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VENTILATORY CAPACITY IN MINERS

A FIVE-YEAR FOLLOW-UP STUDY

BY

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A five-year follow-up of ventilatory capacity in over 95% of a random sample of men living in the Rhondda Fach has been carried out. Miners and ex-miners with and without simple pneumoconiosis have been compared with non-mining controls, and the effect of ageing, mining, dust exposure, and tobacco smoking has been assessed. The change in Indirect Maximum Breathing Capacity (I.M.B.C.) between the two surveys appeared to be independent of age, suggesting that a linear decline in this function with age is a tenable hypothesis. An average decline of 1·865 ± 0·274 litres per minute each year in the I.M.B.C. was observed, and this fall was not significantly increased either by mining or by exposure to coal dust as measured by the number of years spent working underground.

In the non-miners a greater decline in I.M.B.C. was observed in smokers than in non-smokers, and this decline was greater in the heavy than in the light smokers. The decline in the non-smokers was 0·489 ± 0·714 litres per minute compared with 1·524 ± 0·319 litres per minute in the light and 3·338 ± 0·420 litres per minute in the heavy smokers. In the miners and ex-miners without pneumoconiosis a greater decline in I.M.B.C. was observed in smokers than in non-smokers, but there was no relation between the rate of decline and the amount smoked. The decline in the non-smokers was 0·950 ± 1·071 compared with 2·164 ± 0·485 and 2·080 ± 0·428 litres per minute in the two smoking groups. In the men with simple pneumoconiosis (category 3) there appeared to be no relation between decline in lung function and smoking habits. The decline in non-smokers was 1·492 ± 0·594 compared with 1·956 ± 0·357 and 1·438 ± 0·467 in the two smoking groups. The decline in I.M.B.C. over five years in non-miners smoking 15 g. tobacco per day and over was significantly greater than the fall estimated from the age specific trend. A possible explanation is that there has been a recent change in the effect of heavy smoking on ventilatory function resulting in a more rapid decline.

A greater decline in I.M.B.C. was observed in men with respiratory symptoms than in those without.

"*It is a concerto and must be practised.*"
(The infant Mozart on being told by his father that the work he had just composed was too difficult.)

In a number of investigations carried out during the past six or seven years an attempt has been made to assess the relative importance of some of the factors influencing ventilatory capacity by comparing different groups of people seen on a single occasion. In this way associations have been shown between ventilatory function and age, sex, physique, mining, and tobacco smoking. Sometimes such cross-sectional observations enable one to say with certainty that a change in function is due to a particular factor. The increase in ventilatory capacity associated with height in children, for example, is almost certainly due to growth. Again the decline in this function, which occurs with age from about 20 years, is probably attributable to ageing, though in this case how much of the reduction is due to inevitable biological change and how much to prolonged contact with deleterious environmental agents that might possibly be avoided is debatable. More often, however, associations revealed by cross-sectional surveys are hard to interpret. Explanations other than the straightforward cause and effect relation are not only possible but may indeed be more likely. We have found, for example, that miners and ex-miners have lower ventilatory

TABLE 1
THE GROUP REVIEWED

Occupation	No. Living in Area in 1954 (Census, 1953)	Age Group	Radiological Category of Pneumoconiosis	Sampled and Seen in 1954	Followed Up in 1959	Dead	Left Area	Lapsed
Non-miners	440	20-		8	7	0	1	0
	805	25-		22	18	0	3	1
	417	35-		17	14	1	2	0
	235	45-		17	13	2	2	0
	107	55-		51	40	3	3	5
	44	65-69		9	6	1	2	0
		All ages		124 (99·9)	98 (79·0)	7 (5·6)	13 (10·5)	6 (4·8)
Miners and ex-miners	699	25-34	0	47	40	1	5	1
	67		3	48	46	0	2	0
	513	55-64	0	48	34*	12	1	1
	50		3	46	35	9	2	0
Total				313 (100·0)	253 (80·8)	29 (9·3)	23 (7·3)	8 (2·6)

Figures in parentheses are percentages.
*One man omitted from analysis, because records unsatisfactory.

capacities than non-miners of comparable age. It is tempting to attribute this lower capacity to the occupation of mining. But we have not been able to show that the decline is unequivocally related to any measurable characteristic of the miner's life. There does not appear in our studies to be any clear relation between ventilatory capacity and the length of time spent working underground or on the coal-getting shift (Higgins, Oldham, Cochrane, and Gilson, 1956; Higgins, Cochrane, Gilson, and Wood, 1959). We have previously suggested that our inability to demonstrate such a relation could be due to the fact that no such relation exists; or, alternatively, it might be due to the fact that a genuine relation is concealed by some form of selection. An obvious possibility is that the men who are still working on the coal-face after 30 years are the fitter survivors.

One might expect that the review of a group which had previously been investigated might throw light on the effect of various environmental factors on lung function. Changes occurring in the individual between two examinations might be expected to be more closely related to the environment to which he has been exposed than the absolute level at any particular time.

In 1954 the Pneumoconiosis Research Unit studied the ventilatory capacity in a representative sample of men living in the Rhondda Fach Valley of South Wales. The objects of the study were to determine the effect of age, mining, exposure to coal dust, and radiological category of simple pneumoconiosis on this aspect of lung function. Our findings were published in a paper which stressed the importance of population selection (Carpenter, Cochrane, Gilson, and Higgins, 1956). In order to consider further the influence of these and some other additional factors on the ventilatory capacity, we carried out a five-year follow-up in May and June 1959 of the group originally seen in 1954. This paper presents our findings.

The Group Reviewed

The sample originally investigated was stratified by age, occupation, and radiological category of simple pneumoconiosis. Among non-miners, about 10 were chosen in each five-year age group from 20 to 70, with additional men to increase the number in the 55 to 64 age group to about 50. Among miners and ex-miners, 50 category 0's and 50 category 3's were chosen in the two age groups 25 to 34 and 55 to 64. The number who had died or left the area during the five years, the number successfully followed up, and the number who refused are shown in Table 1. Refusals were few and rather more frequently encountered in the non-mining group, as had been found previously (Cochrane, Cox, and Jarman, 1952). The higher proportion of deaths in the mining group also agrees with observations on mortality rates in the area (Carpenter and Cochrane, 1956). The number of deaths (12) in the miners aged 55 to 64 without pneumoconiosis is larger than one would expect from a follow-up of all deaths from 1950 to 1956 in the area (A. L. Cochrane, personal communication). This suggests that some of the low indirect maximum breathing capacity (I.M.B.C.) values in the group which we noted in 1954 may have been due to the chance inclusion in the sample of a number of ill men.

Methods and Procedure

All the men still living in the neighbourhood (or sufficiently near to be studied if they had moved out of it) were visited at their homes. They were told that we were trying to learn more about the health of those men who had kindly helped us five years previously. We now wanted to find out whether there had been any change in lung function, and, if so, whether it could be attributed to the job, to exposure to coal dust, or to any other cause. They were asked to help us in this further study and, if they agreed, they were given an appointment and offered transport to and from the centre where the various tests were carried out.

Details about occupations and dust exposure between the surveys were recorded. A questionnaire about respiratory symptoms, chest illnesses, and smoking habits was completed. The forced expiratory volume was measured and expressed as the indirect maximum breathing capacity (I.M.B.C.) in our usual way (McKerrow, McDermott, and Gilson, 1960). Standing and sitting height and weight were measured. Finally, a postero-anterior chest radiograph was taken. In order to avoid seasonal changes in ventilatory capacity both the initial and final surveys took place at about the same time of the year (March to May). For consistency, I.M.B.C. values are given to three places of decimals; the degree of accuracy thus implied must be discounted in view of the size of the standard errors quoted.

Results

The mean ages, sitting heights, weights, and I.M.B.C. of the men seen in the sample in 1954 and followed up in 1959 are shown in Tables 2 and 3. The similarity of the values suggests that the group followed up was reasonably representative of the whole sample seen in 1954. However, in order to investigate this point further, the mean I.M.B.C. of the men who died between the two surveys was investigated and is shown in Table 4. In all except the 45 to 54 age group the mean I.M.B.C. of the fatal cases was lower than that of the survivors. The number of deaths is, however, small compared with

TABLE 2

MEAN AGES (IN 1954) AND CHANGES IN SITTING HEIGHT AND WEIGHT IN FIVE YEARS

Occupation and Age Group	Complete Sample 1954			Those Sampled 1954 and Followed Up 1959					Changes in Five Years	
				1954			1959			
	Age (yrs.)	Sitting Height (in.)	Weight (lb.)	Age (yrs.)	Sitting Height (in.)	Weight (lb.)	Sitting Height (in.)	Weight (lb.)	Sitting Height (in.)	Weight (lb.)
Non-miners										
20-	21·9	35·9	146·4	22·0	35·9	149·6	36·0	148·4	+0·1	−1·2
25-	28·9	35·2	153·0	28·6	35·1	151·8	35·0	157·1	−0·1	+5·3
35-	39·4	34·9	154·9	39·1	34·9	158·6	34·6	162·2	−0·3	+3·6
45-	47·9	34·9	153·1	48·3	34·7	150·1	34·5	149·2	−0·2	−0·9
55-	59·5	34·6	163·5	59·3	34·6	163·1	34·6	157·0		−6·1
65-69	65·6	34·2	164·3	65·3	33·9	158·8	33·8	164·2	−0·1	+5·4
Miners and ex-miners										
25-34 0*	31·1	35·2	155·6	31·1	35·1	155·9	35·0	160·1	−0·1	+4·2
3	31·0	35·4	156·9	31·0	35·4	157·6	35·4	159·5		+1·9
55-64 0	59·7	33·8	144·5	59·6	33·5	147·7	33·2	146·3	−0·3	−1·4
3	59·6	34·2	147·4	59·1	34·2	146·4	33·8	144·5	−0·4	−1·9

*Radiological category of pneumoconiosis.

TABLE 3

MEAN LEVEL AND CHANGE IN I.M.B.C. IN FIVE YEARS, ACCORDING TO AGE, OCCUPATION, AND RADIOLOGICAL CATEGORY OF PNEUMOCONIOSIS

Occupation	Age Group	Radiological Category of Pneumoconiosis	Complete Sample 1954		Those Sampled 1954 and Followed Up 1959			Mean Level of I.M.B.C. Over Five Years	Mean Fall in Five Years (l./min.)	Mean Annual Fall (l./min.)
			No.	Mean I.M.B.C.	No.	Mean I.M.B.C. 1954	Mean I.M.B.C. 1959			
Non-miners	20-		8	146·5	7	151·9	147·6	149·8	4·3	0·86
	25-		22	137·2	18	137·8	127·9	132·9	9·9	1·98
	35-		17	106·3	14	107·2	96·6	101·9	10·6	2·12
	45-		17	106·9	13	104·2	92·1	98·2	12·1	2·42
	55-		51	92·7	40	94·0	85·8	90·0	8·2	1·64
	65-69		9	80·1	6	78·7	66·7	72·7	12·0	2·40
Miners and ex-miners	25-34	0	47	124·9	40	123·8	117·1	120·5	6·7	1·34
		3	48	121·9	46	121·7	112·3	117·0	9·4	1·88
	55-64	0	48	67·0	33	69·5	60·0	64·8	9·5	1·90
		3	46	77·1	35	80·7	72·4	76·6	8·3	1·66

TABLE 4

MEAN AGE AND I.M.B.C. IN 1954 OF THOSE WHO DIED BETWEEN SURVEYS

Occupation and Radiological Category of Pneumoconiosis		Age Group	Number	Mean Age	I.M.B.C. (l./min.)
Non-miners		20-	0	—	—
		25-	0	—	—
		35-	1	44·0	84·0
		45-	2	46·0	109·0
		55-	3	59·5	72·8
		65-69	1	67·0	61·0
Miners and ex-miners	0	25-34	1	32·0	126·0
	3		0	—	—
	0	55-64	12	60·7	61·2
	3		9	61·0	66·8

the number followed up and in consequence does not affect the mean of the larger group.

Causes of Death.—Table 5 shows the certified causes of death during the five years between the two surveys. The numbers are too few for any generalizations to be made. It is interesting that all five respiratory deaths occurred in the mining group.

TABLE 5

CLASSIFICATION OF CAUSES OF DEATH IN THOSE WHO DIED BETWEEN SURVEYS

Cause of Death	Non-miners	Miners and Ex-miners	All Men
Cardiac:			
Coronary disease	4	4	8
Myocardial degeneration	0	1	1
Other	0	2	2
Respiratory:			
Bronchitis and emphysema	0	3	3
Pneumoconiosis	0	1	1
Tuberculous bronchopneumonia	0	1	1
Cancer:			
Lung	0	2	2
Other	2	2	4
Cerebrovascular	1	3	4
Miscellaneous	0	3	3
Total	7	22	29

Table 6 shows that those who died from respiratory causes tended to be those with a ventilatory capacity of less than 50 litres per minute. Though the number who died is small, the number of excess deaths among those with an I.M.B.C. of less than 50 litres per minute is significant ($p = 0{\cdot}006$). This is not surprising; one would expect that those with the worst lung function would be those at the greater risk of dying of their disease. So far as we are aware, however, the prognostic value of the I.M.B.C. has not been shown previously for the general mining population.

Radiological Change between Surveys.—The chest radiographs were read by Professor A. L. Cochrane to detect cases in whom progressive massive fibrosis (P.M.F.) had appeared between 1954 and 1959. There were 11 such cases, all among the miners initially with category 3 simple pneumoconiosis; five were in the 25 to 34 age group and six in the 55 to 64 group, giving attack rates of 2·2% and 3·4% per annum respectively. These figures are

TABLE 6

NUMBER OF DEATHS ACCORDING TO INITIAL I.M.B.C. (1954) (MEN AGED 55-64)

Occupation	Radiological Category	Classification of Death	I.M.B.C. (l./min.) 1-49	50 and Over	Total
Non-miners		No. in sample	0	49	49
		All causes	0	3 (6·1)	3 (6·1)
		Respiratory	0	0	0
		Non-respiratory	0	3 (6·1)	3 (6·1)
Miners and ex-miners	0	No. in sample	17	30	47
		All causes	6 (35·3)	6 (20·0)	12 (25·5)
		Respiratory	3 (17·6)	1 (3·3)	4 (8·5)
		Non-respiratory	3 (17·6)	5 (16·7)	8 (17·0)
	3	No. in sample	5	41	46
		All causes	3 (60·0)	6 (14·6)	9 (19·6)
		Respiratory	2 (40·0)	1 (2·4)	3 (6·5)
		Non-respiratory	1 (20·0)	5 (12·2)	6 (13·0)

Figures in parentheses are percentages.

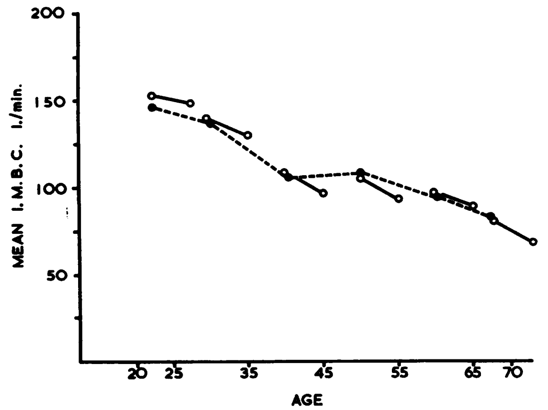

FIG. 1.—Means and changes in I.M.B.C. in five years in a random sample of non-miners aged 20 to 69 seen in the Rhondda Fach in 1954 and followed up in 1959.
●- - - -● Mean values 1954.
○———○ Mean values 1954 and 1959 (followed up).

very close to the figures given by Cochrane, Higgins, and Thomas (1961) for attack rates in the area when these were measured by reading the first and second films at the same time.

The average annual decline in I.M.B.C. in those attacked was 5·0 litres per minute in the 25 to 34 age group and 8·5 litres per minute in the older men. These figures are sufficiently close to the sample means for attacks of P.M.F. to be ignored in considering ventilatory capacity.

Method of Presenting Results.—For each man followed up we have two measurements of I.M.B.C., one in 1954 and one in 1959. There will, in general, be a close resemblance between these measurements and in fact they were correlated to the extent of about 0·8 over the whole sample. In reporting the findings care must be taken to avoid spurious correlations resulting from this fact, which is really equivalent to there being considerable overlapping in the information obtained on the two occasions.

Our special interest is in the changes shown over the period of the follow-up as opposed to the changes predicted from the trend with age in a cross-sectional survey. These changes will be the main results presented. All the remaining information about I.M.B.C. contained in the two sets of measurements is given by their mean, which may be thought of as an estimate of the I.M.B.C. half-way between the surveys. This index is independent of the changes found, and the full I.M.B.C. findings are, therefore, most economically presented in the form of "a change of so much about a mean of so much".

It should be remarked that spurious correlations could arise if one were to present what seems at first to be a more natural pair of indices, "a change of so much from an initial level of so much". These indices are not independent, so that differences in initial level between groups imply an expected difference in the changes shown by them. The interpretation of this pair of indices would therefore present considerable difficulty.

Effect of Age on I.M.B.C. in Non-miners.—Our studies in 1954 led us to conclude that the decline in I.M.B.C. with age was linear and in non-miners was 1·36 ± 0·141 litres per minute for each year of life. Table 3 and Fig. 1 show the mean values observed in non-miners in 1954 and in the follow-up group in 1954 and 1959. The trend of I.M.B.C. with age can be recalculated from the pooled results of those seen on both occasions (Table 3 column 9). Using this information we deduce that the decline in I.M.B.C. in this group was 1·296 ± 0·167 litres per minute for each year.

Our main index of change, the decline actually observed, averaged 1·865 ± 0·274 litres per minute over all ages, and did not vary significantly with age. This figure is 0·579 litre per minute larger than that deduced from the age specific trend and though the difference between the two is not statistically significant, it does nevertheless require some explanation.

There are several possibilities which could explain a difference between age specific and observed trends in ventilatory function. The decline throughout life from about the age of 20 might not be linear as we have assumed but might vary from time to time, being steeper at some periods of life than at others. Our study provides little support for this view. The decline of 2·42 litres per minute in the 45 to 54 group was 0·44 litre per minute greater than that observed in the 25 to 34 age group, but it was 0·78 litre per minute greater than in the 55 to 64 group. On the whole the simplest conclusion is that our results do not deviate from a linear decline.

The second possibility is that there has been a secular change in the initial I.M.B.C. reached at about age 20. Men of average age 60, if their lung function has been declining at the same rate throughout life as we have observed during the past five years, must have started from a higher initial value than men who are now mean age 30 years, in order to have reached their present value. This seems unlikely from what we know about growth trends over the past 50 years. These suggest that the maximum ventilatory capacity attained in early manhood is more likely to be greater now than it was in the past.

The third possibility is a variant of the last one. Instead of postulating that to reach the present level of I.M.B.C. which we have observed at mean age 60 the various age groups must have started at different maximal levels, one might suggest that each group started at about this same maximal level and will reach a lower level at mean age 60 years. This seems more in keeping with secular growth trends. Any effect of mortality has been ignored in these considerations. The men whom we have reviewed are survivors who, as we have already shown, tend to have higher I.M.B.C. values than those who died. The elimination by death of the men with the lower values might result in an apparent reduction in the rate of decline at ages when mortality becomes appreciable. Consequently, it is impossible to be sure that, even if the third hypothesis is correct, the young group is going to reach a lower mean I.M.B.C. at 60 years than their fathers.

Effect of Mining on the I.M.B.C.—In our previous paper we showed that miners and ex-miners aged 25 to 34 and 55 to 64 living in the Rhondda Fach recorded significantly lower mean I.M.B.C. values than corresponding groups of non-miners. Three explanations of this observation have been advanced (Cochrane *et al.*, 1961): that the lower values are due to mining; that recruits into mining tend to be men with lower ventilatory capacities; that a higher proportion of men with higher ventilatory capacities disappears from the mining than from the non-mining group through death and emigration.

There is no evidence to suggest that recruits into mining today are physiologically less able than men going into other occupations (Higgins, Oldham, Merrick, and Dunsdon, 1956), but the occurrence of this type of selection in the past cannot be excluded. The possibility that a disproportionate loss of miners with higher ventilatory capacities may have occurred through emigration from the area during the depression has been discussed at length elsewhere (Cochrane *et al.*, 1961). One could be more confident in attributing the lower ventilatory function of miners to their occupation were it not for the fact that their wives also tend to record lower values than the wives of non-miners (Higgins and Cochrane, 1961). Furthermore, as already mentioned, the association between I.M.B.C. and duration of underground or face-work in cross-sectional studies has not been close.

Does the follow-up over five years suggest that mining is exerting a greater effect than we might conclude from our previous studies? One would expect that if mining lowered the ventilatory capacity we might be able to show a larger mean annual fall in the mining than in the corresponding non-mining group. Table 3 does not suggest that this was so. The mean fall in the non-miners aged 25 to 34 was 1·98 litres per minute compared with 1·34 and 1·88 litres per minute for the two mining groups, while in the 55 to 64 group the corresponding figures were 1·64 and 1·90 and 1·66 litres per minute respectively. The only group in which the miners and ex-miners recorded a larger fall was the elderly men without pneumoconiosis.

As a measure of the effect of mining during the five years this comparison is unsatisfactory in that both miners and ex-miners are included. Clearly only those who have been engaged in the industry for some time during the period could have been affected. The change in I.M.B.C. in five years for miners and ex-miners separately is shown in Table 7. No clear pattern emerges. In three of the four mining groups the miners show a steeper decline than the ex-miners; but in no case is the fall in the miners significantly greater than in the ex-miners.

Effect of Tobacco Smoking on the I.M.B.C.—It has previously been shown that smokers, more particularly cigarette smokers, have a significantly lower mean ventilatory capacity, age for age, than non-smokers (Higgins, 1959), and this has been confirmed by others (Franklin, 1958; Fletcher, Elmes, Fairbairn, and Wood, 1959; Blackburn, Brožek, and Taylor, 1959; Flick and Paton, 1959).

There are three possible explanations of this finding; smoking reduces the ventilatory capacity, those with a lower ventilatory capacity smoke, or some common factor causes both smoking and a lower ventilatory capacity. There seems good reason

TABLE 7

MEAN LEVEL AND CHANGE IN I.M.B.C. IN FIVE YEARS IN MINERS AND EX-MINERS

Age Group	Radiological Category of Pneumoconiosis	Occupation During Five Years	No.	Mean Level of I.M.B.C. Over Five Years (l./min.)	Mean Fall in Five Years (l./min.)	Mean Annual Fall (l./min.)
25-34	0	Miners	33	120·7	7·7	1·54
		Ex-miners	7	124·1	1·9	0·38
	3	Miners	28	117·8	10·1	2·02
		Ex-miners	18	115·8	8·0	1·60
55-64	0	Miners	19	71·8	7·3	1·46
		Ex-miners	14	55·2	12·4	2·48
	3	Miners	18	77·6	10·1	2·02
		Ex-miners	17	75·5	6·2	1·24

TABLE 8

MEAN LEVEL AND CHANGE IN I.M.B.C. IN FIVE YEARS ACCORDING TO AGE, OCCUPATION, RADIOLOGICAL CATEGORY, AND SMOKING HABITS

Age Group Occupation, and Radiological Category	Non-smokers			Smokers						Ex-smokers		
				1 to 14 g./Day			15 g./Day and Over					
	No.	Mean I.M.B.C. Over Five Years (l./min.)	Change in I.M.B.C. in Five Years (l./min.)	No.	Mean I.M.B.C. Over Five Years (l./min.)	Change in I.M.B.C. in Five Years (l./min.)	No.	Mean I.M.B.C. Over Five Years (l./min.)	Change in I.M.B.C. in Five Years (l./min.)	No.	Mean I.M.B.C. Over Five Years (l./min.)	Change in I.M.C.B. in Five Years (l./min.)
Non-miners												
20-	2	168·5	−8·0	4	142·8	+1·0	1	140·0	−18·0	0	—	—
25-	2	154·8	−1·5	6	132·6	−10·5	9	130·0	−12·1	1	116·5	−3·0
35-	2	120·8	−1·5	9	93·0	−3·6	2	123·0	−45·0	1	102·0	−24·0
45-	2	123·5	+5·0	4	94·8	−13·0	5	94·3	−18·6	2	89·0	−11·0
55-	1	111·0	−10·0	20	89·2	−9·5	8	85·3	−14·0	11	92·7	−1·4
65-69	0	—	—	2	68·3	−4·5	1	50·0	−12·0	3	83·2	−17·0
Miners and ex-miners												
25-34 0	3	140·9	−4·3	10	115·3	−11·8	18	117·4	−8·7	9	125·5	+2·3
3	10	108·1	−8·0	17	125·6	−9·2	14	119·5	−7·2	5	98·6	−18·0
55-64 0	1	118·0	−6·0	18	64·3	−10·2	7	52·9	−14·9	7	70·1	−2·7
3	3	88·5	−5·7	19	75·1	−10·4	7	76·6	−7·0	6	75·0	−4·3

to believe that there are genetic differences between smokers and non-smokers (Fisher, 1957) and that these are shown by differences in physique, temperament, and physiological attributes (Heath, 1958; Lilienfeld, 1959; Thomas, 1960; Eysenck, Tarrant, Woolf, and England, 1960). Ventilatory capacity might well be one such genetically determined characteristic. It is difficult to disprove the hypothesis that any differences observed are constitutional in origin. But if it can be shown that there is a downward trend in ventilatory capacity with increasing amount smoked and, furthermore, if this is reversed when the practice is discontinued, then the hypothesis, though still possible, becomes less probable.

Smoking habits were recorded as in our previous surveys and men were classified as non-smokers, current light smokers (1 to 14 g. per day), current heavy smokers (15 g. tobacco per day and over), and ex-smokers. As in the case of respiratory symptoms, smoking habits at the time of the follow-up have been used. The means and changes in I.M.B.C. in each of the groups is shown in Table 8. The numbers are unfortunately small, particularly of non-smokers. In the non-miners the I.M.B.C. fell more over the five years in the smokers than in the non-smokers or ex-smokers, and within the smoking group there was an increasing fall with increasing tobacco consumption. When we consider the miners and ex-miners the pattern is less clear. In three of the four groups the I.M.B.C. of the smokers fell more than that of the non- or ex-smokers; but the fall was usually greater in the light than in the heavy smoking group. It is difficult to understand why there should be this difference between the two occupational groups, and why, if smoking is deleterious to the ventilatory capacity, there should be no apparent relationship between the reduction in I.M.B.C. and the amount smoked. There were some differences between miners and non-miners in the average amounts smoked by the heavy smokers. Thus in the 55 to 64 age group, while the mean of those smoking 1 to 14 g. tobacco per day was 7·5 g. per day for the non-miners and 8·2 and 7·6 g. per day for the two mining groups, the corresponding means for those smoking 15 g. tobacco per day and over were 26·1 g. per day for the non-miners and 18·8 and 16·4 g. per day for the two mining groups. Although the miners who smoked heavily smoked less than the corresponding non-miners, they none the less smoked more than twice as much as the lighter smoking miners, and the difference in quantity smoked cannot explain the different apparent effects of smoking between the two occupational groups. In the young miners with category 3 pneumoconiosis the decline in I.M.B.C. in non-smokers was the same as in the smokers, but a much larger fall was noted in the ex-smokers. This, of course, has the effect of selecting out of the smokers those with lower I.M.B.C. values and thereby reducing any differences between them and the non-smokers. In this group we cannot exclude the possibility that compensation issues may have affected the results. It was shown previously (Gilson, 1958) that the relationship between mean I.M.B.C. and grade of breathlessness was poor in the men with category 3 simple pneumoconiosis, and it was suggested that this might in part be explained by the fact that many of these men were receiving compensation for pneumoconiosis. It seems possible that any interest in smoking habits might be interpreted by the miner as an attempt to attribute disability to smoking rather than to his occupation with a view, however mistaken, of depriving him of the compensation to which he considers himself entitled. Anyone determined to prove that his disability was due to his job would say that he did not smoke. It is at least suggestive that the proportion of non-smokers was very much higher in this group than in any other.

An alternative explanation of the different results in this group is possible. Men who develop simple pneumoconiosis are less liable to be affected by smoking, and there are two ways in which this might come about. First, those whose respiratory tracts are relatively insusceptible to the effect of irritants will be less likely to develop respiratory symptoms, more specifically a productive cough, as a result of smoking. Accumulation of dust in their lungs may be a simple result of their failing to cough it up. Alternatively the accumulation of dust in the lungs may in some way alter the response to tobacco smoke. It must be admitted that there is no evidence to support this latter hypothesis, which seems inherently a little improbable.

Since, in the general population sampled, there are about 10 times as many miners and ex-miners without pneumoconiosis as with category 3 pneumoconiosis, the anomalous behaviour of the latter group revealed in this stratified sample would usually be missed. Nothing of course is known from this survey of the relation of smoking and I.M.B.C. in men in other categories of pneumoconiosis.

One might expect that changes in smoking habits during the five-year period would throw additional light on the effect of smoking on ventilatory function. Men who gave up smoking might, for example, be expected to decline less than those who continued to do so. We have looked into the changes in ventilatory capacity in the men who gave up smoking during the five years but no clear pattern emerges. Possibly this is due to the fact that the reasons for giving up smoking are varied. No inquiry into the reasons for giving up smoking was made in this investigation.

The findings in the present investigation do not clearly favour any of the three hypotheses advanced to explain the lower ventilatory capacity of smokers compared with non-smokers. The increasing decline in I.M.B.C. with the amount of tobacco smoked and the relatively smaller fall in ex-smokers support the causative hypothesis. So also do the changes in three out of the four mining groups. On the other hand the lack of any trend in decline of function with tobacco consumption in the miners without pneumoconiosis and the absence of any apparent relationship at all in the miners with simple pneumoconiosis could be adduced in support of the view that those who smoke differ from those who do not either for constitutional or genetic reasons or because some third factor causes both smoking and a lower ventilatory capacity. Studies in which a larger number of subjects is followed more often than once every five years enable us to relate changes in ventilatory capacity to changes in smoking habit (and other environmental alterations) and so to decide which of the three hypotheses is the true one. Such an investigation is at present being carried out by Dr. C. M. Fletcher (personal communication).

Apart from the effect of smoking on I.M.B.C., Table 8 throws a little additional light on the effect of mining. The fall in I.M.B.C. in the non-smokers was larger in the miners than in the non-miners. The difference, which does not reach the 5% level of significance, suggests that an effect of mining might perhaps be demonstrable were we able to compare larger numbers of non-smokers.

Summary of Effect of Mining, Radiological Category, and Smoking on Ventilatory Capacity, Standardized for Age.—By choosing a suitable standard age and adjusting the means of the different occupational, radiological, and smoking classes to refer to this age by means of linear regressions, we may present a full summary of the results in one Table. No adjustment was needed for the changes observed, since these were found to be independent of age.

Table 9 and Fig. 2 show the mean values of the I.M.B.C., the mean change in I.M.B.C. each year estimated from the regression of the mean I.M.B.C. on age, and the mean change in I.M.B.C. each year from the change observed in the individual subjects over the five years, standardized to age 40 to 45, according to smoking, mining, and radiological category of pneumoconiosis. The age standardization adopted is such as to enable comparisons between smoking classes to be made validly in each occupational and radiological class. Comparisons between the occupational and radiological classes within smoking classes are not strictly valid; indeed in the ex-smokers the relation with age varied significantly between the occupational and radiological classes so that no standardization of the 12-year range of mean age is possible.

In most instances the annual fall estimated from the age trend agrees with that actually observed. But in the heavy smoking non-miners there is a significant difference between the two observations, $1{\cdot}638 \pm 0{\cdot}291$ litres per minute per year compared with $3{\cdot}338 \pm 0{\cdot}420$. This suggests that the decline in ventilatory capacity in this group has been greater than we might have expected during the past five years. Why this should be so is not clear; but the finding suggests that there may have been a recent change in the effect of heavy smoking on lung

TABLE 9

MEAN I.M.B.C. STANDARDIZED TO AGE 40-45 AND MEAN ANNUAL FALL IN I.M.B.C. BASED ON (i) AGE SPECIFIC TREND, AND (ii) OBSERVED CHANGE, ACCORDING TO OCCUPATION, RADIOLOGICAL CATEGORY AND SMOKING HABITS

Occupational Group	Attribute	Non-smokers		Light Smokers		Heavy Smokers		Ex-smokers	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Non-miners	Mean I.M.B.C. (l./min.)	129·4	6·85	104·3	3·07	106·1	3·99	109·8	5·17
	Annual fall (l./min.)								
	from age trend	1·604	0·554	1·284	0·220	1·638	0·291	0·679	0·525
	from observed change	0·489	0·714	1·524	0·319	3·338	0·420	1·278	0·505
Miners and ex-miners without pneumoconiosis	Mean I.M.B.C. (l./min.)	121·4	10·92	90·4	4·17	87·2	4·50	97·8	5·43
	Annual fall (l./min.)								
	from age trend	0·761	0·794	1·700	0·271	2·149	0·306	1·848	0·346
	from observed change	0·950	1·071	2·164	0·405	2·080	0·428	−0·025	0·535
Miners and ex-miners with simple pneumoconiosis, category 3	Mean I.M.B.C. (l./min.)	92·6	5·75	100·1	3·37	98·4	4·48	87·6	6·50
	Annual fall (l./min.)								
	from age trend	0·653	0·452	1·683	0·229	1·429	0·318	0·785	0·416
	from observed change	1·492	0·594	1·956	0·357	1·438	0·467	2·109	0·646

S.E. = Standard error.

function. If this were so, not only would it account for the differences in the heavy smokers, but it might also explain the difference in the apparent effect of ageing in the whole group of non-miners. There did not appear to be any significant differences between the various age and occupation groups in the age of starting smoking.

Effect of Dust Exposure on the I.M.B.C.—The index of dust dosage which we have preferred in our prevalence studies has been the number of years spent working on the coal-getting shift. One would like to see how the ventilatory capacity changed according to the length of time spent on the coal-getting shift during the five years between the two investigations. The number of men who worked for one to four years out of the five on the coal-face was too small to make this possible. Instead the number of years spent underground has been used although again the numbers are few (Table 10). No obvious pattern emerges either in the means or in the changes.

Change in I.M.B.C. in Relation to Respiratory Symptoms.—We have observed previously on a number of occasions that people who have

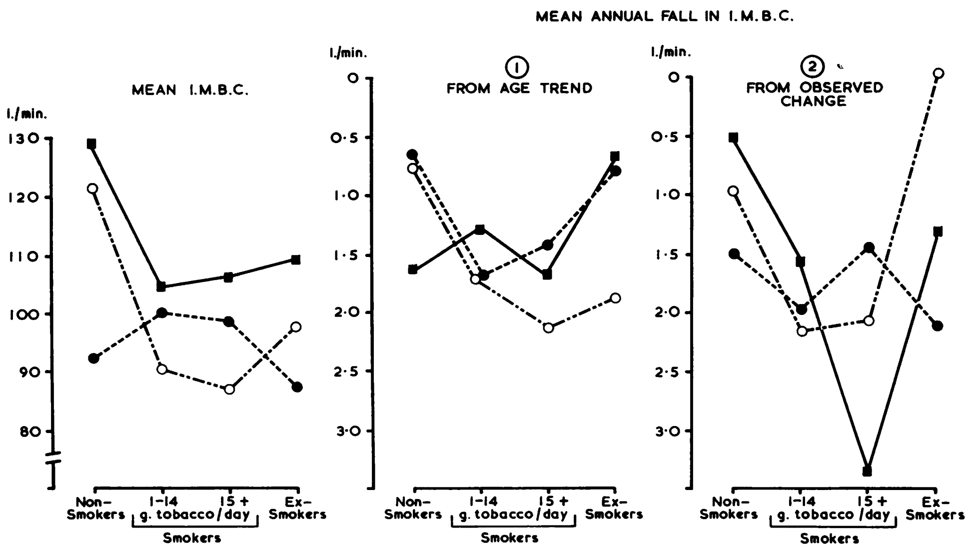

FIG. 2.—Mean I.M.B.C. and mean annual fall in I.M.B.C. based on 1. age trend; 2. observed change, over five years, according to occupation, radiological category, and smoking habits (age standardized to 40 to 45 years).
■——■ Non-miners.
○——○ Miners and ex-miners Category 0.
●- - - -● Miners and ex-miners Category 3.

TABLE 10

CHANGE OF I.M.B.C. ACCORDING TO NUMBER OF YEARS SPENT WORKING UNDERGROUND BETWEEN TWO SURVEYS

Age Group	Radiological Category	No. of Years Under-ground	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years
25-34	0	0	5	113·6	−11·6
		1	2	121·5	+10·0
		2	3	125·2	−6·3
		3	1	108·5	−25·0
		4	2	97·3	−4·5
		5	20	123·0	−8·1
	3	0	1	127·0	+ 4·0
		1	2	101·3	−15·5
		2	0	—	—
		3	1	79·0	−64·0
		4	1	133·0	−4·0
		5	23	119·8	−8·2
55-64	0	0	7	94·0	−4·0
		1	1	31·0	−10·0
		2	0	—	—
		3	2	50·0	−23·0
		4	1	24·0	−10·0
		5	8	68·8	−5·8
	3	0	5	78·1	−7·8
		1	0	—	—
		2	1	75·0	−16·0
		3	1	94·5	−7·0
		4	1	86·5	−13·0
		5	10	74·9	−10·6

respiratory symptoms tend to have a lower mean I.M.B.C. than others who are symptom-free. The present study provided an opportunity to see whether the I.M.B.C. of those with respiratory symptoms also tends to decline more rapidly than that of those who are symptom-free. Table 11 shows decline of the I.M.B.C. for non-miners and for miners and ex-miners respectively. The presence or absence of symptoms at the time of the follow-up rather than at the initial survey was used. Changes in design of the questionnaire took place during the intervening five years, and we felt that the answers recorded on the second occasion more closely represented present practice in deciding whether or not these symptoms were present. In general a greater fall in I.M.B.C. was observed in those with respiratory symptoms than in those without. The pattern is more consistent for the non-miners than for the miners and ex-miners. Among the latter, wheeze alone was usually associated with a minimal decline in I.M.B.C.

Discussion

This study has shown the practicability of following up a high proportion of participants of a survey after an interval of five years. How worthwhile is such an enterprise? For some years the view has

TABLE 11

MEAN LEVEL AND CHANGE IN I.M.B.C. IN FIVE YEARS ACCORDING TO SYMPTOMS

Age, Occupation, and Radiological Category	No Symptoms			Cough and/or Sputum Only			Chest Illness Only			Wheeze Only		
	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years
Non-miners												
20-	5	151·2	+0·4	0	—	—	0	—	—	0	—	—
25-	8	141·7	−6·4	6	127·6	−14·2	1	116·5	−3·0	1	145·5	−13·0
35-	9	110·4	−8·7	0	—	—	0	—	—	0	—	—
45-	4	102·7	−0·8	3	76·0	−16·7	1	96·0	−10·0	2	99·8	−13·5
55-	16	96·3	−7·3	3	101·0	−3·3	0	—	—	7	86·4	−11·0
65-69	3	73·5	−3·7	0	—	—	1	102·5	−35·0	1	50·0	−12·0
Miners and ex-miners												
25-34 0	13	122·0	−5·2	5	118·9	−13·0	0	—	—	7	114·9	−2·0
3	11	116·4	−9·0	8	118·7	−7·3	0	—	—	5	118·8	+1·6
55-64 0	7	91·7	+2·7	2	77·0	−8·0	0	—	—	4	89·0	−2·0
3	5	90·2	−5·2	3	111·7	−21·3	0	—	—	2	82·8	−15·5

Age, Occupation, and Radiological Category	Cough and/or Sputum and Wheeze			Cough and/or Sputum and Chest Illness			Chest Illness and Wheeze			Cough and/or Sputum Chest Illness and Wheeze		
	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years	No.	Mean I.M.B.C. Over Five Years	Change in I.M.B.C. in Five Years
Non-miners												
20-	1	140·0	−18·0	0	—	—	0	—	—	1	—	−14·0
25-	2	115·0	−13·0	0	—	—	0	—	—	0	—	—
35-	3	91·7	−18·0	0	—	—	0	—	—	2	—	−8·5
45-	1	104·0	−38·0	2	118·8	−14·5	0	—	—	0	—	—
55-	7	86·9	−15·0	1	64·5	−11·0	4	89·1	+4·5	2	—	−13·0
65-69	0	—	—	1	63·0	−14·0	0	—	—	0	—	—
Miners and ex-miners												
25-34 0	9	121·0	−7·3	1	108·5	−25·0	1	129·5	+1·0	4	126·6	−7·5
3	10	121·9	−9·1	1	134·5	−15·0	4	110·2	−12·3	6	109·9	−18·8
55-64 0	7	50·9	−14·4	0	—	—	2	51·8	−15·5	11	47·7	−16·1
3	9	83·3	−6·6	0	—	—	0	—	—	16	63·7	−6·8

been widely held that prevalence surveys are of limited value in drawing conclusions about aetiology. They have tended increasingly to be regarded as a useful means of demonstrating associations which, while possibly suggestive of causation, require the further support derived from observation of attack rates and individual change which only a cohort study will reveal.

Perhaps, given a sufficiently long follow-up, a cohort study of the kind envisaged would provide unequivocal evidence of the effect of various agents on the I.M.B.C., but it has been recognized increasingly that longitudinal observations are at least as bedevilled as cross-sectional studies by individual choice. The miner who is exposed to coal dust and whose chest is affected changes to a less dusty job or leaves the industry; the heavy smoker who is becoming short of breath may reduce or give up smoking. In each case what happens to the man's lung function depends on the reversibility or irreversibility of any changes which may have been produced. It seems probable, therefore, that the expectation that follow-up studies would answer many questions that cross-sectional surveys would not, may have been unduly optimistic, and it is probably better to regard them as two aspects of a similar problem. Over a short period of time it is unlikely that follow-up of a sample will provide more than support for conclusions based on a cross-sectional study. Indeed, it is perhaps unreasonable to expect more. If we consider a man of about 50, we should realize that the value of the I.M.B.C. he obtains when performing the test depends on what he started with and what has happened to him during the past 30 years. When we repeat the test five years later any change is due to what has happened to him in the five years. This change admittedly eliminates the innate variability between individuals but it applies to only five out of the 35 years which have been affecting his lung function and consequently any environmental effects are likely to be about seven times as great over his lifetime. The particular value of a follow-up study lies in findings which indicate that a secular trend is present, *e.g.* in the present study the results in the heavy smoking non-miners. Such findings are important whatever their causes because they reveal aspects which will certainly be missed in cross-sectional studies.

The present survey may be justly criticized as a follow-up study on the grounds that the numbers in the groups we are really most interested in—non-smokers, for example, or miners who have spent all the five years at the coal-face in dusty conditions, are too few to make conclusions possible. It must be pointed out that the original sample was drawn in order to answer several specific questions, such as the effect of age, mining, and category of simple pneumoconiosis on the I.M.B.C. as revealed by a cross-sectional study of miners and non-miners. In 1954 no one had any intention of using the group for follow-up purposes. Perhaps it would have been better to have drawn another sample more suitable for such a study. But time is a serious consideration in longitudinal studies, and it is difficult to resist the temptation to use unsuitable samples which have been studied previously rather than to start again with a more appropriate group.

The results in this follow-up have supported our previous findings on the importance of the effect of age and smoking on the ventilatory capacity. The influence of respiratory symptoms such as cough and sputum on the test are also in agreement both in the cross-sectional study and in the follow-up. The study has not shed much light on the question of why miners' values are lower than those of non-miners. After standardizing for smoking the differences remain, so that smoking differences between miners and non-miners are not the explanation. The difference between miners and non-miners is apparent at an early age, and this suggests that any effect of mining must be exerted within at least 10 to 15 years of entering the industry and possibly much sooner. If there is any such effect then we would not expect to observe it in the type of investigation described in this paper. It is difficult to visualize any deleterious agent which reduces the I.M.B.C. within a year or two of starting mining but then apparently ceases to exert any effect. Certainly, the present follow-up study provides little support for the existence of deleterious effect of underground work. Possibly a greater effect might have been observed had the numbers allowed us to evaluate the effect on duration of coal-face work. Further studies are clearly indicated on this problem. Other studies of new mining entrants now in progress may be expected to throw light on any decline in I.M.B.C. shortly after entering the industry.

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