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VITAL CAPACITY AND ONE-SECOND FORCED EXPIRATORY VOLUME IN AUSTRALIAN MALE ASBESTOS CEMENT WORKERS

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Abstract—The VC and FEV_1, corrected for temperature but not pressure, of 955 men engaged in the manufacture of asbestos-cement products were measured, and their age, height in footwear, clothed weight and smoking habit recorded. Although the asbestos-cement workers as a group had a lower VC and FEV_1 than was found in a parallel study of non-asbestos workers, the difference did not achieve statistical significance.

When 952 of these men were placed each into one of five exposure categories, the data clearly showed the effect of asbestos exposure on VC and FEV_1 and their relationship with age and height.

As in our study of non-asbestos workers, smoking habit did not influence the relationship of either VC or FEV_1 with age and height.

THAT the vital capacity (VC) and, consequently, the one-second forced expiratory volume (FEV_1) are reduced in pulmonary asbestosis has been shown by many workers (MURPHY *et al.*, 1972); BECKLAKE *et al.* (1970) have published evidence which suggests that VC may, perhaps, be reduced even before there is radiological evidence of disease. In another paper (MCCULLAGH and BALAAM, in press) we report on the VCs and FEV_1s of a group of 482 Australian factory workers of European race none of whom was, or, so far as could be determined, had been exposed to any pneumoconiogenic agent nor suffered any substantial respiratory impairment. In this paper we study the effects of asbestos exposure on these parameters in a group of men engaged in the manufacture of asbestos-cement products.

MATERIALS AND METHODS

The 955 men studied were drawn from a total male factory workforce, including some clerical workers, of about 1100 men; a few were absent and thus not available, a few declined to be examined and a few were excluded from the study, their performance of the spirometric manoeuvres having been considered unsatisfactory. All were of European race and, as WOOLCOCK *et al.* (1972) have shown, the VCs and FEV_1s of the various European peoples differ little.

The men studied were engaged in the manufacture of asbestos-cement pipes and building products in a factory which commenced production in 1917. Currently the raw materials of the factory consist of 11·6% asbestos, of which by far the greater part is chrysotile and the lesser amosite 39·5% silica, 46·5% cement and a small

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amount of cellulose pulp; although different products are made of different combinations and these have varied over the years. The silica is produced by wet milling of beach sand and is handled as a slurry until its final incorporation in the factory's products.

VC and FEV_1, throughout the study, were measured by the same technician on the same Godart Expirograph; each manoeuvre was performed five times and VC and FEV_1 taken to be the mean of the three largest volumes in each case; gas volumes were corrected for temperature, though not barometric pressure (hence BTS rather than BTPS*). Height (H) in centimetres was measured in footwear and clothed weight (W) in kilograms. Age (A) was recorded in years.

As well as these five quantitative variables a sixth qualitative variable, smoking habit, was also studied, each man being placed in one of the following three categories:

(i) Smoker: A man who habitually carried cigarettes or cigarette tobacco for his own use;
(ii) Ex-smoker: A man who had not been a cigarette smoker for the past year or longer;
(iii) Non-smoker: A man who had never been a cigarette smoker.

A seventh variable was also examined—the Assessed Asbestos Exposure (E). Data for this variable were lacking in three cases. For 952 men a detailed record was compiled listing the various jobs each had performed in the industry, the length of time in the job and the period at which each job had been performed since the level of exposure in various occupations had varied over the years. These records were then independently considered by three officers of the Company who had served many decades in the factory, rising from factory floor to positions of responsibility throughout the plant, of which they thus had a wide knowledge extending over many years. Each assessor was asked to place each man in one category of five degrees of exposure. Agreement was good and where disagreement was only by one assessor and only by one category the majority opinion prevailed; in the few cases where disagreement was greater than this the three met together and reached an agreed categorization.

Other workers (BRITISH OCCUPATIONAL HYGIENE SOCIETY, 1968; WEILL, 1973) have expressed the estimated exposures of groups of asbestos workers in various quantitative terms and, whenever this can be properly done, it provides information of great importance. However, with reluctance we have concluded, as implicitly did NEWHOUSE (1969), that we are not in a position to do this with an acceptable degree of accuracy.

The characteristics of the group on which we here report are shown in Table 1.

METHODS OF STATISTICAL ANALYSIS

Using VC and FEV_1 as dependent variables and A, H and W as independent variables, simple and multiple linear and curvilinear regression equations were found. The significance of these equations was tested by analysis of variance which was also used to compare sets of regression equations and hence to examine the differences in the relationships among the three smoking habit categories. The overall association

* Body temperature and pressure, saturated.

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between the dependent and independent variables was measured by simple and multiple correlation coefficients.

TABLE 1. CHARACTERISTICS OF THE GROUP STUDIED

Smoking Habit Category	Observed Means (& Standard Deviations) VC ml BTS	FEV_1 ml BTS	A years	H cm (in foot -wear)	W kg (clothed)
Smokers (n = 562)	4347 (848)	3314 (804)	40.5 (11.9)	171.9 (7.4)	74.1 (11.5)
Ex Smokers (n = 133)	4333 (761)	3263 (769)	46.9 (10.3)	173.3 (7.0)	79.6 (11.2)
Non Smokers (n = 260)	4449 (861)	3582 (780)	36.6 (12.0)	171.3 (8.2)	74.2 (12.8)
Assessed Asbestos Exposure Category					
E = 1 (n= 283)	4605 (814)	3679 (758)	32.1 (9.6)	171.7 (7.9)	
E = 2 (n= 261)	4534 (891)	3566 (818)	38.2 (11.4)	172.6 (7.8)	
E = 3 (n= 272)	4164 (723)	3105 (648)	47.6 (9.7)	172.0 (6.8)	
E = 4 (n= 96)	4098 (785)	3032 (674)	47.0 (10.0)	171.3 (8.1)	
E = 5 (n= 40)	3626 (844)	2836 (744)	48.4 (9.0)	170.0 (6.5)	

CORRELATIONS BETWEEN VC (AND FEV_1) AND A, H, AND W

The simple and multiple linear correlation coefficients between VC and the independent variables A, H and W and various combinations of these are shown in Table 2. Similar treatment of the dependent variable FEV_1 yielded similar results.

TABLE 2. SIMPLE AND MULTIPLE LINEAR CORRELATION COEFFICIENTS; IN ALL CASES IS $P < 0{\cdot}01$

Independent Variables	Smokers	Ex-Smokers	Non-Smokers	All Pooled
A	-0.49	-0.38	-0.37	-0.44
H	0.60	0.59	0.67	0.61
W	0.29	0.24	0.24	0.26
A,H	0.72	0.70	0.73	0.72
H,W	0.60	0.60	0.67	0.62
A,W	0.58	0.49	0.50	0.55
A,H,W	0.72	0.70	0.73	0.72

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Table 2 may be used to obtain the coefficient of determination (i.e. the square of the correlation coefficient). The coefficients of determination give the proportion of the total variation in the dependent variables which may be attributed to variation in the independent variables. Hence W has little effect in determining VC; a similar result was obtained for FEV_1. H/W was similarly considered as an independent variable and likewise found to add almost nothing to the value of predictive equations.

The possibility of a curvilinear relationship between the dependent variable VC and A and H was then studied. The sets of independent variables in the five regression equations with VC as the dependent variable and in the six regression equations with log VC as the dependent variable are given in Table 3. In none of the eleven regression equations was the fit significantly better than for the multiple linear regression with A and H as independent variables. Similar results were obtained in the case of FEV_1.

TABLE 3. SETS OF INDEPENDENT VARIABLES FOR ELEVEN CURVILINEAR REGRESSION EQUATIONS

	Dependent Variable	
	VC	log VC
Independent Variables	H^3	A
	A,H,H^3	H
	A,A^2,H	A, H
	A,H,H^2	log A
	A,A^2,H,H^2	log H
		log A, log H

The possibility of age affecting motivation was considered. From the workforce were selected those under 25 years of age, those aged 30–39 years and those of 55 years of age or more and the regression coefficients determined within the three age categories were found to be unrelated to age. This finding further supported the conclusion that the relationship between the dependent variables and age was linear.

PREDICTIVE EQUATIONS USING AGE AND HEIGHT

With the exclusion of the non-linear regressions and the independent variable W, three equations were considered for their ability to predict VC and FEV_1. These were:

$$\text{Dependent variable} = \alpha_1 + \beta_1 A \quad (1)$$

$$\text{Dependent variable} = \alpha_2 + \beta_2 H \quad (2)$$

$$\text{Dependent variable} = \alpha_3 + \beta_3 A + \gamma_3 H \quad (3)$$

Regression equations of the above three types were derived for VC and FEV_1, for each of the three smoking habit categories and an analysis of variance used to compare the equations obtained for each of these three categories. The analysis of variance technique was also used to determine how much better the use of both

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A and H was in predicting the dependent variables. For both VC and FEV_1 the equation of type (3) gave significantly better fit than did either type (1) or (2). In the case of neither VC nor FEV_1 did any of the three smoking habit categories result in significant differences among the intercepts or slopes for equations of type (3); indicating that smoking habit should be ignored and that a single equation of type (3) might properly be used for both dependent variables.

The predictive equations obtained for the whole group of asbestos workers are:

$$\text{VC(ml BTS)} = -5432{\cdot}4 - 26{\cdot}50A + 63{\cdot}25H \quad (\text{S.D.} = 586{\cdot}5) \tag{4}$$

$$\text{FEV}_1\text{(ml BTS)} = -3361{\cdot}3 - 35{\cdot}38A + 47{\cdot}52H \quad (\text{S.D.} = 519{\cdot}1). \tag{5}$$

The corresponding predictive equations obtained in the case of 488 non-asbestos workers which we report elsewhere (McCULLAGH and BALAAM, in press) were:

$$\text{VC(ml BTS)} = -6130{\cdot}8 - 21{\cdot}58A + 66{\cdot}97H \quad (\text{S.D.} = 508{\cdot}5) \tag{6}$$

$$\text{FEV}_1\text{(ml BTS)} = -3320{\cdot}8 - 31{\cdot}88A + 47{\cdot}31H \quad (\text{S.D.} = 447{\cdot}0). \tag{7}$$

THE EFFECTS OF ASBESTOS EXPOSURE

Comparison of the regression coefficients of equation (4) with those of equation (6) and those of equation (5) with those of equation (7) showed no significant differences. This is, of course, not to say that asbestos exposure does not lead to reduction of VC, and consequently of FEV_1, but merely indicates that the number of asbestos workers affected in this way is so small that, when the data are treated as a whole, this effect remains undetected.

The consequence of different degrees of exposure was investigated by two methods —each of which is complimentary and gave very similar results. In the first instance regression equations of type (1), (2), and (3) were obtained for each of the five exposure sub-groups and an analysis of variance used to compare the equations obtained for each of these five sub-groups. The analysis of variance technique was also used to determine how much better the use of both A and H was in predicting VC. This method was the same as that used in the preceding section.

Equation (3) gave a significantly better fit than did either type (1) or type (2). The equations obtained for the five exposure groups were

$$\left.\begin{aligned}
&\text{Group 1: VC(ml BTS)} = -6141{\cdot}78 - 19{\cdot}20A + 66{\cdot}19H\\
&\text{Group 2: VC(ml BTS)} = -6910{\cdot}44 - 26{\cdot}17A + 72{\cdot}08H\\
&\text{Group 3: VC(ml BTS)} = -4879{\cdot}43 - 23{\cdot}87A + 59{\cdot}17H\\
&\text{Group 4: VC(ml BTS)} = -3549{\cdot}50 - 25{\cdot}51A + 51{\cdot}63H\\
&\text{Group 5: VC(ml BTS)} = -2022{\cdot}41 - 29{\cdot}42A + 42{\cdot}77\text{H}
\end{aligned}\right\}. \tag{8}$$

The analysis of variance indicated the positions of these regressions were significantly different, as were the regression coefficients. The partial regression coefficients

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of VC on age suggested strongly a linear relationship with exposure number, as did those with height. When the partial regression coefficients of VC on age were regressed against exposure group number, the change in partial regression coefficient with change in exposure group was −1·98 (this can be compared with −2·10 found by the next method). In the case of the partial regression coefficients on height the change was −6·73 (this can be compared with −5·16 found by the next method).

In the second method, and following the indication of linearity with exposure grouping, the consequence of different degrees of exposure was investigated by including exposure as an independent variable in the regression equation and considering an equation of the type

$$\mathrm{VC} = \alpha' + \beta' A + \gamma' H + \delta' E \tag{9}$$

where β' is a function of the type

$$\beta' = \beta'' + K'E. \tag{10}$$

Equation (9) then may be rewritten

$$\mathrm{VC} = \alpha' + \beta'' A + K' (AE) + \gamma' H + \delta' E$$

or more simply as

$$\mathrm{VC} = \alpha_4 + \beta_4 A + \lambda_4 (AE) + \gamma_4 H + \delta_4 E. \tag{11}$$

While the partial regression coefficient with age in the set of equations (8) strongly sugggested a linear relationship, various functions (linear and non-linear) were used in equation (10). However, the linear function (10) which results in equation (11) gave a λ_4 which was highly significant. The additional reduction in residual variation by using (AE) and E in the equation was also highly significant. This reduction was greater than in any other function which was considered.

The regression equation obtained was

$$\mathrm{VC(ml\ BTS)} = -5659{\cdot}5 - 19{\cdot}02A + 63{\cdot}68H + 28{\cdot}26E - 2{\cdot}10(AE) \quad (\mathrm{S.D.} = 580{\cdot}5) \tag{12}$$

This regression equation (12) has a partial regression coefficient on (AE) of −2·10 which compares closely with −1·98 found in the first method.

Equation (12) might be considered unsatisfactory since the partial coefficient on H is 63·68 and remains the same irrespective of the degree of exposure. This is in contrast with the earlier suggestion that the coefficient was linearly related to exposure group.

The analysis was next extended by considering equation (9) where γ' was a function of the type

$$\gamma' = \gamma'' + K'E \tag{13}$$

and rewriting equation (9) as

$$\mathrm{VC} = \alpha_5 + \beta_5 A + \gamma_5 H + \Delta_5 (HE) + \delta_5 E. \tag{14}$$

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The regression equation obtained was

$$\text{VC(ml BTS)} = -7531{\cdot}2 - 23{\cdot}62A + 75{\cdot}64H + 824{\cdot}53E - 5{\cdot}16(HE) \quad (\text{S.D.} = 579{\cdot}2). \tag{15}$$

This regression equation (15) has a partial regression coefficient on (HE) of $-5{\cdot}16$ which compares with $-6{\cdot}73$ found in the first method.

Both equations (12) and (15) are unsatisfactory since the first method suggests that both the partial regression on A and H vary linearly with exposure group. Thus equation (9) was developed using both equations (10) and (13) and a regression equation of the type (16) was fitted.

$$\text{VC} = \alpha_6 + \beta_6 A + \gamma_6 H + \lambda_6(AE) + \Delta_6(HE) + \delta_6 E. \tag{16}$$

The fitted equation was

$$\text{VC(ml BTS)} = -7878{\cdot}2 - 17{\cdot}88A + 76{\cdot}37H - 2{\cdot}59(AE) - 5{\cdot}56(HE) + 1000{\cdot}47E \quad (\text{S.D.} = 578{\cdot}7) \tag{17}$$

which when

$$\left.\begin{aligned} E = 1 \text{ becomes VC(ml BTS)} &= -6877{\cdot}73 - 20{\cdot}47A + 70{\cdot}81H \\ E = 2 \text{ becomes VC(ml BTS)} &= -5877{\cdot}26 - 23{\cdot}06A + 65{\cdot}25H \\ E = 3 \text{ becomes VC(ml BTS)} &= -4876{\cdot}79 - 25{\cdot}65A + 59{\cdot}69H \\ E = 4 \text{ becomes VC(ml BTS)} &= -3876{\cdot}32 - 28{\cdot}24A + 54{\cdot}13H \\ E = 5 \text{ becomes VC(ml BTS)} &= -2875{\cdot}85 - 30{\cdot}83A + 48{\cdot}57H \end{aligned}\right\}. \tag{18}$$

This series of planes, equations (18), after being reduced to a series of lines by substituting H equal to 170 cm (a figure conveniently close to the observed mean of 171·9 cm), is represented in Fig. 1. This series of lines demonstrates clearly the effect

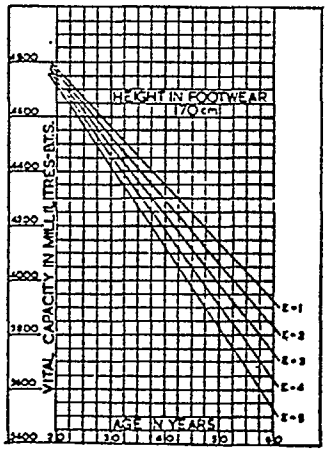

FIG. 1. Asbestos workers. The effect of increasing exposure on the loss of vital capacity with increasing age.

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of differing degrees of asbestos exposure. Other series of lines could be obtained by substituting different values for H in equation (18), or alternatively by plotting VC against H for differing values of A.

Because, in general, the older the man the lengthier and thus the greater his exposure, the differences among categories indicated in equations (18) and Fig. 1 are in part a reflection of differences in age. The effect of increasing asbestos exposure has been in part confounded with age. However, since there are significant age/exposure and height/exposure interactions, no attempt to adjust VCs to a common age-height is made.

A similar study of FEV_1 gave the following equations for the five exposure groups:

$$\left.\begin{aligned}
&\text{Group 1: } FEV_1(\text{ml BTS}) = -3580{\cdot}84 - 36{\cdot}03A + 49{\cdot}03H\\
&\text{Group 2: } FEV_1(\text{ml BTS}) = -4439{\cdot}14 - 36{\cdot}22A + 54{\cdot}38H\\
&\text{Group 3: } FEV_1(\text{ml BTS}) = -2971{\cdot}36 - 27{\cdot}91A + 43{\cdot}04H\\
&\text{Group 4: } FEV_1(\text{ml BTS}) = -2085{\cdot}75 - 30{\cdot}03A + 38{\cdot}11H\\
&\text{Group 5: } FEV_1(\text{ml BTS}) = -\ 808{\cdot}72 - 38{\cdot}09A + 32{\cdot}32H
\end{aligned}\right\}. \qquad (19)$$

These equations, in contrast with the set (8), showed no consistent trend between the partial regression coefficients of FEV_1 on age and exposure number. However the partial regression coefficients of FEV_1 on height suggested, as in the case of VC a strong linear relationship with exposure number. The change in partial regression coefficient with change in exposure number was −4·97 which can be compared with −4·26 found by the second method.

The fitted equation, excluding the (AE) term, by the second method was

$$FEV_1(\text{ml BTS}) = -4996{\cdot}9 - 33{\cdot}43A + 57{\cdot}30H - 4{\cdot}26(HE) + 679{\cdot}02E \qquad (\text{S.D.} = 519{\cdot}3) \qquad (20)$$

$$\left.\begin{aligned}
&E = 1 \text{ becomes } FEV_1(\text{ml BTS}) = -4317{\cdot}9 - 33{\cdot}43A + 53{\cdot}04H\\
&E = 2 \text{ becomes } FEV_1(\text{ml BTS}) = -3638{\cdot}9 - 33{\cdot}43A + 48{\cdot}78H\\
&E = 3 \text{ becomes } FEV_1(\text{ml BTS}) = -2959{\cdot}8 - 33{\cdot}43A + 44{\cdot}52H\\
&E = 4 \text{ becomes } FEV_1(\text{ml BTS}) = -2280{\cdot}8 - 33{\cdot}43A + 40{\cdot}26H\\
&E = 5 \text{ becomes } FEV_1(\text{ml BTS}) = -1601{\cdot}8 - 33{\cdot}43A + 36{\cdot}00H
\end{aligned}\right\}. \qquad (21)$$

The inconsistency between the relationships of A, H and E with VC and those with FEV_1 probably comes about because FEV_1, much more than VC, is affected by factors other than asbestos exposure.

CONCLUSION

We have studied the effects of asbestos exposure on nearly one thousand men engaged in the manufacture of asbestos-cement products and have shown that exposure has a considerable influence on the relationship between age, height, VC and FEV_1.

It had been hoped that by comparing the observed decline in an asbestos worker's VC, as he was examined over the years, and, by comparing this with the slope of our minimally-exposed subjects, to detect any adverse effect of asbestos exposure before

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radiological abnormality had appeared. There are statistical difficulties (intra- and inter-group regressions) in doing this but these have become irrelevant in view of the practical difficulties which have subsequently become apparent. As the Company's employees have undergone regular spirometric examination since the data here reported were collected a majority has become unwilling to perform properly the apparently simple spirometric manoeuvres required despite the fact that the whole purpose of asking them to perform them was to protect their health. It would be wrong to conclude that these men are exhibiting any peculiar indifference or irresponsibility. The two manoeuvres do, in fact, require substantial effort—as it requires substantial effort to cease smoking or to abandon an ill-advised diet. In short, if we may be forgiven a truism, the men we have studied are no more than a part of the society of which they are part.

More sensitive and more acceptable methods of examination must be devised.

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