southeast region of the United States (the Carolinas, Georgia, Florida, and Mississippi). Therefore, only controls in the Southeast were used as a comparison group.

From lists of major employers in all cotton-belt states, NIOSH industrial hygienists selected plants that they felt would have processes in which exposures to dusts and other lung irritants would be low, and whose workforces appeared to match socioeconomically the workforces in the nontextile cotton plants that were studied. If after a "walk-through" the industrial hygienists felt a plant was acceptable, environmental monitoring was done to assess more accurately the qualitative and quantitative exposures. This monitoring included personal respirable dust sampling, area sampling using direct-reading instruments for respirable dust concentration, vertical elutriators and pump-cyclone assemblies, and charcoal tubes for organic solvents and detector tubes for gases. The environmental monitoring indicated minimal vapor, gas, and particulate exposures, well below established threshold limit values, or no exposure at all.

For the most part the methodology of the cotton study was duplicated for the controls. However, there were some important exceptions. Because the control population was selected to serve as a comparison group for other nontextile industries as well as the cotton waste utilization industry, and because most cotton workers in other industries were male, quite often female workers in the control plants were not asked to participate. Furthermore, it was difficult to assess the participation rate of the control workers, who worked in industries in which exposures to dust were not of concern. The participation rate at some plants may have been as low as 75%. In addition it was not feasible to examine the control workers on the first day back to work. The assumption was made that changes in pulmonary function related to exposure to biologically active dusts would be negligible in the control plants.

Finally, the methodological problems with the questionnaire that may have diminished the sensitivity of detecting byssinosis in the cotton workers did not occur in the control workers.

Statistical Analysis

Before the data were analyzed, some of the cotton and control workers were excluded if they had prior occupational exposure to cotton dust from other cotton industries (textile mills, gins, oil mills, etc.) and/or to industries or trades in which exposure to harmful dusts is possible, for a total of at least 5 years or at least one-half of the total working life of the employee. Based on this criterion 75 cotton workers and 75 control workers were excluded, leaving 185 cotton workers and 235 control workers on whom the analysis was performed.

Data on categories of byssinosis and bronchitis were treated as discrete and analyzed by tests of proportions. When expected proportions were large enough, the chi-square test was used; when the expected proportions were small, the Fisher's exact test with two-tails was used.

Matching by age and smoking status was done to minimize the effects of the two independent variables most closely associated with both bronchitis and byssinosis. Within the cotton workers this matching was done by dividing the workers into three groups of nearly equal size according to longevity in industry, < 2 years, 2–7 years, > 7 years. Within each longevity group, nine age/smoking status cells were constructed ($\leqslant 25$ years, 26–45 years, > 45 years, by nonsmoker, exsmoker, and smoker). Three sets of matched individuals were chosen (< 2 years matched with 2–7 years; < 2 years matched with > 7 years; and 2–7 years matched with > 7 years) by randomly eliminating enough individuals from the longevity group with the larger number in each age/smoking status cell, to produce equal numbers for both longevity groups in each cell. If one or another pulmonary function value was missing for an individual selected in the match, that individual, along with a randomly selected counterpart, was eliminated in the pulmonary function analyses. Matching of cotton workers to controls was accomplished analogously.

The pulmonary function data were treated as both discrete and continuous data. The data were grouped according to FEV_1/FEV_1-predicted ratio of $< 80\%$ or $\geqslant 80\%$ and according to an over-the-shift decrement in $FEV_1 \geqslant 10\%$ or $< 10\%$. The predicted values of FEV_1 to which the cotton workers were compared are from Knudson et al [1976]. Since these values are predicted only for whites, the predicted FEV_1 values were multiplied by 0.9 for black subjects [Abramovitz, 1965; Damon 1966; Lapp et al, 1974; Rossiter and Weill, 1975].

As continuous data the pulmonary function indices were analyzed by linear models methods. The dependent pulmonary function indices were before-shift forced vital capacity (BFVC) and forced expiratory volume in 1 second (BFEV), as well as the over-shift change in forced expiratory volume in 1 second (DFEV) and the percentage change in the 1-second forced expiratory volume (PFFEV). All dependent variables were regressed on age, race, sex, and height, as well as variables of particular interest, such as longevity in industry, and dust measurement. The partial sum of squares for each regression variable was calculated by the General Linear Models Program of the Statistical Analysis System software package. If the p value was less than 0.05, the estimated regression coefficient for that independent variable was computed to see the direction of its effect. Regressions were done on all subjects on whom information about all the independent variables was known. Thus, the number of degrees of freedom varied depending upon the regression model used.

RESULTS

Dust Levels in the Cotton Waste Utilization Plants

Table I shows the 8-hour, time-weighted average exposures for workers in the cotton waste plants, and the data from which these plant-wide averages are derived are used in subsequent dose-response calculations. Clearly there were wide variations

TABLE I. Eight Hour Time-Weighted Average (*mean and standard deviation*) Exposure to Cotton Dust by Plant (in milligrams per cubic meter)

Plant	Number of samples	Mean	STD
1	11	.64	.21
2	9	2.17	2.08
3	3	.28	.07
4	8	.57	.93
5	8	.93	.45
6	11	.46	.21
7	19	.54	.46
8	18	4.11	3.91
9	15	7.80	7.92
10	6	.51	.21
11	42	1.58	1.04
12	6	1.08	.52
13	13	.45	.28

in time-weighted average dust levels among the plants. Mean elutriated dust levels by plant and plant area are found in Zey et al [1984].

Characterization of Cotton Waste Utilization Workers and Control Workers

Table II shows the various attributes of the waste utilization workers who were included in the study and those who were excluded because of previous exposures. The racial make-up of the two groups was roughly equivalent. The "excluded" group had a significantly larger proportion of males and was also significantly older than the "included" group, but both groups had roughly equivalent mean number of years in the industry.

There were a rather high number of "excluded" controls on whom we had no smoking status information (12 out of 75), compared to only 1 out of the 24 "included" controls. The remaining "excluded" controls distributed themselves among the three smoking categories similarly to the "included" controls. The mean age of the "excluded" controls was significantly higher than the "included" controls, but their years in industry were not significantly different.

Comparison of Waste Utilization Workers and Controls

The cotton group was significantly older, and had significantly more blacks and women than the control group, necessitating correction for age, race, and sex in the regression analyses of pulmonary function. The cotton workers had a lower mean longevity in industry than the controls, although not significantly so.

Table III compares the prevalences of byssinosis, bronchitis, and the dichotomized pulmonary function indices in newly-employed cotton and control workers (< 2 years), and in longer-tenured cotton and control workers ($\geqslant 2$ years). The prevalences of bronchitis were small and not significantly different. The newly employed cotton workers had significantly more bronchitis than their control counterparts, among all workers as well as among nonsmokers alone. The newly employed cotton workers had an insignificantly greater prevalence of over-shift decrement in $FEV_1 \geqslant 10\%$. When the workers with $\geqslant 2$ years of employment were compared, cotton workers had a significantly greater prevalence of bronchitis than the controls. The same pattern was found for nonsmokers, but this just missed significance ($p = 0.06$). The difference between the prevalences of FEV_1/FEV_1-predicted $< 80\%$ was significant, as was the difference between the prevalences of the FEV_1 decrement of $\geqslant 10\%$.

The pulmonary function data on the set of age/smoking-matched cotton workers and control workers were regressed on a number of independent variables. Table IV shows the results of the absolute (DFEV) and percentage (PFFEV) acute shift changes in FEV_1. For these indices the effect of plant (the facility in which an employee worked), which was nested within group (cotton worker or control worker) was significant. In addition, for the PFFEV there was still a significant effect of group. The least square means for PFFEV were -3.14% for the cotton group and $+0.53\%$ for the control group. For the before-shift FVC (BFVC) and FEV_1 (BFEV) the effect of group was not significant and the nested plant effect just missed significance ($p = 0.053$, not shown in Table IV).

Comparison Within the Control Workers

Table III shows the results of the symptoms and dichotomized pulmonary function data for the control workers. The overall prevalence of byssinosis was 4.7%

TABLE II. Comparison of Cotton Utilization Workers and Control Workers Included and Excluded From Analysis

Attribute	Cotton workers Included (A) (N = 185)	Cotton workers Excluded (B) (N = 75)	Significance (A vs B)	Control workers Included (C) (N = 235)	Control workers Excluded (D) (N = 75)	Significance (C vs D)	Significance (A vs C)
Race							
White	50 (27.0%)	22 (29.3%)		92 (39.1%)	35 (46.7%)		
Black	134 (72.4%)	53 (70.7%)	n.s.	143 (60.9%)	39 (52.0%)	n.s.	$p < 0.01$
Other	1 (0.5%)	0 (0%)		0 (0%)	1 (1.3%)		
Sex							
Male	114 (61.6%)	64 (85.3%)	$p < 0.01$	226 (96.2%)	68 (90.7%)	n.s.	$p < 0.01$
Female	71 (38.4%)	11 (14.7%)		9 (3.8%)	7 (9.3%)		
Smoking status							
Ex-Smoker	28 (15.1%)	5 (6.7%)		35 (14.9%)	8 (10.7%)		
Nonsmoker	61 (33.0%)	22 (29.3%)	n.s.	67 (28.5%)	19 (25.3%)	n.s.	n.s.
Smoker	93 (50.3%)	48 (64.0%)		122 (51.9%)	36 (48.0%)		
Unknown	3 (1.6%)	0 (0.0%)		11 (4.7%)	12 (16.0%)		
Pack years of smoking (Mean ± S.D.)	8.1 ± 13.5 (n = 179)	17.1 ± 22.4	$p < 0.01$	8.7 ± 13.8 (n = 221)	12.3 ± 16.4 (n = 62)	n.s.	n.s.
Age (years) (Mean ± S.D.)	35.8 ± 14.1	43.1 ± 12.9	$p < 0.01$	31.6 ± 11.6	37.3 ± 10.5	$p < 0.01$	$p < 0.01$
Height (cm) (Mean ± S.D.)	172.6 ± 9.8	177.1 ± 9.3	$p < 0.01$	175.8 ± 7.5 (n = 231)	173.9 ± 7.0 (n = 73)	n.s.	$p < 0.01$
Years in industry (Mean ± S.D.)	7.1 ± 8.4	6.5 ± 5.8	n.s.	8.1 ± 8.6 (n = 217)	7.3 ± 6.0 (n = 63)	n.s.	n.s.

TABLE III. Prevalence of Byssinosis, Bronchitis, FEV_1/FEV_1-Predicted $<80\%$ and Over-Shift Decrement of $FEV_1 \geqslant 10\%$ in Cotton and Control Workers, by Longevity in Industry

	Longevity in industry				Significance			
	<2 years		$\geqslant 2$ years					
	Cotton (A)	Controls (B)	Cotton (C)	Controls (D)	(A vs C)	(B vs D)	(A vs B)	(C vs D)
Byssinosis	3/53 (5.7%)	3/44 (6.8%)	8/132 (6.1%)	7/171 (4.1%)	n.s.	n.s.	n.s	n.s.
Bronchitis								
All workers	22/53 (41.5%)	9/42 (21.4%)	26/132 (19.7%)	19/171 (11.1%)	$p < 0.01$	n.s.	$p < 0.05$	$p < 0.05$
Nonsmokers	9/18 (50.0%)	0/15 (0%)	8.43 (18.6%)	2/49 (4.1%)	$p < 0.05$	n.s.	$p < 0.01$	n.s.
FEV_1/FEV_1-Predicted $<80\%$								
All workers	7/53 (13.2%)	2/44 (4.6%)	25/131 (19.1%)	17/167 (10.2%)	n.s.	n.s.	n.s.	$p < 0.05$
Nonsmokers	2/18 (11.1%)	2/16 (12.5%)	4/42 (9.5%)	2/48 (4.2%)	n.s.	n.s.	n.s.	n.s.
Over-shift decrement of $FEV_1 \geqslant 10\%$								
All workers	7/47 (14.9%)	2/40 (5.0%)	13/113 (11.5%)	4/167 (2.4%)	n.s.	n.s.	n.s.	$p < 0.01$
Nonsmokers	2/17 (11.8%)	0/15 (0%)	1/39 (2.6%)	3/47 (6.4%)	n.s.	n.s.	n.s.	n.s.

TABLE IV. Change in FEV_1 Over-Shift (DFEV) and Percentage Change in FEV_1 (PFFEV) Regressed on a Number of Variables for Matched Cotton and Control Workers

Source	Degrees of freedom	DFEV significance	PFFEV significance
Mask worn (yes/no)	1	n.s.	n.s.
Group (cotton or control)	1	n.s.	$p < 0.05$[a]
Plant effect within group	16	$p < 0.05$	$p < 0.05$
Change in spirometer temperature over-shift	1	n.s.	n.s.
Smoked before spirometry[b]	2	n.s.	n.s.
Number of cigarettes smoked during shift	1	n.s.	n.s.
Error	263		

[a]Significantly greater decrement in cotton workers.
[b]Three categories: (1) Smoked within 1 hour before "before"-shift spirometry but did not smoke before "after"-shift spirometry; (2) smoked within 1 hour before "after"-shift spirometry but did not smoke before "before"-shift spirometry; (3) smoked within 1 hour before both spirometries or did not smoke within 1 hour of both spirometries.

(10/215), with no significant difference between the newer and older employee groups.

The overall prevalence of bronchitis was 13.1% (28/213), with more new control employees reporting symptoms of bronchitis, but the difference was not significant. Among nonsmokers, no new employees had symptoms of bronchitis. Finally, the differences in the prevalences of over-shift decrements in $FEV_1 \geqslant 10\%$ and of FEV_1/FEV_1-predicted $< 80\%$ were not significant.

Comparisons Within the Cotton Waste Utilization Workers

The prevalence of byssinosis among all cotton workers was 5.9% (11/185). Ten persons reported grade 1/2 symptoms and only one person reported grade 1 symptoms; no one reported grade 2 symptoms. The individual with grade 1 symptoms was a 21-year-old smoker who had worked 3 years as a bale pressman. He also reported symptoms of chronic bronchitis. Table III shows no significant difference in the prevalences of byssinosis by longevity-in-industry dichotomized at 2 years. There was no relationship observed between the prevalence of byssinosis and smoking status, age, or time-weighted average respirable dust exposure.

The overall prevalence of bronchitis was 25.9% (48/185). Table III also shows that there was significantly more bronchitis in workers with less than 2 years of employment than in workers with more than 2 years. This relationship held true as well for nonsmokers.

The overall prevalence of FEV_1/FEV_1predicted $< 80\%$ was 17.4% (32/184). Workers with less than 2 years and greater than or equal to 2 years of employment had roughly the same prevalences. The overall prevalence in shift decrement of

$\geqslant 10\%$ was 12.5% (20/160). In the employees with less than 2 years of employment it was 14.9% (7/47) and in the employees with greater than or equal to 2 years of employment it was 11.5% (13/113). In nonsmokers the prevalences were 11.8% (2/17) and 2.6% (1/39), respectively. None of these differences was statistically significant.

The before-shift forced vital capacity (BFVC) and before-shift forced expiratory volume in 1 second (BFEV) were regressed on a set of independent variables (Table V). Elutriated dust measurement (DUST), longevity in the industry (YEARS), and the interaction (DUST–YEARS) of these two, together represent a model of exposure. In this model, exposure was significantly related to BFVC, but not to BFEV, although within the overall model of exposure, the interaction (DUST–YEARS) component was significant for BFEV. That is, as DUST-YEARS increases, so did BFVC and BFEV. Based on this finding, we developed tables of hypothetical long-term decreases in these before-shift pulmonary functions using the estimated coefficients of RESP, YEARS, and DUST-YEARS. Table VI(a and b) shows the results at four dust levels and at six longevity periods. The long-term hypothetical decrements for both the BFVC and BFEV were greater for each dust level as longevity in industry increased. The long-term hypothetical decrements for BFVC and BFEV grew larger below 2 years of employment with increasing dust levels. By the second year and beyond, the decreases grew smaller with increasing dust levels.

When, for the cotton workers only, the absolute change in the FEV_1 over the shift (DFEV) and the percentage change in FEV_1 over the shift (PFFEV) were regressed on a set of variables similar to those found in Table IV, exposure was not significantly related to DFEV or PFFEV; however, plant did have a significant effect on the DFEV (not shown in a table). Since a plant effect had arisen in a number of

TABLE V. Regression of Before-Shift Forced Vital Capacity (BFVC) and Forced Expiratory Volume (BFEV) in Waste Cotton Workers on a Number of Variables

		BFVC			BFEV		
Source	Degrees of freedom	Significance	Exposure model	Estimate of coefficient for continuous variables (if $p < 0.05$)	Significance	Exposure model	Estimate of coefficient for continuous variables (if $p < 0.05$)
Plant	12	$p < 0.01$			n.s.		
Mask worn (yes/no)	1	n.s.			n.s.		
Sex	1	$p < 0.01$			$p < 0.01$		
Race (white, black, other)	2	$p < 0.01$			$p < 0.05$		
Age	1	$p < 0.01$		−0.017	$p < 0.05$		−0.026
Height	1	$p < 0.01$		0.051	$p < 0.01$		0.038
Pack years of smoking	1	n.s.			n.s.		
Temperature of spirometer before shift	1	n.s.			n.s.		
Elutriated dust measurement (DUST)	1	n.s.			n.s.		
Years in industry (YEARS)	1	$p < 0.05$	$p < 0.01$	−0.020	n.s.	n.s.	
Interaction (DUST–YEARS)	1	$p < 0.01$		0.009	$p < 0.05$		0.004
Error	139						

TABLE VI. Predicted Long-Term Decreases in Before-Shift FVC and FEV_1 (in Milliliters) by Elutriated Dust Measurements and Years in Industry in Cotton Waste Utilization Workers[a]

(a)

Years in industry	Decreases in before shift FVC dust measurement (mg/m^3) 0.05	0.2	0.5	1
0	−0.6	−2.6	−6.4	−12.9
1	−19.9	−20.5	−21.7	−23.8
2	−39.1	−38.4	−37.0	−34.8
5	−96.9	−92.2	−83.0	−67.7
10	−193.1	−181.9	−159.6	−122.5
20	−385.5	−361.3	−312.8	−232.1

Equation Y = −12.9 (DUST) − 19.7 (YEARS) + 8.7 (DUST-YEARS)[b]

(b)

Years in industry	Decreases in before shift FEV_1 dust measurement (mg/m^3) .05	0.2	0.5	1
0	−0.2	−0.9	−2.3	−4.6
1	−6.2	−6.3	−6.4	−6.6
2	−12.1	−11.6	−10.5	−8.7
5	−30.0	−27.6	−22.8	−14.9
10	−59.8	−54.3	−43.4	−25.1
20	−119.3	−107.7	−84.5	−45.7

Equation Y = −4.6 (DUST) − 6.2 (YEARS) + 4.1 (DUST-YEARS)[b]

[a]After correction for effects of plant, mask use, sex, race, height, age, pack-years, and spirometer temperature.

[b]DUST, elutriated dust measurement; YEARS, years in industry; DUST–YEARS, interaction of dust measurement and years in industry.

the regression analyses, through the use of the least significant difference technique of comparing least square means and by checking on dates of examinations and the specific technicians who conducted spirometry, we attempted to find any obvious reasons for the plant effect. We could not find any seasonal effect or evidence of technician bias. We also compared the least square mean DFEV for each plant with certain characteristics of the material being processed on the day of the study at each plant (Table VII). Much of the information was not obtained and, therefore, this analysis is incomplete. However, it is of interest that plant 8, which had the largest mean shift drop in FEV_1 (−3.3 liters) also had relatively high elutriated dust measurements and the smallest mass median diameter. Also of interest is that plant 1, with a small absolute mean shift drop, used raw materials with high bract and leaf content.

DISCUSSION

The overall prevalence of byssinosis in the cotton waste utilization workers was 5.9%, which was only slightly greater than the prevalence in the controls. This prevalence is well below the prevalences reported in most rooms in textile mills in both England and the United States. Two studies from England that were done in establishments resembling the American cotton waste utilization industry also had higher prevalences of byssinosis. Dingwall-Fordyce and O'Sullivan [1966] published the results of a study done in the early 1950's in the cotton waste utilization industry to determine whether workers in this industry were eligible for benefits as a result of byssinosis. In 140 workers over 35 years of age with at least 10 years of work experience and who had no other work experience, 5% had "disabling" byssinosis and 25% had lesser degrees of byssinosis ("Monday feeling"). Chinn et al [1976] studied five "willowing mills" in England, which used some of the same types of raw material as the American cotton waste operations. Although 53% of the workers had bronchitis, only 3/60 (5%) of the subjects had byssinosis (all grade 1/2), and two of the three of these persons had worked less than 5 years. Their conclusion was that "selection" had taken place and a survivor population remained. Alternatively they suggested that the raw material obtained from conventional textile mills no longer contained any "byssinogenic" agent.

Our 5.9% prevalence bears a striking similarity to the findings of Chinn et al [1976]. There are a few possible reasons for our obtaining such a low prevalence. The first is methodologic. The first nine plants surveyed, including plants 8 and 9, which had the highest mean time-weighted average dust levels, had the erroneously worded questionnaire regarding chest tightness. Compounding this problem was the failure to ask the questions on periodic cough at some plants. More cases of byssinosis may have been uncovered had these methodologic problems not occurred.

A second possibility is that, as Chinn et al [1976] postulated, the raw material may be sufficiently different from the raw materials used by textile mills that the "byssinogenic" agent(s) is missing, or is not bronchoreactive. Our limited qualitative analysis of the dusts in waste utilization plants suggests that the particles were larger, with a range of mass median diameters of 3.8–8.5 μm, than the particles generally found in textile mills, with a range of 1.82–3.40 μm [Hatcher, 1975]. Thus, the dust in the waste utilization plants may not penetrate so deeply into the lungs as dust in the textile mills.

The sections of the questionnaire relating to bronchitis were not beset with any of the methodological problems that affected the byssinosis questions. Thus the prevalences of bronchitis are most likely quite accurate. One possible reason for greater prevalences in the newly-employed workers might be overreporting of symptoms by these individuals. However, other studies in both the cotton industry [Merchant et al, 1972] and other dusty industries [Fairman et al, 1977] generally show an increase in prevalence of bronchitis in older workers. Our study shows that there was no bronchitis reported in nonsmoking, newly-employed control workers. A possible reason for this is that the cotton workers with less than 2 years of employment came from a different socioeconomic group than the control workers with less than 2 years of employment, and therefore may have come from a group with a greater nonoccupational prevalence of bronchitis. Although we did not document closely any indices of the socioeconomic status of the cotton workers and the controls, we did select the controls based upon region of the country and wage scales similar to the cotton workers. Thus, we have little reason to believe that the cotton workers with less than 2 years of employment differ from their control counterparts either in their "background" prevalence of bronchitis or in their propensity to overreport bronchitis symptoms.

Tables V and VI(a and b) are somewhat difficult to interpret. Table V shows significant effect of years in industry on FVC. The trends toward increasingly larger predicted long-term decrements in before-shift FVC and FEV_1 as dust increases in 0–1 years of employment, and toward increasingly smaller predicted long-term decrements in FVC and FEV_1 as dust increases in $\geqslant$2 years of employment (Table

TABLE VII. Least-Squares Mean Shift Change in FEV_1 (DFEV), Raw Materials, Elutriated Dust and Mass Median Diameter (MMD), by Plant

Plant	Least-squares mean DFEV (in liters)	Raw material		Elutriated dust (mg/m^3)				MMD (μg)
		Source	Bract or leaf (%)	Bale press	Machine area	Opening/ feed area	Hand processing	
1	−0.01	Sweeps, filters, gin motes	gin motes = 29% sweeps = 15%	0.45	—	—	1.2	—
2	−0.18	Soft cotton, mill wastes—mix	mix = 11%	0.85	6.0	—	—	—
3	−0.09	Sweeps, mill motes	—	0.18	0.19	0.43	—	—
4	+0.03	Strips, mill motes, soft cotton mill	strips = 8% mill motes = 10% mix = 1%	0.57	0.68	0.69	1.7	—
5	−0.25	Strips, mill motes, gin motes, synthetics	—	0.67	1.9	1.8	—	—
6	+0.02	Gin motes, mill motes, hard cotton wastes, synthetics	—	0.54	0.33	0.78	—	—
7	−0.15	Soft cotton mill waste, mix, mill motes, synthetics	—	0.42	3.4	1.0	—	—
8	−0.33	Sweeps, fly, gin motes, oil mill motes, linters, mill motes, strips	—	2.4	4.0	7.8	0.7	3.8
9	−0.17	Strips, fly, mill motes	—	3.0	2.6	10.3	—	—
10	−0.09	Strips	—	0.71	—	1.0	—	6.5
11	−0.01	Gin motes, sweeps, card motes, synthetics	—	0.47	0.92	2.2	—	5.1
12	—	Sweeps	—	1.2	3.5	1.3	—	—
13	+0.01	Soft cotton mill waste mix, hard cotton wastes	—	0.33	1.3	0.58	1.3	8.5

VIa and b) reflect the greater prevalences of abnormalities in newer cotton workers compared either to their control counterparts or to older cotton workers. On the other hand, it is difficult to determine why these trends reverse for older cotton workers. This may be a "selection" process out of the industry, similar to the one suggested by Chinn et al [1976]. However, the findings of increased symptoms of bronchitis and higher prevalences of FEV_1/FEV_1-predicted $<80\%$ in older cotton workers suggest that if "selection" is occurring for health reasons, it may be quite small. Another reason may be the dust measurements themselves. These were 1-day measurements, which may not reflect the long-term exposures experienced by cotton waste utilization workers, especially those with many years of work. Thus the model itself may be weak.

One problem that emerged in this analysis is the plant effect. It was seen in a number of regressions and it had the only significant effect on shift changes of FEV_1 in cotton workers and in the comparison of cotton workers and controls. Jones et al [1979], found a "mill effect" in the analysis of symptom data in their study of cotton textile and synthetic textile mills, and suggested that variations of "biological potency" of the raw material may be responsible. They also suggested other factors, such as varying histories of environmental control procedures at different plants, leading to differences in "survivorship" or to differences of employee enlightenment of lung disease.

The attempts to single out particular plants in this present study showed no clear results. Our plant effect was found in the analysis of objective data. A number of factors may lie within the plant effect other than the ones that were specifically accounted for in the regression models, including technician coaching differences, varying field conditions (comfortable room, noise levels), language differences, employer/employee relations, and diurnal variation of pulmonary function. Table VII raises many questions about the raw material, such as the importance of particle size and bract content. Other factors, such as bacteria and endotoxin, were not studied. Further studies on these factors are needed to characterize fully exposures in this industry.

CONCLUSION

In summary, this study produced evidence of both acute and chronic effects of exposure to dust in the cotton waste utilization industry. The acute effects were objective in nature and more pronounced. The chronic effects were mainly subjective (excessive bronchitis) with some supporting objective findings. Thus, dust in the cotton waste utilization industry seems to have both the acute bronchoconstrictor properties of dusts found in other cotton operations, producing acute pulmonary function decrements, and the chronic irritant effect of dust found in these operations as well as in other industries, producing bronchitis.

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