

Lung function studies of asbestos workers

by Wang Mai-ling, Lu Pei-lian¹

WANG ML, LU PL. Lung function studies of asbestos workers. *Scand J Work Environ Health* 11 (1985): suppl 4, 34–42. Pulmonary function tests have been conducted on 155 asbestos workers and 130 referents. It was found that the lung function impairment in asbestos workers is predominantly a restrictive ventilatory defect appearing even when radiographic changes are not detectable. There was, however, no evidence of airway obstruction. As the disease progressed, all the pulmonary function indices, including vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 s ($FEV_{1.0}$), maximal ventilation volume (MVV), total lung capacity (TLC), and pulmonary diffusing capacity (DL_{CO}), were reduced dramatically, with the exception of $FEV_{1.0}/FVC$ (%). It is suggested that both radiographic examination and pulmonary function tests should be used as early detection measures of asbestos-induced lung disorders. VC, FVC, and $FEV_{1.0}$ are the simplest, most reproducible, and most valid indices for the health surveillance of asbestos workers, while the FVC test is the most valuable for epidemiologic study. With stepwise regression analysis a quantitative relationship between dust exposure and pulmonary function was demonstrated. There was no significant difference in the small airway function of the exposed workers and the referents. Further study is needed to investigate the possibility of asbestos-induced small airway obstruction and to estimate the roles played by cigarette smoking and air pollution.

Key terms: asbestosis, closing volume, cumulative dust exposure, diffusing capacity (transfer factor), functional residual capacity, maximal expiratory flow volume curve, total lung capacity, vital capacity.

Lung function tests have been utilized since the 1940s as a means of studying asbestosis in various fields, such as clinical diagnosis, early detection, periodic and preemployment physical examination, the estimation of progress of the disease, and epidemiologic surveys.

Based on the radiographic diagnosis, the prevalence rate of asbestosis in the workers of a Shanghai asbestos-products factory was around 20 % in 1980 (7). The present study was designed to identify the characteristics of pulmonary function changes among the asbestos workers in that factory and the relationships between the radiographic signs, the cumulative dust exposure, and the pulmonary function changes and then to evaluate the usefulness of pulmonary function tests in diagnosis, health surveillance, and the epidemiologic study of asbestos workers.

Subjects and methods

The survey was carried out among a category-stratified, random sample of 155 asbestos workers selected from a total of 750 persons with working tenures of over 13 years and an age range of 30–65 years. According to the radiographic diagnosis made by the Shanghai Institute of Industrial Hygiene and Occupational Diseases, the subjects were divided into the following three groups: (i) 50 workers (25 men and 25 women) certified to have asbestosis of categories I and II ($A_{I, II}$) as defined by the Chinese diagnostic criteria established in 1963, (ii) 54 workers (25 men and 29

women) with a history of asbestos dust exposure but without any definite radiographic signs (A_0), and (iii) 51 workers (26 men and 25 women) in whom asbestosis was suspected (A_{0-1}).

For comparison 130 workers (72 men and 58 women) employed in a machine manufacturing plant in Shanghai were chosen as referents from similar age and sex strata.

Expiratory flow and volumes were determined with a 11.0-l water-sealed spirometer made in the People's Republic of China. The following indices were measured with the methods described by Wu et al (13): vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 s ($FEV_{1.0}$), forced expiratory flow 25 to 75 % (FEF_{25-75} or MMEF) and maximal ventilation volume (MVV). Functional residual capacity (FRC) was determined by the closed-circuit oxygen dilution method (13). Residual volume (RV) and total lung capacity (TLC) were calculated (13).

After routine lung function tests, 49 asbestos workers and 35 referents of both sexes were selected by a category-stratified random sampling method. All of these tests were performed in the Lung Function Laboratory of the Zhong-shan Hospital. Pulmonary diffusing capacity (transfer factor) (DL_{CO}) was determined by the single-breath carbon monoxide technique, using a manual method (2). The diffusion constant (K_{CO}) was calculated as the ratio of DL_{CO} to alveolar volume (V_A). Closing volume (CV) was measured by a nitrogen dilution method according to Li et al (5). Closing capacity (CC) was calculated by the addition of CV to the separately determined RV. The test for the maximal expiratory flow volume curve (MEFVC) was done according to routine methods.

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The chest radiographs were taken by the Shanghai Institute of Industrial Hygiene and Occupational Diseases. The earliest date for radiographic evidence of asbestosis was recorded. The radiographs were read again according to the pneumoconiosis classification of the International Labour Office (ILO) (3).

The cumulative dust exposure level was defined as the sum of the products of the average yearly workplace dust concentration (milligrams per cubic meter) and the working tenure (years) and expressed in milligrams · years.

Results

Routine lung function tests

The exposed worker's values for the different lung function indices were adjusted for age, sex, and height by comparison to predicted values. The regression equations for the predicted values were based on the data of the referents (table 1).

The results of the routine lung function tests of the asbestos workers are shown in figure 1. VC, MVV, FVC, FEV_{1.0}, and TLC were decreased in comparison to the corresponding values of the referents, the degree of decline among both sexes increasing for the radiographic categories as follows: A₀, A₀₋₁, A₁, II.

While MMEF, RV, and FRC were also slightly decreased, FEV_{1.0}/FVC % showed no significant difference and RV/TLC % was slightly increased.

Each of the lung function parameters was examined for each sex across all the radiographic categories by the analysis of variance. After this analysis, the Newman Keul Q-test was used to determine the significance of the differences in the mean values for each of the pairs of groups (including the reference group). The results of the testing are shown in table 2 for all the possible pairs.

Diffusion capacity, closing volume and flow-volume curve

The analysis of variance was applied to test the significance of the percentage of the predicted DL_{CO}, K_{CO}, CV/VC %, CC/TLC %, $\dot{V}_{50}$ (flow at 50 % forced expiration), $\dot{V}_{25}$ (flow at 25 % forced expiration), and $\dot{V}_{50}/\dot{V}_{25}$ among 84 persons (35 referents and 49 exposed persons). The expected values were calculated from the regression equations reported by Ling et al (6). It was found that the DL_{CO}, K_{CO}, and CV/VC % of the asbestos workers were declined ($p < 0.001$, 0.01, and 0.01, respectively) and their $\dot{V}_{50}/\dot{V}_{25}$ increased gradually in comparison to the referents' values when they were considered according

Table 1. Predicted regression equations for various lung functions on age, height, and weight according to the referents.

Index ^a	Partial regression coefficients			Intercept	Correlation coefficient	Standard error of the estimate
	Age (years)	Height (cm)	Weight (kg)			
VC (ml)						
Men	-19.13	53.41	-11.90	- 3 324	0.6714	2.55
Women	-19.05	48.02	6.42	- 4 106	0.6258	2.62
MVV (l/min)						
Men	- 1.27	0.439	0.287	79.15	0.6577	0.015
Women	- 0.773	1.559	0.273	- 149.6	0.5838	0.016
FEV _{1.0} (ml)						
Men	-27.37	44.15	- 9.776	- 2 487.4	0.7817	2.24
Women	-25.64	37.59	4.355	- 2 731.0	0.6965	2.33
FVC (ml)						
Men	-21.52	49.66	- 5.49	- 2 943.1	0.6563	2.62
Women	-16.27	53.53	4.067	- 4 924.0	0.6477	2.57
FEV _{1.0} /FVC (%)						
Men	- 0.3181	0.2375	- 0.1344	58.64	0.4584	0.33
Women	- 0.4291	-0.0670	0.0049	105.3	0.5074	0.34
MMEF (l/s)						
Men	- 0.0674	0.0186	- 0.0244	4.403	0.6288	0.1170
Women	- 0.0565	0.0061	0.0211	2.546	0.5821	0.1106
RV (ml)						
Men	14.36	30.91	-11.99	- 3 105.9	0.4127	2.30
Women	17.45	34.595	-13.39	- 3 878.3	0.5050	2.48
FRC (ml)						
Men	10.16	51.47	-28.16	- 4 666.0	0.4864	2.55
Women	13.30	65.83	-30.25	- 7 220.4	0.5558	2.78
TLC (ml)						
Men	1.429	81.90	-19.25	- 6 809.8	0.5684	3.02
Women	2.437	95.02	- 8.475	-10 173.5	0.6277	3.17
RV/TLC (%)						
Men	0.2389	0.0467	- 0.0868	20.91	0.4967	0.244
Women	0.3664	0.0481	- 0.2199	24.226	0.5250	0.305

^a VC = vital capacity, MVV = maximal ventilation volume, FEV_{1.0} = forced expiratory volume in 1 s, FVC = forced vital capacity, MMEF = forced expiratory flow 25 to 75 %, RV = residual volume, FRC = functional residual capacity, TLC = total lung capacity.

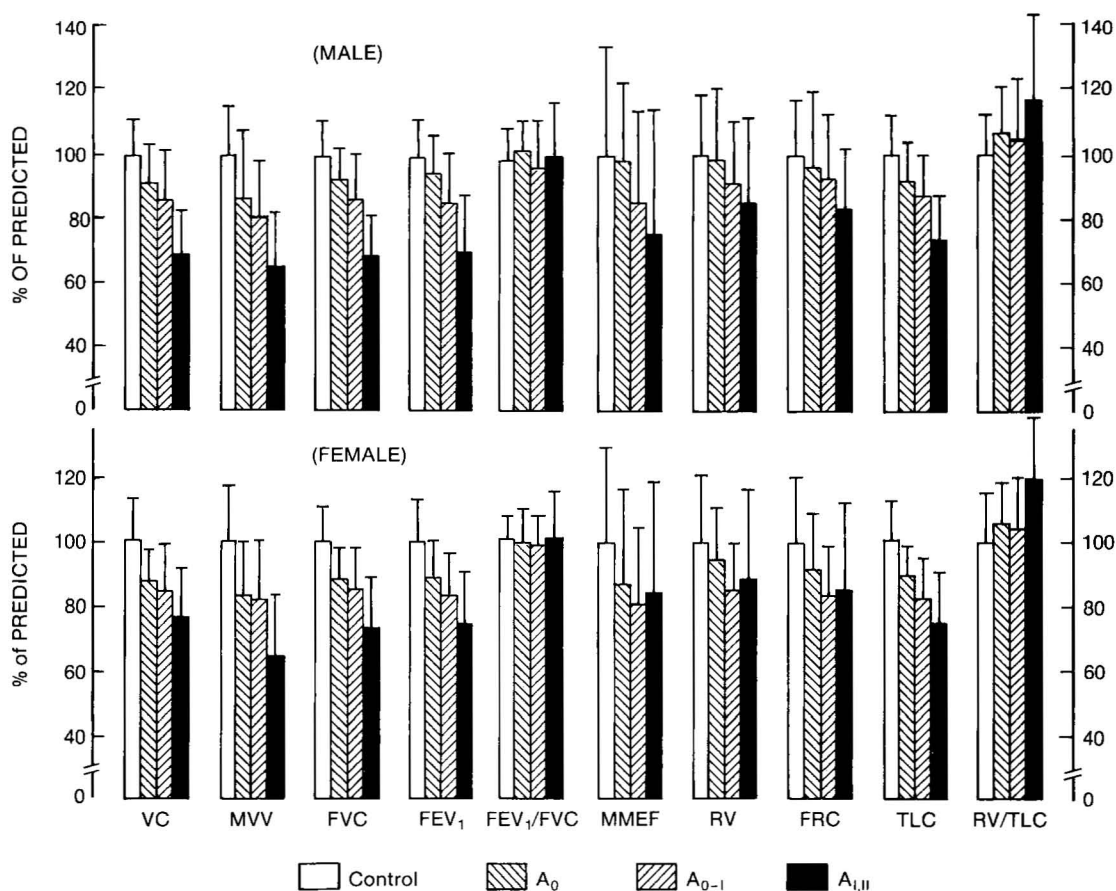


Figure 1. Results of the pulmonary function tests of the reference group (control) and the asbestos workers according to their radiographic category. [For an explanation of the used abbreviations, see table 1 (footnote a) for the pulmonary functions and table 2 (footnote a) for the radiographic categories.]

to the severity of their radiographic category [$A_0 \rightarrow A_{0-1} \rightarrow A_{1,II}$ ($p < 0.05$)]. The differences were statistically significant for all the indices, except $\dot{V}_{50}$ and $\dot{V}_{25}$ (tables 3—5).

Radiographic assessment

The conformity rate between the Chinese radiographic categories of asbestosis and the grades of profusion in the ILO classification was 65 % (table 6). The relationship between the severity of pleural and parenchymal changes and the pulmonary function impairment was recognized; it indicated that pleural and parenchymal changes had independent effects on the decline of VC, FVC, and TLC (tables 7 and 8).

Cumulative dust exposure level and its effect on pulmonary function

One hundred and fifty-five subjects were classified into different dust exposure groups. The average values of the percentage of predicted FVC, $FEV_{1,0}$, MVV, and TLC declined with increasing dust exposure even at a level below 100 mg · years (figure 2). In an exami-

nation of the relationship between dust exposure and lung function, the following eight factors which may affect lung function were considered independent variables: X_1 = age (in years); X_2 = height (in centimeters); X_3 = weight (in kilograms); X_4 = gender (male = 0, female = 1); X_5 = cigarette smoking (in pack-years); X_6 = length of employment (in years); X_7 = cumulative dust exposure (in mg/m³-years, calculated as the average exposure times years at that exposure summed over the lifetime of exposures); and X_8 = duration of exposure (in years). The observed values of ten routine lung function indices for the 285 subjects were considered dependent variables in ten separate multiple linear regression equations using stepwise regression analysis (table 9).

It is of interest that the cumulative dust exposure variable was incorporated into most of the equations. The equation for FVC has been used in figure 3 to illustrate the impact of four different dust levels if 170-cm male workers experienced them for up to a 40-year worklife. The line for no exposure was calculated with the values for X_7 and X_8 set equal to zero. The dust levels were selected to represent (i) the maximum allowable dust concentration for asbestos

Table 2. Results of the test of significance of the differences in lung function between the referents (R) and the asbestos workers according to their radiographic categories.^a

Index ^b	R:A ₀	R:A _{0-I}	R:A _{I,II}	A ₀ :A _{0-I}	A ₀ :A _{I,II}	A _{0-I} :A _{I,II}
VC						
Men	*	**	**	NS	**	**
Women	**	**	**	NS	**	**
MVV						
Men	**	**	**	NS	**	**
Women	**	**	**	NS	**	**
FVC						
Men	**	**	**	NS	**	**
Women	**	**	**	NS	**	**
FEV _{1,0}						
Men	NS	**	**	*	**	**
Women	**	**	**	NS	**	*
FEV _{1,0} /FVC						
Men	NS	NS	NS	NS	NS	NS
Women	NS	NS	NS	NS	NS	NS
MMEF						
Men	NS	NS	**	NS	*	NS
Women	*	*	NS	NS	NS	NS
RV						
Men	NS	NS	*	NS	NS	NS
Women	NS	*	NS	NS	NS	NS
FRC						
Men	**	**	**	NS	*	*
Women	**	**	**	NS	NS	NS
TLC						
Men	**	**	**	NS	**	**
Women	**	**	**	NS	**	*
RV/TLC						
Men	NS	NS	**	NS	NS	*
Women	**	**	**	NS	NS	NS

^a A₀ = asbestos workers without any definite radiographic signs of asbestosis, A_{0-I} = asbestos workers with suspected asbestosis, A_{I,II} = asbestos workers with radiographic ratings of asbestosis of I or II.

^b See table 1 (footnote a) for an explanation of the abbreviations.

* p<0.05, ** p<0.01, NS = not significant (p>0.05).

Table 3. Pulmonary diffusing capacity (DL_{CO}) and the diffusion constant (K_{CO}) of the different radiographic groups and the referents.^a

Radiographic category ^b	DL _{CO} (ml · mmHg ⁻¹ · min ⁻¹) ^c				K _{CO} (ml · mmHg ⁻¹ · min ⁻¹ · l ⁻¹) ^c	
	Observed		Percent of predicted		Observed	
	Mean	SD	Mean	SD	Mean	SD
A ₀						
Men (N = 9)	29.6	3.4	89.5	9.9	.	.
Women (N = 8)	22.8	3.2	101.6	14.1	.	.
Men and women combined (N = 17)	.	.	.	.	6.19	0.69
A _{0-I}						
Men (N = 8)	26.6	3.9	87.5	9.7	.	.
Women (N = 7)	21.0	3.5	93.7	15.5	.	.
Men and women combined (N = 15)	.	.	.	.	6.42	0.46
A _{I,II}						
Men (N = 9)	20.9	3.3	73.3	9.5	.	.
Women (N = 7)	18.1	2.3	84.1	11.1	.	.
Men and women combined (N = 16)	.	.	.	.	6.26	0.87
Referents						
Men (N = 18)	34.0	5.6	111.5	20.8	.	.
Women (N = 15)	27.9	3.9	125.7	17.0	.	.
Men and women combined (N = 33)	.	.	.	.	7.17	1.12
p-Value ^d	<0.001 (for both the men and the women)				<0.001	

^a Based on the regression equation of Ling et al (6).

^b See table 2, footnote a for an explanation of the radiographic categories.

^c 1 mmHg = 133.3 Pa.

^d By analysis of variance.

Table 4. Closing volume of both sexes combined in the different radiographic groups and of the referents.^a (CV = closing volume, VC = vital capacity, CC = closing capacity, TLC = total lung capacity)

Radiographic category ^b	CV/VC (%)				CC/TLC (%)			
	Observed		Percent of predicted		Observed		Percent of predicted	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A ₀ (N = 17)	10.5	4.9	92.5	44.7	39.7	6.2	109.7	16.3
A _{0-I} (N = 15)	14.9	7.4	106.1	40.2	44.9	9.4	111.8	12.8
A _{I, II} (N = 16)	20.4	8.9	105.1	42.5	53.2	9.6	112.6	18.6
Referents (N = 33)	13.6	5.1	94.1	30.3	43.0	5.4	106.7	10.7
p-Value ^c	<0.01				>0.05			

^a Based on the regression equation of Li et al (5).

^b See table 2 (footnote a) for an explanation of the radiographic categories.

^c By analysis of variance.

Table 5. Comparison of the maximal expiratory flow volume curve (MEFVC) for both sexes combined in the different radiographic groups and for the referents.^a ($\dot{V}_{50}$ = flow at 50 % forced expiration, $\dot{V}_{25}$ = flow at 25 % forced expiration)

Radiographic category ^b	$\dot{V}_{50}/\text{height}$ (l · s ⁻¹ · m ⁻¹)				$\dot{V}_{25}/\text{height}$ (l · s ⁻¹ · m ⁻¹)				$\dot{V}_{50}/\dot{V}_{25}$			
	Observed		Percent of predicted		Observed		Percent of predicted		Observed		Percent of predicted	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A ₀ (N = 17)	2.54	0.69	110.6	30.1	0.91	0.25	91.9	25.9	2.81	0.51	115.1	21.1
A _{0-I} (N = 15)	2.25	0.71	101.6	30.8	0.68	0.30	74.1	27.8	3.49	1.01	134.7	34.9
A _{I, II} (N = 17)	1.90	0.96	95.0	47.1	0.50	0.24	67.7	31.0	4.13	1.82	145.5	63.4
Referents (N = 35)	2.06	0.81	89.6	36.6	0.77	0.42	84.7	39.2	2.96	1.06	113.0	35.5
p-Value ^c	>0.05				>0.05				<0.05			

^a Based on the regression equation of Ling et al (6).

^b See table 2 (footnote a) for an explanation of the radiographic categories.

^c By analysis of variance.

Table 6. Comparison of the Chinese radiographic categories with the grades of profusion in the classification of the International Labour Office (ILO).^a

Chinese categories	Grade of profusion in ILO classification				Total
	0		1	2	
	0/0	0/1			
0	28	22	2	.	52
0-I	1	24	24	.	49
I	.	.	41	.	41
II	.	.	3	4	7
Total	29	41	70	4	149

^a Conformity rate = 65 %.

dust which went into effect in the People's Republic of China in 1978 (2 mg/m³), (ii) the average levels encountered in different workplaces in the asbestos products factory in the past (12 mg/m³ in the spinning area and 26.3 mg/m³ in the opening area), and (iii) the average exposure before 1958 in a small textile plant where a number of the older workers had been employed before moving to their current jobs (52.6 mg/m³) (7). From this figure it can be seen that the FVC declined more rapidly as exposure increased.

For those nonexposed workers 30 to 60 years of age the annual decline was 30 ml, while in the different dust exposure groups the annual decline was 52, 59, 68, and 84 ml, respectively.

In figure 4 the equation for FEV_{1.0} is used to illustrate the effect of exposure to cigarette smoking and asbestos dust. In the case of FEV_{1.0} only duration and not cumulative exposure was significant in the regression (table 9). For the example, 170-cm male subjects are considered to have started asbestos exposure at 20 years of age (if exposed) and to have started smoking a pack of cigarettes per day at age 20 (if a smoker). From the regression lines for the four possible combinations of smoking and exposure it can be seen that both smoking and exposure contribute to a steeper slope for the regression line, the steepest slope belonging to smoking exposed workers.

Discussion

The results of the routine lung function tests presented in this paper were consistent with the results of other reports (1, 4, 8, 11, 12). An analysis of diffusing capacity among 35 referents and 49 exposed workers showed that the DL_{CO} and K_{CO} declined from one group to another, starting with the referents and

Table 7. Lung function values in relation to the occurrence of pleural changes. (ILO = International Labour Office)

Grade of profusion in ILO classification	Lung function indices ^a							
	VC (%) ^b		FEV _{1.0} (%) ^b		TLC (%) ^b		MVV (%) ^b	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1/1								
With pleural change (N = 16)	73.0	12.5	74.4	14.7	74.7	15.6	69.9	20.1
Without pleural change (N = 15)	82.2	11.5*	82.1	18.9	78.2	12.8	70.7	16.0
1/0								
With pleural change (N = 11)	73.9	9.8	74.0	12.8	78.9	11.3	67.3	16.1
Without pleural change (N = 22)	83.9	14.1*	83.2	16.3	81.3	13.9	74.9	22.4
0/1								
With pleural change (N = 9)	88.0	15.3	81.1	13.2	88.3	12.4	80.7	13.6
Without pleural change (N = 37)	88.0	11.8	89.1	14.0	87.9	12.2	81.7	15.4

^a See table 1 (footnote a) for an explanation of the abbreviations.

^b Percentage of the predicted value (from table 1).

* $p < 0.05$ (t-test).

Table 8. Lung function values for subjects without pleural change in relation to the occurrence of different grades of profusion in the classification of the International Labour Office (ILO).

Grades of profusion in the ILO classification	Lung function indices ^a							
	VC (%) ^b		FEV _{1.0} (%) ^b		TLC (%) ^b		MVV (%) ^b	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0/0 (N = 29)	92.1	9.3	91.7	11.4	92.3	10.3	88.5	20.3
0/1 (N = 37)	88.0	11.8	89.1	14.0	87.9	12.2	81.7	15.4
1/0 (N = 22)	83.9	14.1	83.2	16.3	81.3	13.9	74.9	22.4
1/1 (N = 15)	82.2	11.5	82.1	18.9	78.2	12.8	70.7	16.0
p-Value ^c	<0.05		>0.05		<0.05		<0.05	

^a See table 1 (footnote a) for an explanation of the abbreviations.

^b Percentage of the predicted value (from table 1).

^c By analysis of variance.

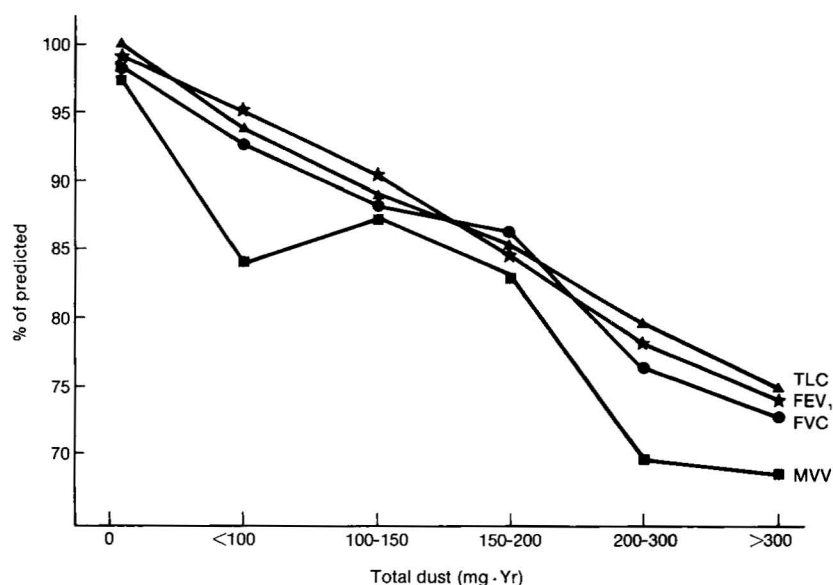
**Figure 2.** Selected spirometric indices of lung function in relation to dust exposure. [Yr = year(s); for an explanation of the lung function abbreviations see table 1, footnote a.]

Table 9. The results of the stepwise regression analysis of multiple factors (N = 285, F = 3).

Lung function indices ^a	F-level ^b	Selected factors ^c	Multiple linear regression equations	R ^d	SEE ^e
VC (ml)	5	X _{2,8,1,4,7}	$Y = -30.13 X_1 + 45.54 X_2 + 550.58 X_4 - 0.60 X_1 - 20.40 X_8 - 2871.3$	0.858251	439
MVV (l)	6	X _{2,8,1,4,7}	$Y = -1.139 X_1 + 0.846 X_2 + 20.623 X_4 - 0.027 X_7 - 0.634 X_8 - 0.592$	0.779003	18.0
FVC (ml)	6	X _{2,1,8,4,5}	$Y = -29.64 X_1 + 47.86 X_2 + 530.71 X_4 - 0.63 X_7 - 21.46 X_8 - 3215.1$	0.854867	457
FEV _{1.0} (ml)	5	X _{2,8,1,4,7}	$Y = -32.94 X_1 + 34.58 X_2 + 469.21 X_4 - 0.40 X_5 - 20.79 X_8 - 1702.8$	0.853666	373
FEV _{1.0} /FVC (%)	11	X _{1,5}	$Y = -0.297 X_1 - 0.010 X_5 + 90.20$	0.437661	7.7
MMEF (l/s)	4	X _{1,4,8,5,2,3}	$Y = -0.053 X_1 + 0.028 X_2 - 0.015 X_3 + 0.833 X_4 - 0.001 X_5 - 0.016 X_8 + 0.878$	0.715746	0.75
RV (ml)	17	X _{2,1,7,3}	$Y = -16.44 X_1 + 43.32 X_2 - 13.52 X_3 - 0.62 X_7 - 5202.1$	0.652977	366
FRC (ml)	7	X _{2,3,7,1,4}	$Y = 10.55 X_1 + 63.72 X_2 - 29.89 X_3 + 204.29 X_4 - 0.86 X_7 - 6836.5$	0.736643	448
TLC (ml)	4	X _{2,8,4,7,3,1}	$Y = 92.27 X_1 - 17.28 X_3 + 498.19 X_4 - 1.55 X_7 - 21.05 X_8 - 9154.8$	0.839336	628
RV/TLC (%)	3	X _{1,8,3,2,4}	$Y = 0.430 X_1 + 0.176 X_2 - 0.166 X_3 - 2.931 X_4 + 0.166 X_8 - 1.525$	0.621404	5.8

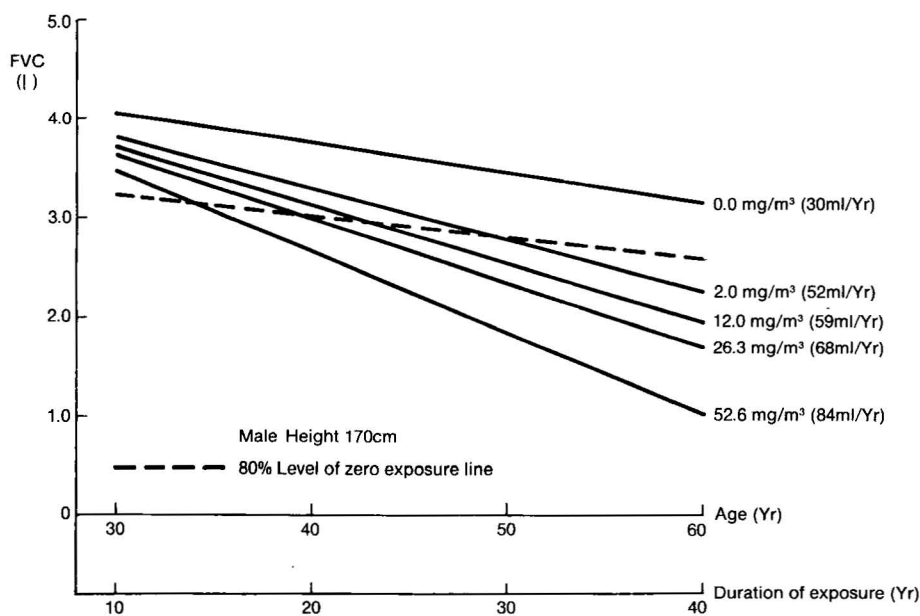
^a See table 1 (footnote a) for an explanation of the abbreviations.

^b F-level refers to the smallest F-value among the selected factors.

^c The selected factors arranged from the largest of the smallest according to their relationship with the dependent variables. (X₁ = age (years), X₂ = height (cm), X₃ = weight (kg), X₄ = gender, X₅ = cigarette smoking (pack-years), X₆ = length of employment (years), X₇ = cumulative dust exposure (mg/m³-years), X₈ = duration of exposure (years)).

^d R = coefficient of multiple correlation.

^e SEE = standard error of the estimate.

**Figure 3.** Rate of decline in forced vital capacity (FVC) in relation to asbestos exposure. [Yr = year(s)]

moving to the A₀, A₀₋₁, A_{1, II} groups consecutively, just as described in other reports (9, 10). As smoking and air pollution were not fully considered in this survey, it is too early to give a conclusive view about small airway impairment as a sensitive index in the early detection of asbestosis.

According to the analysis of the relationship between the profusion and the pleural abnormalities and

selected indices of lung function, it was shown that the main factors associated with lung function were the degree of interstitial fibrosis and pleural changes.

The conformity rate between the categories of Chinese radiographic diagnostic criteria and the profusion grades in the ILO classification was 65 %. The Chinese radiographic diagnostic criteria consider the density of reticular shadows to be of major impor-

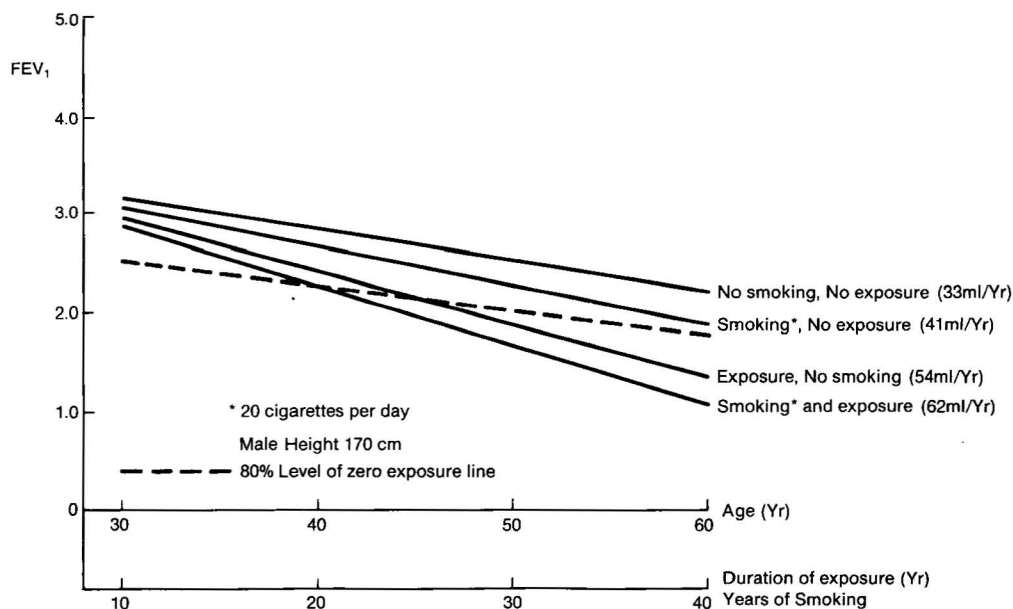


Figure 4. Rate of decline in forced expiratory volume in 1 s (FEV_1) in relation to asbestos exposure and smoking habits. [Yr = years(s)]

tance, while the ILO classification of pneumoconiosis attempts to provide an objective record of the abnormalities found in radiographs and is not designed to be used as diagnostic criteria for pneumoconiosis. The advantage is that the record can more easily be used in an epidemiologic survey.

With a stepwise multiple regression method, a quantitative relationship may be established between the cumulative dust exposure level, the amount of pack-years of cigarette smoking, and lung function. After age, sex, height, and weight were adjusted, the main factor influencing lung function was dust exposure. The routine lung function indices were closely correlated with the dust exposure level and exposure duration, except for $FEV_{1.0}/FVC\%$, which was only related to age and cigarette smoking.

An effort was made to project the impact of the different levels of asbestos exposure in terms of predicting the number of years at a given level during which lung function would be preserved within the normal range. The line for 80 % of the value of the FVC predicted for unexposed workers was used as the lower limit of normal. This line is represented by the broken line in figure 3. The point at which the broken line crosses the prediction line for each of the dust levels indicates the number of years at that level of exposure before the FVC drops below the 80 % line for the unexposed. For the 170-cm male workers used in the example, continuous exposure at 2, 12, 26.3, and 52.6 mg/m^3 would permit work to continue for 35, 27, 20, and 14 years, respectively, before the workers would be expected to have an FVC value of less than 80 % of the unexposed workers. From these equations the work tenure (be-

fore developing abnormal lung function) for any asbestos worker with a known sex, height, and dust exposure level can be estimated. The equations would be less likely, however, to provide good estimates for the old or the undersized. This method of estimation may have value in suggesting a hygienic standard.

From this study, the following conclusions can be drawn: (i) lung function impairment appears in the absence of radiographic changes in the chest; even in the A_0 group, the decline of FVC, VC, TLC, and MVV was statistically significant when compared with the corresponding values of the referents; (ii) as a whole, the severity of lung function impairment is parallel to the category of asbestosis, as defined by Chinese diagnostic criteria; (iii) the basic characteristics of lung function impairment in asbestosis is a "restrictive ventilatory defect," indicated by a prominent decline in VC, FVC, $FEV_{1.0}$, TLC, and MVV, with little evidence of airway obstruction; and (iv) VC, FVC, $FEV_{1.0}$, and $FEV_{1.0}/FVC\%$ are the simplest, most sensitive, most specific, and most repeatable indices, among which the FVC test appears best suited for epidemiologic surveys of asbestosis. It seems best to employ chest radiography and lung function measures at the same time in the diagnosis of asbestosis and the health surveillance of asbestos workers.

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