Can exposure to coalmine dust cause a severe impairment of lung function?

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ABSTRACT It is well recognised that exposure to respirable coalmine dust causes a reduction in lung function but it has not been clear whether the impairment of function is sufficient to cause disability, unless progressive massive fibrosis occurs. From a study of 4059 men without progressive massive fibrosis who worked in the coal industry for at least ten years from the 1950s, and who were followed up and re-examined medically more than 20 years later, a subgroup was selected using criteria intended to favour those who may have suffered greater than average effects of dust exposure. These 199 men had left the coal industry before normal retiral age, had taken other jobs, and had reported symptoms of chronic bronchitis at follow up. The inverse relation between dust exposure and FEV₁ among these 199 men was much more severe than the average effects previously shown among more representative groups of coalminers. The effect of exposure to respirable dust was estimated conservatively as an impairment of about 2 ml FEV₁ per unit of dust exposure (gh/m³). The estimated effect among ex-smokers was more severe. These compare with a previous estimate, based on a less selected population, of 0.6 ml FEV₁ per gh/m³. The new estimate in this group of 199 men corresponds to an average loss of 600 ml FEV₁ in response to a moderately high dust exposure to 300 gh/m³, with correspondingly higher losses in the ex-smokers. These findings show that among a group of men intentionally selected to include those who may have suffered greater than average effects of dust exposure, the relation between exposure and FEV₁ is consistent with the view that in some men even moderately high exposure to dust causes severe impairment of lung function.

An inverse relation between exposure to respirable dust and the lung function of coalminers was established more than ten years ago¹ and confirmed subsequently in other studies.²⁻⁴ The average dust effect was estimated¹ as a loss of 0.6 ml FEV₁ per unit of dust exposure (gh/m³), implying on average a clinically modest reduction in response to a lifetime's working under current conditions in British coalmines.

There are two reasons why some men may nevertheless suffer a clinically important loss of function in response to dust exposure. Firstly, Rogan and colleagues noted that 10% of the coalface workers in their study had experienced dust exposures in excess of 440 gh/m³, associated on average with estimated reductions of 250 ml FEV₁ or more.¹ Such high exposures are, however, extremely unlikely under today's conditions. Secondly, they also considered the unexplained differences in FEV₁ among men with

moderate dust exposures. To some extent these differences may reflect a natural variability in the way that the lung function of coalminers responds to dust exposure. Studies to date, however, have not identified what factors, if any, may be related to a more severe response. Thus there are at present no direct estimates of the effect of dust in the men who respond most severely, and the clinical importance of dust exposure for the lung function of coalminers has remained a controversial issue.⁵⁻⁷

While studying a group of 1867 coalminers and 2192 ex-miners in Britain in whom average dust effects⁸ similar to those reported previously¹ were established, we aimed to characterise and to study in detail subgroups of men who are most likely to include those suffering greater than average effects of dust exposure. One such group, certainly not representative of coalminers generally, included 199 men who showed an exceptionally severe inverse relation between exposure to respirable dust and FEV₁. We now report the results that show this relation and discuss its causes and implications. A more comprehen-

sive report is being prepared that will include other results from the larger study of which this finding forms a part.

Subjects and methods

CONTEXT

The data form part of the pneumoconiosis field research,⁹ in which 53 382 coalminers participated between 1953 and 1980. The men studied were included in a sample¹⁰ of 17 738 coalminers examined between 1953 and 1958 at the first of a series of medical surveys of the current working populations at 24 collieries⁹ throughout Britain. The 24 collieries were grouped into six geographical regions for the purposes of the present analysis.

A full sized chest radiograph was taken at all surveys. The earliest generally reliable measurements of lung function were obtained between 1963 and 1968 at the third of this series of medical surveys, attended by 8128 men in the sample who were still employed in the industry at that time. The exclusion of men with progressive massive fibrosis (PMF) at third survey, and others with missing or unreliable survey data, reduced those available for study to 7624 men. Of these, 4833 attended at a further series of follow up examinations between 1974 and 1980, aimed at re-examining survivors from the sample whether or not they were still working in the industry; 1305 (17%) of the 7624 men had died. The representativeness of the 4833 men relative to the group of 8128 has been described recently.¹¹

Further exclusions for incomplete or unreliable data or the presence of PMF at follow up survey reduced the study group from 4833 to 4059 men, of whom 2192 had left the coal industry by that time. The 4059 men form the basis of continuing study investigating substantive and methodological aspects of the relation between dust exposure and lung function, both cross sectionally and longitudinally. The primary purpose of this work is to determine whether or not ex-miners had responded more severely to dust exposure than had the men who remained employed in the coal industry.

DATA

Questionnaires on respiratory symptoms and smoking habits were administered by trained personnel at all surveys other than the first.¹² Chronic bronchitis at follow up survey was defined on the basis of the questionnaire as the presence of persistent cough and persistent sputum. Lung function was measured by simple spirometry,¹ and the mean of three technically satisfactory measurements of FEV₁ at follow up survey used in the analysis. When only one or two technically satisfactory blows had been recorded, the

mean of these was accepted. Date of birth was recorded and standard anthropometric measurements taken.

All follow up survey chest radiographs were read independently and in random order by a panel of five readers (four of whom were not medically qualified) who had trained themselves¹³ to interpret chest radiographs according to the ILO U/C classification.¹⁴ The median of these five readings was used as the follow up survey classification for each man.

Men were classified as current smokers, ex-smokers, and lifelong non-smokers at follow up on the basis of their responses to the smoking questionnaires. Two approximate indices of cigarette consumption were derived for men who were current smokers of cigarettes only, and not pipes or cigars, at the third medical survey. Firstly, the number of cigarettes smoked at the time of third survey was multiplied by the number of years since the man was aged 16, and expressed as a total number of cigarettes smoked. Then the number smoked at the time of follow up survey was multiplied similarly by the length of the interval between intermediate and follow up surveys. The number of cigarettes smoked during this latter interval had not been recorded for men who had given up smoking between intermediate and follow up surveys, and a value of zero cigarette consumption was assigned to them for this period.

Estimates of the dust concentrations to which men had been exposed were derived from an intensive long term programme of environmental sampling at the 24 research collieries concerned.¹⁵ Continuous monitoring of where men worked within the collieries, supplemented by occupational histories obtained by interviews at the medical surveys, provided information on the time worked by each man in these conditions. Data on concentrations and on time worked were then linked¹⁶ to provide estimates of individuals' lifetime exposures to respirable coalmine dust. The units of dust exposure are grammes of respirable dust per cubic metre of air times hours (gh/m³).

Occupational histories recorded at follow up were also used to classify the 4059 men as miners or ex-miners. Ex-miners were subclassified according to whether they had retired from work, been made redundant, or left voluntarily and taken up other jobs after leaving.

STATISTICAL METHODS

After detailed data descriptions, FEV₁ at follow up survey was related in cross sectional analyses to other characteristics of the men, using linear regression methods.¹⁷ Analyses were carried out using the BMDP suite of programs.¹⁸ Residuals were examined thoroughly.

We found that FEV₁ level varied by geographical

Table 1 Mean (SD) of, or number (%) with, selected characteristics among the 199 men relative to men of similar age from the original study group of 4059 men

	Subjects of this paper	Ex-miners <65 years*	Miners
No	199	1023	1867
Age (years)	53 (7)	56 (8)	53 (7)
Height (cm)	170 (6)	170 (6)	170 (6)
Weight (kg)	77 (12)	75 (13)	76 (12)
Dust exposure (gh/m ³)	158 (103)	167 (107)	174 (100)
FEV ₁ (ml)	2492 (842)	2485 (834)	2751 (759)
Smoking status:			
Non-smokers	11 (6%)	125 (12%)	255 (14%)
Ex-smokers	35 (18%)	273 (27%)	435 (23%)
Smokers	153 (77%)	625 (61%)	1177 (63%)
Geographical region:			
Scotland	35 (18%)	182 (18%)	276 (15%)
West Midlands	6 (3%)	75 (7%)	224 (12%)
North East England	40 (20%)	222 (22%)	379 (20%)
Yorks and Notts	9 (5%)	68 (7%)	412 (22%)
South Wales	49 (25%)	249 (24%)	330 (18%)
Other	60 (30%)	227 (22%)	246 (13%)

*Including the 199 subjects of this paper.

region, and that its relation to age varied according to smoking habit when men were classified as non-, ex-, or current smokers.⁸ These factors, together with height and weight, were found to provide an adequate context in which to study the effect of dust exposure.

SUBJECTS

Analyses of the 4059 men had confirmed that there was a clear effect of dust exposure on FEV₁ taking into account other factors including geographical variations.⁸ There was some evidence that the 1023 ex-miners who were younger than the retirement age of 65 had suffered a more severe response to dust exposure than other men. These ex-miners were classified further according to whether or not they reported symptoms of chronic bronchitis, since men may have been influenced in decisions about jobs by perception of their health and the influence of work on it.

The results suggested a greater than average effect of dust exposure among the 453 ex-miners under 65 who had reported symptoms of chronic bronchitis. These men were therefore examined in more detail according to their reasons for leaving the industry and their subsequent employment, since such decisions could also be influenced by perceptions of health or illness.

The 453 ex-miners with bronchitic symptoms comprised 158 who had left the coal industry voluntarily and did not take other jobs, 199 men who left voluntarily and did take other work, and 96 who had been made redundant or were unclassifiable in terms of subsequent employment.

The 199 men who left voluntarily and took other work are the subjects of this paper. Results for the 158 men who left voluntarily, without taking other jobs, did not show a strong association between dust ex-

posure and FEV₁. They will be included in the main report of the study of 4059 men, which is in preparation.

Results

The data in table 1 compare the 199 subjects with miners and ex-miners of similar age from the larger study group of 4059 men. The three groups are similar in height and weight. The geographical distribution of the 199 men is similar to that of other ex-miners aged under 65 but different from that of the men who stayed in the industry.

There was no evidence (table 1) that the 199 men had experienced particularly high dust exposures. They did, however, include an unusually high proportion of smokers. Nevertheless, their unadjusted FEV₁ was not unusually low, on average, being almost identical with that of other ex-miners aged less than 65 and, like them, worse than the FEV₁ of men who had stayed in the industry.

There are, however, large variations in unadjusted FEV₁ levels within the group of 199 men. The most striking characteristic (table 2) is the association between high dust exposure and low FEV₁. This effect is pronounced in all four age groups considered, and does not appear to be explicable in terms of the height of the men concerned. In addition, the observed values of FEV₁ indicated clinically severe impairment of lung function in some men, particularly among the older and higher exposure groups. Five men had an FEV₁ below one litre, and three of these had experienced dust exposures in excess of 300 gh/m³.

The interpretation of an association such as shown in table 2 is complicated by many factors that may influence FEV₁ level; in particular, the data in table 2 take no account of smoking habit or geographical

Table 2 Numbers of men, mean (SD) of FEV₁ (l), and height (cm), in 199 men grouped by ranges of age and dust exposure

Age (years)	Dust exposure (gh/m ³)				
	0-99	100-199	200-299	≥ 300	All
	No FEV ₁ Height	No FEV ₁ Height	No FEV ₁ Height	No FEV ₁ Height	No FEV ₁ Height
< 50	35 3.2 (0.9) 171 (6)	23 2.9 (0.8) 171 (6)	4 2.5 (1.0) 165 (7)	2 2.4 (0.8) 172 (4)	64 3.0 (0.9) 171 (6)
50-54	9 2.9 (0.5) 172 (7)	13 2.4 (0.5) 170 (5)	11 2.1 (0.6) 170 (3)	6 2.1 (0.9) 171 (5)	39 2.4 (0.6) 171 (5)
55-59	20 2.5 (0.7) 170 (5)	23 2.1 (0.7) 170 (5)	17 2.4 (0.6) 171 (7)	5 1.8 (0.7) 170 (4)	65 2.3 (0.7) 170 (6)
> 60	9 2.2 (0.9) 172 (8)	7 2.1 (0.7) 169 (13)	10 1.9 (0.5) 170 (7)	5 1.4 (0.8) 168 (8)	31 1.9 (0.7) 170 (9)
All	73 2.9 (0.9) 171 (6)	66 2.5 (0.8) 170 (6)	42 2.2 (0.6) 170 (7)	18 1.8 (0.8) 170 (5)	199 2.5 (0.8) 170 (6)

variations. A strong inverse relation between dust exposure and FEV₁ was, however, confirmed ($t = -4.1$, $p < 0.001$) in multiple regression analyses that adjusted simultaneously for the effects of age, height, weight, differences between smoking groups (including different effects of age according to smoking habit), and regional differences. The regression coefficients are given in table 3 and help to explain the structure of the statistical representation. Note that in terms of statistical significance, a relation of FEV₁ is established more clearly with dust exposure than with any other single characteristic.

We next examined in several different ways whether or not changes in the data or in the statistical representation led to substantial changes in the estimated relation of FEV₁ to dust exposure.

Firstly, we checked if the association was due to the presence of a few men with high dust exposures and low lung function. Four such men (mean age 59; dust

exposure 524 gh/m³; FEV₁ 867 ml) were excluded from an analysis that was otherwise identical with that in table 3. In this context the estimated regression coefficient of FEV₁ on dust exposure was somewhat more conservative, at -2.0 ml FEV₁ per gh/m³ of exposure, but remained highly significant statistically ($t = -2.9$, $p < 0.01$).

Secondly, we considered it plausible that we might adjust more reliably for age, height, weight, smoking status, and regional differences by estimating their influence using data from all 4059 miners and examiners, rather than from the smaller subgroup of 199 men. When this was done, and using a representation otherwise identical with table 3, the more conservative estimate of the dust FEV₁ relation was confirmed in size and in statistical significance.

Thirdly, we investigated if the estimated effects of dust exposure were sensitive to the way in which smoking effects were represented. These analyses were

Table 3 Coefficients from the regression of FEV₁ (ml) on other characteristics of the 199 men

	FEV ₁ (ml)	
	Coefficient	t value
Estimated FEV ₁ level (ml)†	2828	
Difference in FEV ₁ level (ml): relative to Scotland, for:		
West Midlands	-359	-1.2
North East England	-42	-0.2
Yorkshire and Nottinghamshire	197	0.7
South Wales	84	0.5
Other	-11	-0.1
Relative to non-smokers, for:		
Ex-smokers (at age 55)	-132	-0.5
Smokers (at age 55)	-87	-0.4
Effect of age (years):		
Non-smokers	-7.8	-0.3
Ex-smokers	-49.8	-1.5
Smokers	-34.9	-1.2
Height (cm)	21.0	2.1*
Weight (kg)	0.5	0.1
Dust exposure (gh/m ³)	-2.4	-4.1**

*0.01 < $p < 0.05$; ** $p < 0.001$.

†For non-smoker in Scotland, age 55, height 170 cm, weight 75 kg.

restricted to the 163 men for whom approximate indices of cigarette consumption were available, comprising 11 lifelong non-smokers and 152 men who at third survey smoked cigarettes only. Several representations were investigated.

(1) The effect of dust was estimated as -2.7 ml FEV_1 /gh/m³ ($t = -4.3$) when the influence of smoking was represented simply as average differences between the three smoking groups, with concomitant adjustments for age, height, weight, and geographical region.

(2) The added inclusion of the two indices of cigarette consumption did not contribute significantly to the fit of the model in this small group, and the size and statistical significance of the estimated dust effect remained unaltered. (Estimates of the numbers of cigarettes smoked were found to be related to FEV_1 in the larger group of 4059 men.)

(3) The effect of smoking was next represented by different losses of FEV_1 with age in the three smoking groups, in addition to differences between the groups. In this context the effect of dust was estimated as -2.6 ml FEV_1 /gh/m³ ($t = -4.0$).

(4) When all the representations of smoking effect, including the indices of cigarette consumption, were simultaneously taken into account along with the other characteristics of table 3, the dust effect was estimated as -2.5 ml FEV_1 /gh/m³ ($t = -3.9$).

Clearly, the estimated dust effect was insensitive to which representation was used.

Finally, we considered whether, within the group of 199 men, the estimated effect of dust exposure varied according to smoke habit. Table 4 gives the characteristics of the men, grouped by smoking status at follow up survey. Few (7%) of the 199 men showed simple pneumoconiosis of category 2 or higher.

Data descriptions indicated that the 35 ex-smokers may have experienced a particularly severe effect of dust exposure. Regression analyses similar to those carried out for all 199 men were applied separately to the smokers and ex-smokers, and confirmed this im-

pression. For example, when the influences of age, height, weight, smoking status, and regional differences were estimated using data for all 4059 miners and ex-miners, then the inverse relation between dust exposure and FEV_1 among the 35 ex-smokers was estimated as a reduction of 3.1 ml FEV_1 per unit of exposure ($t = -4.5$, $p < 0.001$). The estimated response was even more severe when the 199 men, or the 35 ex-smokers themselves, formed the basis for age and other adjustments.

Three of the four men with high dust exposures and low lung function, noted above, were ex-smokers. When these three men were excluded from the analysis the estimated dust effect among ex-smokers remained substantial, at a reduction of 2.5 ml FEV_1 per gh/m³ of exposure, but the statistical significance was reduced to the 8% level ($t = -1.8$).

The clinical effects may be illustrated using the conservative estimate of an average reduction of 2.0 ml FEV_1 per gh/m³ dust exposure among the 199 men. This corresponds to an impairment of 316 ml of FEV_1 in an ex-miner who had experienced the average dust exposure of the group, or an impairment of 600 ml in response to an exposure of 300 gh/m³, a moderately high exposure for this group of men. Note, however, that the greatest exposure experienced was more than twice as high, at 629 gh/m³. These losses are additional to those caused by aging and smoking, and almost certainly underrepresent the experience of the ex-smokers.

Discussion

Exposure to respirable dust is known to impair the lung function of coalminers.^{1-4,8} On average, the reductions in FEV_1 are clinically modest in response to exposures experienced in Britain over a working lifetime.^{1,8} Nevertheless, to understand whether exposure to coalmine dust may lead to disability even in

Table 4 Mean (SD) of, or number (%) with, selected characteristics among the 199 men, by smoking category

	Non-smokers	Ex-smokers	Smokers
No	11	35	153
Age (years)	52 (8)	55 (7)	53 (7)
Height (cm)	171 (6)	172 (6)	170 (6)
Weight (kg)	83 (12)	77 (11)	76 (12)
Dust exposure (gh/m ³)	99 (61)	186 (129)	156 (97)
FEV_1 (ml)	2689 (1008)	2329 (973)	2516 (798)
Estimated amount smoked*:			
By third survey	0	132 (75)	148 (81)
Between 3rd and follow up surveys	0	0	85 (42)
Simple pneumoconiosis:			
Category 0/— or 0/0	11 (100%)	26 (74%)	107 (70%)
Category 0/1 to 1/2	0	4 (11%)	38 (25%)
Category 2/1 or more	0	5 (14%)	8 (5%)

*Thousands of cigarettes; based on 18 ex-smokers and 134 smokers.

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the absence of progressive massive fibrosis information is required about the severity of response in the more susceptible men. To date, such evidence has not been available.

The broad aim of the analysis reported here was to investigate the issue of susceptibility within a study group of 4059 miners and ex-miners. Our specific objective was to identify and study a group of men selected by criteria that favoured those who may respond more severely than average to the effects of dust exposure. This objective has been attained. An unusually severe inverse relation between dust exposure and lung function, more than three times that for less selected groups of coalminers¹⁸ has been established unambiguously among the 199 subjects of this paper. The estimated relation is sufficiently severe that if a cause and effect interpretation is legitimate, we may conclude that dust exposure can lead to severe impairment of lung function in coalminers, other than through the medium of progressive massive fibrosis.

Before discussing the central issue of how to interpret this finding, we wish to emphasise that the 199 subjects of this report are certainly not representative of coalminers generally. This is implicit in the objectives of the analysis, and follows also from the way in which the subgroup was selected. The 199 men are characterised by a combination of health and employment patterns which suggested that they, particularly, might have responded more severely than normal to dust exposure. Specifically, they had left the coal industry voluntarily before normal retirement age, and reported symptoms of chronic bronchitis when re-examined subsequently at medical surveys. Recent studies have shown that men leaving prematurely from another dusty industry had suffered a more rapid decline in FEV₁ than their fellow workers, thus lending some support to the criteria we adopted.¹⁹

Note that the selection procedure did not produce a group of men with unusually high dust exposures, nor with unusually low FEV₁ (though some were clearly clinically ill). What was distinctive was the strength and severity of the association between FEV₁ and dust exposure in the subgroup studied. This association was evident in the data descriptions, and was confirmed by more formal statistical methods. Thus we are dealing with a group which was atypical in respect of its dust exposure/FEV₁ relation, rather than in either of these characteristics alone.

In interpreting the finding of an extreme relation we think it important to recall that the rationale underlying this analysis, and indeed the entire research programme of which it is a part,⁹ is that dust exposure may cause lung damage. Generally, a cause and effect relation between dust exposure and respiratory health is well accepted. Against this background,

the most straightforward interpretation of our results is that the dust related reductions in lung function were in fact a health effect of exposure to dust. We think that this view is correct.

Other explanations are less convincing. The result did not arise from an undue influence of a few men with low lung function and high dust exposures (though even such a limited finding might point to an unusually severe response). Rather, the relation found reflected an experience of the group as a whole. Nor was the result an artefact due to some curious inter-relation between dust exposure and other influential characteristics—for example, age. Our estimation of adjustments for age and other factors using data from all 4059 men guarded against such a possibility. Nor is there any evidence that smoking was the real cause. The many different ways of representing the effect of smoking all led to the same conclusions about the relation of dust exposure to FEV₁.

There were, however, relatively few non-smokers among the 199 men. Possibly smoking influenced the inclusion of men in the group we selected through its influence on symptoms of chronic bronchitis and on lung function insofar as this may have been a reason for job changes. Generally, the average effect of dust exposure is not altered by smoking^{17,8} and further analyses of the larger group of 4059 men are therefore planned to determine whether unusually severe effects of dust on FEV₁ can occur in non-smokers also.

The second smoking related issue concerns why ex-smokers responded more severely than other men. The reasons are not obvious. It may be that some men, recognising a deterioration of respiratory health, took what precautions they could both by stopping smoking and leaving the industry. Or it is possible that stopping smoking in some way accelerated the effect of dust exposure in FEV₁ and this is another aspect which we will investigate further when we study the 4059 men longitudinally.

We know of no other factors which might reasonably be considered a cause of the unusual exposure response relation. The final possibility is that the result we found is a freak and essentially a meaningless one, the chance outcome of circumstances which, if they could be repeated, would show nothing of interest. Results from a small simulation exercise, reported in the appendix, suggest that such an event is extremely unlikely. In our view the evidence is strongly in favour of the simple interpretation that dust exposure caused the lung function impairment.

It is natural then to consider why some men responded severely to dust exposure whereas others did not. One possibility is that the 199 men may have been exposed to environmental influences, at work or elsewhere, different from their colleagues. Or there may be questions of individual susceptibility. We

have not attempted to investigate these issues because the main purpose of the present work has been the more limited objective of seeing whether a severe response of FEV_1 to dust exposure can, and indeed did, occur.

It is natural also to consider whether men experiencing an extreme response are rare in the coal industry. Again, a full answer goes beyond what we have attempted at this stage. It is noteworthy, however, that the 199 subjects of the present paper comprised only 5% of the larger study group from which they were selected. On the other hand, that larger group of 4059 men had worked in the coal industry for about 11 years from the 1950s onwards. Some men who began to show a severe response may have left the industry in that period and so could not be included in these analyses. Thus 5%, as a crude estimate of the proportion of men susceptible to a severe response, may be too low.

In addition, many of those who respond most severely may not experience sufficient dust exposure to cause an important impairment of function. This was so even among the 199 men we studied. All were ex-miners; an effect, and perhaps a purpose, of leaving the industry was to limit their exposure to dust. Also, the men studied experienced the greater part of their exposure to dust in the 1960s or earlier, when dust concentrations were often higher than is now permitted. The maximum exposure likely during a working life under current dust regulations in British mines has been estimated at 245 gh/m^3 .²⁰ The impairment of FEV_1 related to this exposure, estimated from the results for all 199 men considered here, would be on average about 490 ml, or about 760 ml in the ex-smokers. These also would be clinically important losses, though it is unlikely that any men would actually experience this maximum exposure as most of men's working lifetimes are currently spent in dust levels well below the maximum permissible.

In conclusion, we see the atypical experience of this group of men somewhat in terms of a case study. The fact that such an extreme relation can and did occur is important, especially since the most reasonable explanation is that it signifies a clinically important effect of dust exposure on FEV_1 . But this finding should not overshadow the well established result that on average the response of FEV_1 to dust exposure is clinically modest, and that severe lung damage from exposure to respirable dust is likely to be rare.

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Appendix

We carried out a limited exercise to describe the relation between dust exposure and FEV_1 among small randomly selected subgroups of the 4059 men, relative to that of a larger and more representative subgroup.

Each of the 4059 men was allocated at random and with equal probability to one of 116 groups whose average size of 35 was identical to that of the ex-smokers in this paper. Thirty five of the groups, again selected at random, were combined into a single large set with which results from the other 81 groups could be compared. Linear regression analyses of FEV_1 were then carried out among all 4059 men using a representation as in table 3 but extended to provide distinct estimates of FEV_1 level and of dust exposure in each of the 82 groups. This entire process of group construction and regression analysis was repeated three times, giving in all 243 comparisons of dust effect in a small subset with that of a larger combined group.

The effect of dust was estimated from the large combined groups as -0.78 , -0.61 , and -0.65 ml FEV_1 per gh/m^3 exposure on the three occasions respectively and was highly significant statistically. In six (2.5%) of the 243 subgroups the estimated effect differed from this average by -2.0 ml FEV_1 per gh/m^3 or more; while in only one of the 243 groups was the estimated effect greater than -3.1 ml $FEV_1/gh/m^3$, the value estimated among ex-smokers in this paper.

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