

FACTORS INFLUENCING EXPIRATORY FLOW RATES IN COAL MINERS

J. L. HANKINSON, R. B. REGER, R. P. FAIRMAN, N. L. LAPP and W. K. C. MORGAN

*Appalachian Laboratory for Occupational Respiratory Diseases,
National Institute for Occupational Safety and Health,*

and the

*Department of Medicine, West Virginia University Medical Center,
Morgantown, W.V., U.S.A.*

Abstract—The most commonly used tests of ventilatory capacity, viz. the forced expiratory volume in one second (FEV_1) and the forced vital capacity (FVC) are derived from a volume versus time record of a forced expiratory volume manoeuvre. Numerous studies have been unable to show a relationship between radiographic category of simple coal-workers' pneumoconiosis (CWP) and the FEV_1 and FVC. The explanation for this is related to the fact that coal dust responsible for pneumoconiosis is deposited in the alveoli and distal airways below 2 mm in diameter, and that marked increases in the air-flow resistance of these airways may be present without significantly affecting the FEV_1 , FVC, or the total airways resistance.

The flow volume curve has been suggested as a means to detect disease in the small airways since it permits measurement of expiratory flow at both high and low lung volumes. To derive additional information about the effects of coal dust on the small airways, the maximal expiratory flow volume curves of 6014 working coal miners have been analysed. The influence of (1) age, (2) height, (3) weight, (4) underground exposure, and (5) cigarette smoking, on maximal expiratory flows at 75, 50, 25, and 10% of forced vital capacity as well as peak flow was analysed. Age and cigarette smoking had a highly significant effect on flows at all lung volumes. Also prolonged underground exposure had a significant effect on the flow rates at high lung volume and was especially noticeable among the non-smokers. Although previous work has shown that miners have lower flows than do comparable age-matched controls, in the present study neither category of CWP nor major workplace had any detectable effect on flow rates in excess of what may be attributable to age, height, weight, and years spent working underground. The decrement in flow rates at higher lung volumes due to prolonged underground exposure, when considered in conjunction with the absence of an effect on flows with increasing radiographic category, suggests that a dust-induced bronchitis is responsible.

INTRODUCTION

Although there is a definite relationship between the category of simple coal-workers' pneumoconiosis (CWP) and the coal content of the lung (ROSSITER, 1972), the transition from category 0 to category 1, and from category 1 to 2, and so on, is unassociated with a decrement in the standard tests of ventilatory capacity until progressive massive fibrosis supervenes (ROGAN *et al.*, 1961; COCHRANE and HIGGINS, 1961; MORGAN *et al.*, 1974). The location of the coal macule, around the first- and second-order respiratory

bronchioles, explains why simple CWP does not affect ventilatory capacity (HEPPLESTON, 1953). The airways resistance of the lungs can be partitioned into central and peripheral components (MACKLEM and MEAD, 1967). The central component includes the resistance from the trachea to the eleventh generation of bronchi, while the peripheral component is composed of the resistance from the twelfth generation of bronchi (those airways with diameters of 2 mm or less) down to the gas-exchanging portions of the lung. In normal subjects the central resistance constitutes 85–90% of the total, leaving only 10–15% for the peripheral airways. It is therefore possible for a subject to have diffuse involvement of his small airways producing a doubling or tripling of the peripheral resistance, and yet for the total airways resistance still to be within normal limits (MEAD, 1970). Similarly, the most commonly used standard spirometric tests—namely, the forced vital capacity (FVC) and the forced expiratory volume in one second (FEV_1)—depend mainly on flow in the large airways during dynamic compression and, for this reason, the FEV_1 and FVC are usually little affected by changes in the peripheral airways resistance. Previous studies have shown that miners with normal spirometry may show frequency dependence of dynamic compliance suggesting involvement of the small airways (SEATON *et al.*, 1972).

The maximal expiratory flow volume curve has been advocated as a means of investigating the state of the peripheral airways (LAPP and HYATT, 1970). It has been suggested that the latter part of the curve reflects the geometry of the small airways and the mechanical properties of the surrounding lung, and is relatively unaffected by muscular effort. Accordingly, we have used the flow volume curve in our epidemiological studies of coal miners in order to test its usefulness as an index of disordered function in the peripheral airways. This paper describes the effects of radiographic category, bronchitis, underground exposure, age, smoking, and other factors on peak flow and also on expiratory flows at 75, 50, 25, and 10% of forced vital capacity.

METHODS

In 1973 and 1974 the U.S. Public Health Service conducted a study of the miners employed at thirty-six coal mines widely distributed throughout the United States. Thirty of these mines were part of an original study conducted in 1969. The mines were chosen to represent different mining methods and coal seams. Other criteria for inclusion were that the mines should have at least 100 employees and have an expected working life of approximately 10 years. Details of the survey have been previously described (MORGAN *et al.*, 1973).

All participating miners underwent a limited medical examination consisting of standard posteroanterior and lateral chest films and an administration of an adapted form of the Medical Research Council of Great Britain questionnaire on chronic respiratory symptoms, along with an occupational and smoking history (MEDICAL RESEARCH COUNCIL, 1965). In addition, at least five forced expiratory volume manoeuvres were performed using a high fidelity, waterless electronic spirometer (Ohio Medical Products, Madison, Wisconsin, Model No. 800).*

* Mention of brand name products does not constitute endorsement by the U.S. Public Health Service.

The flow and volume signals from the spirometer were recorded on FM analog tape (HANKINSON and ROSE, 1974) and later processed on a PDP-12 laboratory computer (Digital Equipment Corporation, Maynard, Massachusetts). The flow rates at 75, 50, 25, and 10% of the vital capacity were calculated from the flow volume curve which showed the best effort. The best effort manoeuvre was defined as the curve with the largest forced vital capacity (FVC) and a peak flow within 15% of the largest observed peak flow. If the curve with the largest FVC did not also have a peak flow within 15% of the largest observed peak flow, then the curve with the second largest FVC was tested, and so forth until a satisfactory curve was found. In approximately 75% of the miners, the flow volume curve with the largest FVC also had a peak flow within 15% of the largest peak flow.

For the purpose of this study, chronic bronchitis was defined as persistent phlegm production regardless of complaints of coughing. Smoking was considered qualitatively rather than in terms of pack-years or average daily consumption.

Although individual measurements of dust exposure were not available for the participants in this study, it can be assumed that the magnitude of their exposure to dust was related to their job and working place in the coal mines. Previous measurements by the Bureau of Mines (DOYLE, 1970) showed that face workers are exposed to the greatest, and surface workers to the least concentrations of respirable coal dust. In general, based on declining order of dust exposure, the working force can be divided into three groups; i.e. face, other underground, and surface workers.

All radiographs were classified using the I.L.O. U/C Classification System (U.I.C.C. COMMITTEE, 1972), and the results from one of five separate readers were used. Each interpreter had previously passed the U.S.P.H.S. proficiency examination (MORGAN *et al.*, 1973). Ex-smokers were excluded in order to emphasize the clear distinction between smokers and non-smokers, leaving 6014 miners in the study.

RESULTS

The mean flow rates, viz. peak flow, FEF₇₅, FEF₅₀, and FEF₂₅, according to underground exposure, age and smoking status are shown in Figs. 1-8. Table 1 also shows the mean flow rates at 50% of the vital capacity.

With minor exceptions, decreases in flow rates with age were evident for nearly all of the exposure by smoking status groups. Sharp decrements were particularly evident for the cigarette smokers, while declines for non-smoking miners were appreciably less. This was especially true for flow rates at high lung volumes, viz. peak flow and FEF₇₅. Slight decrements in flow rates existed within age categories with increasing dust exposure for the miners who were cigarette smokers; however, they were more striking for the non-smoking miners, particularly at higher lung volumes. For the flow rates at lower lung volumes, the decrements due to exposure were minimal for both smokers and non-smokers. The differences in flow rates between the smokers and non-smokers for each age/exposure group were nearly as great as the decrements due to age; the smokers showed markedly lower flows.

Although years spent working underground is only an indirect measure of dust exposure, it is the only index available to us, and we therefore decided to assess its

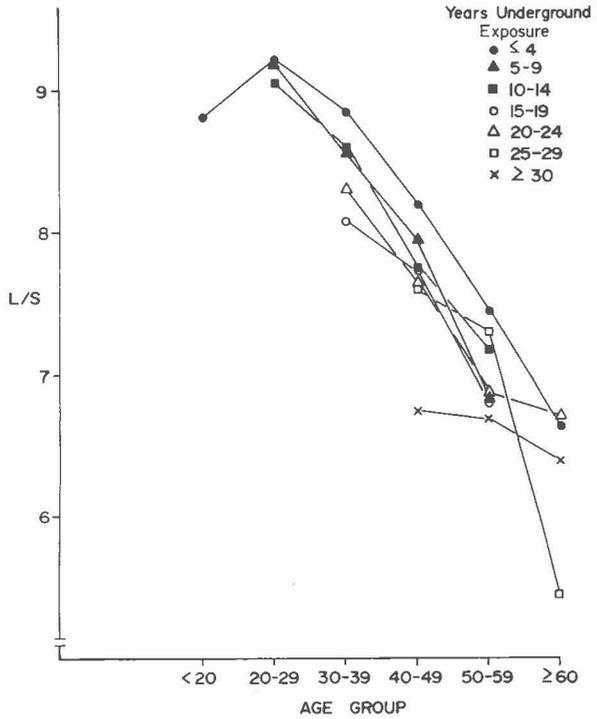


FIG. 1. Mean peak flow × age group × exposure group (smokers).

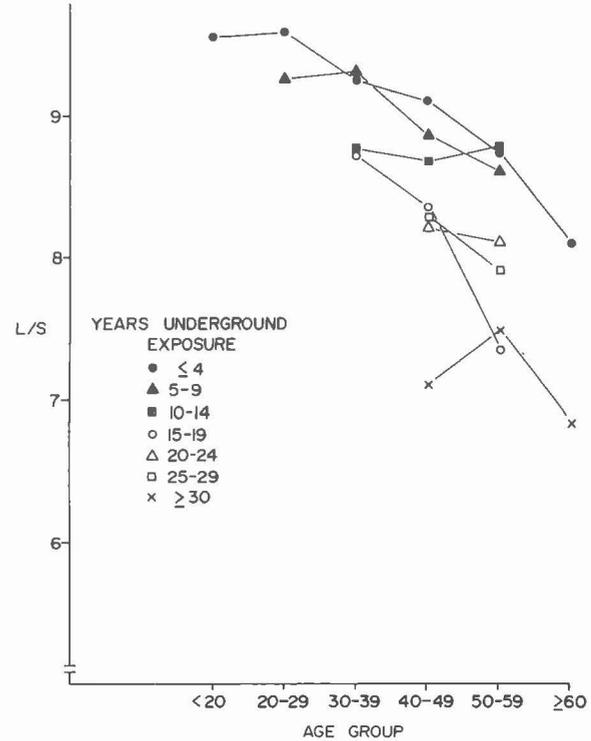


FIG. 2. Mean peak flow × age group × exposure group (non-smokers).

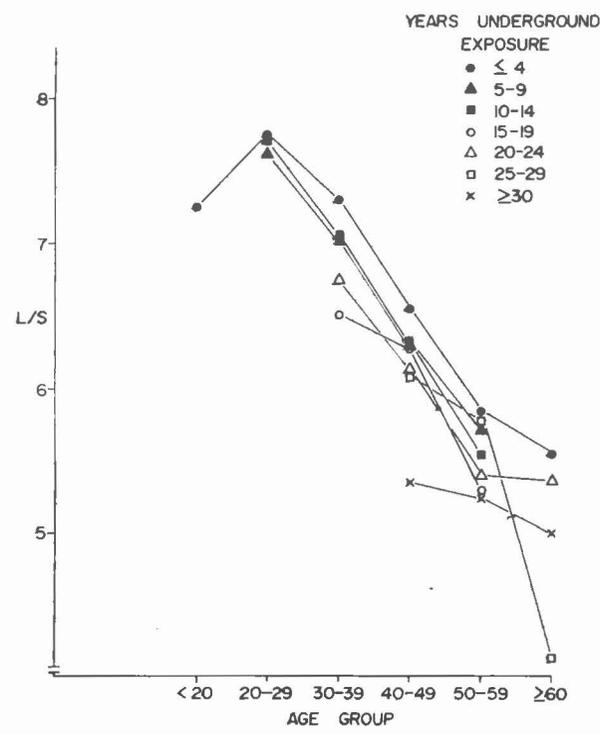


FIG. 3. Mean FEF₇₅ × age group × exposure group (smokers).

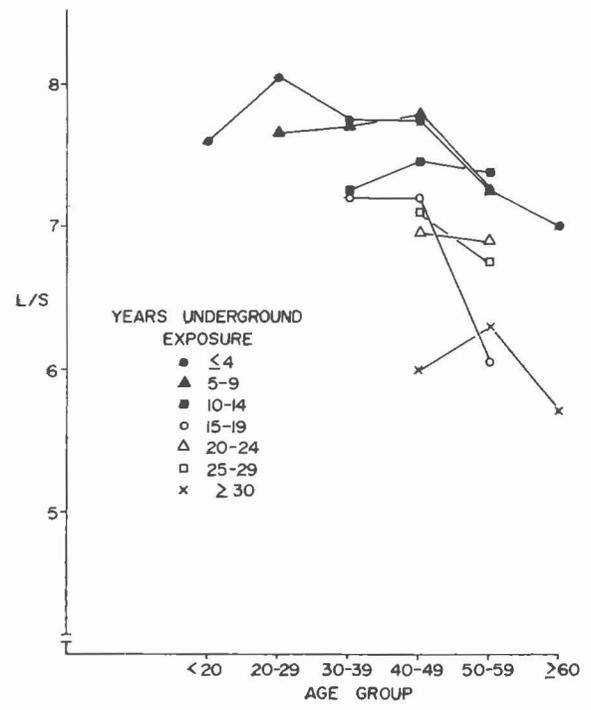


FIG. 4. Mean FEF₇₅ × age group × exposure group (non-smokers).

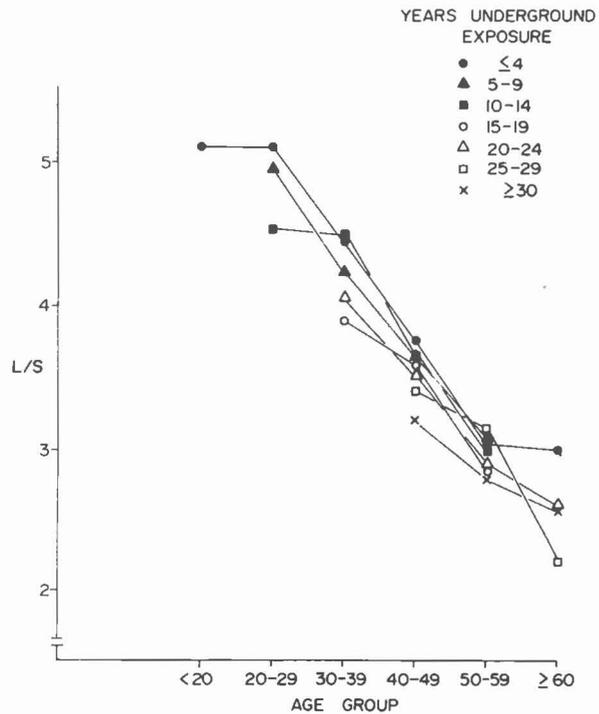


FIG. 5. Mean FEF_{50} \times age group \times exposure group (smokers).

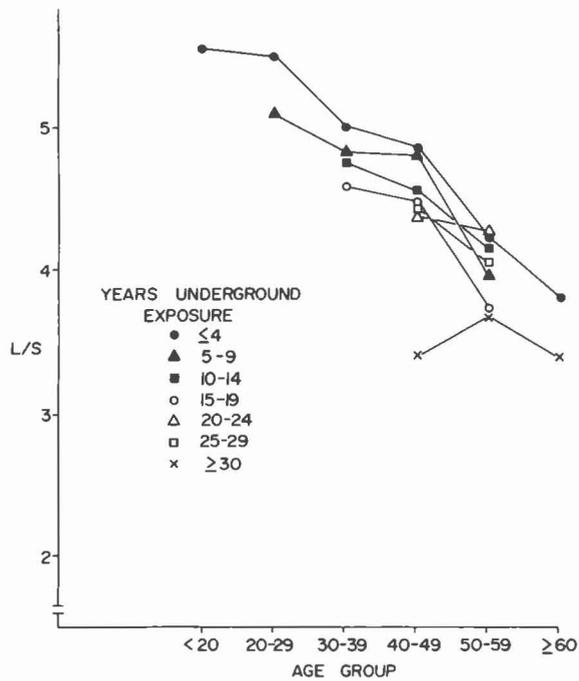


FIG. 6. Mean FEF_{50} \times age group \times exposure group (non-smokers).

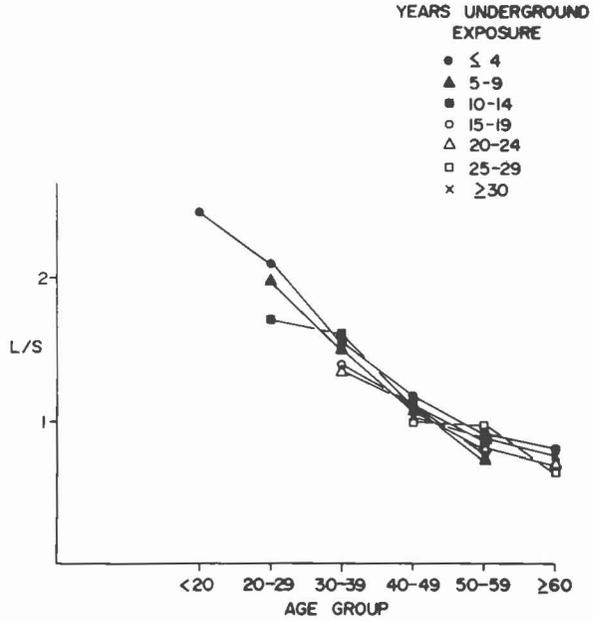


FIG. 7. Mean FEF₂₅ × age group × exposure group (smokers).

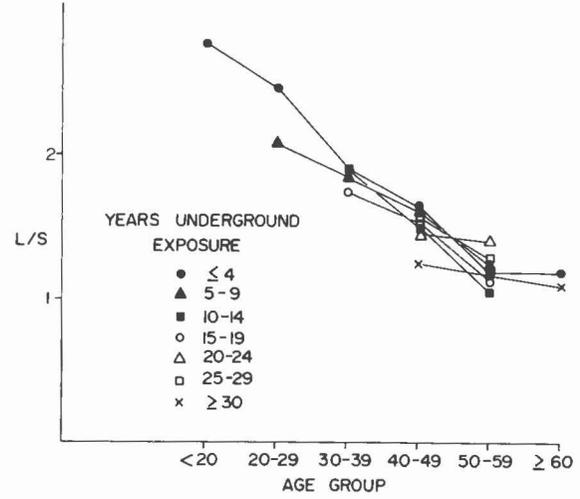


FIG. 8. Mean FEF₂₅ × age group × exposure group (non-smokers).

TABLE 1. MEAN FEF₅₀ FOR 6014 MINERS BY UNDERGROUND EXPOSURE, AGE, AND SMOKING STATUS^a

Underground exposure (Years)	Age											
	20		20-29		30-39		40-49		50-59		≥60	
	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
≥ 4	5.12 (60)	5.56 (34)	5.11 (978)	5.51 (439)	4.45 (428)	5.00 (138)	3.75 (175)	4.86 (68)	3.04 (120)	4.23 (62)	2.99 (11)	3.81 (21)
5-9	—	—	4.96 (207)	5.09 (82)	4.23 (280)	4.83 (92)	3.64 (94)	4.84 (28)	3.07 (29)	3.96 (16)	—	—
10-14	—	—	4.53 (16)	—	4.48 (115)	4.74 (31)	3.65 (90)	4.56 (35)	3.03 (43)	4.15 (16)	—	—
15-19	—	—	—	—	3.88 (83)	4.58 (25)	3.57 (133)	4.47 (39)	2.84 (55)	3.73 (17)	—	—
20-24	—	—	—	—	4.06 (26)	—	3.54 (204)	4.39 (75)	2.89 (104)	4.24 (41)	2.61 (13)	—
25-29	—	—	—	—	—	—	3.42 (214)	4.46 (68)	3.16 (240)	4.06 (74)	2.19 (23)	—
≥ 30	—	—	—	—	—	—	3.22 (43)	3.41 (19)	2.83 (416)	3.69 (193)	2.57 (118)	3.38 (83)

^aFEF₅₀ in l./s. () = no. of men per cell. S = smokers. NS = non-smokers.

importance relative to other variables presumed or known to affect flow rates. Tables 2 and 3 show the results of the stepwise multiple regression analyses for smokers and non-smokers. Details of the statistical methods may be found in the technical notes of this paper.

As expected, the coefficients for age were negative and for height were positive for all flow rates for both smokers and non-smokers. Weight had a very small but positive effect on flow rates at high and medium lung volumes but showed a reversal for FEF₂₅

TABLE 2. MULTIPLE REGRESSION ANALYSES REGRESSION COEFFICIENTS FOR FLOW RATES FROM 4318 MINERS (SMOKERS)

Variable	Peak flow	FEF ₇₅ ^a	FEF ₅₀	FEF ₂₅	FEF ₁₀
Age (years)	-0.0569	-0.0611	-0.0670	-0.0443	-0.0166
Height (cm)	0.0439	0.0270	0.0146	0.0109	0.0085
Weight (kg)	0.0071	0.0097	0.0075	-0.0033	-0.0060
Underground exposure (years)	-0.0183	-0.0138	-0.0030 ^b	0.0034	0.0034
Constant (l./s)	2.4317	3.7678	3.5472	1.4816	0.0345

^a e.g. FEF₇₅ = 3.7678 - (age × 0.0611) + (height × 0.027) + (weight × 0.0097) - (exposure × 0.0138).

^b Non-significant at the 0.05 level.

TABLE 3. MULTIPLE REGRESSION ANALYSES REGRESSION COEFFICIENTS FOR FLOW RATES FROM 1696 MINERS (NON-SMOKERS)

Variable	Peak flow	FEF ₇₅	FEF ₅₀ ^a	FEF ₂₅	FEF ₁₀
Age (years)	-0.0278	-0.0197	-0.0366	-0.0358	-0.0139
Height (cm)	0.0339	0.0193	0.0144	0.0125	0.0085
Weight (kg)	0.0132	0.0132	0.0062	-0.0053	-0.0075
Underground exposure (years)	-0.0349	-0.0319	-0.0155	-0.0001 ^b	-0.0012 ^b
Constant (l./s)	3.2875	4.0725	3.3087	1.4550	0.2052

^a e.g. $FEF_{50} = 3.3087 - (\text{age} \times 0.0366) + (\text{height} \times 0.0144) + (\text{weight} \times 0.0062) - (\text{exposure} \times 0.0155)$

^b Non-significant at the 0.05 level

and FEF₁₀. The effect due to underground exposure, although not consistent, showed a general decline for flow rates at high lung volumes. While the effect was minimal (relative to age) for the smokers, it was highly significant for the non-smokers.

Both smokers and non-smokers without CWP demonstrated flow rates which were higher than for the groups with radiographic evidence of the condition (Table 4, Figs. 9-12). The difference may be attributed mainly to the fact that the miners with CWP were older and had been exposed longer. As a general rule there was no evidence that

TABLE 4. MEAN FEF₅₀ BY CATEGORY OF COAL-WORKERS' PNEUMOCONIOSIS FOR 5853 MINERS^a

	0	1	2 and 3	PMF
No. of miners (smokers)	(3832)	(260)	(66)	(37)
Observed	4.07	3.27	3.10	2.58
Expected ^b	4.07	3.20	2.97	2.79
No. of miners (non-smokers)	(1511)	(98)	(28)	(21)
Observed	4.74	4.18	4.21	2.37
Expected ^c	4.75	3.97	3.89	3.63

^a 161 films of study group of 6014 miners judged unreadable.

^b Obtained from regression in Table 2.

^c Obtained from regression in Table 3.

miners with simple CWP suffered a decrement in their flow rates in excess of what may be attributed to their age, height, and years spent working underground. Nevertheless there were exceptions to this rule. First, the non-smoking miners with categories 2 and 3 had flow rates which were significantly higher than expected. This was probably the consequence of self-selection, whereby the healthy continue to work after the less fit have left mining. The second exception involves those subjects with progressive massive fibrosis (PMF), and again was most noticeable among the non-smokers. Their flow rates were significantly lower than what one might predict on the basis of their age,

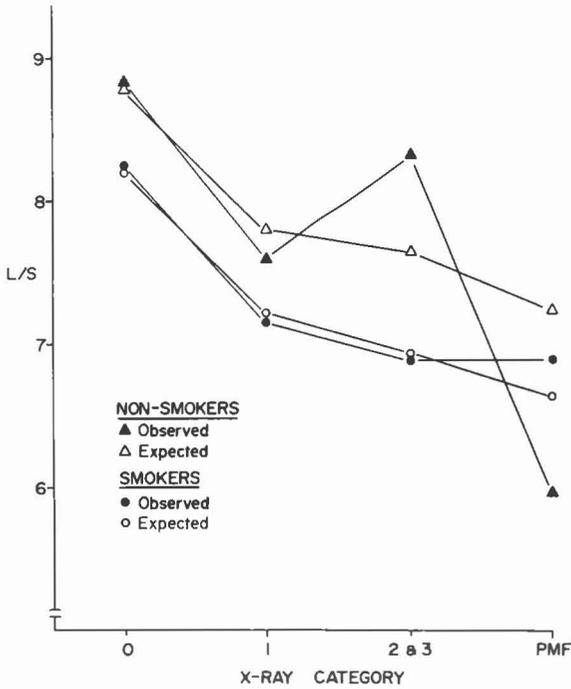


FIG. 9. Observed and expected peak flow by smoking status and by X-ray category of CWP (effect of years underground removed).

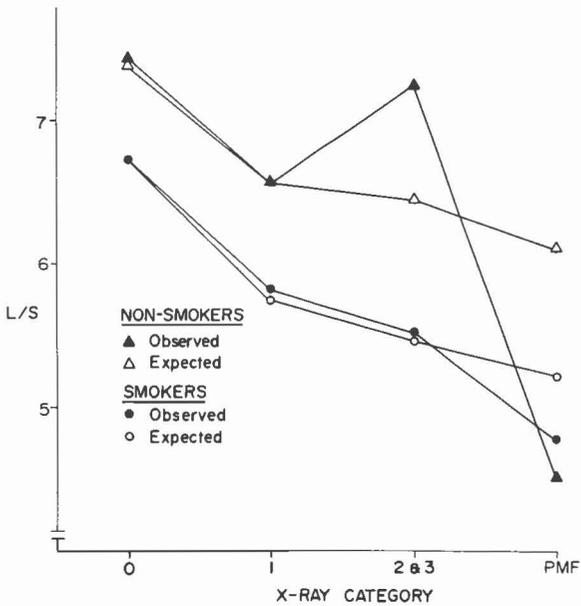


FIG. 10. Observed and expected FEF₇₅ by smoking status and by X-ray category of CWP (effect of years underground removed).

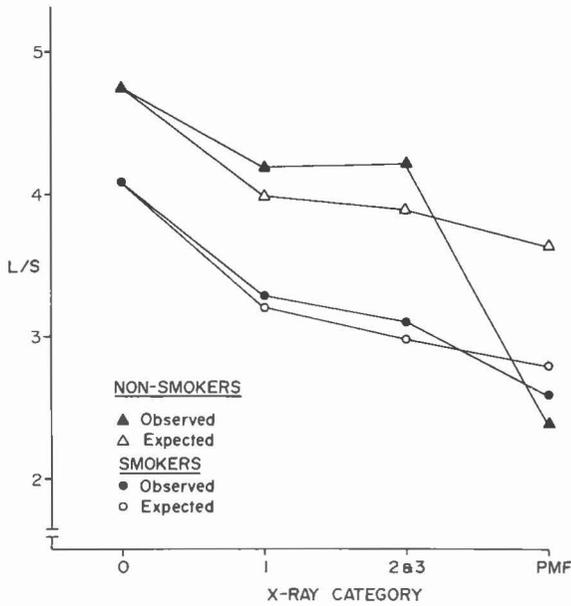


FIG. 11. Observed and expected FEF₅₀ by smoking status and by X-ray category of CWP (effect of years underground removed).

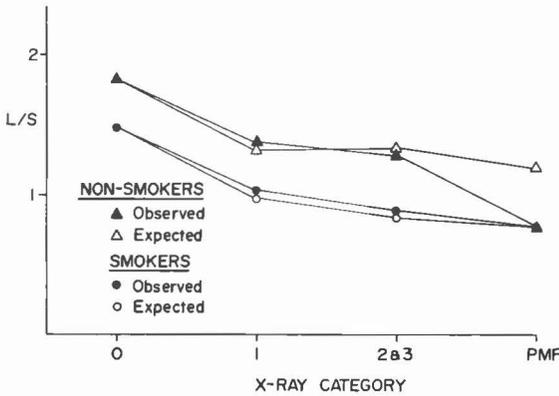


FIG. 12. Observed and expected FEF₂₅ by smoking status and by X-ray category of CWP (effect of years underground removed).

height, and exposure. This was to be expected in that subjects with PMF have been shown to have a significant reduction in ventilatory capacity (ROGAN *et al.*, 1961; MORGAN *et al.*, 1974).

The relationship of bronchitis to the flow rates is shown in Table 5. As anticipated, bronchitics have lower flow rates than do non-bronchitics. The striking results of this portion of the analyses relate to the deviations of the observed from predicted flow rates (Fig. 13). In general, the deviations for the bronchitics were negative, while the

TABLE 5. MEAN FEF₅₀ BY BRONCHITIS FOR 6014 MINERS

	Bronchitic	Non-bronchitic
No. of miners (smokers)	(1869)	(2499)
Observed	3.59	4.29
Expected ^a	3.70	4.20
No. of miners (non-smokers)	(459)	(1237)
Observed	4.22	4.83
Expected ^b	4.29	4.81

^a Obtained from regression in Table 2.

^b Obtained from regression in Table 3.

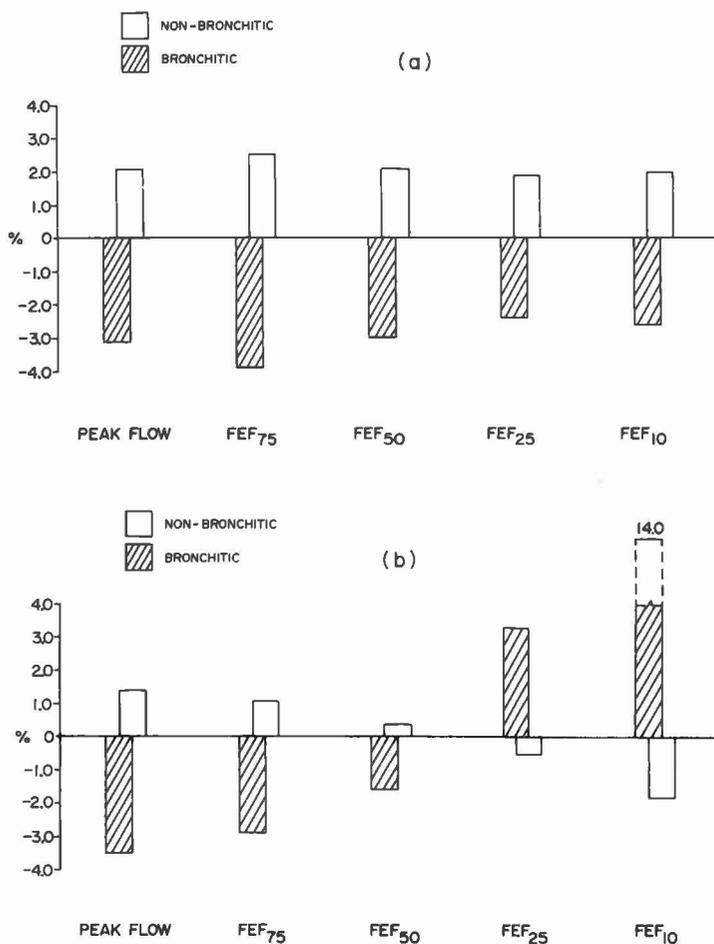


FIG. 13. Flow rate deviations (observed-expected) as a per cent of expected for bronchitics and non-bronchitics. (a) Smokers, (b) Non-smokers.

opposite was true for the non-bronchitics. This was especially evident in the smokers where the pattern existed for flows at all lung volumes. For the non-smokers, the pattern existed for the flow rates at high and medium lung volumes and reversed itself at FEF_{25} and FEF_{10} .

In underground miners, workplace, i.e. face or other underground, seemed to have little to no effect on flow rates over and above what may be accounted for by age, height, and years spent working underground. The results for FEF_{50} are illustrated in Table 6. Analysis of the FEV_1 showed results similar to those reported by others (ROGAN *et al.*, 1973) and which were comparable to those we observed for flows at higher lung volumes.

TABLE 6. MEAN FEF_{50} BY MAJOR WORK PLACE FOR 6014 MINERS

	Face	Other underground	Surface
No. of miner (smokers)	(1950)	(1916)	(452)
Observed	4.01	4.03	3.73
Expected ^a	4.02	4.02	3.74
No. of miners (non-smokers)	(732)	(712)	(252)
Observed	4.60	4.72	4.73
Expected ^b	4.67	4.67	4.68

^a Obtained from regression in Table 2.

^b Obtained from regression in Table 3.

DISCUSSION

Most industrial lung diseases, and in particular the pneumoconioses, affect what MEAD (1970) has aptly termed the quiet zone of the lungs, thereby making early detection difficult. However, previous studies from our laboratory have shown that non-smoking working coal miners with categories 2 and 3 simple CWP, but without evidence of large airways obstruction, often show frequency dependence of dynamic compliance (SEATON *et al.*, 1972) and an increased residual volume (MORGAN *et al.*, 1971). The clinical significance of these findings remains uncertain at the present time. The physiological abnormalities mentioned above are present only in the higher categories of simple CWP, and it can reasonably be inferred that their presence depends on an appreciable dust burden. The results of the present study also showed that certain flow rates seemed to be affected by exposure, but the reduction of flow rates was independent of the radiographic category when the effect of years underground was removed.

The decrement in flows associated with age was as obvious in this study as it has been in others (CHERNIACK and RABER, 1972). Cigarette smoking likewise exerted a detrimental effect on flow rates. In addition, in the non-smokers a significant decrement independent of age occurred with increasing years worked underground, which was not found in miners smoking cigarettes, probably because the effects of smoking were so much greater that they tended to override and mask the effects of dust. The decrement in flow rates that occurred with increasing years underground in the non-smokers

mainly affected flows at higher lung volumes, thereby suggesting large airways involvement. Further support for this inference comes from the fact that the flows showed no additional decrement with increasing category of simple CWP, a condition which is characterized pathologically by lesions located in the distal airways.

The finding of greater than expected flow rates at lower lung volumes in the non-smoking bronchitics is difficult to explain. This seems to imply that dust-induced bronchitis helps to preserve function in the distal airways, but this is difficult to imagine. A better explanation for this anomaly relates to our method of expressing flow rates at a percentage of FVC. If flow rates had been expressed at absolute lung volumes, they probably would not have been as high in the non-smoking bronchitics since the latter may well have had an increased residual volume. However, it is clear that bronchitis caused by a combination of cigarette smoking and dust inhalation induces a much greater decrement in flow rates at lower lung volumes than does bronchitis which is caused by dust inhalation alone.

Since no comparable long-term dust measurements are available in the U.S., we have had to rely on indirect measures of dust exposure (MORGAN *et al.*, 1973). An overall indication of life-long dust exposure can be obtained by measuring the number of years that a miner has spent working underground or at the coal face. Indeed, several studies have shown that a definite relationship exists between radiographic category and increasing underground exposure (LAINHART, 1969; MORGAN *et al.*, 1973). Elsewhere we have shown that bronchitis, as defined by the presence of cough and sputum, occurs most often in the most dust-exposed miners; namely, face workers, and that the prevalence of bronchitis declines the further away from the face and the nearer to the surface that the miner works. Associated with this industrial bronchitis is a minimal decrement in FEV₁, which was significant only when the non-smoking face workers were compared with the non-smoking surface workers (KIBELSTIS *et al.*, 1973). Bearing in mind that ventilatory capacity as determined by the FEV₁ depends almost entirely on the resistance to flow in the large airways during dynamic compression (MEAD, 1970); whatever the process that is responsible for the decrease in FEV₁, it can be assumed that it must predominately affect the larger airways. The most reasonable inference to draw is that industrial bronchitis is the culprit. Since it is mainly the larger non-respirable particles that are deposited in the larger airways, it is logical to assume that the non-respirable dust fraction is mainly responsible for industrial bronchitis. Such a hypothesis explains why no relationship exists between FEV₁ and radiographic category when the effect of years underground had been removed. Larger particles, unlike those of respirable size, are completely removed by the muco-ciliary escalator and thus produce no radiographic changes. It is difficult not to conclude that bronchitis and simple CWP often occur independently and need not be necessarily related. The slight reduction of ventilatory capacity that is sometimes observed in miners as compared to control populations, and which is independent of radiographic category, is best explained by the concept of industrial bronchitis. The decrements in flow at high lung volumes that we observed in the study, and which showed a relationship to years worked underground, provided additional strong support for this concept.

In conclusion, we have shown that flow rates at higher lung volumes are related to years spent working underground. We believe the small reductions in flows that we

observed are produced by industrial bronchitis and are often unaccompanied by radiographic evidence of CWP. Nevertheless, the clinical significance of such minor reductions in flow rates must remain *sub judice* until follow-up studies have been completed. Finally, flow rates at lower lung volumes, as far as this study is concerned, have proved disappointing in the detection of functional impairment of the small airways of the lung.

TECHNICAL NOTES

The purpose of the regression analyses in this paper was to quantify the effects of flow rates from person to person by observing the person's age, height, weight, smoking habits, and underground exposure time on expiratory flow rates. With five linear main effects, there were 10 two-way (e.g. age \times height), 10 three-way (e.g. age \times height \times weight), 5 four-way, and 1 five-way interactions. Thus, when one considered the linear main effects and all possible interactions among these main effects, there were thirty-one "independent" variables. Because it would be difficult, if not impossible, to look at all possible equations, certain ones were selected. There are many methods for doing this (DRAPER and SMITH, 1966); however, we chose the stepwise procedure.

Basically, the procedure is as follows. The variable with the highest simple correlation with the flow rate is "stepped" into the equation if a sufficient amount of variation in the flow is explained. If no variable is stepped in, the selection is terminated. If a variable is stepped in, each variable (at this point there is only one) in the equation is checked to make sure it is still explaining sufficient variation. If not, it is removed from the equation. The process is repeated using partial rather than simple correlations until no more variables can be added to improve sufficiently the equation containing the "independent" variables. What is desired is an equation with only a few variables, but which has an R^2 almost as large as that for the equation containing all the "independent" variables.

A stepwise regression was performed using all thirty-one variables for each flow rate, and then the regression was repeated utilizing only the linear main effects. For a given number of variables in the model, the two regressions yielded similar values of R^2 . However, in the regression involving all thirty-one variables, interactions involving smoking (a dichotomous variable that was 0 for non-smokers and 1 for smokers) were usually stepped in early and were highly significant; i.e. the regression lines for smokers and non-smokers were not parallel. Since it was easy to consider smokers and non-smokers separately, it was decided to do so.

For smokers and non-smokers, the equations involved four main effects and eleven interactions. Again, all fifteen variables were used in one regression analysis, and the four main effects were used in another. In addition, for the linear main effects which were included in the model after the second analysis, a third analysis was performed forcing those linear main effects into the equation and then employing a stepwise selection procedure on the interactions.

The results showed that the analyses involving only linear main effects yielded an R^2 which was essentially as large as those for the regressions involving the interactions. The most significant interactions were accounted for by separating the analyses into smoker and non-smoker groups.

The regression coefficients in the tables can be interpreted as follows: a coefficient, b_x , corresponding to an "independent" variable X is the amount the flow rate changes when X changes by one unit, given the other "independent" variables remain unchanged. For example, assume a particular flow-rate coefficient for age in the smoking group as -0.0441 . Then, for two smokers with the same number of years in underground mining, the same height and the same weight, where one miner is 36 years old and the other is 35, the older miner's predicted flow rate would be 0.0441 litres per second less than that for the younger miner.

It is realized that a certain amount of confounding may exist between the measures of age and exposure as used in this paper. At the present time, there are no statistical manipulations that can totally separate these effects, and only when actual dust measures are used in conjunction with biological phenomena can the effects of age and dust exposure be completely untangled.

Detailed data on flow rates at all lung volumes are available upon request.

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DISCUSSION

D. LIDDELL: You have described stepwise regression analyses in which years of exposure had some influence. Was X-ray change also included in these analyses? If so, at what steps did these two variables enter the regression? In other words, have you any evidence from the regression analyses of the relative importance of these two variables?

Dr HANKINSON: We did perform multiple stepwise regression analysis with the X-ray reading as a variable. However, the X-ray coefficient was not significant, and we did not include it in our regression equations shown in these data.

M. McDERMOTT: It is disappointing that you have not also shown the results for the MEV and MLC so that the effect on these could be compared with that on the flow-volume curve. You state that the reduction in flow at higher lung volumes suggests changes in the larger airways, with which I agree. You then suggest that this is due to a dust-induced bronchitis. But would not this mainly affect either the middle or the end of the volume curve rather than the beginning? You also suggest that the flow at the terminal portion of the vital capacity curve is independent of muscular effort; I would have thought that this would be more likely in the middle range.

Dr HANKINSON: We feel that the least effort-dependent portion of the curve tends to be between 50 and 25% of forced vital capacity. The effect of an individual's effort will show up most at peak flow. Secondly, we did analyse the FEV₁, although we did not include these results in our paper. These results were very similar to those of Rogan *et al.*, referred to in our paper. We can provide the information, if you wish. Finally, the effect of dust-induced bronchitis would be primarily on the large airways and should affect the flows primarily at higher lung volumes. I would refer you to the article by Mead (1970) referenced in our paper.

D. C. F. MUIR: The term "respirable dust" appears to be used increasingly as if it were identical with alveolar dust. This leads to the supposition that there is a separate fraction causing bronchitis which could be measured. In fact, "respirable dust" refers to the aerodynamic size distribution of that fraction of the dust which could have access to the alveoli if inhaled deeply enough. Many such particles deposit in the airways during transit or, because of the anatomical dead space, never reach the alveoli in the first place. These two effects suggest that the mass distribution of dust particles causing bronchitis may not be very different from that causing pneumoconiosis and that the MRE gravimetric sampler provides a good measure of both.

It is pleasing to note that you confirm the findings of the National Coal Board, published by Rogan *et al.*, in 1973 (*Br. J. ind. Med.* 30, 217-226). The essence of that report was that dust exposure underground led to an impairment of ventilatory capacity but that there was little additional effect as a result of the appearance of radiographic simple pneumoconiosis. However, the radiograph does appear to be evidence of excessive dust exposure. Would you therefore accept that it should also be taken as evidence that some functional impairment has taken place—not as a result of the opacities themselves but simply as a result of the dust exposure which they indicate.

Dr MORGAN: I would agree with you that if a man has category 2 or 3 simple pneumoconiosis that he has had an appreciable dust burden. However, if we are going to accept that impaired function in simple pneumoconiosis is occupational in origin, then we should accept that similar impairment in a man with category 0 or 1 simple pneumoconiosis is also of occupational origin.

D. C. F. MUIR: The two cases are not comparable. If a man has an abnormal X-ray, then we know that he has been exposed to excessive dust. It is reasonable to presume that the dust has caused a functional impairment. If his radiograph is normal, there is no method of knowing, in the absence of a detailed occupational history with corresponding environmental measurements, whether he has been exposed to excessive dust or whether other factors, such as cigarette smoke, are the cause of any functional impairment.

D. LIDDELL: How can you be certain that a single X-ray reading of category 2 (or even 3) implies a dust burden? A further reading by another reader of a film taken on another occasion may not show such change. (Dr Dick points out that the reverse is also true!) There is plenty of evidence of such phenomena in the literature.

D. C. F. MUIR: It is not usual for coal workers whose radiographs show category 2 or 3 pneumoconiosis to have a normal film at a later date.

W. T. ULMER: Dr Muir has spoken as a clinician and emphasized the importance of the individual case. However, it is only the mean values of ventilatory capacity of groups of dust-exposed workers which show reductions below normal levels. There is a considerable scatter and many individual results are within the normal range. This makes the assessment of the individual case very difficult.

M. BUNDY: I think that the occupational history can indicate whether disability is due to previous environmental exposure. I do not accept that men with normal radiographs are different, in this respect, from those with evidence of pneumoconiosis.

R. A. FRANCIS: Do I understand that you took five or more curves, but subsequently measured values on only *one* of them?

Dr HANKINSON: We always obtained at least five trials, and more than five when the subject was having coaching problems, but never more than ten trials. Yes, we picked the best curve by our definition. If the curve with the largest FVC had a peak flow within 15% of the largest observed peak flow, we would use it. If not, we would use the curve with the second largest FVC. It is somewhat an arbitrary method and perhaps as more papers come out, a standardized method can be agreed upon. This is a difficult problem, and I would welcome any suggestions.

J. P. LYONS: It is important to remember that we are discussing ventilatory results in mainly working miners. We have recently looked at serial ventilatory capacity tests in miners and ex-miners in Cardiff and it is apparent that impairment continues to progress into the 60s and 70s in many of these cases, with eventual significant disablement.

Also I believe that when smokers and non-smokers are being compared, the normal values for non-smokers should be employed. I believe that there is a difference of almost one litre in the expected values, between smokers and non-smokers, and therefore such comparisons may be quite misleading.

Dr HANKINSON: I would agree with you. Unfortunately, normal values for flow data are not available; at least we have found that our normal values do not agree with those values from other laboratories. Some work needs to be done to establish normal flow rates for both smokers and non-smokers.

P. D. OLDHAM: While I sympathize with the reasons which led the authors to exclude ex-smokers from their presentation, I feel that the decision was regrettable. Men as a whole select themselves into smokers and non-smokers; smokers further select themselves into continuing smokers and ex-smokers. If we wish to have a representative sample, free from this form of self-selection, all three groups must be included.

Dr HANKINSON: We had only a limited amount of material which we could present because of the size of the paper, so ex-smokers were omitted. We did look at them and, in general, their flow rates fell somewhere between non-smokers and smokers. We can make the data available, if you are interested.

M. JACOBSEN: There are three major conclusions from this paper which are so remarkably consistent with results published by Rogan *et al.*, in 1973 on the experience in British coal mines that I believe they deserve special emphasis.

Firstly, increasing impairment of lung function characteristic of damage to the larger airways has been related convincingly to an index of exposure to airborne dust.

Secondly, it has been shown that provided such exposures are taken into consideration then there is no *additional* decrement in lung function associated with increasing radiological category of simple pneumoconiosis. I agree with the interpretation of Mr Hankinson and his colleagues that this implies that impairment of lung function induced by exposure to airborne dust may occur independently of dust-related radiological simple pneumoconiosis. Indeed, we have both shown that dust-related reductions in lung function occur among men with category 0. I agree also with Mr Hankinson that these findings explain the previously reported relatively poor correlation between loss of lung function and radiological category. This low correlation must therefore *not* be interpreted as indicating that exposure to airborne coalmine dust has no important effect on lung function.

Thirdly, the results show that where there is evidence of respiratory symptoms characteristic of chronic bronchitis an *additional* reduction in lung function may be observed which is *not* attributable to dust exposure, age or anthropometric variables. We found the same results, and we suggested 2 years ago that this phenomenon is consistent with an hypothesis that if early bronchitic symptoms (persistent phlegm, persistent cough) are present, then the disease may progress and ventilatory capacity may deteriorate independently of factors initiating the disease process.

The authors of this paper have concluded that flow rates at low lung volumes appear not to be particularly useful for the detection of disease in the small airways of the lung. For this conclusion to be valid it is necessary to assume that small airways disease among coal miners occurs in a way which is related to either one or more of the variables considered. It is possible that "years underground" is not a sufficiently sensitive index of dust exposure to reflect what may be a real relationship between such exposure and reduced flow rates at low lung volumes. In any case, the lack of correlation between the measures used may explain the anomalous results at low lung volumes with respect to body weight among smokers (Table 2) and non-smokers (Table 3). The curious reversal of the algebraic sign for the bodyweight coefficient for FEF₂₅ and FEF₁₀ indicates that it would be premature to conclude from Fig. 14 that "dust-induced bronchitis helps to preserve function in the distal airways." Not only is this "difficult to imagine"; it seems an unjustified inference in a situation where the response variables concerned are exhibiting unexplained, suspiciously artefactual, correlations with fundamental physiological attributes such as body weight.

Perhaps one may be forgiven also for interpreting the results as evidence supporting the view of some epidemiologists that a simple Gaensler spirometer may be at least as useful for studying occupationally related respiratory impairment as some of the more sophisticated equipment now available.

Dr HANKINSON: Although the flow-volume curve did not prove to be more useful than the FEV_1 in studying coal miners with dust-induced bronchitis, it may still prove useful in studying other occupationally exposed groups who may have small airways disease.

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