Fire Fighting and Pulmonary Function

An Epidemiologic Study[1, 2]

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SUMMARY

To determine the effects of exposure to combustion products, 1,768 Boston fire fighters were studied from 1970 to 1971. The majority of fire fighters experienced increased mucus production and a general malaise after such exposures. Requiring oxygen at fires, being overcome, and smoke inhalation were reported with lesser but still significant frequency.

Analysis of the pulmonary function data indicated that lower ventilatory capacity was related to some occupational factors. Cigarette smoking was also important. Prolonged mucus secretion after occupational exposures was associated with lower lung function. Cigarette smoking was also strongly associated with this symptom. The daily exposure indicators were often associated with larger ventilatory capacity. This might have been due in part to self-selection by fire fighters; only healthy firemen can fight fires.

As expected, cigarette smoking was associated with a lower forced vital capacity and forced expiratory volume in 1 second. The latter volume was larger in ex-cigarette smokers than in current smokers, but was less than that of the never-smoker.

Information is presented to suggest that the occupational effect of fire fighting on the lung is underestimated by a cross-sectional study.

Introduction

Although the fire fighter's occupational exposures to combustion products can be severe, the chronic respiratory effects of his work have not been systematically studied. Therefore, an epidemiologic study of fire fighters in Boston was conducted to determine the association between fire fighting and chronic pulmonary abnormalities. This paper reports the relationship of occupational factors to abnormalities of pulmonary function in fire fighters.

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Materials and Methods

The population for study and the information collected were described in a previous paper (1). Past fire fighting exposure was assessed by asking several questions relating to severity of exposure (table 1). "Pasting" or "shellacking," referred to in Question 3 of table 1, are the words fire fighters use to describe the malaise that may persist 24 hours or longer after a severe fire exposure. The objective cough, described by Gan-

TABLE 1

QUESTIONS RELATING TO OCCUPATIONAL FACTORS

1. Do you ever cough up black sputum (black lungers) after a fire?
   If yes, complete the data below:
   Usually for 0–4 hours after a fire _____
   About how many times during the past year? _____
   For up to 4–12 hours after a fire _____
   About how many times during the past year? _____
   For more than 12 hours after a fire _____
   About how many times during the past year? _____
2. Have you ever taken oxygen at a fire?
   If yes, how many times did you take oxygen during the past year? _____
3. Have you ever received a real shellacking or pasting?
   If yes, approximately how many times in your fire fighting career? _____
   How many times in the past year? _____
4. Have you ever been overcome or knocked out in a fire?
   If yes, how many times in your fire fighting career? _____
   How many times during the past year?
5. Have you ever gone to the hospital for smoke inhalation? or for any other reason?
   If yes, complete the data below:
   Date of incident, Diagnosis, Were you hospitalized, Length of hospital stay, Total time off Duty.

devia (2), was evaluated. The participant was asked to cough, this being judged by ear as "dry" or "loose."

Forced vital capacity (FVC) and 1-second forced expiratory volume (FEV_1) were measured on a Stead-Wells spirometer using a paper speed of 32 mm per sec. The FEV_1 was measured after extrapolating the steepest part of the curve to the baseline and using this point as time zero.

The subject performed 3 satisfactory trials while standing, without a nose clip. Any trial judged to be unsatisfactory because of poor coordination, decreased performance, or poor cooperation, was rejected at the time of the test. The average of the 3 trials was taken as the maximum value. All results were corrected to body temperature and pressure, saturated with water (BTPS). Height was measured with the subject in stocking feet; weights were obtained by inquiry.

Much of the data were analyzed with step-up multiple regression. This method tests for an association between a dependent and several independent variables (3). Independent variables were chosen 1 at a time in the order of their ability to explain the variance of the dependent variable. This ordering sequence continued until the addition of a new variable no longer made a statistically significant contribution to the regression in the presence of those previously selected. Those independent variables that did not make a statistically significant contribution were eliminated from the final regression equation.

TABLE 2

MEAN HEIGHT, WEIGHT AND PULMONARY FUNCTION BY AGE CATEGORY OF BOSTON FIRE FIGHTERS

Age Group (years)	Mean Height (cm)	Mean Weight (kg)	FVC (liter)		FEV_1 (liter)		No.
			Mean	SE	Mean	SE	
21–24	174.0	78.1	4.94	0.089	4.24	0.072	54
25–34	175.3	81.1	4.94	0.035	4.11	0.029	329
35–44	173.9	82.0	4.56	0.039	3.67	0.032	361
45–54	173.5	82.3	4.25	0.025	3.33	0.021	783
55+	171.4	80.8	3.89	0.038	3.01	0.036	241
Total	173.7	81.9	4.41	0.018	3.53	0.016	1,768

TABLE 3

REGRESSION MODELS FOR VENTILATORY CAPACITIES APPLIED TO BOSTON FIRE FIGHTER STUDY DATA*

	SE	Multiple Correlation Coefficient
Linear Model: V† = a + b (age) and c (height)		
FVC = −4.04074 − 0.02020 (age) + 0.05608 (height)	0.564	0.667
FEV_1 = −1.71920 − 0.03414 (age) + 0.03887 (height)	0.506	0.671
Polynomial Model: V = a + b $(age)^2$ + c $(age)^3$ + d (age X height) + e (height) + f $(height)^2$		
FVC = −8.63948 + 0.7542 (age) − 0.00060 (age X height) + 0.08257 (height)	0.563	0.669
FEV_1 = −6.56946 + 0.07619 (age) − 0.00064 (age X height) + 0.06681 (height)	0.504	0.674
Logarithmic Model: $\log_{10}$ V = a + b (age) + c $(age)^2$ + d $(age)^3$ + e (age X height) + f (height) + g $\log_{10}$ (height)		
$\log_{10}$ FVC = −4.81765 − 1.69 X 10^{-5} (age X height) + 2.49395 $\log_{10}$ (height)	0.057	0.657
$\log_{10}$ FEV_1 = −3.54217 − 0.00430 (age) + 1.90687 $\log_{10}$ (height)	0.068	0.641

*All variables included in the regression equations are significant at $P \leq 0.05$.
†V = FVC or FEV_1, in liters.

Results

The mean values of FVC and FEV_1 are presented by age group in table 2, together with the mean heights and weights. The expected decrease with age in both FVC and FEV_1 was seen.

Ventilatory capacity is known to be a function of height and age, the relationship being best expressed by the "best fit" multiple regression equations. Linear, polynomial, and logarithmic regression models were assessed to determine which best described the data (4). The resulting regression equations are given in table 3.

The 3 models gave essentially the same multiple correlation coefficient, indicating that they had comparable ability to explain the relationship of ventilatory capacity to age and height. Since the linear model is more widely found in the literature, it was retained for the study.

The ventilatory capacity of never-smokers in the Boston fire department, while consistently lower in all age categories, was not

TABLE 4

PER CENT OF PREDICTED VENTILATORY CAPACITY OF BOSTON FIRE FIGHTERS BY SMOKING GROUP*

Category of Subjects	FVC % of Predicted	FVC SE	FEV_1 % of Predicted	FEV_1 SE	No.
Total population	99.2	0.31	95.1	0.34	1,768
Never-smokers	100.0	0.75	100.0	0.70	291
Smokers					
Ex-cigarette	101.1	0.62	97.1†	0.73	371
Ex-mixed	102.1†	3.07	98.9	3.69	59
Ex-pipe/cigar	99.6	1.53	98.5†	1.88	22
Current cigarette	97.6†	0.47	91.5†	0.50	787
Current pipe/cigar	100.0	1.20	99.5	1.28	99
Current mixed	98.8†	1.78	94.1†	1.36	44
Ex-cigarette — current pipe/cigar	99.9	1.39	95.8	1.43	95

*Expected values based on regression equations for never-smokers.
†Significantly different from never-smokers, $P < 0.05$ by Dunnett's t-test (6).

statistically different from that of other never-smokers (5). Smoking was significantly associated with reduced ventilatory capacity. Percentages of the observed FEV_1 or FVC to the expected value for the several smoking groups is presented in table 4. The expected values were derived from the regression equations of never-smoking fire fighters. This method of data presentation allowed standardization of ventilatory capacity for both age and height so a direct comparison between different smoking groups could be made. As expected, the difference in predicted values of smokers was greater for FEV_1 than FVC.

Current cigarette smokers had the greatest deviation from predicted FEV_1 with results 8.5 per cent lower than that of never-smokers. Those who had a mixed smoking habit or were ex-cigarette smokers who smoked pipes or cigars had the next lowest FEV_1. Fire fighters who smoke only pipes or cigars had essentially the same capacity as never-smokers. The FEV_1 of the ex-cigarette smokers were larger than those of current smokers, but were significantly lower than the never-smokers ($P < 0.05$; t-test).

Occupational factors and ventilatory capacity: Multiple regression analysis was carried out with ventilatory capacity as the dependent variable and age, height, fire exposure indicators, and cigarette smoking as the independent variables. Cigarette smoking factors were introduced since they were co-variables to some of the exposure indicators. The resulting regression equations are given in table 5.

The equations revealed an apparent paradox. An increased total number of "lungers" coughed up during the past year was associated with a larger FVC. Similarly, the large number of "pastings" taken during the past year was associated with a larger FEV_1, and the greater number of years spent on fire duty were associated with a larger FEV_1/FVC. It appeared that those with more adverse fire exposure had a larger ventilatory capacity and, therefore, were apparently healthier.

This paradox can be explained by a selection process among fire fighters. The healthier ones stay on active fire fighting duty, whereas the less healthy seek less active duty or migrate to support functions. For FEV_1 the regression equation showed that the number of years in support functions has a negative coefficient, an indication of this migration. A higher prevalence of chronic nonspecific respiratory disease (CNSRD) was also noted in those not actively fighting fires.

None of the indicators of acute fire episodes, such as being overcome, requiring oxygen, or being hospitalized for smoke inhala-

TABLE 5

MULTIPLE CORRELATION OF VENTILATORY CAPACITY WITH OCCUPATIONAL AND SMOKING VARIABLES – TOTAL BOSTON FIRE DEPARTMENT POPULATION

N = 1,756

FVC = −3.754 + 0.056 (height) − 0.030 (age) − 0.040 (cigarettes/day*) + 0.088 (log of total lungers) − 0.140 (cough blood)
Multiple Correlation Coefficient = 0.674 SD of residual = 0.557

FEV_1 = −1.807 − 0.031 (age) + 0.040 (height) − 0.005 (years smoked) − 0.041 (cigarettes/day) + 0.100 (log of pastings in year) − 0.00001 (life pack) − 0.011 (years non fire duty) − 0.007 (no. of lungers for > 12 hours)
Multiple Correlation Coefficient = 0.718 SD of residual = 0.476

FEV_1/FVC in % = 115.552 − 0.178 (years smoked) − 0.264 (age) − 0.125 (height) − 0.280 (cigarettes/day) + 0.103 (years fire duty) − 2.173 (log of no. of lungers > 12 hours)
Multiple Correlation Coefficient = 0.462 SD of residual = 0.870

*Cigarettes/day in coded form: None = 1; 1–4 cigarettes = 2; 5–14 cigarettes = 3; 15–24 cigarettes = 4; 25–34 cigarettes = 5; 35–44 cigarettes = 6; ⩾ 45 cigarettes = 7.

tion, were associated with lower lung function. This suggested that while such incidents may result in acute distress, the lung may be able to recover from these episodes. The indicators of daily exposure, "lungers" and "pastings," were not associated with decreased lung function.

Occupational exposure versus cigarette exposure: Cigarette smoking made expected contributions to the regression equations (table 5). Current rate of consumption was associated with both lower FEV_1 and FVC. Years smoked was associated with lower FEV_1 and FEV_1/FVC, and lifetime packs with lower FEV_1.

The relative effects of cigarette smoking and occupational factors can be illustrated by an example. For this we chose a fire fighter who smoked a pack a day for 25 years, spent 25 years on the force (all fighting fires), and in the past year had taken 15 "pastings" and brought up "lungers" 10 times for durations lasting 12 or more hours. When these factors are applied to the regression equations, the cigarette smoking factor results in an FEV_1 that is 0.365 liter lower than that of a non-smoker, whereas the occupational factor results in an FEV_1 that is 0.052 liter lower than that of a non-exposed individual. However, because of the selection factors, cross-sectional data probably underestimate the occupational effects.

Fire fighters of Irish extraction had smaller lungs than those of Italian lineage (7). The regression analysis for men of Irish extraction only (the majority of our population) was therefore repeated. No significant changes occurred in the results. The years spent in support functions were negatively associated with FVC but not FEV_1. None of the exposure variables made a significant contribution to the regression equation for FEV_1/FVC.

The analyses were also repeated for each of the cigarette smoking sub-groups, and a negative association was noted between bringing up "lungers" for more than 12 hours and the ventilatory capacity of ex-cigarette smokers. No such association was found for never-smokers. This suggested that cigarette smoking was primarily responsible for an increase in smoke clearance time.

Objective cough: Objective cough was a better predictor of lower ventilatory capacity than history of cough or sputum obtained by questionnaire. Those with loose cough had a mean FEV_1 7.7 per cent lower than those with a dry cough ($P < 0.001$) (table 6). The mean FVC was 3.8 per cent lower in those with a loose cough ($P < 0.001$), compared to those with a dry cough. The ventilatory capacity in fire fighters with a loose cough was lower than in those who admitted cough or phlegm production for at least 3 months of the year.

There was a strong association between

TABLE 6

VENTILATORY CAPACITY OF FIRE FIGHTERS BY OBJECTIVE COUGH AND RESPIRATORY SYMPTOMS

	FVC (% predicted*)		FEV_1 (% predicted*)		
	Mean	SE	Mean	SE	No.
Objective cough					
Dry	100.7	.33	101.5	.37	1,441
Loose	96.9	.78	93.8	.89	326
Cough for 3 months					
No	100.6	.43	101.5	.39	1,379
Yes	97.8	.66	94.7	.77	389
Phlegm for 3 months					
No	100.6	.35	101.1	.39	1,384
Yes	98.0	.69	96.1	.78	384

*Predicted values based on prediction equations generated from entire study population data.

TABLE 7

DISTRIBUTION OF FIRE FIGHTERS IN PER CENT ACCORDING TO PREVALENCE OF OBJECTIVE COUGH WITHIN SMOKING CATEGORIES

		Current Cigarette Consumption (cigarettes/day)					
		0	1–14	15–24	25–34	35+	No.
Objective cough	No	92.6	78.7	73.7	68.1	59.7	1,441
	Yes	7.4	21.3	26.3	31.9	40.3	326
Total no.		940	94	312	185	236	1,767

Chi square test for linear trend:
Due to regression: $\chi^2 = 183$; DF = 1; $P < 0.01$
Due to deviation: $\chi^2 = 2.7$; DF = 3; $P < 0.25$

objective cough and cigarette smoking (table 7). Men who smoked 2 or more packs a day had a six-fold higher rate of loose cough than non-smokers. Fire fighters with a loose cough tended to have more incidents of oxygen usage, hemoptysis, "lungers," prolonged clearance time for "lungers," and being overcome. These associations were statistically significant.

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References

1. Sidor, R., and Peters, J. M.: Prevalence rates of chronic non-specific respiratory disease in fire fighters, Amer. Rev. Resp. Dis., 1974, *109*,
2. Gandevia, B., and Milne, J.: Ventilatory capacity on exposure to jute dust and the relevance of productive cough and smoking to the response, Brit. J. Industr. Med., 1965, *22*, 187.
3. Johnson, J.: Econometric Methods, McGraw-Hill, New York, 1963.
4. Discher, D. P., and Steinborn, J.: LS/MFT: Lung screening by meaningful function testing—part II, Amer. J. Public Health, 1970, *60*, 2361.
5. Morris, J. F., Koski, A., and Johnson, L. C.: Spirometric standards for healthy non-smoking adults, Amer. Rev. Resp. Dis., 1971, *103*, 57.
6. Li, C. C.; Introduction to Experimental Statistics, McGraw-Hill, New York, 1964, p. 418.
7. Sidor, R., and Peters, J. M.: Differences in ventilatory capacity of Irish and Italian fire fighters, Amer. Rev. Resp. Dis., 1973, *108*, 669.