Dose Response Studies in Cotton Textile Workers

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There is evidence of awareness of the fundamental association between increased dust level and increased prevalence of respiratory disease among textile workers since early in this century when efforts were made to minimize disease through suppression of dust from the carding engine.[1] Although this concept of dose-response was appreciated, it was not quantitated until 1960 when Roach and Schilling[2] reported their study of the association between three fractions of cotton dust and its characteristic biological response. They found the strongest linear association between the protein content of the middle fraction of dust (7μ to 2mm-Hexlet) but also a strong linear correlation with total lint and dust. Because of this strong association with gross dust concentration and the simplicity and rapidity of sampling for total dust, they recommended 1 mg/m^3 gross dust as a reasonably safe level of occupational exposure. This recommendation was adopted by the American Congress of Government Industrial Hygienists and is the current threshold limit value for cotton dust.[3]

Roach and Schilling recognized that some fine dust ($< 7\mu$) and medium dust (7u-2mm) was trapped on the lint mat collected on the 2 mm screen, which may have reduced the correlation coefficients for these fractions.[2,4] Subsequent observations showed that the fine fraction of dust ($< 7\mu$) could account for nearly all of the prevalence of byssinosis,[5,6,7] and that gross dust levels, particularly in yarn processing areas (spinning, winding, twisting) could be misleading indicators of biological effect.[8,9,10] In recognition of these findings, new standards for safe levels of cotton dust exposure are being considered in Great Britain and the United States.

The study described in this paper offered the opportunity to observe biological effects in a large working population over a wide range of dust exposure. The primary objectives of this portion of the study were to evaluate the vertical elutriator cotton dust sampler and to develop dose-response relationships to help establish the safe level of exposure to lint-free cotton dust.

Methods

Definitions, the study design, and methods used in collecting data are found in the Methods section of the preceding paper.[11] As previously described, each worker was assigned a

Table 1. — [illegible], 1970-71

[illegible]	[illegible]	[illegible]	[illegible]	Total
[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	215	[illegible]	[illegible]	1076
[illegible]	[illegible]	[illegible]	[illegible]	.654
[illegible]	[illegible]	[illegible]	[illegible]	.405
[illegible]	[illegible]	[illegible]	[illegible]	.411
[illegible]	[illegible]	.013-1.30	.227-2.74	.013-3.56
[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	237
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.204	.122	[illegible]	.270
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	.006-1.37
[illegible]				
[illegible]	[illegible]	121	—	[illegible]
[illegible]	212	[illegible]	—	[illegible]
[illegible]	[illegible]	[illegible]	—	[illegible]
[illegible]	[illegible]	[illegible]	—	[illegible]
[illegible]	[illegible]	[illegible]	—	[illegible]
[illegible]	[illegible]	[illegible]	—	[illegible]

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mean, median and a geometric mean dust level of his work area which was used to develop dose-response curves. Although little difference was apparent in these three measures of central tendency (Table 1), the median dust level was chosen because it reduced the effect of out-liers and provided the best distribution of the population.

Mathematical dose-response curves were fitted to data on byssinosis prevalence by median dust level. Six groups of workers (Table 2), including black and white men and women, in two primary exposure areas (primarily cotton dust and cotton dust plus sizing) by smoking status are considered:

Raw data was categorized by arbitrary dust level groups to provide a wide and balanced (as well as possible) distribution of workers by dust level (Tables 3, 4). Because the number of workers above 1 mg/m^3 represented less than five percent of the total population and was therefore likely to result in unstable rates, and because those exposed to these high dust levels were likely to be a select, relatively more resistant group of workers, they were eliminated from consideration for calculation of linear regressions (except for Group 4). The truncated regression plots and correlation coefficients are displayed for this data in Figs 2, 3 and 4.

Percent change in $FEV_{1.0}$ with six hours of dust exposure for cotton/blend mill preparation and yarn area workers and synthetic/wool mill workers by dust level is shown in Table 5. Linear regressions truncated at 1 mg/m^3 were calculated and the regression lines and correlation coefficients shown in Figure 6.

Kenneth A. Busch, National Institute for Occupational Safety and Health, analyzed prevalence data using a probit model,[12, 13] and developed Table 6 through 9 and the probit curves in Figs 2 through 4. His protocol for analysis was as follows: For each set of data, the method of maximum likelihood was used to fit a straight line to Y = probit (prevalence ratio) vs. X = $\log_{10}$ (median dust level in mg/m^3). A chi-square goodness-of-fit test was made to test jointly for both nonlinearity and excessive variance about the fitted curve as compared to theoretical results expected under the probit model. Ninety-five percent statistical confidence limits were put upon the true dose-response curve as well as upon predicted dust levels corresponding to eight arbitrary levels of hypothetical byssinosis prevalence: p = 1%, 2%, 3%, 4%, 5%, 10%, 25%, and 50%. Pairs of curves for Groups 1 and 2, and for Groups 3 and 4, respectively, were tested for parallelism and, if found to be parallel, a "relative toxicity" metameter R was estimated along with its 95% confidence limits. By "relative toxicity" is meant the ratio between dust levels which produce the same prevalence of byssinosis in the two groups. Thus an R-value of 1.0 would imply the two curves were coincident. When curves for two groups are found to be non parallel, the difference between them is difficult to interpret since relative toxicity would not be constant at all levels of response. In such a case, a conditional relative dose metameter R_p was calculated for several p-levels of prevalence of byssinosis in the two groups.

Table 2 — Six Worker Groups by Smoking Status

Group	Smoking Status	Byssinosis Grades	Exposure
1.	Current Smokers	Grade 1/2, 1, 2	Cotton/blend mill preparation and yarn areas
2.	Never Smoked	Grade 1/2, 1, 2	Cotton/blend mill preparation and yarn areas
3.	All Workers	Grade 1/2, 1, 2	Cotton/blend mill preparation and yarn areas
4.	All Workers	Grade 1/2, 1, 2	Cotton/blend mill slashing and weaving areas
5.	All Workers	Grade 2	Cotton/blend mill preparation and yarn areas
6.	All Workers	Grade 1 and 2	Cotton/blend mill preparation and yarn areas

Results

Table 2 summarizes 985 vertical elutriator (Fig 1) dust samples by mill type, work area, measures of central tendency and range. The greatest number of samples was collected in the preparation areas of the cotton and blend mills. The highest dust levels are recorded in the slashing and weaving areas of cotton and blend mills where sizing is used and contributes to the dust concentration. Where sizing is not used, the dust levels in the preparation area were consistently much higher than in the yarn processing areas. The mean dust levels were generally higher than the median or geometric mean levels, reflecting the effect of high out-liers. In synthetic and wool mills there was little difference in dust level between preparation and yarn processing areas. The highest dust levels in these mills were found in the preparation area of the wool mill and the preparation area of a synthetic mill

Table 3. — Demographic and Smoking Characteristics of Preparation and Yarn Processing Workers in Cotton and Blend Mills by Median Dust Level

Dust Level	0 to .056	.057 to .0838	.0839 to .1254	.1255 to .1877	.1878 to .2088	.2089 to .4201	.4202 to .6286	.6287 to .9084	.9085 to 1.407	1.408 to 2.105
Men										
n	70	34	104	144	61	122	69	65	30	42
Mean Age	39.5	36.9	38.7	42.1	33.6	37.8	38.8	37.1	41.4	38.7
% Current Smokers	67.1	64.7	56.7	54.9	73.8	53.3	73.9	55.4	73.3	66.7
% Former Smokers	14.3	23.5	19.2	22.2	9.8	18.0	10.1	16.9	13.3	14.3
% Black	5.8	8.8	7.7	19.0	26.2	29.2	27.5	36.9	13.3	64.3
Women										
n	75	37	89	135	17	85	77	0	1	0
Mean Age	41.5	43.9	44.4	42.9	39.6	38.8	37.7	-	21.0	-
% Current Smokers	44.0	32.4	25.8	36.3	47.1	36.5	32.5	0	0	0
% Former Smokers	12.0	0	4.5	6.7	5.9	12.9	10.4	0	0	0
% Black	19.2	10.8	5.6	17.9	52.9	16.9	27.3	0	100.0	0

where gasoline driven machinery was used.

Demographic and smoking characteristics for men and women in cotton preparation and yarn areas by dust level are shown in Table 3. No clear age trend is apparent among men or women, nor is there a consistent difference in the proportion of current or ex-smokers between dust subgroups. Among men, a greater percentage of blacks were found with increasing concentration of dust exposure. This was less apparent among women who rarely work in the dustiest areas of the mills.

Busch concluded from his analysis that the log-probit model fitted the data well in every case. The points were scattered randomly about the fitted dose-response curve and the variance of deviations from the curve was not significantly greater than would be expected based upon an assumption of binomially-distributed prevalence ratios at each dust level.

Slopes (b) and intercepts (a) of the fitted log-probit dose-response curves, $Y = a + bx$, are shown in Table 6 together with three calculated points (ordinates Y) for each fitted curve and their 95% confidence limits. The curve equation was then inverted to predict dust levels corresponding to arbitrary prevalence levels. Table 7 shows the predicted dust levels and their 95% confidence limits for the six groups of workers for prevalence levels of 1%, 2%, 3%, 4%, 5%, 10%, 25% and 50%.

Chi-square tests for goodness-of-fit of the individual curves and for parallelism of pairs of curves (1 vs. 2 and 3 vs. 4) are shown in Table 8. Curves for current smokers (Group 1) and those who never smoked (Group 2) were found to be significantly different although nearly parallel but not coincident. A relative toxicity of R = .56 with 95% confidence limits of R = .35 to R = .83 was found (Table 8); this suggests that only 56% (35% to 83%) as much cotton dust is associated with any given prevalence of byssinosis among smokers as among those who never smoked. Curves for all preparation and yarn workers (Group 3) and for all slashing and weaving workers (Group 4) were not found to be parallel. Therefore a single R-value was meaningless and it was necessary to calculate R_p-value as a function of eight arbitrary prevalence levels which are shown in Table 8. Curves for Groups 3 and 4 were found to be significantly different but yielding R_p-values which ranged from .087 at a byssinosis prevalence of 1% to .56 at a prevalence of 50%. Therefore, only approximately 9% (4% to 15%) as much cotton dust is associated with a 1% byssinosis prevalence for workers in the preparation and yarn areas of cotton mills as compared to the amount required for the same prevalence for cotton slashing and weaving workers. At a prevalence of 5% an average of 15% as much dust is required, at a prevalence of 25%, 32% as much, and at the 50% prevalence level 56% as much dust is required.

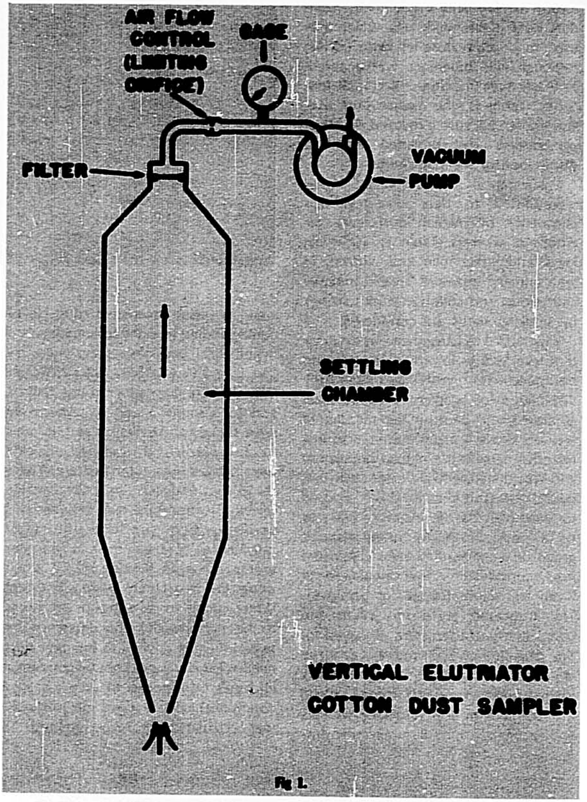

Fig 1.

The probit-dose response curves are shown in Figs 2, 3, 4, together with the linear regression plots and correlation coefficients. The truncated linear plots are observed to fall within the 95% confidence limits of the probit curves below a dust level of 0.5 mg/m^3. Both dose response curves for cotton slashing and weaving workers fell nearly on the same line through 2.0 mg/m^3 of dust. The strength of the linear association between dust level and byssinosis prevalence was uniformly high except for those who had never smoked (Group 2) where the correlation coefficient was .52; however, one subgroup within this population contained only seven workers, none of whom had symptoms of byssinosis. Expected byssinosis prevalence levels are shown in Table 6 and the curves plotted for Groups 3, 5 and 6 in Figure 4. Prevalence of Grade 2 byssinosis (Group 5) ranges from 1.3%

Table 4. — Raw Data on Byssinosis Prevalence vs. Median Dust Levels for Six Groups of Workers

"Mid-Point"* of Range of Median Dust Levels (mg/m³)	Sample Size n	Cases of Byssinosis r	Prevalence (%) p = r/n x 100
Group 1. Cotton Preparation and Yarn Areas — All Grades - Current Smokers			
.05	167	10	6.0
.15	159	21	13.2
.25	82	14	17.1
.35	64	14	21.9
.45	55	15	27.3
.55	26	11	42.3
.75	31	16	51.6
1.1	12	5	41.7
1.5	12	7	58.3
1.9	26	12	46.2
Group 2. Cotton Preparation and Yarn Areas — All Grades - Nonsmokers			
.15	127	3	2.4
.15	145	9	6.2
.25	44	2	4.5
.35	54	16	29.6
.45	49	12	24.5
.55	7	0	0
.75	18	5	27.8
1.1	2	0	0
1.5	3	2	66.7
1.9	8	3	37.5
Group 3. Cotton Preparation and Yarn Areas — All Grades - All Workers			
.0458	145	5	3.4
.0686	71	2	2.8
.1026	193	14	7.3
.1535	279	27	9.7
.2296	78	10	12.8
.3435	208	39	18.8
.5130	147	37	25.2
.7680	65	30	46.2
1.150	31	14	45.2
1.722	42	17	40.5
Group 4. Cotton Slashing and Weaving Workers — All Grades - All Workers			
.35	15	1	6.7
.45	136	7	5.1
.55	2	0	0
.75	195	14	7.2
1.1	34	6	17.6
1.5	87	23	26.4
1.9	44	16	36.4
Group 5. Cotton Preparation and Yarn Areas — Grade 2			
.0458	145	0	0
.0686	71	1	1.4
.1026	193	2	1.0
.1535	279	9	3.2
.2296	78	1	1.3
.3435	208	8	3.8
.5130	147	14	9.5
.7680	65	11	16.9
1.150	31	6	19.4
1.722	42	6	14.3
Group 6. Cotton Preparation and Yarn Areas — Grades 1 & 2			
.0458	145	0	0
.0686	71	2	2.8
.1026	193	2	1.0
.1535	279	11	3.9
.2296	78	2	2.6
.3435	208	23	11.1
.5130	147	22	15.0
.7680	65	15	23.1
1.150	31	8	25.8
1.722	42	9	21.4

(0.7-2.3) at 0.1 mg/m³ to 3.0% (2.1-4.3) at 0.2 mg/m³ to 8.0 (6.1-10.2) at 0.5 mg/m³, as computed from the probit curve. When Grade 1 and 2 byssinotics are combined (Group 6) the probit prevalence levels are 2.1% (1.3-3.3) at 0.1 mg/m³, 5.0% (3.9-6.6) at 0.2 mg/m³, and 13% (10.7-15.8) at 0.5 mg/m³.

Table 5 and Fig 5 show percent change in $FEV_{1.0}$ with increasing levels of exposure among cotton preparation and yarn area workers and synthetic and wool workers. The truncated linear regression (Fig 5) for the cotton population again showed a strong linear association (r = .82) between biological effect and dust level. No decrement in percent change in $FEV_{1.0}$ is seen with increasing levels of exposure to synthetic and wool dust.

Discussion

Dust Sampling. — In the year preceding this study, several cotton dust sampling techniques were evaluated.[14] The sampling device desired was to be relatively easy to operate, portable, durable, operable unattended for a full shift and provide a lint free dust sample. Of the sampling devices evaluated, the vertical elutriator developed by Lynch and Lumsden[14] was found to best fulfill these criteria. The instrument was designed to sample dust with a mass median aerodynamic diameter of 15μ and less which effectively eliminated biologically inert lint while retaining particles of the size expected to be inhaled. Since high correlations between byssinosis symptoms and dust level have been observed with the middle fraction (7μ to 2mm) of dust,[2,15] it was thought that larger particles (7μ-15μ) as well as "respirable" particles ($<7\mu$) should be collected. An added practical advantage of including larger particles is the accumulation of a weighable sample in a shorter interval. A potential disadvantage was the possibility of including fine but inert "linters" in the sample. This has been observed rarely in our experience and appears to occur only under the dustiest of conditions when exact dust levels are not as important.

In the absence of a specific assay for the etiological agent(s) responsible for the biological effects of cotton dust, the

* Arithmetic mean of end-points used for groups 1,2,4.
Geometric mean of end-points used for groups 3, 5, 6.

most important consideration in evaluating a gravimetric sampling technique is the degree of correlation with biological indicators over the range of exposure. As shown in Figs 2 through 5, a strong linear association was found in this population, particularly below 0.5 mg/m^3, the level below which the majority of the population is exposed and where attention is focused concerning establishment of a reasonably safe exposure level.

As a field instrument the vertical elutriator cotton dust samplers have proven to be most practical and durable. The 25 samplers built for this survey have now been in use for two years and have collected over 3000 samples. No modification of the instrument or the sampling procedure has been necessary. Its design lends itself to use within the manufacturing plant; at no time has it interfered with the manufacturing process or personnel. Sampling with this instrument can easily be learned and could be used by manufacturing personnel to monitor their working environment.

Dose-Response. — In developing dose-response curves for byssinosis, tables were developed by sex, smoking groups, work areas (preparation, yarn production and slashing/weaving) and mill type (cotton and blend). A strong linear association was repeatedly observed in these sub-populations. Since there appeared to be no difference in age between individual dust level subgroups (Table 3), there was no reason to age adjust the data. Similarly, no difference in byssinosis prevalence has been found in men and women, allowing both to be considered together. Preparation and yarn processing areas are justifiably combined since the dust is of the same composition, the dose-response curves for each area are similar, and the areas are frequently contiguous. When the yarn arrives in the slashing department, sizing is added to the yarn and has been found consistently to increase the concentration of lint free dust in the slashing and weaving areas. Therefore, the biologically active airborne material in these workrooms is diluted with biologically inert sizing, making it necessary to consider this dust separately when considering these significantly different dose-response relationships. Cigarette smoking has been found to significantly increase byssinosis prevalence[9 11 16 17] and must therefore be considered a potential source for a secondary association. Table 3, however, shows no apparent difference in smoking habits between dust level sub-populations. Probit analysis revealed that byssinosis prevalence for smokers was significantly higher than for non-smokers. Although it may be argued that the most susceptible group (smokers) should be most closely considered when recommending safe levels of exposure, the majority of this working population smoke cigarettes and the dose-response curves for current smokers and all workers regardless of

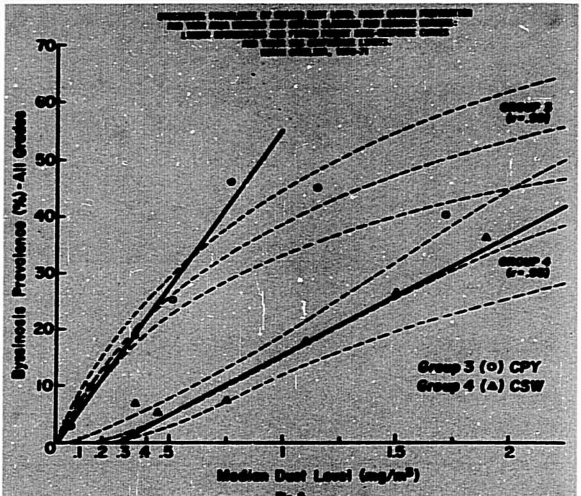

Fig 2

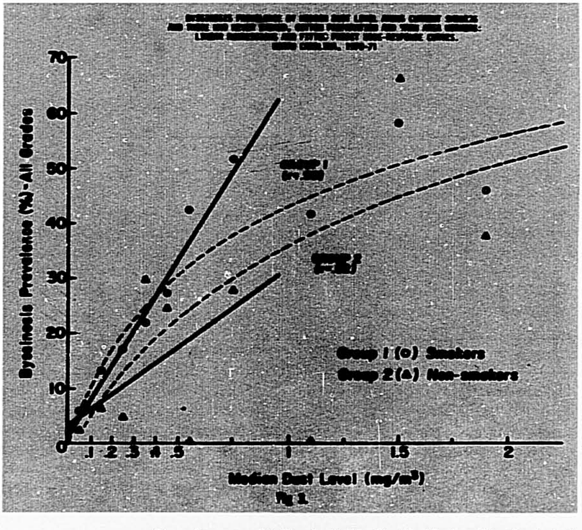

Fig 1

smoking habit are similar. For this reason, and because a standard generally applies to the entire population at risk, consideration of the entire population regardless of smoking habit appears to be most appropriate.

As initially observed by Roach and Schilling,[2] and later confirmed by El-Batawi,[18] Molyneaux,[15] and our group in an independent study,[19] dose-response curves for the association between dust level and byssinosis prevalence and/or change in $FEV_{1.0}$ are strikingly linear. This was found repeatedly in this data no matter how the groups were divided, unless the number of workers in the dust level sub-populations was so low as to produce unstable rates (Group 2, r = .52, Fig 3). With this exception, correlation coefficients were consistently above 0.9. Similarly, the association between percent change in $FEV_{1.0}$ and median dust levels was also strong (r = .82, Fig 5). A source of increase variance in this measurement is diurnal variation in expiratory flow rate which was observed but not adjusted out. The distribution of workers by shift within dust level sub-populations was similar and therefore unlikely to produce a secondary association. Above a median dust level of 1 mg/m^3 the dose-response curves tend to flatten. We suspect that selection, leaving relatively resistant workers in these dustier areas, is responsible for this decrease in prevalence and percent change in $FEV_{1.0}$. As reviewed in the preceding article, there is substantial evidence of selection away from dust exposure in this industry.[9,20,21] In Table 3, a consistent trend toward a higher percentage of black men was found with increasing dust level. Blacks have been found to have lower rates of chronic bronchitis than whites of the same age and environmental exposure.[22] The relatively greater number of blacks with relatively lower response at high dust levels in this textile population may

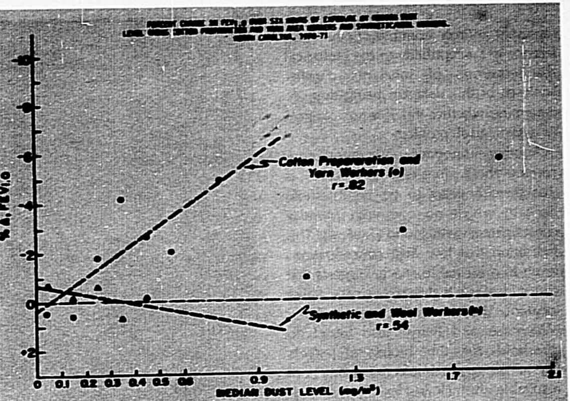

Fig 4.

Table 5. — Raw Data on Percent Change in $FEV_{1.0}$ vs. Median Dust Level among Preparation and Yarn Area Workers in Cotton/Wool Mills and Workers in Synthetic/Wool Mills

Mid-Point of Range of Median Dust Levels (mg/m^3)	Cotton/Wool Mills n	mean % Δ $FEV_{1.0}$	S.D.	Synthetic/Wool Mills n	mean % Δ $FEV_{1.0}$	S.D.
0.05	299	0.4	9.4	241	-0.7	5.5
0.15	309	0.5	9.8	212	-0.2	7.0
0.25	113	-1.8	10.0	141	-0.6	6.7
0.35	130	-4.2	6.1	112	0.7	7.0
0.45	95	-2.6	16.2	7	0.2	3.3
0.55	35	-2.0	8.8			
0.75	61	-4.9	10.1			
1.10	16	-0.9	10.3			
1.50	12	-2.7	6.0			
1.90	35	-5.6	10.9			

Table 6. — Parameters of Log in-Probit Dose-Response Curves and Three Points on Each Fitted Curve with Their 95% Confidence Limits

Group	Intercept (a)	Slope (b)	Expected Prevalence (%) .1 mg/m^3	.2 mg/m^3	.5 mg/m^3
1	4.826	1.108	10.0%(7.3-13.3)	17.1%(14.2-20.5)	30.6%(25.9-35.6)
2	4.641	1.301	4.9%(2.8-7.9)	10.2%(7.5-13.6)	22.7%(17.8-28.3)
3	4.718	1.226	6.5%(5.0-8.5)	12.7%(10.8-14.9)	25.8%(22.5-29.3)
4	3.966	2.134	0.08%(0.01-0.7)	0.6%(0.1-2.1)	4.7%(2.7-7.7)
5	3.944	1.170	1.3%(0.7-2.3)	3.0%(2.1-4.3)	8.0%(6.1-10.2)
6	4.200	1.304	2.1%(1.3-3.3)	5.0%(3.8-6.6)	13.0%(10.7-15.8)

Table 7. — Predicted Dust Levels and Their 95% Confidence Limits for Arbitrary Levels of Prevalence of [illegible]

Prevalence	Predicted Dust Level (mg/m^3) Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
[illegible]	[illegible]	.031(.010-.056)	.021(.012-.033)	.25(.12-.36)	.082(.042-.12)	[illegible]
[illegible]	[illegible]	[illegible]	.030(.021-0.51)	.33(.19-.45)	.14(.086-.19)	.097(.063-.13)
[illegible]	[illegible]	[illegible]	[illegible]	.40(.25-.52)	.20(.13-.26)	.13(.091-.17)
[illegible]	[illegible]	[illegible]	.063(.043-.084)	.46(.31-.58)	.25(.18-.33)	.18(.12-.21)
[illegible]	[illegible]	.10(.057-.15)	.077(.054-.10)	.52(.36-.64)	.31(.24-.41)	.20(.15-.25)
[illegible]	[illegible]	.20(.14-.26)	.15(.12-.18)	.77(.62-.90)	.64(.49-.93)	[illegible]
[illegible]	[illegible]	.57(.41-.97)	[illegible]	1.5(1.2-1.9)	2.1(1.4-4.6)	1.1(.84-1.6)
[illegible]	[illegible]	1.9(1.1-5.5)	1.7(1.2-2.7)	3.1(2.2-5.4)	8.0(3.9-28.5)	3.6(2.3-7.4)

represent another example of ethnic difference in susceptibility to the biological manifestations of inhalants. Further analyses of this data are being done to determine whether this is a sociological or a biological problem.

Another important observation concerning these dose-response curves is that there appears to be no threshold beneath which no one with Monday chest tightness was found (Table 4). This indication that low dust concentrations result in measurable effects suggests that cotton dust is a highly biologically active inhalant. British studies reported by Molyneaux and Berry[15] also found no threshold for the biological effects (byssinosis and simple bronchitis) of respirable dust (< 7μ-Hexlet) and middle fraction dust (7μ to 2mm-Hexlet). Although these dust fractions and the vertical elutriator dust fraction are not strictly comparable, they do contain much of the same dust distribution. When their dose-response regressions are plotted with those presented in this paper, there is good general agreement both in origin and slope. At 0.2 mg/m³, both sets of curves reveal roughly 15% with some grade of byssinosis. As has been observed before, surprising uniformity in byssinosis prevalence has been found in cross-sectional surveys despite differing populations, working conditions, and frequently somewhat different methods of study.

The log-probit model was found to fit this data well and offers the opportunity to consider prevalence at fixed dust levels and conversely, calculate dust levels from any given level of prevalence. This is clearly very useful when considering data for setting standards. Probit analysis (Table 6) shows the expected byssinosis prevalence for all grades of byssinotics at 0.2 mg/m³ to be 12.7%, while only 3.0% for Grade 2 byssinotics. In order to determine what a reasonably safe level of lint free dust might be, the question is raised whether all grades of byssinosis or only Grade 2 byssinosis prevalence is the appropriate indicator. We concluded that overall byssinosis prevalence best estimated byssinosis risk since it was likely to be less affected by selection than Grade 2 byssinosis. In our experience, workers usually do not consider selecting themselves out of exposure if they have only occasional chest tightness or tightness which is not severe and confined to

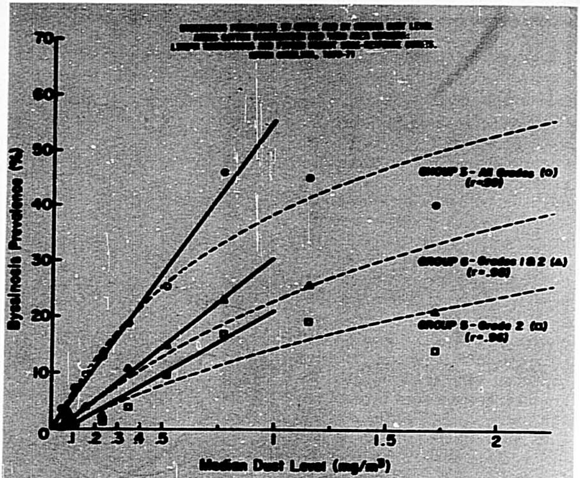

Fig 8.

Table 8. — Chi-Square Tests for Goodness-of-Fit of the Log-Probit Model and for Parallelism of Pairs of Fitted Lines.

Group	Goodness-of-Fit x^2	df	P	Parallelism x^2	df	P
1	6.0	8	.65			
2	14.1	8	[illegible]			
3	7.5	8	.52			
4	3.8	5	.58			
5	8.3	8	[illegible]			
6	10.0	8	.26			
1 & 2	20.1	16	.21	0.53	1	.47
3 & 4	11.3	13	.59	6.0*	1	.015

Symbols: df = degrees of freedom
P = probability of x^2 as large or larger than observed value
* = significant at the .05 probability level

Table 9. — Relative Toxicities and Their 95% Confidence Limits

Byssinosis Prevalence Groups	P	Relative Toxicity R	95% Confidence Limits
1 & 2	All levels	.56	.35 to .83
3 & 4†	.01	.09	.04 to .17
	.02	.11	.06 to .19
	.03	.12	.08 to .20
	.04	.14	.09 to .21
	.05	.15	.10 to .22
	.10	.20	.15 to .26
	.25	.32	.24 to .43
	.50	.56	.32 to .96

Symbols: p = No. of subjects with byssinosis/total No. of subjects
R = ratio of dust levels producing same prevalence
(eg., dust level for group 1/dust level for group 2)
† = Note: Dose-response curves for groups 3 and 4 are non-parallel, so that relative toxicity varies with level of prevalence.

Monday. Those with tightness on Monday and other days (Grade 2) frequently also complain of dyspnea and fatigue; as a result it is not uncommon to find that these workers request a change in job location. Therefore, those with Grade 2 byssinosis symptoms are likely to represent a highly selected group which would very likely result in an underestimation of risk.

Also to be considered is the sensitivity of the biological indicators used in this study; the standard indicators in studying the effects of cotton dust have been byssinosis symptoms and change in $FEV_{1.0}$. There is now evidence that use of flow-volume loops[9, 23, 24] and measurement of the leukocyte response[24] increase sensitivity in detecting biological effects. Therefore, because of selection and because the indicators of response in developing this dose-response data although well standardized are probably still dull tools, we conclude that, for cotton and blend mill preparation and yarn areas, a reasonably safe level of cotton dust exposure is 0.1 mg/m³. Even at this low level an expected byssinosis prevalence of 6.5% was found by probit analysis. A separate level of 0.75 mg/m³ is suggested as a reasonably safe level in slashing and weaving areas. It will be necessary to include in any cotton dust standard provisions for periodic testing of workers to detect those most susceptible and to avoid placement of those with impaired lung function in dusty areas.

Dust Control. — There is now substantial evidence that biological effects result from low levels of lint-free cotton dust exposure, even with relatively crude indicators of response. To make the cotton textile mill working environment reasonably safe, very great strides must be taken in controlling fine dust. Initially, this requires a reorientation in thinking regarding dust handling from suppressing primarily lint to suppression of fine dust as well. Currently, machine exhaust and ventilation and filtration systems are designed primarily to control lint and large dust particles and not fine dust. As a result, the workroom frequently appears lint free and relatively clean, yet lint free dust levels may be relatively high. To solve this problem, two basic approaches may be taken. One is the traditional approach of dust control after the dust has been introduced into the mill; the second is removal of dust from lint prior to manufacturing. Clearly, the most desirable approach would be a method to harvest cotton without contamination with trash. New methods to improve picking are now under consideration. Dust reduction at the ginning stage would be the next most desirable location to control dust. There is now experimental evidence that the application of steam to cotton is compatible with manufacturing and reduces lint free dust levels and biological activity by roughly one half.[19] A plant wide intervention trial is now underway to test the effectiveness of steaming under manufacturing conditions. The feasibility of steaming cotton at a gin is also being tested. Although steaming may provide improvement in environmental conditions, it is apparent that much improved dust control, particularly in preparation areas will also be required.

Table 2 shows that lint free dust levels are particularly high in the preparation areas of cotton mills. Review of dust levels from six cotton mills (three from this study; 670 samples) revealed vertical elutriator median dust levels of 1.50-1.59 mg/m³ in opening and blending areas, 1.60-1.69 mg/m³ in picking areas, 1.70-1.79mg/m³ in carding areas, then dropping to 0.70-0.79 mg/m³ in drawing, 0.40-0.49 mg/m³ in roving, 0.20-0.29 mg/m³ in spinning, winding and twisting, and then up again in weaving to 1.00-1.09 mg/m³. In eleven blend mills (50% cotton or less), two of which are part of the study reported in this paper, 1232 vertical elutriator dust samples found a median dust level of 0.30-0.39 mg/m³ in opening and blending, 0.50-0.59 mg/m³ in picking, 0.60-0.69 mg/m³ in carding, 0.30-0.39 mg/m³ in drawing, 0.10-0.19 mg/m³ in roving, 0.00-0.09 mg/m³ in spinning. 0.10-0.19 mg/m³ in winding and twisting and 0.50-0.59 mg/m³ in weaving areas.[10] In these eleven blend mills, the spinning and weaving areas show median dust levels that may be considered reasonably safe and levels in roving, winding and twisting approach this level. Since less than 10% of the work force is employed in areas preceding roving, roughly 90% of those working in these eleven blend mills could be considered as working in a reasonably safe or marginally safe working environment. Those remaining, although exposed to hazardous dust levels, are working in a third or less the dust concentration of their counterparts in cotton mills.

By contrast, it appears from these figures that there is no work area in the cotton mills that could be considered reasonably or marginally safe, although yarn processing and weaving areas are not far from these levels. The areas clearly in acute need of attention are those of opening, blending, picking and carding. Because drawing and roving are almost invariably in the same work area as the carding engine, much of the dust exposure in these latter two areas probably arises from the carding engine. To protect these workers, the carding area should be partitioned from drawing and roving and each area provided with an independent ventilation system. Under such conditions the dust levels in drawing and roving are expected to more closely approximate those in spinning. Close attention to recirculation of lint free dust ($<$ .05 mg/m³)[25] should further reduce dust levels to more acceptable levels. Preprocessing removal of fine dust by steam may also contribute to achieving safe levels in these areas. But even if steaming were to reduce dust levels by a half, the processes of opening, blending, picking and carding will require efficient exhaust systems. Fortunately, in each of these machines, the area in which the fiber is most vigorously processed is in a relatively enclosed part of the machine. Further enclosure of each of these machines with well designed exhaust systems does not appear to be insurmountable. Efficient removal of fine dust, without recirculation, should markedly improve these preparation areas and perhaps could also remove some dust which previously was released from the yarn in subsequent processes, thereby contributing to control in these work areas.

In summary, the following statements can be made:

1. This study confirms the finding of others, that a strong linear association exists between prevalence of byssinosis and decrement in expiratory flow rate with concentration of lint free dust.

2. The log-probit model, curves of which followed the linear regression plot below 0.5 mg/m³, fit this data well and provided both expected byssinosis prevalence and conversely expected dust levels, both of which proved to be useful in interpretation of the dose-response

relationship.

3. Based on these curves, it is concluded that a reasonably safe level of lint free cotton dust is 0.1 mg/m³, a level at which nearly 94% of the population exposed were found to have no symptoms of byssinosis. A separate level of 0.75 mg/m³ is suggested for slashing and weaving areas.

4. Probit dose-response curves for smokers and those who never smoked, showed that smokers had a significantly higher prevalence of byssinosis.

5. The vertical elutriator cotton dust sampler, over a period of two years, has proven to be a durable and practical instrument which collects a biologically active lint free fraction of dust linearly associated with indicators of biological response.

6. Lint free dust levels by work area suggest that no work area in the cotton mills sampled had reasonably safe dust levels and that the areas of opening through carding had very high levels. By contrast, in blend mills all areas beyond drawing had reasonably safe or marginally safe dust levels while levels preceding roving are considered only moderately elevated.

7. It is recommended that carding machines be isolated from drawing and roving processes by partitioning and the use of independent ventilation systems.

8. Serious attention should be given to more complete enclosure of opening, blending, picking and carding machines and design of a highly efficient exhaust system to remove fine dust.

9. At the present time, a successful occupational health program for the cotton textile industry should include efforts to remove or reduce dust prior to processing, efficient machine exhaust and ventilation systems, and medical surveillance to detect susceptible workers before they acquire permanent pulmonary impairment.

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