Maximal Expiratory Flows in Coal Miners[1-3]

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SUMMARY

From a group of approximately 9,000 working coal miners studied by the U. S. Public Health Service in 1973 and 1974, 4 groups of 428 age- and height-matched subjects were selected according to their smoking habits and according to whether or not they had bronchitis. Flow-volume curves, lung volumes, and the more commonly used indices of ventilatory capacity, the forced vital capacity and the forced expiratory volume in 1 sec, had been measured previously in each subject.

A larger total lung capacity was observed in smoking than in nonsmoking miners, whether bronchitic or not. This phenomenon is believed to indicate a loss of retractive forces due to destruction of the lung parenchyma associated with cigarette smoking. No comparable change in total lung capacity was observed in the nonsmoking miners with bronchitis. Because dust-induced bronchitis in nonsmoking miners is associated with a decrease in flows at high lung volumes in the absence of an increase in total lung capacity, it is inferred that industrial bronchitis leads to large airway obstruction but not emphysema. It was also apparent that flows, when expressed as percentages of forced vital capacity exhaled, offered little or no advantage over the 1-sec forced expiratory volume or the ratio of the 1-sec forced expiratory volume to vital capacity as an index of ventilatory capacity, except that peak flow and the flows at higher lung volumes were sometimes helpful in differentiating bronchitic from nonbronchitic subjects. In longitudinal studies, however, the flow-volume curve when related to absolute lung volumes may have advantages over the conventional time versus volume tracing.

Introduction

The inhalation of coal dust may lead to the development of either coal worker's pneumoconiosis or chronic bronchitis (1), and, not infrequently both conditions exist in the same subject. Coal worker's pneumoconiosis develops as a consequence of the prolonged inhalation of coal dust particles smaller than 6 to 7 μm in size. Particles of this size are usually referred to as the respirable fraction and for the most part are deposited in the gas-exchanging portions of the lung. In contrast dust-induced bronchitis affects the conducting airways or dead space, a region of the lung in which it is known that many larger and nonrespirable particles are deposited (2).

The symptoms of chronic bronchitis, cough and sputum, are similar whether they are induced by cigarette smoking or by chronic dust inhalation, and in a smoker exposed to dust, the relative contributions of dust and smoking cannot be apportioned on the basis of the answers to a questionnaire. Nonetheless dust-induced bronchitis among nonsmoking coal miners is associated with less impairment of ventilatory capacity, at least as far as the forced vital capacity (FVC)

(Received in original form January 13, 1977 and in revised form April 19, 1977.)

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2 Mention of brand names does not constitute endorsement by the U. S. Public Health Service.

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or the forced expiratory volume in 1 sec (FEV_1) is concerned, than is the type of bronchitis found in cigarette smokers (1). Similarly, it is pertinent to bear in mind that the characteristic pathologic lesion of simple coal worker's pneumoconiosis, the coal macule, is situated around the first- and second-order respiratory bronchioles. Moreover, it has been shown repeatedly that increasing radiographic category of simple coal worker's pneumoconiosis per se is not associated with a decreasing FEV_1 or FVC (3, 4). Because the forced expiratory volume maneuver, for the most part, reflects air flow in the central airways during dynamic compression, and because flow at lower lung volumes may reflect the earlier changes of airway obstruction, we decided to compare the relative sensitivity of the flow-volume curve to the more commonly used and standard spirometric indices of ventilatory capacity. It was hoped that by using the flow-volume curve we might detect early changes in air flow resistance in the small airways of the lungs that were not detected using the FEV_1 and FVC.

As a second part of the investigation we decided to ascertain whether in large-scale field studies the determination of lung volumes contributed any additional information of value that was not available from spirometry alone. Although flows are usually expressed as percentages of FVC exhaled there exists a theoretic advantage to relating flow to absolute lung volumes, and we therefore decided to compare the 2 methods of expressing maximal flows.

Materials and Methods

A matched sample was selected from a group of approximately 9,000 working coal miners studied by the U. S. Public Health Service in 1973 and 1974. Each miner was employed at one of 36 coal mines widely distributed throughout the United States, representing different mining methods and coal seams. Criteria for inclusion of mines 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 (5).

All participating miners underwent a limited medical examination consisting of standard posteroanterior and lateral chest films, and a modified form of the Medical Research Council of Great Britain questionnaire on chronic respiratory symptoms (6) was administered along with an occupational and smoking history questionnaire. In addition, at least 5 forced expiratory volume maneuvers were performed using a waterless electronic spirometer (Ohio Medical Products, Madison, Wis., Model 800). The flow response of the spirometer was checked using a forced expiratory volume simulator (Novatek, Inc., Burlington, Mass.), and the spirometer was found to measure accurately peak flows at least as high as 13 liter per sec.

The flow-volume signals from the spirometer were recorded on analog tape (7) and were later processed on a PDP-12 computer (Digital Equipment Corp., Maynard, Mass.). The flows at 5 per cent intervals of the vital capacity were calculated from the flow-volume curve that showed the best effort, i.e., the curve with the largest FVC and a peak flow within 15 per cent of the largest observed peak flow. If the curve with the largest FVC did not also have a peak flow within 15 per cent of the largest observed peak flow, the curve with the second largest FVC was tested, and so forth, until a satisfactory curve was found. The FVC, FEV_1, and peak flow were taken from the largest observed value regardless of the curve on which they occurred.

All radiographs were classified using the ILO/UC Classification System (8), and the results from one of 5 separate readers were used. Each interpreter had passed the U. S. Public Health Service proficiency examination (9). Total lung capacity (TLC) was obtained from the chest radiograph by the method of Barnhard and associates (10). It has been shown previously that this radiographic method of determining TLC agrees with the plethysmographic method in miners with category 0 or simple coal worker's pneumoconiosis (11).

Subjects with unreadable radiographs or progressive massive fibrosis were excluded from the study, as were ex-smokers. Chronic bronchitis was defined as persistent phlegm production, regardless of complaints of cough.

The study population was divided into 4 groups of working miners: nonsmokers without bronchitis (N = 1,210); nonsmokers with bronchitis (N = 428); smokers without bronchitis (N = 2,376) and smokers with bronchitis (N = 1,809). All groups were then matched with respect to age and height, i.e., for each miner in the nonsmoking bronchitic group of a certain age and height, another miner of the same age and height was selected from the other group. The selection process yielded 428 miners in each group. Perfect matching with the nonsmoking bronchitic group was obtained for approximately 72 per cent of the subjects. For the remaining 28 per cent, the closest match was selected. Any differences in mean pulmonary function values between the groups, therefore, cannot be attributed to differences in age or height. Each group had an average age of approximately 46 years, within 0.2 years, and an average height of approximately 68 inches, within 0.07 inches.

All means were compared to the nonsmoking, nonbronchitic group. The t statistic used in this analysis was regarded as a normalized distance measure between 2 population means and was proportional to the Mahalanobis distance measure for a 2-class univariate normal case (12). A larger t value can be interpreted as a greater relative separation of means.

Results

As expected, both groups of miners with bronchitis had spent more years working underground than had those without bronchitis. The average durations spent underground for nonsmoking and smoking miners without bronchitis were 16.18 and 17.96 years, respectively, compared to 20.17 and 19.91 years for the nonsmoking and smoking miners with bronchitis. The association of higher prevalence of bronchitis with increasing years spent working underground has been reported previously by Kibelstis and associates (1) and by Hankinson and co-workers (13).

The mean values for the various indices of pulmonary function are shown in table 1. There was a general decrease in all of these pulmonary function values with increasing symptoms and smoking history. Although the FVC decreased across the groups, the relative decrease in FEV_1 was greater. Peak flow also decreased across the groups and showed a greater relative decrease than either the FVC or FEV_1. Of the standard spirometric indices, the FEV_1/FVC, % showed the most significant difference between smokers with bronchitis and nonsmokers without bronchitis, the t value being 9.11; however, there was no significant difference between the 2 subgroups of nonsmokers.

The values for the maximal expiratory flows at 25, 50, 75, and 90 per cent, respectively, of the exhaled FVC ($\dot{V}max_{25}$, $\dot{V}max_{50}$, $\dot{V}max_{75}$, and $\dot{V}max_{90}$) are also included in table 1 (14). The flows at high and mid-lung volumes, $\dot{V}max_{25}$ and $\dot{V}max_{50}$, showed the greatest relative decrease with increasing symptoms and smoking history. It is pertinent to recall that the FEV_1/FVC, % mean difference between smoking categories had a t value of 9.11 (table 1), a relative mean difference that was as great as that of the $\dot{V}max_{50}$ and $\dot{V}max_{25}$. We again observed the apparently anomalous finding that the $\dot{V}max_{90}$ was greater in the nonsmokers with bronchitis than in the nonsmokers without bronchitis (13).

TABLE 1

PULMONARY FUNCTION STUDIES OF 4 GROUPS OF MINERS (428 SUBJECTS PER GROUP)

	Nonsmokers		Smokers	
	Without Bronchitis	With Bronchitis	Without Bronchitis	With Bronchitis
FVC, liter	4.89	4.71 (2.90)*	4.77 (2.16)	4.66 (3.73)
FEV_1, liter	3.77	3.60 (2.93)	3.49 (5.06)	3.34 (7.65)
Peak flow, liter/sec	8.80	8.23 (4.15)	8.20 (4.53)	7.64 (8.44)
FEV_1/FVC, %	76.78	76.48 (0.63)	73.06 (6.74)	71.28 (9.11)
$\dot{V}max_{25}$, liter/sec	7.17	6.70 (3.69)	6.54 (4.93)	5.97 (9.38)
$\dot{V}max_{50}$	4.40	4.21 (1.84)	3.72 (6.62)	3.43 (9.42)
$\dot{V}max_{75}$	1.54	1.53 (0.06)	1.23 (5.55)	1.14 (7.36)
$\dot{V}max_{90}$	0.44	0.48 (−1.21)	0.38 (2.13)	0.34 (3.61)
TLC, liter	7.09	7.03 (0.74)	7.30 (2.51)	7.41 (3.87)
RV, liter	2.20	2.32 (1.40)	2.54 (4.13)	2.75 (6.54)
RV/TLC, %	29.82	31.78 (2.07)	33.66 (4.24)	36.03 (6.68)

*Numbers in parentheses are t values. All groups were compared to nonsmokers without bronchitis (column 1).

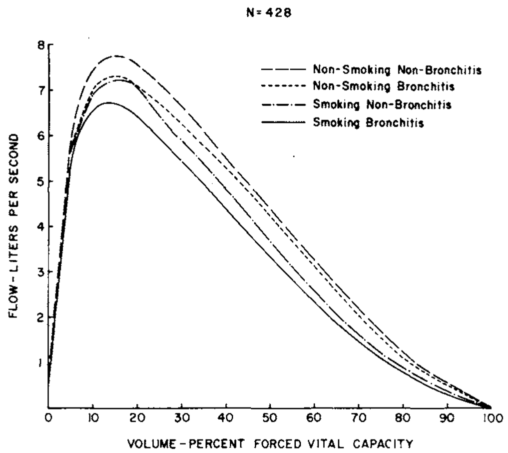

Fig. 1. Mean flow-volume curves expressed as percentages of forced vital capacity.

A plot of the mean flow-volume curves for each of the 4 groups expressed as percentages of FVC exhaled is shown in figure 1. The greatest differences (for nonsmokers or those with bronchitis) occurred at high and middle lung volumes. The flows at lower lung volumes were approximately equal for bronchitic and nonbronchitic subjects, but still separated smokers from nonsmokers.

The changes in the flows at lower lung volumes for the various groups can be more clearly seen if the flows are expressed as percentages of TLC (figure 2). For all intents and purposes, the flows of the nonsmokers with bronchitis were decreased only at higher lung volumes, whereas the smoking groups demonstrated decreased flows at all lung volumes. The striking difference between figures 1 and 2 is due primarily to an increase in residual volume (RV). Because of the increased TLC seen in smokers, and in order to standardize for differences in lung size, the flows were divided by TLC in the hope of effecting a better separation of smokers from nonsmokers (figure 3). The maximal flow at 70 per cent of the vital capacity (TLC/sec) was not more sensitive than the $\dot{V}max_{50}$ in separating the nonsmokers without bronchitis from the smokers with bronchitis ($t = 9.5$ compared to 9.4 for the $\dot{V}max_{50}$).

The mean values for RV, TLC, and RV/TLC, % for each of the 4 groups are shown in table 1. The increase in RV seen in table 1 is also apparent in figures 2 and 3. A slight but significant increase in TLC occurred in the smoking groups, and smokers also tended to have decreased flows at all lung volumes. This increase in TLC was not as great as that in RV; consequently, the RV/TLC, % still showed an increase, as seen in table 1. The nonsmokers with bronchitis tended to have increased RV along with a decreased FEV_1 and decreased flows at higher lung volumes in the absence of hyperinflation, findings suggesting that dust-induced bronchitis is primarily affecting the larger or upper airways, and is not associated with concomitant destruction of lung parenchyma.

The mean flows expressed at absolute lung volume are shown in figure 4. When the flows are expressed in this manner, all of the changes previously described are apparent, namely, an increase in TLC and RV, and decreased flows at all lung volumes.

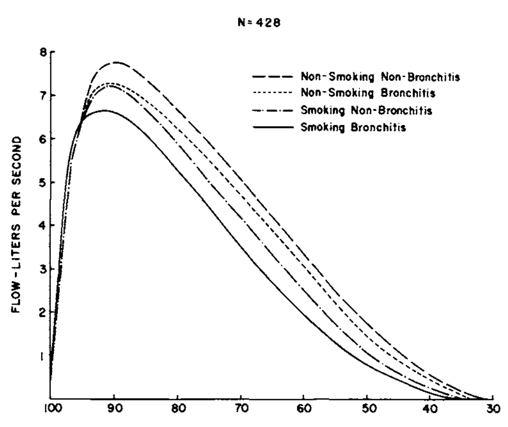

Fig. 2. Mean flow-volume curves expressed as percentages of total lung capacity.

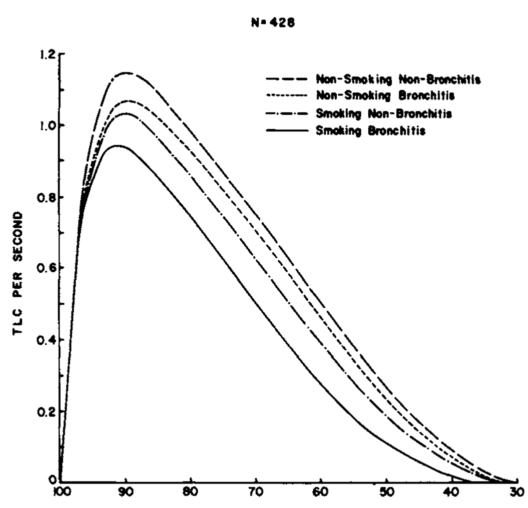

Fig. 3. Mean curves derived by dividing flows by total lung capacity (TLC).

The occurrence of simple coal worker's pneumoconiosis in each of the 4 groups is shown in table 2. There is a slightly higher, although nonsignificant, prevalence of simple coal worker's pneumoconiosis with increasing bronchitic symptoms and smoking history. This is no doubt due to the fact that the bronchitic groups spent a slightly greater amount of their working lives underground; however, this minor disparity was to be expected.

Discussion

Several conclusions can be drawn from these results. First, it appears that flows, when expressed as percentages of FVC exhaled, offer little advantage over FEV_1 and FEV_1/FVC, % as indices of ventilatory capacity, particularly when it comes to separating smokers from nonsmokers; however, peak flow and the flows at higher lung volumes were useful for differentiating those with bronchitis from those without bronchitis. Dust-induced bronchitis was associated with a decrease in peak flow and $\dot{V}max_{50}$, but flows at lower lung volumes were unchanged unless expressed either at absolute lung volume or as percentages of TLC, this probably being a reflection of an increase in RV. Nonetheless, when expressed in the latter manner, a decrease in flows at lower lung volumes was associated with cigarette smoking, and, by inference, small airway obstruction. The lack of sensitivity of the $\dot{V}max_{50}$ has been observed by Merchant and associates (15), who found that the $\dot{V}max_{50}$ offered no advantage over the FEV_1 in detecting decrements during a work shift in a group of cotton workers. Similarly, Parry and associates (16) reported the FEV_1 to be a more sensitive index than the $\dot{V}max_{50}$ in their comparison of the partial and full maximal expiratory flow-volume curves before and after isoproterenol. Nevertheless, serial determination of flows expressed at absolute volume may prove useful in the detection of early changes in industrial populations.

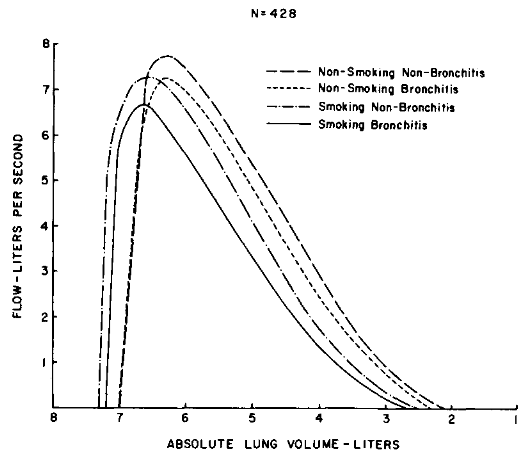

Fig. 4. Mean flow-volume curves expressed at absolute lung volume.

Second, the anomalous observation of a higher average $\dot{V}max_{75}$ and $\dot{V}max_{90}$ in nonsmokers with bronchitis, when compared to nonsmokers without bronchitis (12), is clearly a consequence of the increased RV that occurs in industrial bronchitis. When the flows are expressed as percentages of FVC exhaled, the increase in RV is not taken into account. Whereas dust-induced bronchitis predominantly affects the larger airways, lesser changes in the mucous glands and goblets cells of the smaller airways are to be anticipated. Such changes could well affect flow in the peripheral airways, and could probably account for the increased RV. Changes in RV associated with bronchitis have previously been described by Bates (17), although, in our study, RV did not provide the greatest separation between those with and those without bronchitis.

Under ideal circumstances, it would have been desirable to include a group of nonsmoking, nonbronchitic nonminers for comparison. This was not possible for several reasons. The miners studied were drawn from 10 states and 29 mines, and, to be truly representative, a control group of comparable socioeconomic status would have

TABLE 2

NUMBER OF SUBJECTS IN EACH RADIOGRAPHIC CATEGORY

	Radiographic Category			
	0	1	2	3
Nonsmokers without bronchitis	385	35	8	0
Nonsmokers with bronchitis	371	45	12	0
Smokers without bronchitis	371	47	10	0
Smokers with bronchitis	356	54	15	3

had to be selected for each mine studied. This was clearly impossible, because in parts of West Virginia and Kentucky, more than 80 per cent of the male population have spent some time working as miners. One of the writers (JH) compared the flows in just more than 100 non-smoking, nonbronchitic miners with a matched control population of nonminers, and found no essential difference.

Another important observation in this study was the larger TLC observed in both smoking groups compared to the nonsmokers. The increase in the smokers' TLC is probably the result of loss of elastic recoil due to destruction of lung parenchyma, although hyperinflation without parenchymal destruction cannot be totally excluded. In the nonsmoking subjects with bronchitis, reduced flows at higher lung volumes were apparent, reflecting air flow obstruction in the large airways. In contrast to the smokers, the nonsmoking subjects with bronchitis did not appear to have any concomitant loss of retractive forces.

Finally, the recording of flow-volume curves in conjunction with the measurement of lung volumes makes it possible to express flows at absolute lung volumes, thereby yielding valuable information that is not available from spirometry alone. As such, the technique may be useful in monitoring industrial populations, and, in this regard, there seems little doubt that Barnhard's radiographic method offers a practical means of determining TLC in field studies (10, 11).

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