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Epidemiology of Chronic Lung Disease in a Cotton Mill Community *

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Abstract. We recorded respiratory symptoms and maximum expiratory flow-volume curves in 645 white male and female cotton textile workers, aged 45 years and older, with an average of 35 years employment in carding, spinning, yarn preparing, weaving and other jobs in cotton textile mills. We included retired as well as active workers, to avoid the biases inherent in studies of active workers only. We compared the data on the textile workers with those of 662 female and 498 male white residents of three communities without cotton textile mills (controls), considering sex, age and smoking habits. Textile workers of both sexes, irrespective of age, had significant excesses of chronic cough, wheezing, dyspnea and other symptoms, in comparison with the controls. Work in textile mills was the prime variable affecting symptom prevalence, with smoking as an additional significant variable for all symptoms except dyspnea. The lung-function data confirmed that textile workers were at much greater risk of chronic lung disease, with loss of function, than the controls, in all smoking categories. There was evidence that chronic lung disease often led to premature retirement among the male textile workers. The excess risk of lung-function loss occurred among workers in yarn preparing and weaving, as well as in carding and spinning, but not among workers employed in clothrooms and in other dust-free jobs. At least 35,000 men and women in the U.S. may suffer from disabling lung-function loss, owing to chronic lung disease, as a result of their work in cotton textile mills. Adequate programs of prevention and control of chronic lung disease, a late stage of byssinosis, as well as of the earlier acute manifestations of byssinosis, are urgently needed.

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Chronic lung disease in textile workers resembles chronic airway obstruction, a common disease in the general population. Mortality statistics probably underestimate deaths from chronic lung disease [27], and death and disease rates in the U. S. are usually not linked to specific risk jobs. Therefore, the prevalence of airway obstruction among textile workers, and the excess prevalence due to cotton dust exposure, must be assessed in relation to a comparable control population.

The population at risk includes workers who have left the mills as well as those still active. Among retired workers, cases of disabling lung disease due to cotton dust exposure were described in the U. S. in 1967 [9]. Among hemp workers, retired men were more frequently affected by disabling chronic lung disease than active workers [8]. Hence, studies of only active workers may underestimate disease prevalence. Also, among active workers, dust exposure during work may affect lung function and symptoms, whereas among retired workers, only chronic effects of dust exposure would be observed.

As controls, one needs sufficiently large groups of persons who are similar to the textile workers, but who lack exposure to cotton dust. Populations in communities without cotton textile mills are exposed to common risk factors in chronic airway obstruction, including cigarette smoking and other environmental exposures. A comparison of the prevalences of respiratory symptoms and of lung function loss between these community groups and groups of textile workers, taking into account such factors as sex, race, age, and smoking habits, should allow detection of any added risk of chronic lung disease associated with work in cotton textile mills. We have performed such a comparative study and report the results in this paper.

METHODS

All surveys were carried out with a mobile laboratory equipped for computerized recording of respiratory histories, personal data and maximum expiratory flow-volume (MEFV) curves [11]. An interviewer asks questions on respiratory symptoms, smoking habits, residence and occupational exposures, reading from a standard questionnaire [6], and enters the answers into computer memory. Next, the subject performs five maximally forced expirations, after a full inspiration, through a pneumotachograph. The flow signal is recorded by the computer and integrated to volume; flow and volume data are plotted on a graphic terminal connected to the computer. The resulting MEFV curve can be viewed immediately; final results are displayed on the terminal after completion of the five blows.

The test system includes several quality control features. Inadequate blows can be detected immediately, from the shape of the resulting flow-volume curve. Numerical results (forced vital capacity, FVC; forced expiratory volume, $FEV_{1.0}$) are displayed for each blow. Inadequate blows can be deleted from computer memory; these do not influence the result. Averages from the best two blows are used for analysis. An index of variability between these blows (i. e., the difference in $FEV_{1.0}$) is part of the final output report. Hence, during data analysis one can examine the extent to which inconsistent effort on the part of some subjects has influenced the results. The system is calibrated with measured flows and volumes; calibrations are checked every two hours by a computer subroutine and a special calibration device that reproduces a standard MEFV curve [12].

The curve which results from averaging flows at 50 ml intervals throughout the forced vital capacity is used as the MEFV curve from which quantitative data are derived: FVC, $FEV_{1.0}$ and instantaneous maximum expiratory flow rates (peak flow, PEF; and maximum expiratory flow at 50% and at 25% of the FVC, MEF50% and MEF25%). The final report of the MEFV curve includes actual data as well as a comparison with previously reported normal values [19], to help identify persons with significant lung function loss. To test for reversibility of function loss, 23 textile workers with low $FEV_{1.0}$ values and no history of heart disease were treated with isoproterenol aerosol; MEFV curves were recorded again 20 min later.

For the textile workers, the questionnaire was expanded with detailed questions on jobs in the mills and on symptoms on return to work after weekends or holidays. Otherwise, the methods used in the study of textile workers and of control subjects were identical.

SELECTION OF POPULATIONS

(a) Textile Workers. In March 1973 we studied textile workers who lived in or near Columbia, South Carolina, at altitudes less than 600 ft. We used union membership lists and company personnel records to define a cohort of workers who (1) had started work in one or more of four Columbia cotton mills in or before 1946, and (2) had worked at least three years in either card- or weaverooms in these mills (see Table 1 for description of cohort). A concurrent mortality study [3] had identified those who had died. Mill records, telephone directories and inquiries through fellow workers were used to verify the addresses of those we assumed to be alive at the time of our study. However, in spite of concerted efforts, more than half of these persons could not be located. Most of these probably had moved away from the area; in some instances we were able to verify a move. Among those who were available for study, the number of refusals was small.

Since we found early on that many weaveroom workers had chronic respiratory symptoms, we decided to broaden the scope of the study to include spinning room workers, yarn preparers and other mill workers as well. Most of these additional workers were recruited by word of mouth. We included workers who had worked for three years by 1955, including some who met the original cohort criteria but were not on the lists. We do not

Table. 1. Cohort of card- and weaveroom workers

Descriptor	Number of persons Cardroom	Weaverooms
(1) On list	231	320
(2) Assumed alive	153	224
(3) Moved	5	1
(4) Not traced	78	133
(5) Available for study	70	90
(6) Refusals	5	3
(7) Studied	65	87

(1) All workers who had worked at least 3 years in mills, starting in or before 1946.

(2) Number remaining after removal of those known to have died before our study.

(3) Persons known to have moved away.

(4) Persons whose address could not be verified or who could not be con- contacted despite repeated attempts; many of these had probably moved from the area.

know what percentage of the population which met these expanded criteria was actually seen. Table 2 shows the distribution, according to sex, race and age, of the total population. The data on black workers and on whites under age 45 were excluded from analysis; they were too few in number. The workers in the four different mills were considered as one group, since we found no consistent differences among them in either symptoms or lung function.

(b) Control Populations. These consisted of white subjects, aged 45 years or older, who were studied at various times between October 1972 and June 1974 in three communities [26]. They included residents of an urban area in Connecticut (30%), a semirural South Carolina town (25%), and a rural town in Connecticut (45%), all at altitudes less than 600 feet. We excluded the few individuals who had worked more than one year in a textile mill. Persons with respiratory symptoms, with overt disease such as asthma, or with occupational exposures other than textile dust are included in the control population groups. Thus, we believe that these populations provide the best available control data for comparisons

Table 2. Sex, age and race of textile workers[a]

Age	Total	Males		Females	
		Whites	Blacks	Whites	Blacks
$\leq$ 44	32	23	1	7	1
45-54	178	78	3	97	0
55-64	296	128	3	164	0
65-74	146	60	6	80	0
75+	40	15	2	23	0
Total	692	304	15	371	1

[a] All textile workers studied in the mobile laboratory who had worked three or more years in one or more of four mills in the Columbia, S C area, and who started work before 1955

with textile workers. The control group is sufficiently large to allow for age, sex and smoking habits in the comparisons with textile workers.

The three community populations also provided data on normal lung function in adult, healthy, lifetime nonsmoking white men (n = 194) and women (n = 581) [31]. Regression equations of function values on age, height and weight that gave the best fit to the data were developed separately for males and females. We used these equations to calculate the predicted function values for each textile worker. From the predicted data we calculated residual lung function data for each subject (rFVC, $rFEV_{1.0}$, etc.), where the residual equals the difference between the observed and the predicted value. The residuals express an individual' s lung function decrement in absolute values, which is consistent with the assumptions made in regression analysis. In contrast, the more common expression of lung function decrements in percentages of predicted values implies a greater function loss in a young person (who has large predicted values) than in an older person, whose predicted values are lower.

Data analysis was performed on a PDP 11/40 computer, using data storage on magnetic tape. Details on statistical methods are included, where necessary, with the results.

RESULTS

Validity of Textile Worker Population Sample. We first compared members of the original cohort (Table 3, A) with those card- and weaveroom workers who were included later in the total study popula-

Table. 3. Respiratory symptoms, smoking habits, and lung function in cotton textile workers

	Cardroom				Weaveroom			
	Females		Males		Females		Males	
	A[a]	B[a]	A	B	A	B	A	B
No. of subjects	20	8	40	32	50	104	34	80
Age ± S.E. (yrs.)	65.4±1.9	55.4±2.7[g]	60.7±1.1	59.9±1.3	61.2±1.4	57.4±0.7[g]	60.1±1.5	59.8±1.1
SYMPTOMS								
Usual cough, > 3 mo. (%)	30	12	25	44	22	32	24	39
Usual sputum, > 3 mo. (%)	30	50	32	38	22	36	38	41
Frequent chest tightness or wheezing[b] (%)	35	38	32	50	28	35	29	35
Dyspnea 2+[d] (%)	10	38	26	22	21	26	16	23
Symptoms on return to work[c] (%)	20	12	38	31	24	25	24	20
SMOKING HABITS								
Lifelong nonsmokers (%)	65	75	30	22	70	69	24	15
Ex-cigarette smokers (%)	20	0	52	34	16	8	44	34
Cigarette smokers (%)	15	25	18	38	14	23	29	41
Smokers, only pipe or cigars (%)	0	0	0	6	0	0	3	10
LUNG FUNCTION								
rFVC[e] ± S.E. (ℓ)	-0.35±0.07	-0.20±0.12	-0.50±0.13	-0.47±0.16	-0.23±0.05[f]	-0.39±0.04[f]	-0.50±0.14	-0.28±0.08
rFEV$_{1.0}$[e] ± S.E. (ℓ)	-0.32±0.08	-0.29±0.12	-0.54±0.11	-0.50±0.12	-0.21±0.04	-0.32±0.04	-0.50±0.12	-0.42±0.07.

[a] A = workers in the original cohort (Table 1, line 7), excluding blacks and subjects < 45 years.
B = all other workers, i.e., total seen in each category, minus no. in group A.

[b] A few times each week or worse.

[c] Wheezing, chest tightness or dyspnea on return to work after week-end or vacation.

[d] Dyspnea when walking at own speed on level ground, or worse.

[e] Residual FVC and FEV$_{1.0}$; see text.

tion (Table 3, B). Because of the different employment criterion (start before 1955 rather than before 1947), the subjects added later were younger. None of the differences in symptom prevalence or in smoking habits between A and B (for the same sex and job) were statistically significant, nor were there any consistent trends.

All groups in Table 3 had negative lung function residuals, i.e., their averages were less than predicted for white, healthy, lifetime nonsmokers of the same age, sex, height and weight. This was also true for PEF, MEF50% and MEF25% (data not shown). Although among female weavers, B had a significantly lower FVC than A, there was no consistent trend towards greater or lesser function decrements in B than in A.

We conclude from the comparisons in Table 3 that the expanded definition of the textile worker population, while adding younger persons who were essentially volunteers, caused no systematic change in symptom prevalence, smoking habits or lung function. We have therefore combined groups A and B for further data analysis.

Prevalence of Respiratory Symptoms. Three key respiratory symptoms - usual cough, frequent wheezing or chest tightness, and dyspnea grade 2+ - were more prevalent among textile workers (all jobs) than among the controls (Table 4). The data on ex-smokers (not shown in Table 4) followed the same pattern, with symptom prevalence similar to that in nonsmokers. Especially striking is the high prevalence of all three symptoms among nonsmoking female textile workers, the largest subgroup, whose rates are from 2 to 5 times higher than among comparable controls. A similar analysis for usual sputum production followed the pattern shown for usual cough in Table 4. Analyses for other grades of dyspnea or wheezing gave results similar to those shown for dyspnea grade 2+ and frequent wheezing, respectively. There are also differences in symptom prevalence between smoking categories and between sexes (Table 4). For example, male smokers have more cough and frequent wheezing than female smokers. Smokers generally have much higher symptom prevalences than nonsmokers, except for dyspnea.

In order to examine the relative importance of work in mills, of other factors such as sex, age and smoking status, and of interactions between these risk factors, we performed a weighted least squares analysis [21]. We found that an additive model (which describes the proportion, x, of subjects with symptoms as a sum of contributions from each source of variation) did not fit the data as well as a logistic model (see p values for goodness of fit in Table 5). The latter uses a logarithmic transformation of x, i.e., $\ln[x/(1-x)]$ as the sum of the main effects of mill work, sex, etc., and their interactions. In all instances, work in textile mills is the most significant source of variation in symptom prevalence (Table 5); for dyspnea grade 2+, it is the only one. For all other symptoms, smoking is also a significant variable. Sex and smoking interaction terms are significant for usual cough and frequent wheezing. Age is not a significant factor in the prevalence of any symptom except usual sputum ($p = 0.04$). There is also a significant interaction between work and sex, for usual sputum production. The interaction terms for sex × smoking and sex ×

Table 4. Respiratory symptom prevalence in textile workers and control subjects

		Age:	45-64				65+				Total (45+)			
			Textile workers		Controls		Textile workers		Controls		Textile workers		Controls	
Symptoms	Smoking categories	Sex	%	(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	(n)
Usual cough > 3 mos.	NS	M	17	(42)	10	(69)	28	(14)	19	(26)	20	(56)	13	(95)
		F	23	(168)[c]	9	(266)	26	(86)[a]	11	(115)	24	(254)[c]	10	(381)
	S	M	59	(76)[c]	30	(142)	57	(21)	43	(28)	59	(97)[c]	32	(170)
		F	33	(61)[a]	18	(164)	56	(9)	25	(12)	36	(70)[b]	18	(176)
Frequent wheezing or chest tightness	NS	M	19	(42)	6	(69)	21	(14)	11	(26)	20	(56)[a]	7	(95)
		F	26	(168)[c]	7	(266)	23	(86)[b]	8	(115)	25	(254)[c]	7	(381)
	S	M	42	(76)[b]	22	(142)	62	(21)[b]	18	(28)	46	(97)[c]	22	(170)
		F	33	(61)[c]	12	(164)	44	(9)	8	(12)	34	(70)[c]	12	(176)
Dyspnea grade 2+	NS	M	11	(35)	2	(62)	10	(10)	0	(22)	11	(45)[a]	1	(84)
		F	24	(125)[c]	5	(234)	20	(55)[a]	7	(87)	23	(180)[c]	6	(321)
	S	M	17	(53)	6	(125)	27	(11)	5	(21)	19	(164)[a]	6	(146)
		F	22	(49)[b]	7	(141)	14	(7)	0	(7)	21	(56)[b]	7	(148)

The table shows percentage prevalence (%) and number of persons (n) in each group. For definition of symptoms, see Table 3. [a] $p < 0.05$; [b] $p < 0.01$; [c] $p < 0.001$ for χ^2 test of differences between textile workers and controls in the same age sex and smoking categories.

Table 5. Weighted least squares analysis of key symptoms

Symptoms	Sources of variation[a]: Work in mill		Smoking		Sex x smoking		Sex x ex-smoking		Age		Goodness of fit
	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p	p[b]
Usual cough, > 3 mos.	52. 81	< 0. 0001	14. 81	< 0. 0001	16. 06	< 0. 0001	NS		3. 56	0. 06	0. 826
Frequent wheezing or chest tightness	79. 26	< 0. 0001	6. 63	0. 01	7. 90	0. 005	11. 14	< 0. 001	NS		0. 891
Dyspnea, grade 2+	52. 22	< 0. 0001	NS		NS		NS		NS		0. 961

For definition of symptoms, see text. NS = not significant

[a] Other sources of variation tested: age (p = 0. 04 for usual sputum, NS for all other symptoms); work-sex interaction (p = 0. 01 for usual sputum, NS for all other symptoms).

[b] Large p value indicates good fit of the logistic model.

ex-smoking probably reflect the higher tobacco consumption among men (Table 7). However, under-reporting of cough by women smokers might also contribute to these interactions (unpublished data).

For most symptoms, prevalences do not differ significantly between textile workers in different job categories (Table 6). However, those in "other jobs" had, in many instances, the lowest prevalence. Smoking habits are not significantly different among persons of the same sex in different job categories. Hence, the comparison of symptom prevalences between job categories is not seriously affected by an unequal distribution of smokers among persons in different jobs. For symptoms on return to work after a weekend or holiday (now or in the past), prevalence is highest among male cardroom workers (Table 6). The classical acute symptoms of byssinosis (chest tightness or wheezing on return to work on Mondays) occurred in 12.5% of all male cardroom workers and less frequently in other subgroups of textile workers (2.6% among all textile workers). Only 5 of the 1118 control subjects (0.4%; 4 current smokers) reported this symptom.

Lung Function. For the analysis in Table 7, we considered only cardroom workers, spinners, preparers and weavers as textile workers at risk (see below). In each sex and smoking category, these workers have lower values for rFVC and $rFEV_{1.0}$ than control subjects. Among smokers and ex-smokers, differences in smoking habits do not explain the results. Male textile workers smoked slightly but not significantly more than controls. The differences in lung function between textile workers and controls persisted after adjusting for age and pack-year differences, in an analysis of co-variance. The effects of textile mill work and of smoking on lung function are additive. When one adds rFVC and $rFEV_{1.0}$ of nonsmoking textile workers and of smoking controls, the sums are close to the observed decrements of smoking textile workers. Flow rates on MEFV curves were analyzed in the same way. The differences between textile workers and controls were similar in direction to those for rFVC and $rFEV_{1.0}$, and, for the most part, statistically significant.

When the textile workers were subdivided according to jobs in the mills (Table 8), the four categories of workers at risk (defined above) had lower function values than "others", i.e., persons in jobs away from dusty areas (mainly clothroom workers). The differences cannot be explained by differences in smoking habits. The same comparison for only nonsmokers gave similar differences, significant among the women but not among the men (there were only 56 male nonsmokers in all jobs). All differences between the total group of workers at risk and control subjects were highly significant. Among workers not at risk, lung function losses were similar to or smaller than those in the control groups.

There were no differences in lung function among nonsmoking women, aged 45-64 years, comparing those who still worked in the mills with those who retired prematurely (Table 9). Retired men, however, had a significantly greater loss of $FEV_{1.0}$ than men who still worked. The comparisons between active and retired male smokers are less clear because the retired men smoked more than the active men. Among all retired workers (regardless of smoking habits), the prevalence of cough, wheez-

Table 6. Symptom prevalence, smoking habits and textile mill job categories (age 45+)

Sex	Symptom or smoking category	Carding	Spinning	Preparing	Weaving	Others[b]	x^2
M	No. of subjects	72	49	26	114	20	
	% usual cough, > 3 mos.	33	33	35	34	25	0. 75
	% usual sputum, > 3 mos.	35	33	38	40	40	1. 44
	% frequent wheezing	40	33	27	33	25	2. 67
	% dyspnea, grade 2+[c]	24 (50)	13 (38)	6 (18)	21 (87)	6 (17)	5. 91
	% symptoms on return to work	35	18	8	21	10	11. 98[a]
	% nonsmokers	26	18	8	18	30	6. 06
	% ex-cigarette smokers	44	45	42	37	35	2. 21
	% cigarette smokers[d]	26	37	50	38	20	7. 40
F	No. of subjects	28	126	29	154	27	
	% usual cough, >3 mos.	25	26	24	29	22	0. 71
	% usual sputum, > 3 mos.	36	25	24	31	7	8. 20
	% frequent wheezing	36	17	17	32	26	10. 70[a]
	% dyspnea, grade 2+[c]	24 (17)	23 (87)	10 (20)	25 (117)	14 (21)	2. 99
	% symptoms on return to work	18	20	14	25	11	4. 04
	% nonsmokers	68	70	69	69	74	0. 30
	% ex-cigarette smokers	14	10	14	10	11	0. 66
	% cigarette smokers	18	20	17	20	15	0. 56

For definition of symptoms, see Table 3.

[a] $p < 0.05$; [b] includes cloth room workers and miscellaneous job categories.

[c] Number in parentheses is number of subjects who said they were not disable from working by other than lung diseases (e. g. , heart disease, arthritis).

[d] Pipe and cigar smokers not shown; therefore percentages for smoking habits do not always total 100%.

Table 7. Lung function residuals in textile workers at risk and in control subjects (age 45+)

		rFVC (liters)		$rFEV_{1.0}$ (liters)		Pack-years		Current smoking (cig. /day)	
Sex	Smoking category	Textile[a] workers	Controls	Textile workers	Controls	Textile workers	Controls	Textile workers	Controls
M	NS	-0.315±0.118[b] (50)	+0.102±0.060 (95)	-0.272±0.090[b] (50)	+0.004±0.044 (95)	0	0	0	0
M	XS	-0.315±0.071[b] (107)	-0.045±0.046 (191)	-0.445±0.061[c] (107)	-0.188±0.036 (191)	34.3±2.8	28.2±1.5	0	0
M	S	-0.585±0.072[b] (93)	-0.326±0.055 (170)	-0.711±0.059[b] (93)	-0.464±0.048 (170)	39.1±2.0	36.5±1.4	20.4±0.8	22.1±0.9
M	PC	-0.038±0.198 (11)	+0.141±0.101 (42)	-0.159±0.077 (11)	+0.037±0.087 (42)	N.A.	N.A.	0	0
F	NS	-0.283±0.029[c] (234)	-0.057±0.028 (381)	-0.246±0.023[c] (234)	-0.054±0.021 (381)	0	0	0	0
F	XS	-0.297±0.084 (37)	-0.116±0.049 (105)	-0.297±0.064 (37)	-0.155±0.038 (105)	13.7±2.0	12.8±1.3	0	0
F	S	-0.446±0.057[c] (66)	-0.156±0.033 (176)	-0.467±0.052[c] (66)	-0.241±0.028 (176)	21.1±1.5	21.3±1.0	15.3±0.8	17.7±0.8

[a] Cardroom workers, spinners, yarn preparers and weavers (see Table 6).
rFVC, $rFEV_{1.0}$ = observed-predicted values (see text); mean ± standard error of mean; number of subjects in parentheses.
NS = lifetime nonsmokers; XS = ex-cigarette smokers; S = current cigarette smokers; PC = smokers of pipes or cigars only.
NA = not applicable.
P values, unpaired "t" test; see Armitage [2] for approximation in cases where the variances in textile workers and controls differed significantly: [b] $p < 0.01$; [c] $p < 0.001$.

Table 8. Lung function residuals according to job category

		Carding	Spinning	Preparing	Weaving	Total	Others	Controls
Males	n	72	49	26	114	261	20	498
	Age	60. 3±0. 9	59. 6±1. 3	58. 9±1. 5	59. 9±0. 9	59. 9±0. 5	60. 5±1. 6	57. 6±0. 4
	rFVC (ℓ)	-0. 488±0. 098	-0. 427±0. 095	-0. 336±0. 137	-0. 346±0. 068	-0. 400±0. 046	-0. 082±0. 188	-0. 097±0. 031
	$rFEV_{1.0}$ (ℓ)	-0. 524±0. 080	-0. 588±0. 082	-0. 460±0. 111	-0. 433±0. 058	-0. 494±0. 039[a]	-0. 119±0. 156	-0. 226±0. 025
	Pack-yrs.	26. 3±3. 8	35. 7±4. 2	26. 5±4. 3	25. 2±2. 3	27. 6±1. 7	24. 6±6. 1	23. 3±1. 03
Fe-males	n	28	126	29	154	337	27	662
	Age	62. 5±1. 7	61. 3±0. 7	59. 3±1. 7	58. 6±0. 7	60. 0±0. 4	63. 2±1. 3	58. 0±0. 4
	rFVC (ℓ)	-0. 310±0. 063	-0. 311±0. 046	-0. 227±0. 079	-0. 339±0. 034	-0. 316±0. 025[a]	-0. 109±0. 086	-0. 092±0. 020
	$rFEV_{1.0}$ (ℓ)	-0. 312±0. 067	-0. 311±0. 037	-0. 247±0. 078	-0. 288±0. 028	-0. 295±0. 021[b]	-0. 057±0. 052	-0. 120±0. 016
	Pack-yrs.	5. 3±2. 1	5. 9±1. 0	4. 8±1. 9	5. 6±1. 0	5. 6±0. 6	4. 4±1. 8	7. 7±0. 5

Total = sum of carding, spinning, preparing and weaving groups.
Others = workers in clothroom and miscellaneous jobs.
Controls = community residents in South Carolina and Connecticut; non-textile workers.
Significance of differences:
[a] $p < 0.05$, [b] $p < 0.001$ for differences in lung function between "total" and "other" groups."Others" and controls do not differ significantly in any respect. Differences between "total" group and controls: $p < 0.01$ for all lung function comparisons.

Table 9. Lung function residuals in active and retired workers (age 45-64 years)

	rFVC (liters)		$rFEV_{1.0}$ (liters)	
	Active	Retired	Active	Retired
Males, NS	-0.177±0.139 (34)	-0.648±0.276 (8)	-0.083±0.102 (34)	-0.645±0.271[a] (8)
Females, NS	-0.261±0.049 (99)	-0.244±0.051 (69)	-0.238±0.038 (99)	-0.225±0.042 (69)

See Table 7 for explanation of residuals.

NS = lifetime nonsmokers.

[a] $p < 0.05$ for difference between active and retired men.

ing and dyspnea was significantly higher, for both men and women, than among comparable active workers. Workers who said they retired because of chest symptoms (n = 39, i. e., 18% of those who retired prematurely) had significantly more function loss than those who gave other reasons for retiring or who were laid off. This was true for nonsmokers as well as for smokers and ex-smokers.

In all smoking categories, men or women who had experienced one or more of the acute symptoms of byssinosis had lower function values than those who had not. However, the differences were significant only among female smokers and ex-smokers ($p < 0.05$) for $rFEV_{1.0}$. Age at start of employment, which varied from under 15 to about 35 years, had no significant relation to later lung function values. The subjects in our study had worked an average of 35 years in the mills; very few of them had worked less than 20 years. When age and smoking were accounted for, there were no significant trends in lung function with duration of employment.

The differences in prevalence of dyspnea and of lung function loss between textile workers and controls might be explained if the textile worker population included a larger proportion of obese individuals; obesity can lead to dyspnea as well as to loss of lung function. We suspected that this might be the case among women. However, a comparison of indices of obesity [20] showed no differences between female textile workers and controls. There was a weak association between obesity, on the one hand, and the prevalence of dyspnea and frequent wheezing (but not of cough), on the other. However, the excess prevalence of dyspnea and other symptoms among female textile workers cannot be explained by obesity, since these women were not more frequently obese than the control group.

DISCUSSION

Most studies of byssinosis in the textile industry have used the prevalence of acute respiratory symptoms on return to work ("Monday-dyspnea") and loss of lung function during the workday as indices of responses to textile dust exposures [7, 29]. By relating these acute responses to airborne dust concentrations one can construct dose-response curves [6, 24]; these can be used in programs to prevent the disease [17, 32].

However, textile workers also suffer from chronic lung disease. To relate the prevalence of chronic disease to dust levels in the mills requires knowledge of both current and past exposures, which is not available. Until adequate records are kept of dust concentrations in mills over long periods of time, dose-response relations for the long-term effects of cotton-dust exposure cannot be established. Until then, the acute response to dust exposure offers the only available quantitative basis for programs of prevention.

Most surveys in industry have shown an excess of chronic respiratory symptoms, as well as loss of lung function, among active workers at risk [29, 34]. However, the total population of textile workers at risk of chronic disease also includes retired workers. Active workers form a group biased in favor of healthy individuals. Retired workers, in contrast, include those who left the mills because of disabling lung disease, and thus this group is biased in favor of diseased persons. We had previously identified several cases of disabling byssinosis among retired workers who lived in mill communities [9]. To describe the prevalence of chronic lung disease adequately, we therefore decided on a community-based study which would include retired as well as active workers.

We are confident that our results in members of the original cohort of carders and weavers (Table 1; Group A in Table 3) provide a reasonably accurate picture of the respiratory health of active and retired cotton textile workers who continue to live in the community surrounding the mills. Of those whom we identified and traced, 95% participated in the study. The results obtained in this cohort were similar to those in the additional group of men and women studied (Group B in Table 3). We have concluded that the total study group, too, is representative for active and former cotton textile workers in that community.

However, many persons on the employment lists could not be traced; probably most of these left the mills and moved away. They may have moved to find jobs elsewhere, or they may have moved to a better climate. Since we studied persons 45 years of age and older, the first motive is probably infrequent. Also, we were more likely to trace active rather than retired workers. The prematurely retired men whom we studied had lower function values and more symptoms than the men who were still active in the mills. Therefore, those we could not trace may also be a group biased in favor of diseased subjects. If so, our data underestimate the true prevalence of chronic disease among the total population at risk. In a similar study of hemp workers in Spain [8], disabling lung disease among men was more prevalent than it was in the present study [14]. We know that hemp dust is more toxic than cotton dust [33], but it is also possible that we were better able to trace older disabled men in Spain, since few of them had moved away.

We are confident that the differences in lung function between textile workers and controls reflect excess loss of lung function among the textile workers. All methods were standardized and identical for textile workers and controls. Throughout all studies, our MEFV curve recordings were calibrated every two hours with a device that accurately reproduces a standard MEFV curve [12]. In addition, the computer methods are inherently more accurate than methods which rely on analog readouts and graphical recordings. Flow measurements with the computer system are accurate to about 0. 3%; the system reproduces the $FEV_{1.0}$ of the calibration device to within 0. 6% [12]. Hence, we minimized technical sources of error.

The data on respiratory symptoms and lung function indicate an excess of chronic lung disease among the cotton textile workers (Tables 4, 7, 8). It is almost certain that the difference in lung function and in symptom prevalence between textile workers and controls is caused by dust exposure of the workers in the mills. For the symptoms, the weighted least squares analysis indicates that work in mills is the prime variable - the only one for dyspnea grade 2+ - while smoking is a contributing factor for cough, phlegm and wheezing. For lung function, the differences between workers in risk jobs and in other jobs (Table 8) suggest that the lung function decrements are caused by exposure to dust. For both symptoms and lung function loss, the differences between textile workers and controls persist when sex, age and smoking habits are taken into account. Other factors (e. g. , urban air pollution, indoor air pollution, altitude) have been considered and may be excluded. Within our control populations there are no systematic differences in lung function that might be related to urban air pollution outdoors [31]. Indoor air pollution has so far not been linked to excess airway obstruction, e. g. , among nonsmokers who live in homes with smokers [30]. All subjects lived at similar altitudes, near sea level.

It is important that the small group of textile workers in other jobs, not exposed to dust, was similar to the control subjects in other communities. The workers at risk and those not at risk were studied on the same days and with the same methods, and lived in the same community under similar conditions. Thus, we can exclude the possibility that the textile worker population as a whole differed, for some unknown reason, from the control populations. The differences in lung function are related to specific jobs in the mills, not to some unknown characteristic such as social class of textile workers as a group.

We found an excess of chronic lung disease not only among carders and spinners - groups long known to be at risk of byssinosis - but also among yarn preparers and weavers. It has frequently been stated that byssinosis is absent or uncommon among weavers. However, a detailed study of one mill showed that most weavers in a factory which produced heavy cloth from unsized yarns had byssinosis [5], and in a more recent study [24], the average prevalence of acute byssinosis symptoms among 431 workers in slashing or weaving was 13. 1% (36. 5% in a subgroup exposed to high dust levels).

The excess of chronic disease among textile workers might be overestimated if the control populations were biased in favor of healthy persons. However, we have evidence that our control subjects provide an accurate picture of the respiratory health of the total populations in their communities [26]. The prevalence of key respiratory symptoms in our control subjects is roughly similar to that in other populations not exposed to major risks of occupational lung disease [1, 28]. Furthermore, the negative lung function residuals among most subgroups of control subjects (Table 7) reflect the inclusion of diseased persons and smokers.

Chronic lung disease among cotton textile workers is obviously an important public health problem. Among those who retired before the age of 65, 18% gave chest symptoms as the prime reason. Of all textile workers, 5.0% of those aged 45-64 years, and 17.4% of those 65 years and older, had $FEV_{1.0}$ values of 1.20 liter or less, i.e., values consistent with considerable disability in most instances. On the basis of these data, and of employment figures in the U.S. cotton textile industry, we have estimated that about 35,000 men and women in the U.S. suffer from disabling lung function loss as a result of their work in cotton textile mills [14]. This figure may be too low, since we may underestimate the prevalence of chronic lung disease among the total population of workers at risk (see above).

Retired workers are usually not included in studies of occupational diseases since they are difficult to trace, at least in the U.S. [4]. Hyatt et al. [23] studied active and former coal miners in West Virginia, and found a higher prevalence of pneumoconiosis than other investigators, who studied active workers only. If laws such as the Occupational Safety and Health Act in the U.S. are to protect workers from the consequences of occupational exposures throughout their lifetime, systematic follow-up of workers who leave risk industries is required. This may benefit those who left the industry, by detection of late effects of exposures, as well as those who still work, by elucidating needs for environmental controls.

The pathology of the chronic lung disease of textile workers remains unclear. Loss of lung elastic recoil as well as intrinsic small airway obstruction may contribute to their function loss [22]. At autopsy, the lungs of byssinotic cotton textile workers show varying degress of emphysema and chronic bronchitis [18]. However, no correlative studies of symptoms, function loss, and histological findings in the lungs have been reported so far. In the present study, the decrements of FVC were similar to those of $FEV_{1.0}$ (Tables 7 and 8). In contrast, acute exposures to textile dust lead to greater decreases of $FEV_{1.0}$ than of FVC [10, 15]. The additional decrement of FVC in the chronic disease might be related to airway closure. Isoproterenol does not materially improve function in textile workers with chronic lung disease; the average improvement of $FEV_{1.0}$ in 23 workers was 0.13 liters, less than half the difference between textile workers and controls. However, airway obstruction and closure may, in part, be reversible since thiazinamium (Multergan®) increases both FVC and $FEV_{1.0}$ [13]. Among hemp workers, chronic loss of lung function was found only in subjects whose maximum expiratory flows decreased during acute dust exposures [15]. However, we are not certain that only workers who experience airway obstruction on acute exposure to dust are at risk of developing chronic disease. But pronounced "reactors" to acute dust exposure are probably at greater risk than those who are less sensitive to the acute effects of textile dust exposure [8].

A 7-year follow-up study of hemp workers in Spain showed continued deterioration of lung function among men no longer exposed to dust [16]. Cotton textile workers who remain active in the industry suffer greater yearly losses of lung function than the retired Spanish hemp workers, i. e., up to nearly 0.3 liters per year [25]. We believe that textile workers with chronic lung disease should avoid further dust exposure at a time that their ventilatory reserves are still sufficient, i. e., their $FEV_{1.0}$ should be large enough so that they will not develop disabling lung function loss during the rest of their lifespan, in spite of a continuing accelerated loss of lung function [16].

There is continuing discussion about the definition of the term "byssinosis," and confusion about the presumed co-existence of chronic bronchitis and of byssinosis among textile workers. To a large extent this debate is one of semantics [8]. Cotton and other textile workers are at risk of acute as well as chronic respiratory symptoms and lung function loss. There can be little doubt that both are caused by exposure to respirable dust in textile mills. The progression from repeated acute insults to the chronic disease has not been traced with certainty, but there is no good evidence against - and much evidence for - such a train of events. It seems most logical to define byssinosis as a dust-induced disease with initial acute responses followed by a stage of chronic lung disease characterized by chronic airway obstruction. This definition is implicit in the description of the clinical stages of byssinosis given by Schilling [29]. For purposes of compensation and prevention, acute responses to textile dust as well as chronic airway obstruction in textile workers should be considered as two stages of one disease syndrome, byssinosis.

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