Final Performance Report

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Evidence Based Medical Examinations for Firefighters

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Abstract

Our study evolved from an investigation of medical surveillance for one of six Massachusetts hazardous materials teams from 1993 – 1995. The principal investigator later received a special emphasis research-career award (1996-1999) from NIOSH to investigate incident and medical surveillance in firefighters and the program included all six hazardous materials teams of Massachusetts. The current award (1998-2002) was designed to focus on medical examinations and had the following specific aims: (1) To evaluate the ability of objective fitness guidelines, and baseline health ratings to predict increased risks of injury, cardiac events or other adverse outcomes. (2) To evaluate whether firefighters with abnormal hearing are at increased risk for injury or other adverse outcome. (3) To examine the clinical utility of various examination components among firefighters. (4) To help develop evidence-based medical evaluations for firefighters. In the past five years, the firefighters have been followed on an annual basis and a computerized state repository has been maintained with data on physical examinations of firefighters and other tests including various blood tests, vision and hearing tests and electrocardiograms.

Several research projects were completed using the available information. Nine peer-reviewed articles have been published in scientific journals, and several national and regional invited presentations were given from the current award. A number of evidence-based improvements in firefighter medical evaluations have been identified. We found that significant exposures and injuries identified by medical surveillance during hazardous materials duty are infrequent and the use of biochemical testing is of limited utility, and the frequency of this testing may be reduced. With regards to respiratory exposures, we found that the hazardous materials technicians do not appear to lose pulmonary function at a faster rate than regular firefighter.

One other important consideration is the evaluation of fitness for duty in firefighters with blood pressure readings >/=160/100 mm Hg. Our research suggests that firefighters with high blood pressure readings should receive further evaluation and demonstrate improved blood pressure control prior to receiving medical clearance as "fit for duty." With respect to myocardial infarctions, the 10-year estimated CHD risk of fire fighters is similar to the general population and increases with age. Extrapolation from general population paradigms, risk assessment and stratification, previous studies and a case-control analysis of on-duty CHD fatalities, all suggest similar risk profiles for those at elevated risk for cardiovascular disease. Our research supports that medical screening could have an important impact on reducing fire fighters' risk for adverse outcomes.

Project History

Our study evolved from an investigation of medical surveillance for one of six Massachusetts hazardous materials teams from 1993 - 1995 supported by an award from the Agency for Toxic Substances and Disease Registry (ATSDR). In 1996, the surveillance program became statewide by incorporating the other five regional hazardous materials teams in Massachusetts, and the principal investigator received a special emphasis research-career award to investigate incident and medical surveillance (1996-1999). The present award was received in 1998 to more closely examine the medical evaluation process for firefighters. Although our cohort of firefighters are examined under the OSHA hazardous waste standard, the members are all municipal firefighters whose primary occupational activities were regular duty firefighting for various Massachusetts communities. A much smaller percentage of their time is spent as independent contractors working with the state's regional hazardous materials teams.

In the past five years, the firefighters have been followed and a computerized state repository has been maintained with data on annual physical examinations of firefighters and other tests including various blood tests, vision and hearing tests and electrocardiograms. Using this data, we completed and published peer-reviewed studies on most of the major medical issues facing firefighters: pulmonary function, hearing loss, obesity, fitness for duty, cardiovascular disease and risk factors and hazardous materials surveillance under the OSHA standard.

Specific Aims

Briefly, the project's aims are described below:

(1) To evaluate the ability of objective fitness guidelines, and baseline health ratings to predict increased risks of injury, cardiac events or other adverse outcomes.

(2) To evaluate whether firefighters with abnormal hearing are at increased risk for injury or other adverse outcome.

(3) To examine the clinical utility of various examination components among firefighters.

(4) To help develop evidence-based medical evaluations for firefighters.

Significant findings / Usefulness of findings

The present research award helped develop a number of evidence-based improvements in firefighter medical evaluations. We found that significant exposures and injuries identified by medical surveillance during hazardous materials duty are infrequent and the use of biochemical testing is of limited utility. The end-organ effect markers commonly used for firefighters and hazardous materials handlers have low sensitivity and low specificity for duty-related effects and therefore the frequency of this testing may be reduced.

With regards to respiratory exposures, which are the most common in hazardous materials releases, we found that the hazardous materials technicians do not appear to lose pulmonary function at a faster rate than regular firefighters. The short period of follow-up, the small excess decline in FEV1 for the entire cohort, and others' consistent findings of acute effects from smoke exposure are strong reasons to continue spirometric testing. Furthermore, the circumstances under which asthma and other pulmonary conditions become disqualifying conditions for active fire fighters remain controversial.

One other important consideration is the evaluation of fitness for duty in firefighters with blood pressure readings greater than 160/100 mm Hg. Our research suggests that firefighters with high blood pressure readings should receive further evaluation and demonstrate improved blood pressure control prior to receiving medical clearance as "fit for duty."

With respect to myocardial infarctions, the 10-year estimated CHD risk of fire fighters is similar to the general population and increases with age. Extrapolation from general population paradigms, risk assessment and stratification, previous studies and a case-control analysis of on-duty CHD fatalities, all suggest similar risk profiles for those at elevated risk for cardiovascular disease. We have also found that most firefighters with hypertension and dyslipidemias are not receiving treatment. Our research supports that medical screening could have an important impact in reducing firefighters' risk for adverse outcomes.

Relevance of publications to the aims of the project

<u>Aims 1 and 3</u>

Correlates of body mass index among hazardous materials firefighters. *J Occup Env Med 1999;41: 589-595*

Excess body weight is a major health problem. We analyzed the relationships between body mass index (BMI) and other parameters in 340 firefighters. Heights and weights were available for 98% of the subjects (333/340). The mean BMI was 28.9 +/- 4.1 kg/m^2. Eighty seven percent were overweight (BMI >/=25) and 34% were obese (BMI >/=30). Two percent were morbidly obese (BMI >/= 39). For comparison purposes, we divided subjects into three groups of low BMI <27, medium BMI 27 to <30, and high BMI >/= 30. The results demonstrated adverse associations between increasing BMI and resting blood pressure, forced vital capacity (FVC), levels of alanine aminotransferase (ALT), and levels of aspartate aminotransferase (AST), serum cholesterol, and overall morbidity scores.

Table 6: Correlates of Body Mass Index

VARIABLE	LOW BMI <27	MEDIUM BMI 27-<30	HIGH BMI >/=30	ANOVA P
AGE	38 +/- 6 n = 100	40 +/- 7 n = 108	40 +/- 7 n = 107	<0.05
SBP	119 +/- 13 n = 106	123 +/- 13 n = 114	125 +/- 13 n = 113	< 0.005
DBP	77 +/- 9 n = 106	79 +/- 9 n = 114	80 +/- 9 n = 113	< 0.05
FVC %	105 +/- 13 n = 104	104 +/- 13 n = 112	100 +/- 13 n = 111	< 0.05
FEV1 %	103 +/- 14 n = 104	104 +/- 14 n = 112	102 +/- 14 n = 111	n.s.
ALKPHOS	82 +/- 22 n = 103	81 +/- 22 n = 113	85 +/- 22 n= 113	n.s.
CHOL	219 +/- 39 n= 57	224 +/- 39 n= 69	242 +/- 39 n= 62	< 0.005
BUN	15 +/- 4 n= 105	16 +/- 4 n= 114	16 +/- 4 n= 113	n.s.
CR	1.08 +/- 0.16 n= 105	1.13 +/- 0.16 n= 114	1.13 +/- 0.16 n= 113	< 0.05
AST	24 +/- 10 n= 104	24 +/- 10 n= 114	27 +/- 10 n= 112	< 0.05
ALT	31 +/- 20 n= 104	35 +/- 20 n= 114	43 +/- 20 n= 112	< 0.001
Morbidity Rating	3.2 +/- 1.3 n= 106	3.7 +/- 1.3 n= 114	4.2 +/- 1.3 n= 113	< 0.001

The cross-sectional results, strongly associated obesity with several adverse health effects. Recently, a study of municipal firefighters in Texas showed very similar health profiles and results. Those results strongly suggest that health data from the Massachusetts cohort of firefighters are generalizable to other firefighters. Further study is required to prospectively examine the effects of obesity on cardiac risk profiles, exercise tolerance, other stress test results, and employment consequences. Investigations of this kind are crucial as the obesity epidemic increases nationwide.

Aims 1, 3 and 4

Correlates of fitness for duty in hazardous materials firefighters. A*m J Ind Med 1999; 36: 618-629.*

From baseline examinations, we identified firefighters who were deemed "unfit" for duty by attending physicians (unfit for duty according to a physicians, n=9) and those who would have been disqualified by applying selected criteria from the 1997 National Fire Protection Association (NFPA) guidelines (Firefighters who failed by NFPA criteria, n=27) and criteria recommended by a medical Workshop (firefighters who failed by workshop criteria, n=16). The subjects who were "unfit" or failed numerical criteria were compared with firefighters found to be "fit for duty" and who passed all selected criteria (fit for duty group, n=302). All subjects also received an overall morbidity rating by a board-certified internist. We found a significant tendency towards worse results (e.g. higher blood pressure or lower spirometric function) among those firefighters who failed the NFPA or workshop criteria compared with the fit for duty group. The firefighters who failed the above criteria shared only a small overlap, however, with the firefighters with the highest morbidity ratings, lowest predicted exercise tolerance (VO_2 max), and highest coronary heart disease (CHD) risks.

Table 7: Surrogate measures of fitness for Fit versus Various Fail Groups

VARIABLE	FIT BY ALL N=302	NFPA FAIL N= 27	WORKSHOP FAIL N= 16	UNFIT PER MD N= 9
PREDICTED 10-YEAR CHD RISK	+/- 4.1% N= 138	9.3 +/- 4.6% N =15; p =0.063	8.0 +/- 3.1% N=6; p=0.393	Insufficient Data
PREDICTED VO_2 MAX	33 +/- 7 N=281	31 +/- 7 N= 24; P=0.217	28 +/- 6 N= 14; P=0.017	30 +/- 5 N=8; P=0.118

High morbidity scores were associated with advancing age, lower pulmonary function and predicted VO_2 max; and increasing cholesterol, BMI, and predicted coronary heart disease risk to a greater extent than being in a "Fail" group.

Table 8: Surrogate measures of fitness by morbidity ratings			
VARIABLE	Low Morbidity N=173	Moderate Morbidity N= 158	High Morbidity N= 9
PREDICTED 10-YEAR CHD RISK	5.3 +/- 2.6 % N=81	8.1 +/- 3.9 % N= 67; p = 0.000	16.3 +/- 6.2 % N=7; p = 0.003
PREDICTED VO_2 MAX	35 +/- 6 N= 160	31 +/- 7 N= 147; p=0.000	25 +/- 6 N= 9; p=0.001

Therefore, we showed that certain single-measure criteria may help select firefighters with more adverse risk profiles than average, but those same criteria were not sensitive for selecting those clinically rated as in worse health, nor those with the highest calculated coronary heart disease risks, nor the lowest predicted exercise tolerances. Table 9 shows the relationship between age and coronary heart disease risk, and compares the firefighters' to the Framingham population.

Table 9: Calculated CHD Risk and Age			
Age Group	N	Mean Predicted 10 Year CHD Risk	Average 10 Yr CHD Risk (Framingham Study)
< 30	6	3.0 +/- 0.9 %	NA
30-34	35	4.3 +/- 1.5 %	3 %
35-39	36	5.1 +/- 2.4 %	5 %
40-44	36	7.1 +/- 2.9 %	7 %
45-49	30	10.8 +/- 3.5 %	11 %
50-54	10	14.4 +/- 5.4 %	14 %
55-59	1	13.0	16 %
Total	154	7.1 +/- 4.2 %	NA

When the age-based NFPA guidelines for stress testing (age >/40 years old) were compared with the multivariate Framingham coronary heart disease risk prediction formula, the NFPA age-based guidelines were a sensitive selection tool for identifying firefighters above certain thresholds, but have the disadvantage of selecting a large proportion of firefighters for stress testing who did not have high coronary heart disease risks. Table 10 demonstrates the test characteristics of age >/40 years old as a selection criteria for firefighters with Five-year coronary heart disease risks >/=5%.

Table 10: Test characteristics for selecting five-year CHD risk >/=5%			
AGE	Five-Year CHD Risk >/=5%	Five-Year CHD Risk <5%	TOTALS
>/=40 years old	40	37	77 (50%)
<40 years old	2	75	77 (50%)
TOTALS	42 (27%)	112 (73%)	154 (100%)

Sensitivity=95% (40/42)
Specificity=67% (75/112)

Negative Predictive Value=97% (75/77)
Positive Predictive Value=52% (40/77)

Thus, this cross-sectional study demonstrated that distinct subjective and objective methods are all capable of stratifying firefighters' risk profiles to some degree. Yet, as Gochfeld observed in an accompanying editorial, further prospective study would be needed to determine which criteria of most predictive of adverse employment consequences. Moreover, in the case of cardiac fatalities, which account for about 45 annually for the entire U.S., other types of investigation would be required to study these relatively infrequent events.

Aims 1, 3 and 4

Firefighters' Blood Pressure and Employment Status in Hazardous Materials Teams in Massachusetts: A Prospective Study. ***J Occup and Environ Med 2002;44:669-676.***

Blood pressure control is a major criterion in the determination of fitness for duty for firefighters because uncontrolled hypertension may pose significant risks. We evaluated the association between hypertension and changes in employment status in 334 firefighters. Firefighters were categorized by blood pressure at baseline (1996/97) and subsequent examinations (1997, 1998 and 1999) and followed for up to four years. In several statistical models we found that firefighters with stage II hypertension (blood pressure ≥160/100 mm Hg) were consistently 2-3 times more likely to experience an adverse outcome compared to those with normal blood pressure. In multivariable-adjusted Cox proportional hazard regression models we found that the hazard ratio for stage II hypertension was 3.1 (95% CI, 1.47-6.60, p=0.003), and 4.6 (95% CI, 2.08-10.11, p=0.0002) for untreated stage II hypertension.

Table 11: Employment Status Changes between 1996-2000 per person-years of follow up in different blood pressure categories at each individual examination 1996-1999

Adverse Events in Events/100 Person-years	Person -years (PYRS)	Blood pressure categories (mm Hg) Normotensive Readings	Stage I Hypertension readings	Stage II or higher Readings	p*
All participants	1262	3.81	4.54	10.81	<0.05
On BP med excluded †	1186	3.68	4.48	14.81	<0.005
Excludes BMI<30 ‡	413	5.3	6.9	14.3	NS
BMI<30‡ or on BP med excluded†	376	5.3	8.1	21.4	<0.05

* Fisher's exact tests comparing adverse events in Stage II vs. normal and Stage I categories combined

† Excluding firefighters who were receiving an anti-hypertensive medication in 1996

‡ Excluding all firefighters with a body mass index less than 30

Table 12: Multivariable-adjusted Hazard Ratios and 95% CI for Hypertension and change in Employment Status in Hazardous Materials firefighters (N=334) *

	Hazard Ratios (95% CI)	p-value
Hypertension (model 1) ‡	**3.1 (1.47 - 6.60)**	**0.003**
Firefighters with BMI≥30	**3.0 (1.12 – 8.07)**	**0.03**
Firefighters with no medication use for BP	**4.3 (1.96 – 8.81)**	**0.0002**
Hypertension (model 2 – trend) ¶	**1.8 (1.26 - 2.67)**	**0.0014**
(Firefighters with BMI≥30)	**2.0 (1.19 - 3.26)**	**0.008**
(Firefighters with no medication use for BP)	**2.1 (1.44 - 4.14)**	**0.0001**
Hypertension (model 3) §		
Stage I hypertension	**0.9 (0.48 - 1.57)**	**0.6**
Stage II or higher	**3.2 (1.50 - 7.04)**	**0.003**
Firefighters with BMI≥30		
Stage I hypertension	**1.1 (0.52 - 2.30)**	**0.8**
Stage II or higher	**2.93 (1.06 – 8.09)**	**0.04**
Firefighters with no medication use for BP		
Stage I hypertension	**0.8 (0.40 - 1.50)**	**0.45**
Stage II or higher	**4.6 (2.08 – 10.11)**	**0.0002**

* Adjusted for age, smoking, total cholesterol, BMI and blood pressure medication use.

‡ Hypertension was defined as a dichotomous variable with <160/100 mm Hg as the reference category.

¶ Hypertension was defined as a three-category variable: normal blood pressure (BP<140/90 mm Hg), stage I hypertension (140/90≤BP<160/100 mm Hg) and stage II hypertension or higher (BP≥160/100 mm Hg). Hazard ratios represent risk for employment status change for every change from one category to the next.
§ Hypertension was defined as a three-category variable. Normal blood pressure (BP<140/90 mm Hg) was used as the reference category. Stage I hypertension (140/90≤BP<160/100 mm Hg) and stage II hypertension or higher (BP≥160/100mm Hg) was compared to the reference category to explore possible dose-response relationships.

Several consensus panels have proposed occupational blood pressure criteria. Lacking evidence from occupational cohorts, each agency reached different conclusions. Our study provides strong evidence that the most appropriate blood pressure guideline for firefighters is blood pressure < 160/100 mm Hg. In addition, we showed that two modifiable risk factors, obesity and untreated hypertension augmented the risk of adverse events. Firefighters who have high blood pressure should receive further evaluation and demonstrate improved blood pressure control prior to being determined fit for duty.

Aims 2 and 3

Firefighters' Hearing: A Comparison with Population Databases from the International Standards Organization. ***J Occup Env Med 2001;43:650-656.***

We investigated firefighters' hearing relative to the general population to adjust for age-expected losses. For groups of male firefighters with increasing mean ages, we compared hearing thresholds at the 50th and 90th percentiles with normative, age- and sex-matched data from the International Standards Organization (Databases A and B). At the 50th percentile, from a mean age of 28 to a mean of 53 years old, relative to databases A and B, the firefighters lost an excess of 19-23 dB, 20-23 dB, and 16-19 dB at 3000, 4000, and 6000 Hz, respectively. At the 90th percentile, from a mean age of 28 to a mean of 53 years old, relative to databases A and B, the firefighters lost an excess of 12-20 dB, 38-44 dB, 41-45 dB and 22-28 dB at 2000, 3000, 4000, and 6000 Hz, respectively. The results are consistent with hearing loss in excess of age-expected loss among the firefighters especially at or above the 90th percentile.

Table 4: Mean Hearing Thresholds in dB for the Firefighters by Age at the 50th and 90th Percentiles								
Age Group	**Mean Age +/- SD (N)**	**Percentile**	**500 Hz**	**1000 Hz**	**2000 Hz**	**3000 Hz**	**4000 Hz**	**6000 Hz**
20-30	**28 +/- 3 (33)**	50th	5	5	5	5	5	10
31-40	**36 +/- 3 (143)**	50th	5	5	5	5	10	15
41-45	**43 +/- 1 (76)**	50th	10	5	5	10	15	20
46-50	**48 +/- 1 (53)**	50th	10	5	10	15	21	25
>50	**53 +/- 2 (14)**	50th	5	10	10	40	45	48
20-30	**28 +/- 3 (33)**	90th	18	10	15	10	15	25
31-40	**36 +/- 3 (143)**	90th	15	15	15	25	32	40
41-45	**43 +/- 1 (76)**	90th	15	15	20	40	50	45
46-50	**48 +/- 1 (53)**	90th	22	15	20	45	50	50
>50	**53 +/- 2 (14)**	90th	16	16	46	72	82	76

Table 5: Excess threshold shift for Firefighters in dB HL from Age 28 to 53 Years Old versus General Population Databases							
Database	**Percentile**	**500 Hz**	**1000 Hz**	**2000 Hz**	**3000 Hz**	**4000 Hz**	**6000 Hz**
A	50th	-4	0	-2	23	23	19
B	50th	-4	0	-3	19	20	16
A	90th	-9	-1	20	44	41	22
B	90th	-8	-2	12	38	45	28

Longitudinal investigation is needed to examine the hypothesis suggested by our cross-sectional study that firefighters' experience accelerated hearing loss. Also, the 2000 NFPA medical standard states: "there are currently no hearing tests that will...accurately predict whether the firefighter will adequately be able to perform essential job duties." Therefore, additional studies are needed to determine whether those firefighters with advanced hearing loss are more prone to adverse employment and/or health consequences.

Aims 3 and 4

A Prospective Study of Hepatic, Renal, and Haematologic Surveillance In Hazardous Materials Firefighters. *Occup and Env Med 2001;58:87-94.*

We analyzed hepatic, renal, and hematologic testing from 1996-98 in 288 hazardous materials technicians (81%) and 68 support members (19%). We also analyzed the same end-organ markers in a subgroup of technicians (n=35) from 1993 to 1998. The support members are excellent controls because they are also municipal firefighters, but have low potential for hazardous materials exposure. During the study period, no significant injuries or exposures were reported. We found no significant, cross-sectional differences in any of the markers studied, between technicians and support members at either first or third year. Adjustment for a change in laboratory explained a small longitudinal decrease in platelets among technicians. Otherwise, we found no significant longitudinal changes except for serum creatinine (Cr), which decreased for both technicians ($p<0.001$) and controls ($p<0.01$).

Table 1: Paired, longitudinal comparisons for Hazmat technicians and support members:

Variable		Year 1 (1996-97)	Year 3 (1998)	P
Alk Phos (U/L)	Technicians (n=246)	83 +/- 21	83 +/- 20	0.721
	Support (n=53)	87 +/- 23	85 +/- 20	0.206
AST (U/L)	Technicians (n=245)	25 +/- 10	25 +/- 10	0.982
	Support (n=54)	24 +/- 10	26 +/- 9	0.273
ALT (U/L)	Technicians (n=245)	36 +/- 20	37 +/- 18	0.364
	Support (n=54)	38 +/- 23	39 +/- 18	0.646
BUN (mmol/L)	Technicians (n=247)	5.7 +/- 1.4	5.3 +/- 1.4	0.050
	Support (n=54)	5.3 +/- 1.4	5.7 +/- 1.4	0.324
Creatinine (μmol/L)	Technicians (n=247)	97 +/- 18	88 +/- 8.8	0.000
	Support (n=54)	97 +/- 18	88 +/- 18	0.005
WBC ($\times 10^9$ / L)	Technicians (n=245)	6.7 +/- 2.3	6.6 +/- 1.8	0.891
	Support (n=54)	6.6 +/- 1.3	6.7 +/- 1.5	0.635
HCT	Technicians (n=244)	0.45 +/- 0.02	0.46 +/- 0.03	0.332
	Support (n=54)	0.46 +/- 0.03	0.46 +/- 0.03	0.133
PLT ($\times 10^9$ / L)	Technicians (247)	240 +/- 52	232 +/- 54	0.000
	Support (n=54)	254 +/- 60	248 +/- 55	0.176

Duty-related health effects are infrequent among hazardous materials technicians and effects on biochemical markers were not seen. Our results are consistent with a previous study of one of the teams and a large investigation of hazardous waste workers. The results also suggest that current work practices and personal protective equipment are effective in protecting the firefighters. We concluded that the frequency of such testing could be reduced for most firefighters and others workers subject to the OSHA hazardous waste standard.

Aims 3 and 4

Spirometric Surveillance in Hazardous Materials Firefighters: Does Hazardous Materials Duty Affect Lung Function? *J Occup Env Med 2001;43:1114-1120.*

We analyzed spirometry from 351 male firefighters from 1996 to 1999: 276 (79%) technicians and 75 (21%) support members. Support members have limited potential for hazardous materials exposure and served as a comparison group. In cross-sectional comparisons, the technicians' average forced vital capacity (FVC) and forced expiratory volume in the first second (FEV1) were either statistically better or non-significantly different than that of the support members at all examinations.

Table 2: Spirometry; Technicians compared to Support Controls

Variable	YEAR	Technician	Support	P-Value (2-tailed)
FVC (% predicted)	1996-7	103 +/- 13 (n=263)	102 +/- 10 (n=66)	0.719
	1997	102 +/- 13 (n=169)	98 +/- 10 (n=40)	0.049
	1998	103 +/- 13 (n=261)	100 +/- 9 (n=60)	0.040
	1999	103 +/- 12 (n=249)	98 +/- 10 (n=52)	0.003
FEV1 (% predicted)	1996-7	102 +/- 13 (n=263)	103 +/- 12 (n=66)	0.998
	1997	103 +/- 13 (n=169)	102 +/- 12 (n=40)	0.661
	1998	101 +/- 14 (n=261)	98 +/- 13 (n=60)	0.165
	1999	100 +/- 13 (n=249)	96 +/- 14 (n=52)	0.041

Longitudinally, no significant differences were seen for FVC. The mean percent of predicted FEV1 fell by 3% for technicians (p=0.029), support controls (p=0.433) and the total cohort (p=0.014).

Table 3: Spirometric Values by Job Type (ANOVA time analyses)					
Job Type	**1996-97**	**1998**	**1999**	**Total**	**ANOVA p-value**
Technician FVC %pred	103 +/- 13 (n=225)	103 +/- 13 (n=226)	103 +/- 13 (n=228)	103 +/- 13 (n=679)	0.780
Support FVC %pred	100 +/- 10 (n=46)	99 +/- 9 (n=47)	98 +/- 10 (n=46)	99 +/- 10 (n=139)	0.568
Total FVC %pred	103 +/- 12 (n=271)	102 +/- 12 (n=273)	102 +/- 12 (n=274)	102 +/- 12 (n=818)	0.621
Technician FEV1 %pred	103 +/- 13 (n=225)	101 +/- 14 (n=226)	100+/- 13 (n=228)	101 +/- 14 (n=679)	0.029
Support FEV1 %pred	100 +/- 12 (n=46)	99 +/- 13 (n=47)	97 +/- 13 (n=46)	99 +/- 12 (n=139)	0.433
Total FEV1 %pred	103 +/- 13 (n=271)	100 +/- 14 (n=273)	100 +/- 13 (n=274)	101 +/- 13 (n=818)	0.014

Among unprotected victims, inhalation is the most common route of exposure due to hazardous materials releases, and pulmonary irritant exposure and respiratory complaints are the most common health effects. Therefore, group spirometry may provide physiologic measurement of safe work practices and personal protection. The preliminary results are reassuring, suggesting that technicians do not lose pulmonary function faster than control firefighters. Several factors support continued annual spirometry and longitudinal study: the relatively short follow-up period, the high prevalence of risk factors, such as asthma, associated with lower baseline pulmonary function, and the small excess decline in FEV1 for the entire cohort. Despite respiratory protection, acute adverse effects from smoke exposure have consistently been demonstrated. In addition, we found a slight excess of pulmonary risk factors among those lost to follow-up. Some authorities regard asthma as a condition that should exclude a firefighter from active duty, while others feel the contraindication is relative based on pulmonary function abnormalities or symptoms and medication use. None of these guidelines have been validated. Therefore, further study should include a longer period of follow-up as well as examine separately those firefighters with respiratory problems, such as asthma, or other individuals possibly susceptible to accelerated losses of pulmonary function.

Aim 4

The Lipid Profile of Hazardous Materials Firefighters Over Time: Opportunities for Prevention. *J Occup and Environ Med 2002;44:840-846.*

We examined the lipid profile of our firefighters over four years of follow up. The mean total cholesterol in 285 firefighters included in the follow-up analysis declined from 224 (+/-39) mg/dl at baseline examination (1996/97) to 214 (+/-36) mg/dl at follow-up in 2000 ($p<0.0001$). Conversely, both obesity (34% vs. 40%, p=0.008) and triglycerides ≥200 mg/dl (27% vs. 35%, p<0.047) increased significantly from 1996 to 2000. The proportion of firefighters taking lipid-lowering medications increased from 3 at baseline to 12% at follow-up (p<0.0001). Among firefighters with high total cholesterol (>/=240 mg/dl), high triglycerides (>/=200 mg/dl) and high LDL cholesterol (>/=160 mg/dl), however, only 22% were taking lipid-lowering medications at follow-up. Moreover, among firefighters with persistent high total cholesterol, only 15% were on lipid-lowering medications in 2000.

Since firefighters were notified in writing of their examination results each year, the decline in mean cholesterol and increased rates of lipid-lowering treatment over time suggest a small positive influence of the surveillance program. On the other hand, despite repeated examinations and recommendations to follow-up with their primary care physicians, most firefighters had persistently elevated cholesterol; obesity and increased triglycerides over time; and few were receiving adequate treatment. Thus, the study demonstrates that screening and referral did not result in adequate management of dyslipidemia in most cases.

<u>**Aims 1, 3 and 4**</u>

Firefighters and On-Duty Deaths from Coronary Heart Disease: A Case Control Study. (In preparation*)*

We performed a case-control study to evaluate recognized cardiovascular disease risk factors as predictors of coronary heart disease (CHD) fatalities. We compared on-duty CHD fatalities occurring (1997-2001) in firefighters across the United States with control firefighters from our cohort of Massachusetts's municipal firefighters. As cases, we included all male firefighters who died of coronary heart disease (N=45) that had been investigated by the NIOSH's Fire Fighter Fatality Investigation and Prevention Program from its inception through December 2001. As controls, we selected 310 male firefighters from our cohort who underwent baseline medical examinations in 1996/1997, and whose vital status and continued professional activity were re-documented in 1998. We analyzed the following cardiac risk factors: age >/= 45 years old, age > 50 years old, current smoking, diabetes, hypercholesterolemia, hypertension and prior diagnosis of CHD or other vaso-occlusive (arterial) disease. Odds ratios (OR) for all of the traditional risk factors were significantly associated with increased risk in unadjusted analyses.

Table 13: Characteristics of the study groups: CHD death and active firefighter controls.			
	CHD Death (n=45) % (n)	**Active Firefighters (n=310) % (n)**	**P-value**
Professional firefighters	**68.9 (31)**	**100 (310)**	**<0.001***
Age >/= 45 years old	**84 (38)**	**21 (64)**	**<0.001**
Age > 50 years old	**51 (23)**	**4 (14)**	**<0.001**
Current Smoking	**53 (19/36)**	**10 (31)**	**<0.001**
Hypertension	**77 (30/39**	**21 (65)**	**<0.001**
Diabetes Mellitus	**19 (7/36**	**3 (8)**	**<0.001***
Cholesterol ≥200 mg/dl	**85 (23/27**	**63 (196)**	**0.022**
Prior Diagnosis of CHD or other vaso-occlusive disease	**25 (11/44**	**1 (3)**	**<0.001***

* Fisher's Exact Test

Table 14: Unadjusted odds ratios for CHD risk factors: CHD deaths compared to controls.			
	OR (95% CI)		
	Model 1 All Cases and Controls *	**Model 2 Age <60 and no prior CHD diagnosis†**	**Model 3 Age 40-59 ‡**
Age >/= 45 years old	**20.9 (8.9 – 48.9)**	**13.8 (5.3 – 35.7)**	**7.3 (2.9 – 18.6)**
Age > 50 years old	**22.1 (10.0 – 48.8)**	**16.9 (6.5 – 44.2)**	**8.0 (3.4 – 18.5)**
Current Smoking	**10.0 (4.7 – 21.3)**	**18.5 (6.9 – 49.3)**	**11.4 (4.7 – 27.9)**
Hypertension	**12.6 (5.7 – 27.8)**	**25.0 (7.2 – 87.3)**	**9.7 (3.7 – 25.1)**
Cholesterol ≥200 mg/dl	**3.3 (1.1 – 9.9)**	**1.6 (0.5 – 5.1)**	**2.3 (0.7 – 7.0)**
Diabetes Mellitus	**9.0 (3.1 – 26.8)**	**4.7 (0.9 - 24.4)**	**5.3 (1.6 – 17.3)**
Prior Diagnosis of CHD or other vaso-occlusive disease	**34.1 (9.0 – 128.5)**	**-**	**21.0 (5.5 – 80.5)**

* Includes all cases (n=45) and all controls (n=310).

† Restricted to firefighters less than 60 years of age without a Prior Diagnosis of CHD or other evidence of vaso-occlusive disease. Cases (n=27) and controls (n=307)

‡ Restricted to firefighters between 40 to 59 years of age. Cases (n=38) and controls (n=152)

We found that age of >/=45 years, current smoking, hypertension, and a prior diagnosis of CHD remained strong independent predictors of coronary heart disease death in firefighters.

Table 15: Multivariate-adjusted odds ratios and 95% confidence intervals for the CHD/CHD death risk factors for on-duty CHD deaths compared to active control firefighters.

	OR (95% CI) *	
	Model 1 Age <60 †	**Model 2 Age <60 and no prior CHD diagnosis ‡**
Age >/=45 years old	**6.9 (2.6 - 18.5)**	**6.7 (2.4 - 19.3)**
Current Smoking	**6.7 (2.6 - 17.3)**	**8.2 (3.1 - 22.3)**
Hypertension	**4.3 (1.7 - 10.6)**	**5.4 (2.0 - 14.8)**
Diabetes Mellitus	**1.5 (0.3 - 6.9)**	**1.5 (0.2 - 9.4)**
Prior Diagnosis of CHD or other vaso-occlusive disease	**15.5 (3.3 - 72.6)**	**-**

* Odds ratios are adjusted for all other risk factors in the table.
† Model 1 included all CHD death cases (n=39) and active control firefighters (n=308) less than 60 years old.
‡ Model 2 was restricted to firefighters less than 60 years of age without a prior diagnosis of CHD or other evidence of vaso-occlusive disease. Cases (n=27) and controls (n=305).

Gochfeld stated in an editorial "it is not sufficient to know that a firefighter who collapses…was an overweight smoker with inadequately controlled hypertension. What is required is a prospective study…of all different combinations of risk factors…" Due to the small absolute number of fatalities, we used a case-control study design. This is the first controlled investigation in firefighters to demonstrate that detectable, mostly modifiable cardiac risk factors and underlying coronary heart disease are responsible for most on-duty CHD fatalities. Fitness promotion, medical screening and medical management could prevent many of these premature deaths. Further prospective study of stress testing in firefighters is needed to determine the most appropriate fitness for duty determination strategy.

<u>Aims 3 and 4</u>

Prospective Surveillance of Hypertension in Firefighters *(Submitted to the Journal of Clinical Hypertension).*

We evaluated blood pressure and anti-hypertensive medication use in 334 firefighters in an occupational medical surveillance program. Firefighters received written summaries of their examination results, including blood pressures, and were encouraged to see their personal physicians for any abnormal results. The mean age of the participants was 39 years and the vast majority were men (n=330). The prevalence of hypertension was 20% at baseline (1996); 23% in 1998; and 23% in 2000. Among firefighters with high blood pressure readings, only 17%, 25% and 22% were taking anti-hypertensive medications at the baseline, 1998 and 2000 examinations, respectively. Medical surveillance was effective in detecting hypertension in firefighters, however, after four years of follow up, over 75% of firefighters with hypertensive readings were not receiving anti-hypertensive treatment.

Our findings are important because several lines of evidence suggest that uncontrolled hypertension puts firefighters at greater risk for adverse outcomes. We previously reported, that stage II hypertension among firefighters (blood pressure >/=160/100 mm Hg), was associated with increased risks for adverse employment status. Second, coronary heart disease is responsible for 45% of on-duty fatalities in firefighters, and we previously found that hypertension was an independent predictor associated with a 4- to 5-fold increased risk of on-duty death. In our case-control study, autopsy results showed that many of the deceased firefighters had left ventricular hypertrophy (LVH) suggesting uncontrolled hypertension for significant time periods. Another important finding from the present study was the observed cardiovascular disease risk factor clustering among individuals with high blood pressure. The results call for renewed efforts among occupational and primary care physicians for improved detection, treatment and control of hypertension among firefighters. The NFPA may need to consider stricter and more specific blood pressure guidelines in order to improve the current figures, including a provision requiring periodic re-evaluation until adequate control is achieved.

List of Publications

(a) Publications from the Cohort since NORA Award

1) Kales SN, Polyhronopoulos GN, Aldrich JM, Dimitriadis EA, Christiani DC. Interlaboratory comparisons of red blood cell cholinesterase activity. J Environ Med 1999;1:19-26.

2) Kales SN, Polyhronopoulos GN, Aldrich JM, Leitao ED, Christiani DC. Correlates of body mass index in hazardous materials firefighters. J Occup and Environ Med 1999;41: 589-595.

3) Kales SN, Aldrich JM, Polyhronopoulos GN, Leitao EO, Artzerounian D, Gassert T, Hu H. Correlates of Fitness for Duty in Hazardous Materials Firefighters. Am J Ind Med 1999; 36: 618-629.

4) Kales SN, Christiani DC. Cardiovascular Fitness in Firefighters. J Occup Environ Med 2000;42:467-468.

5) Kales SN, Polyhronopoulos GN, Aldrich JM, Mendoza PJ, Suh JH, Christiani DC. A Prospective Study of Hepatic, Renal, and Haematologic Surveillance in Hazardous Material Firefighters. Occup Environ Med 2001;58:87-94.

6) Kales SN, Freyman RL, Hill JM, Polyhronopoulos GN, Aldrich JM, Christiani DC. Firefighters' Hearing: A Comparison with Population Databases from the International Standards Organization. J Occup Environ Med 2001;43:650-656.

7) Kales SN, Mendoza PJ, Hill JM, Christiani DC. Spirometric Surveillance in Hazardous materials Firefighters: Does Hazardous Materials Duty Affect Lung Function? J Occup Environ Med 2001:43: 43:1114-1120.

8) Kales SN, Soteriades ES, Christoudias SG, Tucker S, Nicolaou M, Christiani DC. Firefighters' blood pressure and Employment Status on Hazardous Materials Teams in Massachusetts: A Prospective Study. J Occup Env Med 2002;44:669-676.

9) Soteriades ES, Kales SN, Christoudias SG, Tucker S, Liarokapis D, Christiani, DC. The Lipid Profile of Firefighters Over Time: Opportunities for Prevention. J Occup Env Med 2002;44:840-846.

(b) Related Regional and National Invited Presentations since NORA award

1) Kales SN. "Firefighting Medical Requirements - The Science Behind NFPA 1582." National Fire Protection Association Fall Meeting, Atlanta, Georgia, 1998.

2) Kales SN. "Fitness for Duty in Firefighters: Some of the Issues", Occupational

Medicine Grand Rounds, Center for Occupational and Environmental Health, University of California at Irvine, 1999.

3) Kales SN. "Epidemiology of Massachusetts Hazmat Incidents 1990-1996, and Medical Surveillance of Hazmat Firefighters 1993-1998", Massachusetts Hazardous Materials Technicians Annual Conference, Plymouth, Mass, 2000.

4) Kales SN, Christiani DC. "Evidence-based Medical Examinations for Hazardous Materials Firefighters." Workshop on Best Practices in Workplace Surveillance, NIOSH, Cincinnati, Ohio, November 2001.

5) Kales SN, Soteriades ES, Christoudias SG, Christiani DC. "Firefighters and on-duty deaths from coronary heart disease." Poster presented at the American Occupational Health Conference 2002, American College of Occupational and Environmental Medicine, Chicago, April 2002.

6) Kales SN. Medical Examinations of Firefighters: Issues in Medical Surveillance & Fitness for Duty. Seminar, University of Connecticut Health Center Division of Occupational & Environmental Medicine, Farmington, Connecticut, September 2002.

7) Kales SN. Occupational Hazards of Firefighters: from the Fire Ground to the Clinic-Where can the Occ Doc make a Difference?. Occupational Health + Rehabilitation, Inc, National Annual Providers' Meeting, Merrimack, New Hampshire, October 2002.

(c) Prior publications related to the Massachusetts Hazardous Materials Cohort

1) Kales SN, Pentiuc F, Christiani DC. Pseudo-elevation of carboxyhemoglobin levels in firefighters. J Occup Med 1994;36:752-76.

2) Kales SN, Castro M, Christiani DC. Epidemiology of hazardous materials responses by Massachusetts District Hazmat Teams. J Occup Environ Med 1996; 38:394-400.

3) Kales SN, Polyhronopoulos GN, Christiani DC: Medical surveillance of hazardous materials response firefighters: a two-year prospective study. J Occup Environ Med 1997; 39:238-47.

4) Kales SN, Polyhronopoulos GN, Castro MJ, Goldman RH, Christiani DC. Injuries due to hazardous materials accidents. Ann Emerg Med 1997; 30:598-603.

5) Kales SN, Polyhronopoulos GN, Castro MJ, Goldman RH, Christiani DC.

Mechanisms of and facility types involved in hazardous materials accidents. Environmental Health Perspectives.1997;105:998-1001.

6) Kales SN, Aldrich JM, Polyhronopoulos GN, Artzerounian D, Gassert T, Hu H, Kelsey K, Sweet C, Christiani DC. Fitness for duty evaluations in hazardous materials firefighters. J Occup Environ Med 1998; 40:925-931.

(d) Anticipated publications related to the Massachusetts Hazardous Materials Cohort under review

1) Soteriades ES, Kales SN, Liarokapis D, Christiani, DC. Prospective Surveillance of Hypertension in Firefighters. J Clinical Hypertension.

2) Kales SN, Soteriades ES, Christoudias SG, Christiani, DC. Firefighters and On-Duty Deaths from Coronary Heart Disease. In preparation

ORIGINAL ARTICLE

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Interlaboratory Comparisons of Red Blood Cell Cholinesterase Activity

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KEY WORDS
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Comparisons of red blood cell cholinesterase values (AChE, EC 3.1.1.7) from different laboratories can be difficult. This study evaluated different methods of interlaboratory comparison. Eleven subjects gave triplicate samples for analysis by three commercial laboratories. Comparisons were made relative to the mid-point of each laboratory's reference range (mid-range), and by transformation to Ellman assay activity in U/mL using published/derived conversion factors. To observe each laboratory's reliability, four subjects submitted two additional duplicate samples to each laboratory. The mean intraspecimen variabilities were 3%, range 1%–8%; 4%, range 0–9%; and 13%, range 2%–24% for laboratories 1–3, respectively. The mean mid-range percent for laboratory 3 was substantially lower than the means for laboratories 1 and 2. Therefore, laboratory 3 values were adjusted based on the means for laboratories 1 and 2 and the mid-point suggested by laboratory 3's assay kit. The mean AChE relative to these mid-points were 109%, 107%, and 107% for laboratories 1–3, respectively. Ellman activities were 19.0, 19.9 and 20.8 U/mL for laboratories 1–3, respectively. Intra-subject differences for both comparison methods showed agreement that approximated intraspecimen variabilities for each laboratory. Comparisons involving laboratory 3 showed the poorest agreement consistent with laboratory 3's greater intraspecimen variation. AChE from different laboratories can be compared by both methods evaluated in this study. All comparisons are limited by the precision and reliability of the laboratories involved.

Introduction

Measurement of red blood cell cholinesterase activity (AChE) is useful for assessing cholinesterase inhibition by organophosphorus pesticides (OPs), nerve gas agents (NGs), and carbamate pesticides (CPs).[1–4] Such testing is indicated in the diagnosis of acute overexposures, for the purpose of establishing baseline values in workers with the potential for future exposure, and for serially monitoring chronically exposed workers.

Large variations in baseline AChE activity are found among healthy individuals.[5] Within individuals, however, little physiological variation exists in the AChE.[6] Therefore, relatively small depressions within an individual's AChE may be indicative of overexposure. For example, California law requires investigation of the workplace if either AChE or plasma cholinesterase (BuChE, EC 3.1.1.8) drop to below 80% of baseline, and removal of the worker from exposure if the AChE is less than 70% of baseline.[4] The World Health Organization suggests worker removal for depressions below 75% of baseline.[7] Therefore, establishing an individual's baseline AChE is desirable.

While two or more values performed at the same

Abbreviations: AChE, red blood cell cholinesterase; BuChE, plasma cholinesterase; OPs, organophosphorus pesticides; NGs, nerve gas agents; CPs, carbamate pesticides; Hb, haemoglobin.

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laboratory can be readily compared, comparisons between values from different laboratories can be extremely difficult. First, many different methodologies for assessing AChE are in current use.[1,2,4,8] Second, different reporting units may be used by different facilities. Finally, even normal ranges may differ among laboratories using the same assays.[4]

We are currently involved in surveillance of Hazardous Materials Firefighters. Due to their potential for exposure to OPs, CBs or NGs during chemical accidents or terrorist scenarios, their medical examinations include a baseline determination of AChE. Because such an exposure could occur anywhere within a firefighter's region of the state, the post-exposure AChE is likely to be sent to a different reference laboratory. Therefore, we undertook this study to systematically evaluate different methods of interlaboratory comparison.

Methods

Subjects

Firefighters

The firefighters were members of the Commonwealth of Massachusetts' six regional hazardous materials teams. Medical surveillance examinations including baseline AChE activity for all firefighters were performed at one of three hospitals in 1996 or 1997 in the first year of a statewide surveillance programme. If a previous baseline was available, this value was used. A total of 306 baseline AChE values performed at three laboratories between 1993 and July 1997 were available for the study. Twenty-two AChE were performed at laboratory 1, 101 at laboratory 2, and 183 at laboratory 3.

Comparison study subjects

Study subjects were 11 volunteer staff members of the Cambridge Hospital. None had known exposure to agents that inhibit AChE. Each subject was informed of the purpose of the study and consented to the submission of blood specimens for AChE determination.

Reference subjects

Laboratories 1, 2 and 3 were contacted by the investigators and asked for AChE values or summary data from a group of reference subjects. Laboratory 1 provided 977 values for AChE determinations including the 11 comparison study subjects' values performed in October 1997 and associated summary statistics. Given the large sample size, the inclusion of the 11 comparison study subjects' values was not felt to influence the summary data significantly.

Laboratory 2 provided summary statistics for 50 subjects. They are a control population of healthy employees who undergo various laboratory studies that are used by the laboratory to establish its reference ranges.

Laboratory 3 provided daily means and sample sizes for all AChE determinations from 4 August to 3 November 1997. This yielded a grand total mean from 436 individual AChE values. These did not include data from the comparison study subjects.

Sample Preparation and Handling for Comparison Study Subjects

Phase I

On 2 July 1997, all 11 comparison study subjects had venepuncture for three tubes of blood (triplicate samples). Tube types were specified by the protocols of each of the three respective commercial laboratories for the analysis of AChE. All of the specimens were drawn within a period of 1 h. Each specimen was immediately labelled and stored on ice. One set each of specimens were then transported on ice to facilities of laboratories 1 and 3, respectively. The third set of specimens was packaged on ice and sent by courier to laboratory 2.

Phase II

On 22 October 1997, 9 of the 11 comparison study subjects were available and all again agreed to give blood samples. All specimens were drawn within a 2 h period. In order to observe the reliability within each of the three laboratories, four of the subjects (all co-authors) submitted an additional three specimens. These three additional specimens were labelled with pseudonyms and one from each subject was submitted to each of the three laboratories. Therefore, personnel analysing the samples were blinded to the fact that four of the samples were duplicate. Transport, handling and analysis procedures were the same as in July.

Due to an administrative error at laboratory 3, none of the specimens were analysed for AChE on 22 October at this facility. Therefore, the four subjects who had participated in the reliability study had duplicate specimens drawn at laboratory 3 on 4 November 1997. Again, pseudonyms were used on the second of each duplicate sample.

AChE Analysis Methodologies

Laboratory 1 uses the Boehringer Manheim Corporation (BMC) kit.[9] This assay measures acetylcholinesterase activity via thiocholine production from the substrate, acetylthiocholine, (the preferred substrate of

AChE) based on the Ellman reaction. Thiocholine combines with Ellman's reagent to form thionitrobenzoic acid which is measured spectrophotometrically at 405 nm.

Laboratory 2 also measures acetylcholinesterase activity via thiocholine production from the substrate acetylthiocholine using BMC kit reagents based on a modification of the Ellman assay.[10]

Laboratory 3 uses the Sigma Diagnostics kit with the Sigma Diagnostics Cholinesterase (PTC) reagent and propionylthiocholine (the preferred substrate of BuChE) as a substrate (SIGMA Diagnostics).[11] This assay also measures thiocholine formation spectophotometrically using methodology based on the Ellman reaction.[12]

Table 1 summarizes the assay conditions for the three laboratories.

Intralaboratory (Reliability) Comparisons

Reliability

The reliability of each laboratory's AChE determinations was studied by comparing the duplicate samples from the four co-author subjects described above. The intrasample variation was calculated as the absolute value of 1 minus the quotient of the AChE values for the duplicate samples multiplied by 100%. For example:

$$|1\text{-(specimen 1 AChE/specimen 2 AChE)}| \times 100\%$$

Interlaboratory Comparisons

Percent of laboratory mid-range

Subject values or means were transformed by dividing by the mid-point of the reference range for each laboratory and multiplying by 100%.

Percent of the mean of the laboratory reference subjects

Subject values or means were transformed by dividing by the mean of the reference population for each laboratory and multiplying by 100%.

Interlaboratory comparisons

Paired comparisons of study subjects' baseline AChE activities (July) were done by comparing the percent mid-ranges from each laboratory. Ideally, the ratio of one subject's percent mid-ranges from two different facilities should be 1. Therefore, the absolute differences of the ratios of different percent mid-ranges from 1 were calculated and multiplied by 100%. For example:

$$[1\text{-(\%mid-range lab 1/\%mid-range lab 2)}] \times 100\%.$$

The same calculations were also done for the percents of the reference means.

Comparisons were further tested by estimating the change in AChE activities between July and October as a percent of baseline (July). First, the percent change was calculated by comparing the absolute values from the same laboratory for each subject. Such values could not be determined for laboratory 3 since no AChE were analysed on 22 October (see above). For example:

$$[\text{(AChE October)/(AChE July)}] \times 100\%.$$

Then, these values were compared with interlaboratory comparisons between July and October using both the percent mid-ranges and the percents of the reference means. For example:

$$[\text{(\% mid-range lab 1 October)/(\% mid-range lab 2 July)}] \times 100\%.$$

Published conversion factors

Wilson *et al.*[2] have published preliminary conversion factors for transforming results of BMC and Sigma results to Ellman assay activity in U/mL. Comparison subjects data in U/mL from laboratory 1 (BMC) were multiplied by 1.43, and for laboratory 3 (Sigma) were multiplied by 3.04.

Although laboratory 2 uses a modified Ellman assay, these values could not be compared directly because this laboratory reports AChE activity in U/g Hb, rather than U/mL. Therefore, a conversion factor for laboratory 2 values was derived by dividing the laboratory 2

Table 1. AChE assay conditions for laboratories 1–3

	Lab 1	Lab 2	Lab 3
Buffer pH	7.2	7.2	7.2
Substrate	Acetylthiocholine	Acetylthiocholine	Propionylthiocholine
Substrate concentration	169 mmol/L	169 mmol/L	4 mmol/L
Dithionitrobenzoate concentration	0.25 mmol/L	0.25 mmol/L	0.25 mmol/L
Wavelength	405 nm	405 nm	405 nm

All concentrations and pHs are after reconstitution.

mean for the comparison subjects by the mean of the Ellman activities from laboratories 1 and 3:

Conversion Factor= cf
cf = Lab 2 mean AChE/((lab 1 mean Ellman + lab 3 mean Ellman)/2).

Transformation of firefighter AChE values

Since the comparison subjects were tested simultaneously at all three laboratories, the percent of the comparison subjects' mean at each laboratory should provide the best way to compare firefighter values from the three reference facilities. Therefore, the other comparison methods were compared against this model.

Results

Table 2 summarizes the reporting characteristics of each commercial laboratory and the raw data for each of the subject groups at these three laboratories. For laboratory 3, the range and mid-range point were higher relative to all three group means and ranges than for the other two facilities. The manufacturer's suggested range and mid-range point were in better agreement with the subjects' data and the other two laboratories.

The ranges for intraspecimen variability were 1%–8% for laboratory 1, 0–9% for laboratory 2, and 2%–24% for laboratory 3. Both intra- and interspecimen variability was greatest for laboratory 3.

Percent of laboratory mid-range

Table 3 lists each comparison study subject's July AChE transformed to percent mid-ranges for all three laboratories. The absolute differences of the ratios of different percent mid-ranges from 1 (e.g. $|1\text{-(ratio)}| \times 100\%$) were calculated and summarized below.

Lab 1/Lab 2: mean of 5% ± 4%, range 0–13%.
Lab 1/Lab 3: mean of 23% ± 18%, range 4%–57%.
Lab 2/Lab 3: mean of 21% ± 16%, range 2%–49%.

Because the mean mid-range percent for laboratory 3 was substantially lower than the means for the other two facilities and the mid-range point was higher relative to the various subject means, the mid-range percents for laboratory 3 were adjusted by multiplying by 1.19. This is the ratio of the mean percent mid-ranges for laboratories 2 and 3 (107/90 = 1.19). These values are shown in the final column of Table 3. This is also in agreement with the mean of 108% derived from the percent of the manufacturer's (Sigma diagnostics) suggested mid-range. The absolute differences in the ratios

Table 2. Reporting characteristics and raw data for laboratories 1–3

	Laboratory values	Reference population	Firefighter sample	Comparison study subjects (July '97)
Laboratory 1				
Units	IU/L	n = 977	n = 22	n = 11
Range	11000–15000 11167–16667[a]	0–18200	11460–17620	11890–16610
Mid-range	13000 13917[a]			
Mean		13118	14355 ± 1530	14203 ± 1480
Mean % intrasample variation				3% (n = 4, October '97)
Laboratory 2				
Units	U/g Hb	n = 50	n = 101	n = 11
Range	26.7–49.2		33.1–56.4	38.2–46.1
Mid-range	37.95			
Mean		41.9	44.6 ± 3.8	40.6 ± 2.6
Mean % intrasample variation				4% (n = 4, October '97)
Laboratory 3				
Units	U/mL	n = 436	n = 183	n = 11
Range	5.20–10.0 4.4–8.2[b]		3.74–12.33	5.3–8.9
Mid-range	7.6 6.3[b]			
Mean		6.65	7.8 ± 1.5	6.8 ± 1.0
Mean % intrasample variation				13% (n = 4, November '97)

[a]Suggested by BMC.
[b]Suggested by Sigma Diagnostics.

Table 3. Percent mid-ranges for individual comparison study subjects July 1997

Subject	Laboratory 1 % mid-range	Laboratory 2 % mid-range	Laboratory 3 % mid-range	Laboratory 3 Adjusted % mid-range
1	128	121	82	97
2	125	114	87	103
3	121	115	117	139
4	112	105	89	106
5	110	105	103	122
6	105	101	84	100
7	104	105	97	116
8	103	101	70	83
9	102	102	92	110
10	100	101	89	106
11	91	106	78	92
Mean	109	107	90	107

of percent mid-ranges from 1 were re-calculated for laboratory 3 and summarized below.

Lab 1/Lab 3: mean of 12% ± 10%, range 1%–32%.
Lab 2/Lab 3: mean of 12% ± 8%, range 1%–25%.

AChE values for 9 of the comparison study subjects were available for 22 October 1997 from laboratories 1 and 2. For laboratory 1, the October AChE activity as a percent of the baseline (July 1997) ranged from 93%–111% with a mean of 100% ± 5%. For laboratory 2, the percent of baseline ranged from 98%–108% with a mean of 103 ± 4. The differences between individuals for the percent of baseline activity as measured by the two different laboratories ranged from 1%–13% with a mean of 6% ± 4%.

Percent of baseline activities were then recalculated using percent mid-ranges from the two laboratories as summarized below.

Laboratory 2 October percent mid-range/Laboratory 1 July percent mid-range:
mean of 102% ± 5%, range 96%–113%. The differences in the percent of baseline activity as calculated above versus that using laboratory 1 data alone ranged from 1%–9% with a mean of 4% ± 3%.

Laboratory 1 October percent mid-range/Laboratory 2 July percent mid-range:
mean of 102% ± 6%, range 91%–109%. The differences in the percent of baseline activity as calculated above versus that using laboratory 2 data alone again ranged from 1%–9% with a mean of 4% ± 3%.

Percent of the Mean of the Laboratory Reference Subjects

Table 4 lists each comparison study subject's July AChE transformed to percent mean of the reference subjects for all three laboratories. Ideally, the ratio of one subject's percent mean of the reference subjects from two different facilities should be 1. Therefore, the absolute differences of the ratios of different percent mean of the reference subjects from 1 (e.g. |1-(ratio)|) were calculated and summarized below.

Lab 1/Lab 2: mean of 12% ± 4%, range 5%–20%.
Lab 1/Lab 3: mean of 13% ± 12%, range 2%–36%.
Lab 2/Lab 3: mean of 12% ± 6%, range 4%–22%.

Because the average percent of the reference mean for laboratory 2 was lower than the averages for the other two facilities and the percent mid-ranges for laboratory 2 showed good agreement with laboratory 1, the percents for laboratory 2 were adjusted by multiplying by 1.11 which is the ratio of the means for laboratories 1 and 2 (108/97 = 1.11). These values are also shown in Table 4. The absolute differences in the ratios of laboratory 2 percent mid-ranges from 1 were re-calculated and summarized below.

Lab 1/Lab 2 Adjusted: mean 4% ± 4%, range 1%–15%.

As above, the October AChEs as percent of baseline activities were recalculated using percents of the reference means from laboratories 1 and 2 as summarized below.

Laboratory 2 Adjusted October percent reference mean/Laboratory 1 July percent reference:
mean of 104% ± 5%, range 98%–114%. The differences in the percent of baseline activity as calculated above versus that using laboratory 1 data alone ranged from 1%–8% with a mean of 4% ± 3%.

Lab 1 October percent reference mean/Lab 2 Adjusted July percent reference:
mean of 100% ± 6%, range 90%–108%. The differences in the percent of baseline activity as calculated above versus that using laboratory 2 data alone again ranged from 0–9% with a mean of 5% ± 3%.

Table 4. Percent of reference means for individual comparison study subjects July 1997

Subject	Laboratory 1 % mean	Laboratory 2 % mean	Adjusted % mean	Laboratory 3 % mean
1	127	110	122	93
2	124	104	115	99
3	120	104	115	134
4	110	95	105	102
5	109	95	106	117
6	104	92	102	96
7	103	95	106	111
8	102	91	101	80
9	101	92	102	105
10	99	92	102	102
11	91	96	106	89
Mean	108	97	108	103

Published Conversion Factors

Conversion of BMC data for the comparison subjects from laboratory 1 using Wilson *et al.*'s conversion factor gave a mean of 19.0 ± 2.0 U/mL. Conversion of laboratory 3 values to Ellman activity using the conversion factor gave a mean of 20.8 ± 3.0 U/mL. Intrasubject differences for Ellman activity between laboratories 1 and 3 ranged from 6%–22% with a mean difference of 14% ± 6%.

For laboratory 2, a conversion factor of 2.04 was found:

(Lab 2 mean AChE U/g Hb)/((mean Ellman lab 1 +mean Ellman lab 3)/2).

Ellman activity for laboratory 2 was then calculated with the conversion factor:

Ellman lab 2 U/mL = (lab 2 AChE U/g Hb)/2.04 g Hb/mL).

This gave a mean Ellman activity of 19.9 ± 1.3 U/mL. Intrasubject differences for Ellman activity between laboratories 1 and 2 ranged from 0–19% with a mean difference of 5% ± 5%. Intrasubject differences for Ellman activity between laboratories 2 and 3 ranged from 3%–27% with a mean difference of 13% ± 7%.

Transformation of Firefighter AChE Values

Group means for the firefighter subjects' AChE values transformed to Ellman activity, as percents of the mid-range point, as percents of the reference subjects' mean, and percents of the comparison subjects' mean are shown in Table 5. Based on the comparison subjects, the group tested at laboratory 3 had the highest mean AChE activity, followed by the groups tested at laboratories 2 and 1. Independent *t*-tests showed significant differences between the means of all three groups: 1 vs. 2, $p < 0.01$; 1 vs. 3, $p < 0.01$; and 2 vs. 3, $p < 0.05$ (pooled variances).

When adjustments were made (see Table 5), the rank order of the groups held for all comparison methods.

Discussion

This study presents some initial suggestions to clinicians attempting to compare AChE values (and possibly other cholinesterase values) from different laboratories. It also emphasizes the need for greater standardization of analysis and reporting methods among reference laboratories and greater precision within laboratories. We agree with others[4] who have called for standardization of acetylcholinesterase assays by professional organizations in pathology and clinical chemistry.

This study has several limitations. First, only three laboratories were investigated. Second, we studied 'uninhibited' samples from presumably non-exposed subjects. In the presence of cholinesterase-inhibiting agents, the dose-response curve for AChE activity may vary from one instrument and/or assay to another.[13] The preliminary conversion factors of Wilson *et al.*[2] used in this study were based on linear dose-response curves established by dilution of enzyme activity (as opposed to inhibition).

Even the most ideal methods of comparison will always be limited by the precision and reliability of the laboratories involved. Duplicate samples from the same laboratory should not differ by more than 15%.[4] For laboratory 3, intersubject and intrasubject variation was the highest. In two cases of four, a difference greater than 20% between simultaneous samples from the same subject occurred and the mean variation was 13%. It is likely that all comparisons involving laboratory 3 were limited by this facility's lower precision.

Bearing this in mind, we can better judge the performance of the various comparison methods. In this study, comparing values by the percent of the mid-

Table 5. Group means for firefighter subjects

Laboratory used		Mean Ellman activity	Mean % mid-range	Mean % reference mean	Mean % comparison subjects' mean
1	$n = 22$	20.5 ± 2.2 U/mL (100%)[a]	110 ± 12% (100%)	110 ± 12% (100%)	101 ± 11% (100%)
2	$n = 101$	21.8 ± 1.9 U/mL (106%)	117 ± 10% (106%)	106 ± 23% 118 ± 10%[b] (107%)	110 ± 9% (109%)
3	$n = 183$	23.8 ± 4.6 U/mL (116%)	103 ± 20% 122 ± 24%[b] (111%)	118 ± 23% (107%)	115 ± 22% (114%)

[a]Values in parentheses are mean activity relative to group 1
[b]Adjusted

range point performed well overall, but required adjustment of the mid-range for laboratory 3. Such adjustment correlated well with the mid-point suggested by the manufacturer of the assay kit. After adjustment, the means for the comparison subjects were very similar: 109%, 107% and 108%, respectively.

It is best to examine comparisons between laboratories 1 and 2 since they both showed little intrasample variation. Mid-range point comparisons between laboratories 1 and 2 had a mean variation of 5% with a range of 0–13%. This rivals the intrasample variations for these two reference facilities (range 0–9%). The same was true for comparisons of the percent of baseline activity (October versus July) based on values from these two laboratories. This demonstrates the validity of the mid-range as a comparison point for these two laboratories.

When adjusted values were considered for laboratory 3, the variation between laboratories approximated the intralaboratory variation for laboratory 3. Finally, for the transformation of the firefighters' values, the percent of the mid-range derived values gave group means that showed similar relative mean activities as those derived from the comparison subjects' means.

Comparisons between laboratories using Ellman activity based on Wilson *et al.*[2] conversion factors and the one we derived had a performance which also approximated intralaboratory variation. For the three firefighter groups, the relative mean Ellman activities were in close agreement with the relative mean activities obtained by other methods. These results confirm the validity of Wilson *et al.*[2] preliminary conversion factors.

The slightly superior performance of the mid-range as a comparison point versus the reference population means is probably due to differences in subject selection. For example, laboratory 2 provided data from a group of 50 healthy subjects, while laboratories 1 and 3 provided us with large samples that would have included sick and/or pesticide intoxicated subjects as well as healthy individuals.

The obvious advantage of the mid-range over both reference means, and conversion factors is its immediate availability for all laboratories. Published conversion factors may not exist for all assay methods, and reference subject data must be requested. The usefulness of the mid-range, of course, is limited by how appropriately a laboratory chooses to set its reference range.

Based on this investigation, we recommend the following protocol for interlaboratory comparisons when a baseline from a different laboratory is available.

1. Assess the AChE (and the BuChE if acute exposure is suspected).
2. AChE values (baseline and follow-up) should be transformed to the percent of the laboratory's mid-range point and then directly compared.
3. AChEs can also be compared using Ellman activity provided that the Ellman assay, Sigma, or BMC kits are used. For Sigma results in U/mL, multiply by 3.04. For BMC results in U/mL, multiply by 1.43. For modified Ellman results (for assays with conditions like laboratory 2 in Table 1) in U/g Hb, divide by 2.04.
4. Although worker safety must be protected by initially assuming that depressions of 20%–25% in the AChE are significant, confirmation is necessary. (In our study, non-physiological variation alone sometimes exceeded 20%.) Apparently significant AChE depressions can be confirmed by serial assays of AChE and BuChE done over days to weeks at the same facility. Confirmation is based on increasing values post removal from exposure and/or treatment with oximes.[5]

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Correlates of Body Mass Index in Hazardous Materials Firefighters

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We analyzed results from the medical examinations of 340 hazardous materials (HAZMAT) firefighters and observed the relationships between selected parameters and body mass index (BMI). Heights and weights were available for 98% of the subjects (333 of 340). The mean BMI was 28.9 ± 4.1 kg/m². Eighty-seven percent (290 of 333) of subjects were overweight (BMI ≥ 25) and 34% (113 of 333) were obese (BMI ≥ 30). Two percent (7 of 333) were morbidly obese (BMI ≥ 39). For comparison purposes, we divided subjects into low (BMI < 27), medium (BMI 27 to <30), and high (BMI ≥ 30) BMI groups. The results demonstrated adverse associations between increasing BMI and resting blood pressures, forced vital capacity, alanine aminotransferase, aspartate aminotransferase, serum cholesterol, and overall morbidity scores. The high prevalence of overweight and obesity and the associated adverse health effects support the development and implementation of fitness-promotion programs for firefighters.

Excess body weight is an increasing health problem in the United States. Based on the previous National Center for Health Statistics' definition of overweight as a body mass index (BMI) of 27.3 for women and BMI of 27.8 for men, approximately 70 million adult Americans were considered to be overweight.[1] Using the new National Institutes of Health standard for healthy weights (BMI < 25), it is estimated that 97 million, or 55%, of adult Americans will be considered overweight.[2] Likewise, obesity, or a BMI ≥ 30, is also epidemic, with a prevalence of 22.5% in the United States, according to the third National Health and Nutrition Examination Survey conducted from 1988–1994.[3]

Overweight individuals are at increased risk for the development of diabetes, high blood pressure, and coronary heart disease. Obesity is associated with an increased risk for many comorbidities, including insulin resistance and type II diabetes mellitus,[4,5] dyslipedemias,[4,5] elevated liver function tests and fatty liver,[4–7] hypertension,[4,5] coronary heart disease,[4,5] cholelithiasis,[4,5] pulmonary disorders (decreased lung capacity, obstructive sleep apnea, and Pickwickian syndrome),[4,5,8,9] excess daytime sleepiness,[8] certain cancers,[4,5] and degenerative joint disease.[4,5] In addition, good evidence exists that obesity increases mortality as well.[10] When smoking and weight loss from coexisting diseases are adjusted for, the risk of death appears to increase linearly with increasing BMI.[11]

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Obesity is associated with additional serious concerns for occupational medicine, including decreased physical fitness (work capacity),[12] increased risk of heat-related illness,[13] the confounding effects of obesity on medical surveillance for potential hepatotoxins (eg, obesity-related increases in liver function tests[6–7]) and safety hazards due to decreased alertness (eg, excess daytime sleepiness due to obesity-related sleep disorders[8,9]). Obesity has also been shown in recent employer and health maintenance organization–based studies to be associated with increased health care and other associated costs.[14,15]

Given the potential adverse health, safety, and economic consequences of obesity, we determined the prevalence of overweight status and obesity and investigated the effects of increasing BMI on physiologic, metabolic, and morbidity profiles in a large cohort of hazardous materials (HAZMAT) firefighters.

Methods

Subjects

The subjects were all members (n = 340) of six regional HAZMAT teams of the Commonwealth of Massachusetts. They included 268 (79%) HAZMAT technicians and 72 (21%) support members. The population included four women (1%). The team members' ages ranged from 21 to 58 years, with a mean of 39 and a standard deviation of 6.9.

Baseline and Periodic Medical Examinations

Medical surveillance examinations for all subjects were performed at three hospitals—Massachusetts Respiratory, Marlborough, or Holyoke Hospitals—in 1996 or 1997 in the first year of a statewide surveillance program. All examinations were conducted in a similar fashion. Examinations included a detailed medical, smoking, and environmental/occupational history tailored to emergency responders; physical examination; visual and audiometric testing; routine laboratory tests (complete blood count, blood urea nitrogen, creatinine, alkaline phosphatase, aspartate aminotransferase [AST] and alanine aminotransferase [ALT], and urinalysis); and spirometry.

Summary results of each firefighter's examination, including a face problem sheet and the attending physician's determination of fitness for duty, were transferred to the Massachusetts Respiratory Hospital, where they were entered into a statewide computerized medical records repository.

Gestalt Morbidity Rating

The face problem sheet of each subject was reviewed by a board-certified internist (E.O.L.). The internist never examined any of the firefighters and was blinded to the subjects' fitness for duty outcomes. The face problem sheet lists gender, age, height and weight, medical problems, medications, allergies, immunizations, and smoking history. Each subject was rated on a scale of 1 to 10 for increasing morbidity. A rating of 1 was considered most healthy, and 10, least healthy. This parameter was labeled "fit rank." This rating is not blind to BMI status because the face sheet includes height and weight and obesity may be listed as a medical problem.

Body Mass Index

The BMI of each subject was calculated and reported in kilograms per meter^2 from his/her height in inches and weight in pounds, using the following formula[16]: BMI = 703.1 × (weight in pounds)/(height in inches)^2

Statistical Analyses

For the purposes of statistical comparisons, the cohort was divided into three groups. The low BMI group was defined as those subjects with a BMI <27, the medium BMI group as those with a BMI of 27 to <30, and the high BMI group as those with a BMI ≥ 30.

Because of the small number of women in the cohort (n = 4), only males were included in multivariate models. Smoking information was obtained from the face problem sheets, where it was categorized as "never," "former," or "current." Ethanol consumption was quantified as the number of drinks per week. Ethanol consumption information was available for the male firefighters who were examined at the Massachusetts Respiratory Hospital (35% of total cohort; 114 of 329). Because ethanol intake is not listed on the face problem sheets, the centralized database does not contain ethanol intake information for the remaining firefighters.

Analyses of variance were used to compare the means of the three groups (low, medium, and high BMI). If these analyses demonstrated a significant difference ($P < 0.05$) among the means, then independent t tests were used to compare the mean of the low BMI group with the means of the other two groups.

Results

Distribution of Body Mass Indices for the Cohort

Heights and weights were available for 333 of 340 subjects (98%).

The mean BMI was 28.9 ± 4.1 for these 333 firefighters. The mean BMI for the four women was 27.7 ± 6.6 (range, 22.6 to 36.9), and 29.0 ± 4.0 (range, 19.3 to 43.8) for the 329 males. Eighty-seven percent (290 of 333) of the firefighters were overweight, with BMIs of 25 or greater. Fifty-nine percent (198 of 333) were above the previous US guidelines for overweight: BMI 27.8 and 27.3 for men and women, respectively. Obesity (BMI ≥ 30) was present in 34% of the cohort (113 of 333). Finally, 2% (n = 7) met the criterion for morbid obesity (BMI ≥ 39).

Thirty-two percent (106 of 333) of the firefighters with measured BMIs fell into the low BMI category, with a mean BMI of 24.7 ± 1.9; 34% (114 of 333) comprised the medium

TABLE 1
Correlates of Body Mass Index: Males and Females*

Variable	Low BMI	Medium BMI	High BMI	ANOVA *P*
Age	38 ± 6 *n* = 100	40 ± 7 *n* = 108	40 ± 7 *n* = 107	<0.05
SBP	119 ± 13 *n* = 106	123 ± 13 *n* = 114	125 ± 13 *n* = 113	<0.005
DBP	77 ± 9 *n* = 106	79 ± 9 *n* = 114	80 ± 9 *n* = 113	<0.05
FVC %	105 ± 13 *n* = 104	104 ± 13 *n* = 112	100 ± 13 *n* = 111	<0.05
FEV_1 %	103 ± 14 *n* = 104	104 ± 14 *n* = 112	102 ± 14 *n* = 111	NS
ALKPHOS	82 ± 22 *n* = 103	81 ± 22 *n* = 113	85 ± 22 *n* = 113	NS
CHOL	219 ± 39 *n* = 57	224 ± 39 *n* = 69	242 ± 39 *n* = 62	<0.005
BUN	15 ± 4 *n* = 105	16 ± 4 *n* = 114	16 ± 4 *n* = 113	NS
CR	1.08 ± 0.16 *n* = 105	1.13 ± 0.16 *n* = 114	1.13 ± 0.16 *n* = 113	<0.05
AST	24 ± 10 *n* = 104	24 ± 10 *n* = 114	27 ± 10 *n* = 112	<0.05
ALT	31 ± 20 *n* = 104	35 ± 20 *n* = 114	43 ± 20 *n* = 112	<0.001
FITRANK	3.2 ± 1.3 *n* = 106	3.7 ± 1.3 *n* = 114	4.2 ± 1.3 *n* = 113	<0.001

* Unadjusted data. SBP, systolic blood pressure; DBP, diastolic blood pressure; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; ALKPHOS, alkaline phosphatase; CHOL, cholesterol; BUN, blood urea nitrogen; CR, creatinine; AST, aspartate aminotransferase; ALT, alanine aminotransferase; FITRANK, increasing morbidity parameter.

BMI group, with a mean BMI of 28.5 ± 0.8; and 34% (113 of 333) comprised the high BMI group, with a mean BMI of 33.3 ± 2.8.

Physiologic, Metabolic, and Morbidity Profiles of Firefighters, Classified by Body Mass Indices (BMI)

Table 1 describes the metabolic, physiologic, and morbidity profiles of the cohort, grouped by low, medium, and high BMI. Table 2 describes the same profiles for males only, adjusting for the confounding influence of age.

The low BMI group was significantly younger than both the medium and high BMI groups (both, $P <$ 0.05). Greater BMI was consistently associated with higher resting blood pressures. Mean systolic resting blood pressure ($P < 0.001$) and diastolic resting blood pressure ($P <$ 0.05) were both significantly higher in the high BMI group, compared with the low group. When we adjusted for age, the low BMI class still exhibited significantly lower systolic ($P < 0.005$) and diastolic ($P < 0.05$) blood pressure values than did the high BMI group. The unadjusted difference was also statistically significant for systolic pressure between the low and medium BMI groups ($P < 0.01$) and remained so when the effect of age was adjusted ($P <$ 0.01).

Firefighters in the high BMI group had a significantly lower mean percent predicted forced vital capacity (FVC) versus the low BMI group ($P < 0.05$). This difference became more significant when we adjusted for the effect of age ($P < 0.01$). In both the univariate and the age-adjusted models, there were no significant differences between the spirometric function of the low and medium BMI groups.

Increasing BMI was associated with increasing serum cholesterol levels. The age-adjusted differences were less marked. The mean serum cholesterol level of the high BMI group was significantly higher than the mean of the low group, whether unadjusted ($P < 0.01$) or adjusted ($P < 0.05$) means were considered.

The mean creatinine values for the medium and high BMI groups were significantly higher ($P < 0.05$ for both) than those of the low BMI group, although the differences were quite small. Adjusting for age had little effect on the groups' mean creatinine values. In the age-adjusted models, the creatinine value for the low BMI group remained significantly lower versus the high group ($P < 0.05$) and nonsignificantly lower versus the medium group at the trend level ($P < 0.10$).

Increasing BMI was consistently associated with increasing serum transaminase levels. Significant increases in AST ($P < 0.05$) and ALT ($P < 0.001$) levels were seen in the high BMI group versus the low group. When we adjusted for age, both differences between the low BMI and high BMI groups were still present at the same levels of significance. A second multivariate model for transaminase values adjusted for the influences of both age and cholesterol. In this model, only the mean ALT value for the high BMI group remained significantly higher than that of the low group ($P < 0.05$).

Reported ethanol consumption data were available for 114 males. There was no significant relation between the number of alcoholic drinks consumed per week and AST ($r = 0.05$; $P = 0.58$), ALT ($r =$ 0.16; $P = 0.085$), or alkaline phosphatase ($r = 0.05$; $P = 0.601$). When AST and ALT were examined for the three BMI groups and adjusted for ethanol intake, alcohol consumption had no significant effect ($P = 0.57$ and $P = 0.12$, respectively). In this model, the effect of BMI on AST and ALT was reduced to the trend level in both cases (both $P < 0.10$), prob-

TABLE 2
Correlates of Obesity: Males Only*

Variable	Low BMI	Medium BMI	High BMI	ANOVA *P*
SBP	119 ± 13 *n* = 99	123 ± 13 *n* = 107	125 ± 13 *n* = 106	<0.003
DBP	77 ± 9 *n* = 99	79 ± 9 *n* = 107	80 ± 9 *n* = 106	NS
FVC %	105 ± 13 *n* = 97	105 ± 13 *n* = 105	100 ± 13 *n* = 104	<0.01
FEV_1 %	103 ± 14 *n* = 97	104 ± 13 *n* = 105	102 ± 13 *n* = 104	NS
ALKPHOS	82 ± 21 *n* = 96	80 ± 21 *n* = 106	86 ± 21 *n* = 106	NS
CHOL	223 ± 38 *n* = 50	223 ± 38 *n* = 66	241 ± 38 *n* = 57	<0.05
BUN	16 ± 4 *n* = 98	16 ± 4 *n* = 107	16 ± 4 *n* = 106	NS
CR	1.09 ± 0.17 *n* = 98	1.14 ± 0.16 *n* = 107	1.14 ± 0.16 *n* = 106	NS (*P* = 0.089)
AST	24 ± 10 *n* = 97	24 ± 10 *n* = 107	27 ± 10 *n* = 105	<0.05
ALT	30 ± 20 *n* = 97	35 ± 20 *n* = 107	42 ± 20 *n* = 105	<0.001
FITRANK	3.4 ± 1.2 *n* = 99	3.6 ± 1.2 *n* = 107	4.1 ± 1.2 *n* = 106	<0.001

* Age-adjusted data.

ably because of the decreased sample size ($n = 112$).

The mean fit rank of the low BMI group was significantly lower than the means for the high group ($P < 0.001$) and the medium BMI group ($P < 0.01$). In the age-adjusted models, only the mean fit rank of the high BMI group remained significantly higher than that of the low group ($P < 0.001$).

Smoking and Body Mass Index

Complete data on smoking history were available for 82% (269 of 329) of the male firefighters. The mean BMI was 29.1 ± 4.3 for the never-smokers ($n = 180$), 28.3 ± 3.1 for the former smokers ($n = 57$), and 27.7 ± 3.6 for the current smokers ($n = 32$). When the BMI of never-smokers was compared with the BMI of the other two groups, neither difference was statistically significant. However, the mean BMI of the never-smokers was significantly higher ($P < 0.05$) when compared with the mean BMI of the combined group of current and former smokers ($n = 89$) (28.1 ± 3.3).

To control for the effects of smoking, we examined the same physiologic, metabolic, and morbidity profiles as above for all male never-smokers ($n = 180$). These data are presented in Table 3. The age-adjusted means for each of the three BMI groups and their rank orders were similar to the age-adjusted means in Table 2. The exception was for mean fit rank scores, which improved for all three groups. Overall, the significance level of the differences was attenuated most likely by the decrease in sample size.

The high BMI group continued to have a significantly higher mean serum cholesterol level ($P < 0.05$), ALT level ($P < 0.01$), and fit rank score ($P < 0.001$) than the low group. The magnitude of the differences between the high and low groups for creatinine level and percent predicted FVC decreased to the trend level ($P < 0.10$). The medium group had significantly higher creatinine values ($P < 0.05$) and a trend toward a higher percent predicted forced expiratory volume in one second (FEV_1) ($P < 0.10$) than did the low group. When adjustments were made for both age and smoking, the medium group had the highest mean percent predicted FEV_1 and FVC.

Discussion

This study documented high prevalence of both overweight status (87%) and obesity (34%) in our cohort. Morbid obesity was present in 2% of the cohort. The mean BMI was 28.9 ± 4.1 kg/m^2. This mean is above the 85th percentile for both men and women for BMI, based on National Health and Nutrition Examination Survey data.[17] In addition, the majority of the cohort (59%) was above the 85th percentile for BMI.

The results of our investigation are consistent with the literature in demonstrating adverse associations between increasing BMI and resting systolic and diastolic blood pressures; FVC; AST, ALT, and serum cholesterol levels; and overall morbidity.[4–7,10]

Increasing age was also associated with increasing BMI, and therefore the physiologic and metabolic effects of BMI were confounded by age. Nonetheless, in multivariate models that adjusted for age, all of the adverse associations with increasing BMI remained statistically significant, with the exception of resting diastolic blood pressure. Smoking, conversely, was associated with having a lower BMI. When the confounding effects of smoking were eliminated by examining never-smokers only, the results were similar, but the significance level of the differences was attenuated most likely by the large decrease in sample size.

There are, however, some limitations to the study. First, although BMI is a reliable and cost-effective measure of obesity and its related risks, it does not distinguish between excess weight due to body fat and weight as a result of bone and muscle mass.[12] We did find a positive association between BMI and creatinine, which suggests that muscle mass increases in addition to increased adi-

TABLE 3
Correlates of Obesity: Male Never-Smokers Only*

Variable	Low BMI	Medium BMI	High BMI	ANOVA *P*
SBP	120 ± 12 *n* = 62	122 ± 12 *n* = 50	124 ± 12 *n* = 66	NS
DBP	78 ± 9 *n* = 62	78 ± 9 *n* = 50	80 ± 9 *n* = 68	NS
FVC %	104 ± 14 *n* = 61	106 ± 14 *n* = 49	99 ± 14 *n* = 67	<0.05
FEV_1 %	102 ± 14 *n* = 61	107 ± 14 *n* = 49	102 ± 14 *n* = 67	NS
ALKPHOS	82 ± 22 *n* = 60	80 ± 22 *n* = 50	86 ± 22 *n* = 68	NS
CHOL	217 ± 42 *n* = 30	224 ± 41 *n* = 31	244 ± 41 *n* = 31	<0.05
BUN	16 ± 4 *n* = 61	16 ± 4 *n* = 50	16 ± 4 *n* = 68	NS
CR	1.10 ± 0.17 *n* = 61	1.18 ± 0.17 *n* = 50	1.16 ± 0.16 *n* = 68	<0.05
AST	23 ± 11 *n* = 61	25 ± 11 *n* = 50	27 ± 11 *n* = 68	NS (*P* = 0.068)
ALT	29 ± 20 *n* = 61	34 ± 20 *n* = 50	41 ± 20 *n* = 68	<0.01
FITRANK	2.9 ± 1.0 *n* = 62	3.0 ± 1.0 *n* = 50	3.9 ± 1.0 *n* = 68	<0.001

* Age-adjusted data.

pose tissue as BMI increases. Moreover, BMI measurements do not describe a subject's fat distribution, which is an important consideration in obesity-related risk factors.[4,5,12] Central fat distribution appears to enhance the risk for several obesity-related conditions, including coronary artery disease, hypertension, blood lipids, and diabetes.[4]

Overall, however, BMI measurements correlate strongly to body-fat percentage[18,19] and to the waist-to-height ratio, a measure of abdominal fat distribution.[12] BMI is widely recognized as a good epidemiologic measurement of obesity, with strong relationships to various health risks.[4,5,10,12] Indeed, when we analyzed data from only non-overweight subjects (BMI of 19 to <25), resting blood pressures, serum cholesterol levels, serum transaminase levels, and morbidity ratings were all even lower than those for the low group (BMI < 27). Finally, the literature documents a direct association between BMI and mortality and morbidity risk in adult men.[4,5,10]

Second, because of limitations in our database, we were unable to control completely for some confounding factors. Our database provided qualitative smoking data, ie, "current," "former," or "never," but not quantitative smoking information, ie, cigarettes/day or pack-years. Also, information on ethanol consumption was available for only about one third of our cohort. Ethanol consumption may also have been underreported because the subjects were public safety officers undergoing fitness for duty examinations. Lastly, our study population was predominantly white and male, and therefore, we could not investigate the effects of race and gender.

Several of our findings deserve further discussion. The prevalences of both overweight status and obesity among our HAZMAT firefighters were strikingly high and greater than those of the US adult population. Thus our cohort would appear to be at a heightened risk for morbidity and mortality when compared with the general US population. Within the cohort, there was a clear and consistent increase in morbidity scores with increasing BMI. This is consistent with the findings of previous studies.[4,10] It must be acknowledged, however, that the internist-generated morbidity ratings were not blinded to height and weight.

Another important finding is the adverse relationship between BMI and liver transaminases: AST and, especially, ALT. Our results, including the more marked effect of increasing BMI on ALT, compared to AST, are consistent with the results of other investigators' cross-sectional studies of BMI and liver enzyme activity.[6,7] These studies provide further support that obesity is a risk factor for the development of fatty liver. In addition, this current study in HAZMAT firefighters, the investigation of hazardous waste workers by Hodgson et al,[6] and the study by Burns et al[7] of chemical workers demonstrate that obesity definitely confounds medical surveillance for potential hepatotoxins.

Consistent with other studies, we found that BMI was significantly and consistently associated with increasing cholesterol levels.[4] Although the mean differences were small, BMI was also associated with higher resting systolic and diastolic blood pressures, which is also consistent with the literature.[4,12] Epidemiologic studies suggest increased cardiac mortality rates for firefighters.[20] In addition, fatality statistics have consistently shown that myocardial infarctions account for approximately 45% of firefighter deaths in the line of duty.[21] They also demonstrate that most of these persons have a prior history of heart and/or other vascular disease. Others have shown obesity to be associated with insulin resistance, type II diabetes, and cardiovascular disease itself.[4] Therefore, the high prevalence of obesity in our cohort and its adverse associations with heart disease and documented cardiac risk factors provide strong arguments for the development of effective fitness and health-promotion programs for firefighters.

Numerous studies have examined the association between obesity and other problems not investigated in this study. The Jette and Sidney[12] study documented decreased muscular endurance and diminished aerobic and anaerobic capacity in obese military personnel. Similar results have been found in firefighters.[22–24] Therefore, some obese firefighters may not be able to meet the well-documented physical demands of their jobs.[24–26] Decreased work capacity and higher energy expenditures for the same work also predispose obese workers to heat-related disorders.[13]

Other researchers report a strong association, especially in men, between obesity and sleep apnea,[9,27–32] sleep disturbances,[8,9] and increased daytime sleepiness even in the absence of apnea.[8] In obese males with BMIs between 32 and 39 and no primary sleep complaints, Vgontzas et al[9] found a 20% prevalence of obstructive sleep apnea that was severe enough to warrant treatment. Among morbidly obese males with BMIs $\geq$ 39, the prevalence was 50%. These BMI ranges correspond to 17% and 2% of our cohort, respectively. If the results from Vgontzas et al[9] are generalizable to our cohort, we would expect a 4.5% (15 of 329) prevalence of sleep apnea that was severe enough to warrant treatment. Additional sleep deprivation and sleep disturbances due to shift work may potentiate these safety risks. The possible presence of an obesity-related sleep disorder that could impair a firefighter's abilities and heighten the risks to personal and public safety should be addressed in fitness for duty examinations.

Consistent with Jette and Sidney,[12] we found that increasing age was associated with increases in BMI. Because BMI is likely to increase with age, we can reasonably conclude, as did Jette and Sidney[12] with armed forces recruits, that a firefighter who is overweight at hire will probably remain overweight and gain additional weight over time. Again, this likely scenario emphasizes the need for effective fitness and health-promotion programs. A review of several physical fitness intervention programs for firefighters documents that such programs can be effective.[33] Positive outcomes include increased maximum oxygen consumption, muscular strength and flexibility, and a decreased percentage of body fat. In conclusion, the high prevalences of obesity and overweight status, their adverse health and fitness associations, and their potential reversibility argue for the development and implementation of fitness-promotion programs for firefighters.

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Correlates of Fitness for Duty in Hazardous Materials Firefighters

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Background and Methods *From a statewide medical examination program, we identified firefighters who were deemed unfit for duty by attending physicians (ATTENDING FAIL, $n = 9$) and those who would have been disqualified by the application of selected numerical criteria from the 1997 National Fire Protection Association (NFPA) guidelines (NFPA FAIL, $n = 27$) and criteria from a Medical Workshop (WORK FAIL, $n = 16$). The subjects who were unfit for duty or failed numerical criteria were compared with those who were fit for duty and passed all objective criteria (FIT group, $n = 302$). All subjects were given an overall morbidity rating by a board certified internist. Comparisons on two surrogate measures of fitness, VO_2 max predicted and predicted coronary heart disease (CHD) risk, were also performed.*

Results *We found a significant tendency towards worse results (e.g. higher blood pressure or lower spirometric function) among the three FAIL groups compared with the FIT group. The FAIL groups shared only a small overlap, however, with the firefighters with the highest morbidity ratings, lowest predicted VO_2 max, and highest CHD risks. Increasing morbidity was associated with higher age, lower spirometric function, lower predicted VO_2 max, increasing cholesterol, greater BMI, and higher predicted 10 year CHD risk.*

Conclusion *Although the presence of a single serious or poorly controlled condition may render an individual unfit for safe performance as a firefighter, examination of our cohort suggests that multiple risk factor models or overall clinical assessments are superior means of identifying firefighters with poor health status and increased CHD risk.* Am. J. Ind. Med. 36:618–629, 1999. *© 1999 Wiley-Liss, Inc.*

KEY WORDS: firefighters; fitness for duty; morbidity; body mass index; pulmonary function; cardiac/coronary risk predictors

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INTRODUCTION

There are an estimated one million persons in the United States involved in firefighting [Morse et al., 1992]. The 1997 National Fire Protection Association (NFPA) Standard Medical Requirements for firefighters [NFPA 1582, 1997] recommend medical examinations for all of these individuals. Additionally, an increasing number of communities have developed hazardous materials (hazmat) teams composed of specially-trained firefighters to respond to chemical spills, fires, and accidents. The OSHA standard on Hazardous Waste Workers [29 CFR.1910.120, 1989] requires medical surveillance for these hazmat firefighters and other potentially exposed workers. In Massachusetts, new firefighter candidates must now pass a physical abilities test, preplacement medical examination, and periodic medical examinations every two years thereafter. Most current incumbent firefighters in Massachusetts, however, do not undergo any required periodic medical testing.

Despite widespread recommendation and practice, it is unknown if medical examination programs can decrease morbidity and mortality, or if they correctly select persons who are medically capable or incapable of firefighting. Most surveillance tests and fitness for duty criteria are currently advocated on theoretical grounds, and limited scientific evidence is available to support their use in medical surveillance examinations and fitness for duty determinations [Kales et al., 1997, 1998]. Fitness guidelines (e.g., NFPA 1582) traditionally review at what point, or in the presence of what manifestations, specific conditions or diseases become "incompatible with the safe performance of essential job functions..." [Samo and Bogucki, 1999]. Even less data can be used to support or refute various cutoff values beyond which point a firefighter is suggested to become unfit for duty [Kales et al., 1998; Kales and Christiani, 1999]. No "gold standard" for determining fitness or for validating proposed fitness criteria exists.

Given the absence of a "gold standard" or a prospective study of outcomes, surrogate measures of fitness could be considered. The NFPA [NFPA 1582, 1997] regards the following to be among the essential capabilities of a firefighter: the ability to "... make rapid transitions from rest to near maximal exertion without warm-up periods"; to wear about 50 pounds of personal protective equipment, and at the same time to "... perform physically demanding work . . . at near maximal heart rates for prolonged periods of time...". Therefore, an adequate aerobic capacity or exercise tolerance might be one surrogate of fitness for duty.

Another goal of fitness determination is the identification of individuals at high risk for incapacitation and death during firefighting. Fatality data collected by the NFPA show that the on-duty death rate is over six times higher for firefighters over 60 years of age and three times higher for 50–59 year olds than for those 20–39 years old [Washburn, 1998]. The NFPA has also shown that heart attacks are consistently the most frequent cause of death among firefighters, accounting for 45% of US fatalities during the period 1977–1996 [NFPA, 1998]. Over 90% of these deaths occurred in individuals with known heart disease or significant coronary heart disease risk factors. Fifty per cent had prior myocardial infarctions or bypass surgery, another 32% had severe coronary atherosclerosis, and an additional 12% had diabetes or hypertension [Washburn, 1998]. The absolute number of heart disease deaths, however, is about 40–45 per year [NFPA, 1998; Washburn, 1998], so the overall risk of death is low. Therefore, it is unclear how to best exclude those at the highest risk while avoiding age discrimination and without disqualifying a large number of firefighters from duty who, despite risk factors, will perform without significant problems.

We previously examined the clinical yields of various examinations, and the practical implications of applying selected NFPA and other fitness criteria to a cohort of hazardous materials firefighters [Kales et al., 1998]. We also compared these suggested fitness criteria to the attending physicians' determinations of fitness for duty. Because no "gold standard" exists for determining fitness or for validating proposed fitness criteria, we could not test the sensitivity, specificity, or predictive values of the fitness criteria or the physicians' clinical fitness determinations.

Although the hypothesis might be considered intuitive, we are unaware of any investigations that demonstrate that firefighters who are found "unfit for duty" or who fail to meet selected NFPA or other proposed criteria are actually less healthy than their "fit" colleagues as measured by objective testing. Likewise, it has not been shown that such persons are incapable of safely performing as firefighters. Therefore, in this study, we compared the health profiles of firefighters who failed fitness for duty determinations by attending physicians and those who failed various objective criteria with the profiles of firefighters who were judged fit for duty and passed all objective criteria. We included comparisons on two surrogate measures of fitness, VO_2 max predicted and predicted coronary heart disease (CHD) risk, as both a poor aerobic capacity and/or high risk of cardiac incapacitation may impair the safe and successful performance of essential firefighting job functions. We also examined the same health/fitness profiles in association with low, moderate, and high clinical morbidity ratings.

METHODS

Subjects

The subjects were all members (n = 340) of six regional hazardous materials response teams of the Commonwealth of Massachusetts as well as regular municipal firefighters for local departments. The population included four women

(1%). The team members' ages ranged from 21 to 58 with a mean of 39 and a standard deviation of 6.9. Some had undergone previous surveillance examinations, while for others, these were their baseline medical examinations after joining the teams.

Baseline and Periodic Medical Examinations

These examinations were performed for the dual purposes of medical surveillance of hazardous materials response duty and determination of fitness for the state hazardous materials teams. These fitness determinations for state duty do not apply to firefighters' work status/capacity with their municipal (non-hazmat) fire departments.

Medical surveillance examinations for all subjects were performed at three hospitals: Massachusetts Respiratory, Marlborough or Holyoke Hospital in 1996 or 1997 in the first year of a statewide surveillance program. All examinations were conducted in a similar fashion: similar history forms, laboratory tests and standardized physical examination procedures were utilized. The components of the examinations were in accordance with both the OSHA standard on Hazardous Waste Workers (29 CFR.1910.120, 1989) and the NFPA 1582 medical requirements for firefighters [NFPA 1582, 1997]. Determinations of fitness were left up to the judgment of the attending physicians. No predetermined fitness criteria were applied. The attending physicians were all board certified in occupational medicine, and all except one were also board certified in internal medicine.

Examinations included a detailed medical, smoking, and environmental/occupational history tailored to emergency responders; physical examination; visual and audiometric testing; routine laboratory tests (complete blood count, blood urea nitrogen, creatinine, alkaline phosphatase, AST and ALT, and urinalysis); and spirometry. All individuals also underwent a minifitness evaluation: this test required a firefighter to ascend and descend two flights of stairs while wearing a respirator with pre- and post-test assessment of vital signs. Electrocardiogram, posterior–anterior chest roentgenogram, and RBC cholinesterase activity were also done as baselines if the 1996/1997 exam was the individual's baseline examination or the test had not been done previously.

Summary results of each firefighter's examination, including the attending physician's determination of fitness for duty, were transferred to a statewide computerized medical records repository at the Massachusetts Respiratory Hospital. The body mass index (BMI) in kg/m^2 of each subject was calculated from his/her height in inches and weight in pounds using the following formula [Pi-Sunyer, 1992]:

$$BMI = 703.1 \times \text{weight in pounds}/(\text{height in inches})^2$$

Fitness Criteria

Various methods and criteria for determining "fitness" were selected for study. These included: (1) the fitness for duty determinations by the examining attending occupational medicine physician; and (2) simulated *post hoc* fitness determinations based on (A) selected guidelines from NFPA 1582 [1997]; and (B) criteria agreed upon by the investigators and examining physicians at a medical "workshop" meeting.[1] Those determined to be unfit by the attending physician are identified as the "ATTENDING FAIL" group. The subjects who failed either the proposed NFPA or the workshop criteria during the *post hoc* review were identified as the "NFPA FAIL" and "WORKSHOP FAIL" groups, respectively. Those firefighters who satisfied all of the selected NFPA and medical workshop criteria and were determined to be fit by an attending physician were classified as the "FIT" group. Table I shows various cutoffs for resting blood pressure, post minifitness test blood pressure, and visual and audiometric deficits based on NFPA and workshop consensus criteria for determining that a firefighter is unfit for duty.

Determination of the Severity of Visual and Acoustic Deficits

All firefighters with corrected far visual acuity worse than 20/30 in one or both eyes were selected for further review. Binocular acuities were obtained from their examination charts for baseline or hazmat clearance at the 3 participating hospitals and compared to the study criteria.

The audiograms for all firefighters ($n = 124$) judged abnormal by the attending physician were obtained and systematically reviewed against the NFPA and medical workshop criteria. Those who were judged normal or "borderline" were assumed to pass the study criteria.

Overall Morbidity Rating ("fitrank")

The face problem sheet of each subject was reviewed by a board-certified internist (EOL). EOL had never examined any of the firefighters and was blinded to the subjects' fitness outcomes. The face problem sheet lists gender, age, height and weight, medical problems, medications, allergies, immunizations, and smoking history. All information listed on the face sheets except fitness outcomes was available to the reviewer. EOL rated each subject on a scale of 1–10 for increasing morbidity. A rating of 1 was considered most

[1] The workshop took place in January 1997. Actual examination results were discussed, and the proposed NFPA criteria were reviewed with state officials, firefighter representatives, and the examining physicians. Participants in developing the workshop criteria were Drs. Kales and Christiani, SNK, DCC and the examining physicians Drs. Artrerounian, Gassert, Hu, Kelsey, and Sweet. DA, TG, HH, KTK, and CS.

TABLE I. Objective Criteria for Exclusion from Fitness for Duty

Source	Resting blood pressure	Minifitness evaluation	Visual acuity	Audiometry	Pulmonary function
1997 revision of NFPA 1582	SBP > 179, DBP > 99	NA	Corrected binocular vision worse than 20/30	Hearing deficit in *unaided* worst ear: >25 dB in 3 of the 4 frequencies: 500, 1000, 2000, 3000 Hz or; >30 dB in either 500, 1000, or 2000 Hz *and* average >30 dB for: 500, 1000, 2000, 3000 Hz	No cutoff given
Medical workshop	DBP > 109	Post exertion SBP > 219 or DBP ≥ 109	Corrected binocular vision worse than 20/40	Same as NFPA, but for best *aided* ear.	No cutoff given

Please note, Table I presents objective study criteria and does not refer exclusively to our cohort of hazardous meterials firefighters.

healthy and 10 least healthy. This variable was labeled FITRANK. For the purpose of comparisons, low, moderate and high morbidity groups were defined as follows: low, FITRANK of 1–3; moderate, FITRANK of 4–6, and high, FITRANK of 7–10.

Calculation of Estimated Aerobic Capacity (VO_2 max)

We used the mean age, BMI, and VO_2 max for each 10 year age grouping from three studies [Lemon et al., 1977; Horowitz and Montgomery, 1993; Kilbom, 1980] and the overall means for VO_2 max, mean age, and mean BMI from two other studies [Davis et al.,1982; Boreham et al., 1994], to derive a regression equation for VO_2 max based on age and BMI. The equation is shown here:

$VO_2 \text{ max} = 94.02 - 0.44(\text{age}) - 1.52(\text{BMI})$;

Multiple R = 0.961; Squared Multiple R = 0.923; Age ($P < .0001$); BMI ($P = .006$)

Predicted Risk of Coronary Heart Disease

Each firefighter's risk of coronary heart disease over a period of 10 years was calculated from data from the Framingham study [Wilson et al., 1998]. The Framingham study formulated sex-specific coronary prediction algorithms according to age, diabetes, smoking, Joint National Committee blood pressure categories, National Cholesterol Education Program total cholesterol and LDL cholesterol categories, and HDL cholesterol. The algorithm predicts an average risk based on the CHD experience of a sample of 2489 men and 2856 women 30–74 years old at the point of their baseline examination between 1971 and 1974. We selected this prediction model because our cohort of predominantly white, suburban Massachusetts firefighters is similar to the white subjects drawn from a community in the western suburbs of Boston.

The CHD score sheet assigns a point value for each of the six categories and the predicted average risk is determined from the point total. Because of the small number of women (n = 4) in our cohort and the fact that the prediction equations for men and women are different, we excluded females from the CHD risk analysis. We assigned points in each of the six categories for the 154 firefighters for whom all necessary data are available. It is important to note the total cholesterol categories in the Framingham study were based on a blood test after an overnight fast. The total cholesterol values for the firefighters in our cohort were not fasting values, and this may slightly skew the results toward greater risk. On the other hand, we did not have direct information for HDL-cholesterol. Because the average cholesterol was over 225 mg/dL, we assumed that the average HDL value for our cohort would be lower than 44 mg/dL. Therefore, based on a point system in which <35 mg/dL = 2 points, 35–44 mg/dl = 1 point, 45–49 and 50–59 both = 0 points, and ≥60 = −2 points, we conservatively assigned a value of 1 point to each firefighter for the HDL category.

To validate our modified prediction model, we compared the mean 10 year CHD risks that we calculated with the average risks of the male subjects in the Framingham Study for five year age groupings. This is shown in Table II. The mean 10 year CHD risks for our male firefighter cohort correspond closely with those in the Wilson et al. [1998] Framingham study.

We derived each firefighter's estimated risk of coronary disease over a five year period from an earlier Framingham study [Anderson et al., 1991] of predicted CHD risk with a similar predictive model to the Wilson study. The Anderson et al. [1991] study's risk prediction equation provides estimates of both five and ten year risk. Given the similar

TABLE II. Predicted Coronary Heart Disease Risk of Firefighter Age Groups (Males Only), Hazardous Materials Firefighters, Massachusetts

Age group	N	Mean predicted 10 year CHD risk	Average 10 year CHD risk (Framingham study)
<30	6	3.0 ± 0.9%	NA
30–34	35	4.3 ± 1.5%	3%
35–39	36	5.1 ± 2.4%	5%
40–44	36	7.1 ± 2.9%	7%
45–49	30	10.8 ± 3.5%	11%
50–54	10	14.4 ± 5.4%	14%
55–59	1	13.0	16%
Total	154	7.1 ± 4.2%	NA

ANOVA: Between age groups (Combined).
Sum of squares = 1487.3; df = 6; mean square = 247.9; F = 31.1; $P < 0.001$.

predictive capabilities of the two algorithms, the ten year risk values derived from the Wilson et al. [1998] study approximate closely ten year risk values reported in the Anderson et al. [1991] study. Each firefighter's approximate five year risk was determined by selecting the five-year probabilities that correspond to each ten year probability in the Anderson et al. [1991] study.

Statistical Analyses

We hypothesized *a priori* that the various unfit groups would be older, have higher mean resting blood pressures, serum cholesterol, BMI, and overall morbidity ratings, and lower pulmonary function than the FIT group. Likewise, we hypothesized *a priori* that the groups with higher overall morbidity ratings would be older, have higher resting blood pressures, cholesterol levels, BMIs, and lower pulmonary function than the groups with lower overall morbidity ratings.

We used independent two-tailed t-tests to determine if the variable means of a FAIL group differed from the FIT group. Determinations of statistical significance were based on the assumption of separate variances between groups. Proportions were compared using the standard (Pearson's) chi-square test with the exception of comparisons where one or more cells had a frequency of less than five. Fisher's exact test was used to compare these proportions.

To compare groups with respect to differences on multiple variable means simultaneously, we used the sign test [Hines and Montgomery, 1980]. Dependent, closely related variables (e.g. systolic and diastolic blood pressure, and FVC % and FEV1%) were treated as one variable and variables calculated from independent variables (VO_2 max predicted, and predicted 10 year CHD risk) were not considered. This avoided counting differences on non-independent variables twice.

RESULTS

Fitness for Duty Determinations

A total of 331 (97%) firefighters were determined to be fit for duty by the attending physicians, and nine (3%), all males, were judged unfit. Seven failed, at least in part, due to their elevated resting and/or post exercise blood pressures. Two of these seven also were cited for abnormal liver function tests. One was unfit due to an orthopedic injury. The rationale for the ninth individual's failure was not explicitly present in the central database.

A total of 27 firefighters, the NFPA FAIL group, failed one or more of the selected NFPA criteria. A total of 16 firefighters, the WORKSHOP FAIL group, failed one or more of the medical workshop criteria. Table III summarizes the performance failures of the entire cohort on selected NFPA and medical workshop criteria. A total of 302 firefighters, the FIT group, satisfied all of the selected NFPA and medical workshop criteria and were determined to be fit by an attending physician. Figure 1 illustrates the overlap of the various FAIL groups.

Physiological/Metabolic/Morbidity Profiles of Fit vs. Various Fail Groups

Table IV describes the metabolic, physiological, and morbidity profiles of the FIT, NFPA FAIL, WORKSHOP FAIL, and ATTENDING FAIL groups. The FIT group was younger than all three FAIL groups and significantly younger than the NFPA and WORKSHOP FAIL groups (both $P < .05$). Resting blood pressures were also higher for all three FAIL groups when compared to the FIT group. Both the systolic and diastolic blood pressures of the ATTENDING FAIL group were significantly higher (both $P < .01$). The systolic blood pressure

TABLE III. Performance Failures of Total Cohort on Study Criteria, Hazardous Materials Firefighters, Massachusetts

Source	Resting blood pressure	Minifitness evaluation	Visual acuity	Audiometry	Total
1997 revision of NFPA 1582	7/340 (2.0%)	NA	5/335(1%)	16/330 (5%)	27
Medical Workshop	1/340 (0.3%)	7/336 (2%)	1/335 (0.3%)	8/330 (2%)	16

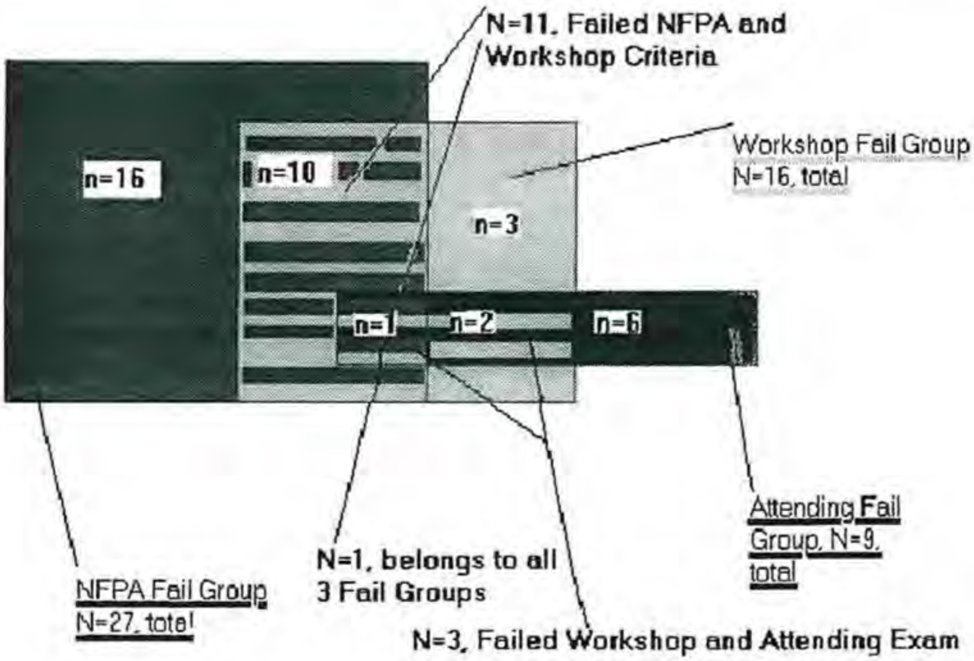

FIGURE 1. Overlap of various FAIL groups, Hazardous Materials Firefighters, Massachusetts.

of the WORKSHOP FAIL group was also significantly higher ($P < .05$).

The mean BUN of the FAIL groups were higher than that of the FIT group and was significantly higher for the ATTENDING FAIL group ($P < .05$). Other significant differences were observed between the WORKSHOP FAIL and FIT groups for FIT RANK (overall morbidity rating) ($P < .05$), and the mean predicted VO_2 max ($P < .05$).

We found a significant tendency towards slightly worse results (e.g. higher blood pressure or lower spirometric function) for the profile variables for the NFPA FAIL, WORKSHOP FAIL, and ATTENDING FAIL groups compared with the FIT group. In a Sign Test of the 35 possible variable comparisons[2], there were 4 ties, while 28 of 31 variable means were worse for the FAIL groups when compared to the FIT group ($P < .01$). Moreover, another Sign Test considered only those variables[3] for which we had an a priori hypothesis that the FAIL groups would perform worse than the FIT group. In this comparison of 20 variable means, there was one tie and 19 of the 19 total comparisons ($P < .01$) between variable means were worse for the FAIL groups compared to the FIT group.

Physiological/Metabolic/Morbidity Profiles of Firefighters Classified by Overall Morbidity Rankings ("fitrank")

Table V describes the metabolic, physiological, and morbidity profiles of the cohort grouped by low, moderate, and high overall morbidity rankings. The low morbidity group was significantly younger than both the moderate and high morbidity groups (both $P < .01$). Increasing morbidity was associated with lower spirometric function: both the mean percent predicted FVC and FEV1 were significantly lower for the high morbidity group than the low morbidity group ($P < .05$ and $P < .01$, respectively).

The increasing morbidity was associated with the increasing cholesterol and BMI. The mean cholesterol was significantly higher for the moderate and high morbidity groups ($P < .05$). The mean BMI of the low group was

2 Systolic and diastolic blood pressure are considered as one variable, as are FVC % and FEV1%.

3 Age, SBP, DBP, FVC %, FEV1%, cholesterol, BMI, and Overall Morbidity Rating.

TABLE IV. Physiological, Metabolic, and Morbidity Profiles of Fit vs. Various Fail Groups, Hazardous Materials Firefighters, Massachusetts

Variable	Fit by all N = 302	NFPA fail N = 27	Workshop fail N = 16	Unfit per MD N = 9
Age	39.0 ± 6.8	43.3 ± 7.5	44.3 ± 7.1	40.7 ± 8.4
	N = 287	N = 25; P = .011	N = 15; P = .014	N = 9; P = .577
SBP	122 ± 12	127 ± 21	135 ± 21	134 ± 11
	N = 302	N = 27; P = .181	N = 16; P = .022	N = 9; P = .008
DBP	78 ± 8	82 ± 15	85 ± 14	90 ± 9
	N = 302	N = 27; P = .202	N = 16; P = .062	N = 9; P = .005
FVC %	103 ± 13	103 ± 13	100 ± 13	96 ± 15
	N = 298	N = 25; P = .816	N = 14; P = .398	N = 9; P = .189
FEV1%	103 ± 13	101 ± 14	99 ± 12	96 ± 13
	N = 298	N = 25; P = .381	N = 14; P = .192	N = 9; P = .157
ALKPHOS	82 ± 21	85 ± 24	84 ± 21	91 ± 31
	N = 298	N = 27; P = .499	N = 16; P = .691	N = 9; P = .427
CHOL	226 ± 40	237 ± 39	246 ± 43	Insufficient data
	N = 173	N = 19; P = .234	N = 8; P = .226	
BUN	16 ± 4	17 ± 4	18 ± 5	19 ± 3
	N = 301	N = 27; P = .094	N = 16; P = .143	N = 9; P = .026
CR	1.1 ± 0.2	1.1 ± 0.1	1.1 ± 0.2	1.1 ± 0.2
	N = 301	N = 27; P = .378	N = 16; P = .593	N = 9; P = .517
AST	25 ± 10	24 ± 8	24 ± 5	26 ± 0
	N = 299	N = 27; P = .823	N = 16; P = .882	N = 9; P = .672
ALT	36 ± 20	39 ± 18	35 ± 12	45 ± 25
	N = 299	N = 27; P = .362	N = 16; P = .788	N = 9; P = .285
BMI	28.9 ± 4.1	28.9 ± 3.3	30.4 ± 3.2	30.8 ± 3.1
	N = 296	N = 26; P = .980	N = 15; P = .088	N = 8; P = .119
FITRANK	3.7 ± 1.3	3.9 ± 1.4	4.4 ± 1.2	3.8 ± 0.7
	N = 302	N = 27; P = .550	N = 16; P = .039	N = 9; P = .683
VO_2 max predicted	33 ± 7	31 ± 7	28 ± 6	30 ± 5
	N = 281	N = 24; P = .217	N = 14; P = .017	N = 8; P = .118
Predicted 10 year CHD risk	6.8 ± 4.1%	9.3 ± 4.6%	8.0 ± 3.1%	Insufficient data
	N = 138	N = 15; P = .063	N = 6; P = .393	

significantly lower than the means for both the moderate ($P < .01$) and the high morbidity groups ($P < .05$). The mean predicted VO_2 max of the moderate and high morbidity groups was significantly lower than that of the low morbidity group (both $P < .01$). Finally, the predicted 10 year CHD risks were significantly higher for the moderate and high morbidity groups ($P < .001$ and $P < .005$, respectively) compared to the low morbidity group.

When all the profile means of the low morbidity group were compared with those of the moderate and high morbidity groups, the Sign Test did not reach statistical significance for either group. For the moderate morbidity group, 7 of 8 means were worse, with 3 ties ($P = .10$). For the high morbidity group, 7 of 9 were worse, with 2 ties ($P \geq .10$). However, when only those variables[4] for which we had an *a priori* hypothesis were considered, the Sign Test was significant in both cases. Both the moderate and high morbidity groups performed worse on 6 of 6 means compared to the low morbidity group (both $P < .05$).

The prevalence of ever smoking and current smoking increased with increasing morbidity. This was expected, as the rating internist was not blinded to smoking status and used this information in rating subjects. In the low morbidity group, 14% (20/138) were current or former smokers compared to 50% (65/131) of the moderate ($P < .01$) and 78% (7/9) of the high morbidity group ($P < .00$, Fisher's Exact Test). No current smokers were found in the low morbidity group (0/153) compared to 20% (29/142) of the moderate ($P < .01$) and 44% (4/9) of the high morbidity group ($P < .01$, Fisher's Exact Test).[5]

[4] Age, SBP, DBP, FVC %, FEV1%, cholesterol, BMI, and Overall Morbidity Rating.

[5] The N's for smoking prevalence vary due to non-uniform answers; i.e. never smoker vs. non-smoker.

TABLE V. Physiological, Metabolic, and Morbidity Profiles of Firefighters Classified by Overall Morbidity Ratings ("FITRANK"), Hazardous Materials Firefighters, Massachusetts

Variable	Fitrank 1–3 N = 173	Fitrank 4–6 N = 158	Fitrank 7–10 N = 9
Age	37.4 ± 6.7	40.9 ± 6.5	49.4 ± 4.4
	N = 162	N = 152; *P* = .000	N = 9; *P* = .000
SBP	122 ± 13	123 ± 13	127 ± 17
	N = 173	N = 158; *P* = .673	N = 9; *P* = .438
DBP	79 ± 9	79 ± 9	79 ± 10
	N = 173	N = 158; *P* = .490	N = 9; *P* = .972
FVC %	104 ± 14	102 ± 12	92 ± 12
	N = 168	N = 157; *P* = .130	N = 9; *P* = .021
FEV1%	104 ± 14	102 ± 12	89 ± 10
	N = 168	N = 157; *P* = .096	N = 9; *P* = .002
ALKPHOS	82 ± 20	83 ± 22	89 ± 30
	N = 169	N = 158; *P* = .736	N = 9; *P* = .539
CHOL	220 ± 43	235 ± 34	247 ± 22
	N = 105	N = 82; *P* = .011	N = 7; *P* = .019
BUN	16 ± 4	16 ± 4	16 ± 4
	N = 172	N = 158; *P* = .165	N = 9; *P* = .863
CR	1.1 ± 0.2	1.1 ± 0.2	1.1 ± 0.1
	N = 172	N = 158; *P* = .014	N = 9; *P* = .269
AST	25 ± 12	25 ± 8	24 ± 7
	N = 171	N = 157; *P* = .724	N = 9; *P* = .818
ALT	37 ± 23	36 ± 18	30 ± 14
	N = 171	N = 157; *P* = .427	N = 9; *P* = .194
BMI	27.9 ± 3.5	30.0 ± 4.3	31.2 ± 3.3
	N = 171	N = 153; *P* = .000	N = 9; *P* = .015
Predicted 10 year CHD risk	5.3 ± 2.6%	8.1 ± 3.9%	16.3 ± 6.2%
	N = 80	N = 67; *P* = .000	N = 7; *P* = .003
VO_2 max predicted	35 ± 6	31 ± 7	25 ± 6
	N = 160	N = 147; *P* = .000	N = 9; *P* = .001

The likelihood of failing the attending physician's fitness determination and/or any one of the study criteria was essentially the same across morbidity rankings of 2–6, varying only from 10–13%. It differed only at the extremes: 0% (0/11) for those with a morbidity rating of 1, and 22% (2/9) for those with ratings of 7–10. Figure 2 shows the minimal overlap between the high morbidity group and the FAIL groups.

Predicted Coronary Heart Disease Risk

An examination of the mean predicted CHD risk for 5 year age categories (Table II), discussed above in the Methods section, demonstrates a statistical association between increasing categorical age and mean predicted 10 year CHD risk (ANOVA between age groups, $P < .001$). Based on the NFPA recommendation that firefighters age 40 and older undergo exercise stress testing, we examined the ability of this guideline to identify individuals with 5 year CHD risks $\geq 5\%$ and $\geq 3\%$. These data are displayed in Figure 3.

Implementing a guideline of exercise stress testing for all firefighters aged 40 years or more would select for stress testing 40 of the 42 firefighters (95%) with a 5 year CHD risk of 5% or greater. This guideline, however, would also select 37 firefighters for stress testing who have a 5 year CHD risk that is less than 5%. For selecting firefighters with a 5 year CHD risk $\geq 3\%$, the age-based guideline is less sensitive: 59 of 74 (80%). For 5 year CHD risk $\geq 3\%$, the age-based guideline is more specific in that only 18 of the 77 (23%) subjects selected for testing by the age-based guideline would have had predicted 5 year CHD risk that is $<3\%$.

The overlap of the low, moderate, and high morbidity groups with the subgroups with increased CHD risk is shown in Table VI. Although elevated CHD risks are more

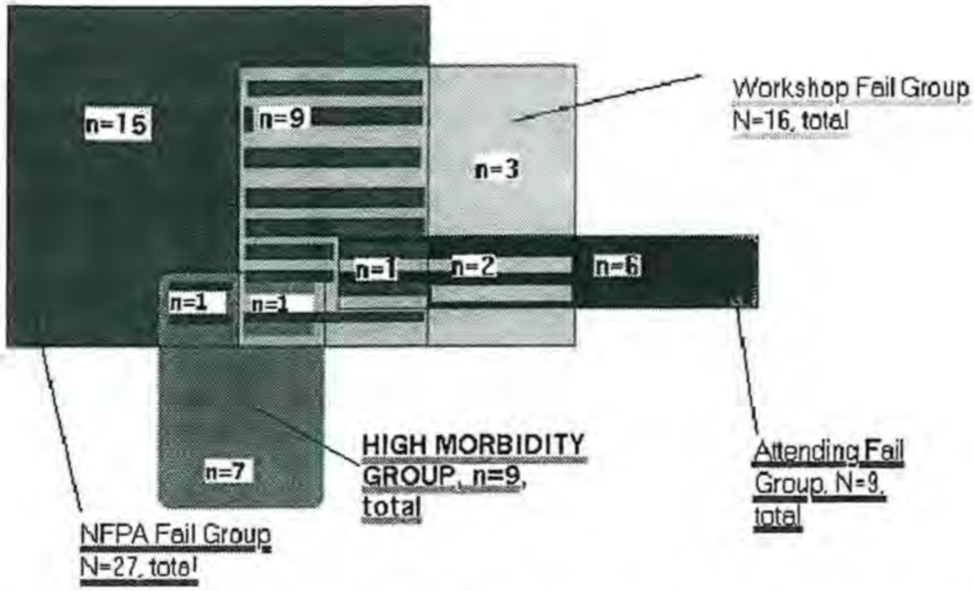

FIGURE 2. Overlap between FAIL groups and physician-derived "high" morbidity group, Hazardous Materials Firefighters, Massachusetts.

TABLE VI. Overlap Among Morbidity Groups and 5 Year Coronary Heart Disease Risk Groups, Hazardous Materials Firefighters, Massachusetts

5 year coronary heart disease risk	<3% N (% of row total)	3 to <5% N (% of row total)	≥ 5% N (% of row total)
Low morbidity group N = 80	55 (69%)	15 (19%)	10 (12%)
Moderate morbidity group N = 67	25 (37%)	16 (24%)	26 (39%)
High morbidity group N = 7	0 (0%)	1 (14%)	6 (86%)

likely with increasing morbidity scores, substantial numbers of firefighters with low or moderate morbidity ratings also had 5 year CHD risks ≥5%.

DISCUSSION

In this study, we have demonstrated that firefighters who failed a physician's fitness for duty determination, as well as those who failed selected numerical fitness criteria, on average had worse physiological and metabolic profiles than firefighters who passed the attending examination and all study criteria. On the other hand, these criteria did not tend to select firefighters with the highest morbidity scores, lowest predicted VO_2 max, and highest predicted CHD risks. The overlap of the FAIL groups with the high morbidity group is shown in Figure 2.

The converse criticism can be made for the NFPA age-based guidelines for stress testing (see Fig. 3). Since the NFPA also suggests stress testing for persons over 35 with "one or more coronary artery disease risk factors [premature family history (less than age 55), hypertension, diabetes mellitus, cigarette smoking, and hypercholesterolemia (total cholesterol >240 or HDL cholesterol <35) [NFPA 1582, 1997]", the sensitivities for identifying all persons with CHD risks at or above the cutoff values would be even higher than those shown in Figure 3. Despite the strong statistical association between 10 year CHD risk and increase in categorical age in this study and the documented increased on-duty death rates for older firefighters [Washburn, 1998], CHD risk is dependent also on other factors. Implementation of primarily age-based guidelines would lead to testing large numbers of firefighters with low CHD risks. Given that our data for the firefighter cohort for five year age intervals match closely with the Framingham data [Wilson et al., 1998] (see Table II), our investigation suggests that a multivariate risk factor selection protocol is the most accurate and cost efficient method of selecting firefighters for exercise stress testing.

Age	Five-Year CHD Risk ≥ 5%	Five-Year CHD Risk < 5%	Totals:
≥ 40	40	37	77 (50%)
< 40	2	75	77 (50%)
Totals:	42 (27%)	112 (73%)	154 (100%)

Sensitivity = 95% (40/42)
Specificity = 67% (75/112)
Positive predictive value = 52% (40/77)
Negative predictive value = 97% (75/77)

Age	Five-Year CHD Risk ≥ 3%	Five-Year CHD Risk < 3%	Totals:
≥ 40	59	18	77 (50%)
< 40	15	62	77 (50%)
Totals:	74 (48%)	80 (52%)	154 (100%)

Sensitivity = 80% (59/74)
Specificity = 78% (62/80)
Positive predictive value = 77% (59/77)
Negative predictive value = 80% (62/77)

FIGURE 3. Overlap between cohort subgroup ≥40 years of age and and coronary heat disease risk groups, Hazardous Materials Firefighters, Massachusetts.

In light of the NFPA data showing that heart attack is the predominant cause of death among firefighters, and the evidence that 90% of these fatalities occurred in firefighters with known CHD or CHD risk factors, our findings regarding CHD risk are particularly relevant. Moreover, the use of an evidence-based CHD prediction model is more likely to avoid violations of the Americans with Disabilities Act (ADA) because it would not identify firefighters for further testing on the basis of their age alone. It is still unclear, however, at what level of increased CHD risk the threshold for exercise stress testing should be set. Also unknown is how stress testing and subsequent evaluations of positive results would actually perform in distinguishing those at the highest risk of myocardial infraction and death. Such questions can only be answered by prospective studies.

Other findings that deserve further consideration regard the high morbidity group. Our data show that the predicted CHD risk is greater for both the moderate and high morbidity groups when compared to the low morbidity group. The high morbidity group had a 10 year CHD risk of 16.3%, while based on their age, an average risk of 12.6% is expected. This group was older, had a larger proportion of smokers, higher cholesterol, lower pulmonary function, more obesity (mean BMI >30), and a lower VO_2 MAX predicted (mean VO_2 max 25 ± 6 mL/kg · min). A recent study [Hegmann and Tavris, 1998] directly measured aerobic capacity in firefighters. They found the same risk factors or closely related ones (increased age, smoking, lower % FVC, and adverse lipid profiles) to be predictors of an aerobic capacity <30.0 mL/kg · min. In addition, other studies have consistently demonstrated that an increasing BMI is also inversely associated with aerobic capacity [Davis et al., 1982; Jette and Sidney, 1990].

The high morbidity group appears to be the least healthy 3% of our cohort. Our findings suggest that such individuals with multiple medical problems are likely to have both low exercise tolerances and elevated cardiac risks. Therefore, stress testing of firefighters high morbidity should be helpful in quantifying their work capacities and risks for cardiac incapacitation.

Despite known predictors of poor aerobic capacity, the appropriate minimum work capacity required of a firefighter is unclear. In a study of simulated firefighting, the mean VO_2 was 41.5 mL/kg · min during the most demanding operations. To support this work effort for a period of ten minutes requires a VO_2 max of 47.4 mL/kg · min [Gledhill and Jamnik, 1992]. Both Gledhill and Jamnik [1992] and Horowitz and Montgomery [1993] recommended that firefighter applicants should have a minimum aerobic capacity of 45 mL/min · kg. The NFPA suggests a minimum exercise capacity of 37 mL/min · kg (10 METS) as one of the prerequisites for the clearance of persons with known coronary artery disease [NFPA 1582, 1997]. They do not require or suggest a minimum aerobic capacity criterion for firefighters in general.

In contrast to these recommendations, studies of actual firefighter cohorts have shown considerably lower mean aerobic capacities. Based on the present study, and six other studies of incumbent firefighters that found aerobic capacities to range between 33 and 42 mL/min · kg [Davis et al., 1982; Lemon and Hermiston, 1977; Horowitz et al., 1993; Kilbom, 1980; Boreham et al., 1994; Hegmann and Tavris, 1998], we can reasonably conclude that substantial proportions of these actual cohorts lack the proposed "minimum" exercise tolerances. One possible explanation is that those firefighters with greater aerobic capacities are generally assigned or self-select the most demanding firefighting operations. Alternatively, simulations and recommended criteria may overestimate the actual minimum requirements. Simulated tasks measure one's ability to accomplish a task in one specific manner, while experienced firefighters may know less physically demanding ways to accomplish the same task. Such discrepancies emphasize the difficulty in reconciling physical testing standards with actual job performance. This is one of the reasons that NFPA 1582 was designed as a "medical standard" to identify medical conditions incompatible with the safe performance of essential job functions, but not a "physical standard" which would be designed to evaluate specific physical capabilities [Samo and Bogucki, 1999].

Several additional observations should be made regarding the selected numerical fitness criteria which were related to blood pressure, vision and hearing. Unlike blood pressure guidelines, the minimum hearing and vision criteria are advocated to reduce safety problems related to poor sensory input. One weakness of this study was the small number $(n = 10)$ of firefighters who failed one or more of the proposed blood pressure guidelines and for whom we had incomplete data for cardiac risk factors. Therefore, we were unable to examine the CHD risks of those failing blood pressure guidelines independent of those who failed vision and hearing criteria.

Obviously, the appropriateness of minimum vision and hearing guidelines cannot be judged on the basis of selection for poor health, prediction of low aerobic capacity or increased CHD risk. The validation of vision and hearing criteria needs to come from prospective studies that document increased risks of adverse outcomes for firefighters who fail the said criteria. This cohort is being followed prospectively and should provide some information on whether firefighters who lack the minimum proposed criteria actually have an increased risk of adverse outcomes. The fact that firefighters who failed the selected numerical fitness criteria have on average worse physiological and metabolic profiles probably relates to the association of increasing age with increasing blood pressure and declining vision and hearing. We did not control for age in this study because under the ADA, fitness determinations should not be made on the basis of age. In addition, being an outlier in one area might be associated with other health problems, and such individuals may be at an increased risk for several reasons. Again, the prospective studies should help clarify such risks.

This study has several limitations. First, its cross-sectional nature and lack of exercise stress testing do not allow us to directly validate the aerobic capacities and CHD risks that we predicted. Although we did not directly measure aerobic capacity, our prediction model is likely to be fairly accurate on average based on the independent results of Hegmann and Tavris [1998]. The mean age of our cohort was essentially the same as theirs: 39.4 ± 6.9 and 39.6 ± 6.8 years, respectively. Our cohort's mean predicted VO_2 max of 32.8 ± 7.1 mL/kg · min is quite close to the directly measured aerobic capacity in their study: 32.9 ± 7.3 mL/kg · min. In addition, the high morbidity group which had a higher proportion of the risk factors (increased age, smoking, lower % FVC, and adverse lipid profiles) as found by Hegmann and Tavris to predict VO_2 max < 30 mL/kg · min, had a predicted mean VO_2 max of 26 ± 5 mL/kg · min. Therefore, our regression equation might be helpful in identifying persons who are likely to have low aerobic capacities.

Regarding our CHD risk predictions, we used a model developed from a large cohort of white subjects drawn from a community in the western suburbs of Boston. Since our firefighters were predominantly white and from Massachusetts, the Framingham model should be generalizable to our cohort. Indeed, the mean CHD risks by age for our male firefighter cohort correspond closely with those found in the Wilson et al. [1998] Framingham study. A definite weakness, however, was the lack of complete CHD risk factor data (primarily cholesterol) for over half the cohort. The present article is based on the results of the first year of a 5 year longitudinal study. During the analysis of this data, we realized that cholesterol was not consistently being reported to the central data base. We have modified our reporting form to correct this deficiency. Therefore, we should have more complete information on CHD risk for the remainder of the study. Again, prospective follow-up of the cohort should reveal whether our predictions were accurate or not.

CONCLUSIONS

Although criteria are needed to guide physicians when the presence of a single advanced or poorly controlled condition may render a firefighter unfit for the safe performance of his/her essential job functions, poor fitness may be the result of a combination of several problems or risk factors. Based on examination of the data from our firefighter cohort, it seems that many of the least healthy or highest risk firefighters do not display extreme results on the tests usually considered in fitness determinations. Therefore, methods based on multiple risk factors or overall clinical assessments are superior means of identifying firefighters with poor health status and increased CHD risk when compared to selection methods based on single variables. The use of a multivariate CHD risk prediction formula appears to be the most accurate, cost-effective, evidence-based, and least arbitrary means of selecting firefighters for exercise stress testing. The age-based guideline suggested by NFPA is a sensitive selection tool, but has the disadvantage of selecting for stress testing a large proportion of firefighters who do not have a high CHD risk. It is still unclear, however, what threshold of increased CHD risk should trigger exercise stress testing. Such a threshold needs to be determined and validated in prospective studies of firefighter cohorts.

Our investigation also demonstrated that the group clinically rated below the 3rd percentile for health status (the high morbidity group) was a sub-group with high CHD risk, decreased pulmonary function, and low predicted aerobic capacity. The results suggest that firefighters clinically assessed to be in relatively poor health should undergo additional testing to further delineate their CHD risks and exercise tolerance. The minimum required aerobic capacity for firefighting remains unknown.

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Letters to the Editor

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Cardiovascular Fitness in Firefighters

To the Editor: The landmark report by Prezant et al[1] documented a dramatic decrease in burn injuries among New York City Fire Department (FDNY) firefighters after the adoption of a more protective "modern" uniform. A second article from the FDNY group (Malley et al[2]), a well-designed, controlled trial, demonstrated that the superior protection of the modern uniform comes at a cost of an increased cardiac workload because it is heavier, hotter, and stiffer. Treadmill exercise time in the modern uniform was significantly decreased as compared with the traditional uniform. Because of the high recommended aerobic capacity ($\geq$39 mL/kg/min MVO2) for safe performance as a firefighter,[3] and the increased work demands of the modern uniform, the authors stressed the "need for firefighters to maintain above average levels" of health and fitness.[2] We wholeheartedly agree with the authors that firefighters must maintain good physical fitness, and we think that this point deserves greater emphasis. In addition, some of the authors' interpretations, based on their small sample (n = 23) of volunteers, may have painted an overly optimistic picture of aerobic fitness among firefighters.

The authors found no relation between body mass index and maximal venous oxygen consumption (MVO2).[2] In a large study of military personnel, however, obesity was associated with both lower aerobic capacity and decreased muscular endurance.[4] Similar results have been found for firefighters.[5–7] The FDNY sample was likely biased toward healthier, lighter, and more fit individuals. They were all non-smokers with stable exercise regimens, stable body weights, and no significant medical problems.[2] In contrast, we found a 34% prevalence of obesity (body mass index $\geq$ 30) and a 12% prevalence of current smoking among firefighters on hazardous materials teams (n = 336).[8] In addition, 49% of our cohort were rated as having at least moderate medical problems.[9] A study that included 73% (n = 1303) of the Montreal fire department found those firefighters to have higher body mass indexes and lower cardiovascular endurance than the norms for the Canadian population.[5] The adverse impact of the modern uniform on exercise duration, hydration status, and thermoregulation is likely to be greater in individuals with obesity and/or other medical problems.

With respect to aerobic capacities, the FDNY sample had a mean MVO2 of 46 $\pm$ 9 mL/kg/min (range 35 to 64 mL/kg/min).[2] Studies of more inclusive samples of firefighters,[5,10,11] however, have found lower average MVO2 values ranging from 33 to 40 mL/kg/min, even though their subjects were slightly younger (mean ages 35 to 40) than the average age of 43 $\pm$ 8 in Malley et al's investigation.[2] In the most recent of these studies that tested an entire department (n = 93), 33% of the firefighters were found to have MVO2 values less than 30 mL/kg/min.[10]

Malley et al[2] also implied that current fitness levels seemed adequate because most (15 of 23, 65%) of their subjects exceeded the minimum MVO2 recommended by O'Connell et al[3] (39 mL/kg/min) for safe and effective performance as a firefighter. Conversely, however, this means that 35% of the volunteer sample was unable to achieve the cited minimum MVO2. These failures included 7 of 13 (54%) of those over 40, 6 of 8 (75%) over 45, and 4 of 5 (80%) over 50 years of age. In the Montreal study,[5] older firefighters performed even worse, with a mean MVO2 of 33 mL/kg/min for those 40 to 49 years old and a mean MVO2 31 mL/kg/min for those 50 to 59 years old.

Although most fire departments require recruits to pass certain physical standards, few departments require incumbent firefighters to maintain these physical standards.[5] The effects of increasing age on cardiovascular fitness are probably very important to the health and safety of firefighters. The on-duty fatality rate is more than 6 times higher for firefighters over 60 years old and 3 times higher for those 50 to 59 years old compared with those 20 to 39 years old.[12] Myocardial infarctions are the number one cause of on-duty deaths among firefighters, accounting for almost half of all deaths overall and about two-thirds of deaths in firefighters over 45 years old.[12] Over 90% of these deaths occurred in persons with known heart disease or significant risk factors,[13] suggesting that health and fitness promotion and medical screening could have important impacts. Indeed, the FDNY group did not find an increase in heat exhaustion or cardiac injuries with the new uniform despite its increased workload.[1] They attributed this to a number of initiatives and educational programs taken proactively with regard to work procedures, physical fitness, and hydration practices. They also acknowledged that "less fit, older firefighters may have retired rather than risk injury."

There is a consensus that firefighting is a physically demanding occupation in which good cardiovascular fitness is desirable.[1–3,5,7,9,11,13,14] Most fire departments, however, have not made fitness maintenance and health promotion major priorities. On the basis of the FDNY's impressive results, the modern uniform will be adopted by many other fire departments. Engineered safety advances, however, have their limitations.[13] It is hoped that improvements in personal protective equipment will be accompanied by the widespread implementation of health and fitness promotion programs for the firefighters.

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Prospective study of hepatic, renal, and haematological surveillance in hazardous materials firefighters

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Abstract

***Objectives*—To evaluate possible health effects related to work with hazardous materials as measured by end organ effect markers in a large cohort over about 2 years, and in a subcohort over 5 years.**

***Methods*—Hepatic, renal, and haematological variables were analysed from 1996–98 in hazardous materials firefighters including 288 hazardous materials technicians (81%) and 68 support workers (19%). The same end organ effect markers in a subcohort of the technicians were also analysed (n=35) from 1993–98. Support workers were considered as controls because they are also firefighters, but had a low potential exposure to hazardous materials.**

***Results*—During the study period, no serious injuries or exposures were reported. For the end organ effect markers studied, no significant differences were found between technicians and support workers at either year 1 or year 3. After adjustment for a change in laboratory, no significant longitudinal changes were found within groups for any of the markers except for creatinine which decreased for both technicians ($p<0.001$) and controls ($p<0.01$).**

***Conclusions*—Health effects related to work are infrequent among hazardous materials technicians. Haematological, hepatic, and renal testing is not required on an annual basis and has limited use in detecting health effects in hazardous materials technicians.**

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Keywords: hazardous materials; firefighters; medical surveillance

Accidents that involve hazardous materials may potentially occur during the manufacture, transport, storage, sale, use, or disposal of a chemical substance. The United States Agency for Toxic Substances and Disease Registry (ATSDR) has suggested that over 400 000 people in the United States may be involved as first responders to accidents that involve hazardous materials. These include emergency medical technicians, firefighters, police, and others.[1] An increasing number of communities and industries have developed hazardous materials (hazmat) teams composed of people specially trained to respond to chemical spills, fires, and accidents. Also, there are over 1 million people in the United States involved in firefighting.[2] Firefighters have become increasingly involved in the response to accidents that involve hazardous materials.[3 4]

The United States Occupational Safety and Health Administration (OSHA) standard on hazardous waste workers (29 CFR 1910.120) requires medical examinations for hazardous waste workers including members of hazardous materials response teams.[5] An identical United States Environmental Protection Agency (EPA) standard (40 CFR 11) applies to state and municipal employers in states without designated OSHA programmes.[1 6] The OSHA standard requires examinations before starting work as well as periodic examinations at least every 2 years, but the content of the examinations is not specified.

Because of the myriad and mixed nature of the exposures, most medical surveillance programmes have included end organ effect markers (complete blood counts, renal and hepatic function tests, etc) in their examination programmes.[7] These common practices agree with recommendations that such haematological and biochemical testing be considered as part of the medical examination process for hazardous waste workers[1 8 9] and for firefighters.[10-12]

Despite the widespread use of these medical surveillance tests, limited information is available at present on the health effects of work with hazardous materials and the usefulness of monitoring end organ effect markers. A cross sectional study contrasted 55 clinical chemistry, haematological, and urinary variables between workers with more or less exposure to hazardous waste.[13] The only variable that consistently distinguished the two groups was a clinically unimportant one, mean corpuscular volume. In a small, prospective study of 40 hazardous materials firefighters, we found few biochemical abnormalities and none that could be specifically linked to exposures or response to accidents.[14] We did, however, find significant (but not clinically important) changes in paired means testing of some of the indices which warranted longer longitudinal follow up.

The current study was undertaken to further evaluate possible health effects of hazardous materials firefighting work as measured by end organ effect markers in a larger cohort over a period of about 2 years, and in our original cohort over 5 years.

Methods

SUBJECTS

The subjects were 356 members of six regional hazmat response teams of the Commonwealth of Massachusetts who underwent state man-

Table 1 Study population 1996–8

	Total (n (%))	Technicians (n (%))	Support (n (%))
1996/97 Year 1:			
Examined	340 (100)*†	268 (79)	72 (21)
Changes between year 1 and year 3 examinations:			
Dropouts or inactive after initial examination	24 (100)†	19 (79)	5 (21)
New members joined after initial examination	16 (100)*	10 (62)	6 (38)
Position changes‡	14 (100)†	2 (14)	12 (86)
1998 Year 3:			
Examined	332 (100)	269 (81)	63 (19)

*Total examined 1996–8 was 356=340+16.
†Total who were examined in both years and did not change jobs was 302=340−(24+14).
‡12 Support became technicians and two technicians became support.

dated medical surveillance and fitness for duty examinations in either 1996–97 (year 1) or 1998 (year 3) of the primary study. All firefighters were examined on a confidential basis. The review of the medical records of firefighters for research purposes was approved by the institutional review boards of the Harvard School of Public Health and The Cambridge Hospital.

All of the subjects were also members of municipal fire departments as well as their hazmat duty with the state teams. In 1996–97 (year 1) of the primary study, the initial cohort (n=340) included 268 (79%) hazardous materials technicians and 72 (21%) support workers. Most of the technicians were already members of the hazardous materials teams before the start of the study.

Of the initial cohort (n=340), 24 firefighters (19 (79%) hazardous materials technicians and five (21%) support workers) were examined only in year 1. They either left the teams before the 1998 (year 3) examination, became inactive members and were not reexamined in 1998, or their 1998 results (n=2) were missing from the medical record repository. Also, between year 1 and year 3, a total of 16 new members (10 (62%) technicians and six (38%) support workers) joined the teams and were examined only in 1998 (year 3).

Three hundred and sixteen firefighters (249 (79%) hazardous materials technicians and 67 (21%) support workers) were examined in 1996 or 1997 (year 1) and remained active with the team to the 1998 (year 3) examination. However, within these 316 firefighters, 14 changed positions at some point after the year 1 and before the year 3 examination. More specifically, 12 support workers became technicians, and two technicians became support workers. The study population is summarised in table 1.

Therefore, 302 firefighters (247 (82%) hazardous materials technicians and 55 (18%) support workers) were examined in 1996 or 1997 (year 1), remained active with the team to the 1998 (year 3) examination, and did not change positions between 1996 and 1998.

EXPOSURE

Technicians are involved with the actual assessment and mitigation of accidents that involve hazardous materials within the "hot" or contaminated zone of the accident. Most situations are responded to on a "level A" basis which entails the use of vapour tight clothing and a positive pressure self contained breathing apparatus (SCBA). Field decontamination is routinely performed after all accidents unless the hazard poses a threat only by pulmonary absorption—for example, carbon monoxide.

During work with hazardous materials, support workers are presumed to have very limited potential exposure compared with technicians, as they do not enter the hot or contaminated zone of an accident and their role is ancillary. Both technicians and support workers perform regular fire duty with their non-state, local fire departments. As support workers are not exposed in their hazmat duties but do serve as municipal firefighters, they are an ideal control group for the investigation of potential health effects limited to those arising from duty within the contaminated zone of hazmat accidents.

BASELINE AND FOLLOW UP MEDICAL EXAMINATIONS

Year 1 medical surveillance examinations for 340 firefighters were performed at one of three hospitals in 1995 (1%), 1996 (82%), or 1997 (17%) during the first year of a statewide surveillance programme. Less (n=214) were examined during the year 2 examinations in 1997. This was due to an administrative decision by the Commonwealth of Massachusetts in 1997 to have all teams' subsequent examinations conducted within a 2 month period in the autumn of each year. As the year 1 examinations were conducted throughout 1996 and part of 1997 and 16 months is the maximum period allowed between examinations, some firefighters were not re-examined until the autumn of 1998. Nearly all year 3 examinations (98%) were done in September or October of 1998.

Forty technicians from team 1, the major Boston area hazmat team, had baseline examinations conducted at hospital 2, one of the three hospitals already mentioned, between November 1992 and August 1993. Thirty seven technicians from this group had follow up examinations performed in April and May of 1995. We previously reported on the results of their 1992–3 and 1995 examinations.[14] Thirty seven technicians from this original cohort participated in the statewide year 1 (1996–7) and 34 in the year 2 (1997) examinations conducted in the statewide programme. Finally, 35 of the original technicians remained active to year 3 and were examined again in 1998. Therefore, this subgroup (n=35, 10%) of the total cohort (n=356) had longitudinal follow up data over 5 years at 5 time points available for study.

All examinations were conducted in a similar way. Examinations included a detailed medical, smoking, environmental, and occupational history tailored to emergency responders; physical examination; visual and audiometric testing; routine laboratory tests (complete blood count, blood urea nitrogen, creatinine, alkaline phosphatase, aspartate aminotransferase (AST), alanine aminotransferase (ALT), and urinary analysis); and spirometry.

Table 2 Characteristics of technicians versus support (year 1)

	Technicians (n=268)	*Support (n=72)*	*p Value*
Age (mean (SD))	40.60 (6.43)	34.89 (6.89)	<0.001
BMI (mean (SD))	29.10 (4.16)	28.35 (3.61)	0.137
Sex (male) (n (%))	267 (99.63)	69 (95.83)	0.031
Increased blood pressure (n (%))	31 (11.57)	5 (6.94)	0.258
Antihypertensive medication (n (%))	18 (6.72)	2 (2.78)	0.268
Increased blood pressure or antihypertensive medication (n (%))	44 (16.42)	5 (6.94)	0.042
Diabetes mellitus (n (%))	8 (2.98)	0	0.211
Lipid lowering agent(s) (n (%))	8 (2.98)	0	0.211
Cholesterol >6.22 mmol/l (>240 mg/dl) (n (%))*	63 (23.50)	12 (16.67)	0.024

MEDICAL RECORDS REPOSITORY

Summary results of each firefighter's examination were transferred to hospital 2 where they were entered into a statewide computerised medical record repository. The repository facilitates tracking any incident related injuries and exposures requiring transport to a hospital. In such cases, the local treating hospital requests medical information from the repository and each request is dated and logged with the name of the firefighter and the hospital requesting the records. This enables the investigators to obtain additional medical information from the local treating hospital.

STATISTICAL ANALYSES

Differences between groups at a single time point were examined with independent *t* tests and separate variances. Differences in mean values for paired comparisons within groups—for example, year 1 *v* year 3—were examined with paired *t* tests. Differences in proportions were compared with the standard (Pearson's) χ^2 test unless one or more cells contained an expected value less than 5. In that case, we used Fisher's exact test. For the team 1 subcohort, analyses of variance (ANOVAs) were used to look for differences among the means as a factor of time for the 5 years studied. If a significant difference among the 5 years was found, then a paired *t* test was used to compare the 1992–3 mean with the 1998 mean. The level of significance for all analyses was $p < 0.05$, and was two tailed for all tests.

ADJUSTMENT OF 1998 ALT VALUES DUE TO A CHANGE IN REFERENCE LABORATORY

In preliminary analyses, in independent *t* tests between technicians and support workers for both years 1 and 3, we found no differences between groups for ALT. In paired *t* tests, however, ALT increased significantly and to a similar magnitude for both subject groups from year 1 to year 3. Further analyses of ALT values (appendix 1), showed that the increases in 1998 were limited to one hospital that changed its reference laboratory in 1998. The reference interval of this laboratory had the same range but the minimum and maximum normal values were both 20 units higher than the reference interval of the previous laboratory . The mean ALT values at this hospital in 1998 were about 20 units higher than those of previous years but had similar SDs. Therefore, 1998 ALT values obtained from this laboratory were lowered 20 units for each affected subject before the statistical analyses presented here. Values for the other hospitals were not adjusted.

Results

DEMOGRAPHICS: BASELINE AND FOLLOW UP

At year 1 of the study, the cohort of 340 firefighters had a mean (SD, range) age of 40 (6.4, 28–58.) years. At year 3, the follow up cohort of 316 firefighters and the total population of those who were examined in year 3 (n=332) both had a mean (SD, range) age of 41 (6.9, 22–59) years. The population included the same four women (1%) at both time points.

Table 2 summarises the characteristics of the technicians and support controls in year 1. The mean (SD) age of the technicians was significantly greater (p<0.001) than the mean age of the support workers ((n=253) 41 (6.4) versus (n=70) 35 (6.9)). Although both groups were predominantly men, there was a higher proportion of female (4.2%) support controls than female technicians (0.4%, p<0.05). Higher proportions of technicians than support workers had increased blood pressures (systolic>140 or diastolic>90), reported taking antihypertensive medications; had a diagnosis of diabetes mellitus; were on lipid lowering agents, and had increased cholesterol measurements (cholesterol >6.22 mmol/l or >240 mg/dl). These differences were significant for cholesterol >6.22 mmol/l and for increased blood pressure and use of antihypertensives (both p<0.05).

χ^2 Tests showed no differences in the proportions of technicians (78%–81%) and support workers (20%–22%) examined at each of the three hospitals in year 1 (p=0.971). Likewise, these proportions of technicians (77%–84%) and support workers (16%–23%) did not differ significantly among the three hospitals in year 3 (p=0.852).

We found no difference at year 1 between the mean (SD) age of firefighters who remained on the teams (n=303) 39 (6.9) and the mean (SD) age of those who left the teams or were inactive in year 3 (n=20) 40 (8.2). Among the 24 subjects who either left the teams or were inactive in 1998 (year 3), the proportions of technicians and support workers were the same as the rest of the initial cohort: 79% and 21% (χ^2, p=1.000), respectively.

MEDICAL RECORDS REPOSITORY

We had no record requests from outside treating hospitals for assistance in the treatment of any team member. During the study period, no significant injuries or exposures due to work with hazardous materials were reported to the Commonwealth of Massachusetts Office of Hazardous Materials Response, which administers the teams.

LIVER FUNCTION TESTS

We found no significant differences between the liver function tests of technicians and support controls at year 1 (baseline) nor year 3 (follow up, table 3). We also found no differences in liver function tests at year 1 between subjects who remained active to the

Table 3 Cross sectional comparisons of hazmat technicians v support controls at year 1 and year 3 examinations (independent samples t tests)

Variable	Year	Technicians	Support	p Value
Liver function tests:				
Alkaline phosphatase (U/l)	Year 1	82 (21) n=266	84 (22) n=70	0.491
	Year 3	82 (20) n=269	84 (19) n=63	0.339
Aspartate aminotransferase (U/l)	Year 1	25 (10) n=266	24 (9) n=71	0.360
	Year 3	25 (10) n=269	25 (9) n=63	0.805
Alanine aminotransferase (U/l)	Year 1	36 (20) n=266	35 (21) n=71	0.652
	Year 3	36 (18) n=269	38 (18) n=62	0.418
Renal function tests:				
Blood urea nitrogen (mmol/l)*	Year 1	5.7 (1.4) n=268	5.7 (1.4) n=71	0.999
	Year 3	5.3 (1.4) n=269	5.7 (1.4) n=63	0.145
Creatinine (μmol/l)†	Year 1	97 (18) n=268	97 (18) n=71	0.161
	Year 3	88 (18) n=269	88 (18) n=63	0.938
Haematological tests:				
White blood cells (×10⁹/l)	Year 1	6.6 (2.2) n=266	6.6 (1.4) n=71	0.876
	Year 3	6.6 (1.7) n=269	6.7 (1.6) n=63	0.682
Packed cell volume (fraction)	Year 1	0.45 (0.02) n=265	0.45 (0.03) n=71	0.698
	Year 3	0.46 (0.03) n=269	0.46 (0.03) n=63	0.165
Platelet count (×10⁹/l)	Year 1	239 (51) n=268	252 (58) n=70	0.099
	Year 3	231 (53) n=269	246 (52) n=63	0.053

*mg/dl=2.81 (mmol/l).
†mg/dl=μmol/(88 l).

Table 4 Comparisons of year 1 data for active (remained active to the end of year 3) v inactive team members (not active in year 3) (independent samples t tests)

Variable	Active	Inactive	p Value
Liver function tests:			
Alkaline phosphatase (U/l)	83 (21) n=313	76 (25) n=23	0.231
Aspartate aminotransferase (U/l)	25 (10) n=313	24 (9) n=24	0.927
Alanine aminotransferase (U/l)	36 (20) n=313	38 (22) n=24	0.694
Renal function tests:			
Blood urea nitrogen (mmol/l)*	5.7 (1.4) n=315	5.7 (1.1) n=24	0.660
Creatinine (μmol/l)†	97 (18) n=315	106 (8.8) n=24	0.102
Haematological tests:			
White blood cells (×10⁹/l)	6.6 (2.1) n=313	6.1 (1.3) n=24	0.078
Packed cell volume (volume fraction)	0.45 (0.02) n=312	0.45 (0.02) n=24	0.256
Platelet count (×10⁹/l)	243 (53) n=314	228 (48) n=24	0.151

*mg/dl=2.81 (mmol/l).
†mg/dl=μmol/(88 l).

year 3 examination and those who did not remain active (table 4).

In paired *t* tests, of year 1 versus year 3 liver function tests no significant changes were found for either hazmat technicians or support controls (table 5). We also made paired comparisons of liver function tests between year 1 and year 3 for the 12 support workers who subsequently became technicians (table 6). Again, we found no significant differences. Finally, we found no significant variation in mean liver function test values as a function of time for the team 1 subcohort over the period of 1993–8 (table 7).

RENAL FUNCTION TESTS

We detected no significant differences between hazmat technicians and support controls when comparing either the mean blood urea nitrogen or creatinine values in independent sample *t* tests at years 1 and 3 (table 3). We also found no differences in either mean blood urea nitrogen or creatinine at year 1 between subjects who remained active to the year 3 examination and those who did not remain active (table 4).

For blood urea nitrogen, no significant differences were found in paired testing (tables 5 and 6). For technicians and for support workers who became technicians, the means for year 3 blood urea nitrogen showed a trend to be lower. Over the period 1993–8, we found no significant variation in mean blood urea nitrogen as a function of time for the team 1 subcohort (table 7).

We did find a significant decrease in mean creatinine concentrations from year 1 to year 3 for both technicians and support cohorts (table 5), and for the 12 support workers who subsequently became technicians (table 6). Moreover, we found a significant longitudinal decrease in creatinine concentrations for the team 1 subgroup from 1993 to 1998 (table 7). The 1998 mean creatinine concentration was lower than the 1993 concentration (114(8.8) *v* 97 (8.8), p< 0.001).

Because no differences were found across exposures, subsequent analyses were done for each examining hospital. For two of the hospitals (including one that had changed laboratories) the year 3 mean creatinine was significantly lower (both p<0.001), but for the third hospital the year 3 mean creatinine was non-significantly higher (p=0.177) (data not shown).

HAEMATOLOGICAL TESTS

For mean white blood count and packed cell volume, we found no significant differences between groups (tables 3 and 4) nor within groups over time (tables 5–7).

Independent *t* tests between the mean platelet count of technicians and support controls at year 1, showed a trend towards a lower mean platelet count for the technicians in both years (table 3). There was no significant difference in mean platelet count between subjects who remained active to the year 3 examination and those who did not remain active (table 4).

Paired *t* tests of platelet count at years 1 and 3 for both technician and support worker subgroups showed significant changes for technicians (n=247): 240 (52) to 232 (54) from baseline to follow up examination (p< 0.001; table 5), whereas within support workers the decrease was non-significant. We also found a significant decrease in mean platelet count for the support workers who subsequently became technicians (table 6).

Also, we found significant longitudinal variation in mean platelet counts among the team 1 subgroup from 1993 to 1998 (table 7) as a function of time. The 1998 mean platelet count decreased significantly from the 1993 value of 237 (42) to 210 (40) (n=35; p< 0.01).

Table 5 Paired, longitudinal comparisons for hazmat technicians and support members: year 1 v year 3 (paired samples t tests)

Variable	*Year 1 (1996–7)*	*Year 3 (1998)*	*p Value*
Liver function tests:			
Alkaline phosphatase (U/l):			
Technicians (n=246)	83 (21)	83 (20)	0.721
Support (n=53)	87 (23)	85 (20)	0.206
Aspartate aminotransferase (U/l):			
Technicians (n=245)	25 (10)	25 (10)	0.982
Support (n=54)	24 (10)	26 (9)	0.273
Alanine aminotransferase(U/l):			
Technicians (n=245)	36 (20)	37 (18)	0.364
Support (n=54)	38 (23)	39 (18)	0.646
Renal function tests:			
Blood urea nitrogen (mmol/l):*			
Technicians (n=247)	5.7 (1.4)	5.3 (1.4)	0.050
Support (n=54)	5.3 (1.4)	5.7 (1.4)	0.324
Creatinine (μmol/l):†			
Technicians (n=247)	97 (18)	88 (8.8)	0.000
Support (n=54)	97 (18)	88 (18)	0.005
Haematological tests:			
White blood cells (×10⁹/l):			
Technicians (n=245)	6.7 (2.3)	6.6 (1.8)	0.891
Support (n=54)	6.6 (1.3)	6.7 (1.5)	0.635
Packed cell volume (fraction):			
Technicians (n=244)	0.45 (0.02)	0.46 (0.03)	0.332
Support (n=54)	0.46 (0.03)	0.46 (0.03)	0.133
Platelet count (×10⁹/l):			
Technicians (n=247)	240 (52)	232 (54)	0.000
Support (n=54)	254 (60)	248 (55)	0.176

*mg/dl=2.81 (mmol/l).
†mg/dl=μmol/(88 l).

Table 6 Paired, longitudinal comparisons for firefighters who started as hazmat support members and later became technicians by 1998: year 1 v year 3 (paired samples t tests)

Variable	*Year 1 (1996–7)*	*Year 3 (1998)*	*p Value*
Liver function tests:			
Alkaline phosphatase (U/l)	70 (17) n=12	74 (20) n=12	0.093
Aspartate aminotransferase (U/l)	23 (5) n=12	22 (7) n=12	0.535
Alanine aminotransferase (U/l)	23 (9) n=12	24 (16) n=12	0.695
Renal function tests:			
Blood urea nitrogen (mmol/l)*	6.4 (1.8) n=12	5.7 (1.1) n=12	0.065
Creatinine (μmol/l)†	106 (18) n=12	97 (8.8) n=12	0.007
Haematological tests:			
White blood cells (×10⁹/l)	6.8 (1.7) n=12	6.3 (1.3) n=12	0.458
Packed cell volume (fraction)	0.44 (0.03) n=12	0.44 (0.03) n=12	0.428
Platelet count (×10⁹/l)	252 (47) n=11	227 (53) n=11	0.003

*mg/dl=2.81 (mmol/l).
†mg/dl=μmol/(88 l).

Because hospital 2 had changed reference laboratories in year 3, we performed further paired analyses stratified by examination site (appendix 2). For the other two hospitals, we found no differences over time in mean platelet count for either technicians or support workers. For hospital 2, the new reference laboratory had a lower reference interval, and in year 3 both technicians (n=82) and support (n=14) workers had lower mean platelet counts ($p<0.001$ and $p<0.005$, respectively).

Of the 12 support workers who became technicians by 1998, 10 (83%) were examined at hospital 2. Thus, the change in laboratories would explain the relative decrease in mean platelet count from 1996 to 1998. Finally, a second ANOVA as a function of time with only the means from the original laboratory (1993–7), showed no longitudinal variation in mean platelet count for the team 1 subcohort ($p=0.110$).

PROPORTION OF TECHNICIANS AND CONTROLS WITH VALUES OUTSIDE THE EXPECTED RANGE FOR THE COHORT

Comparison of mean values between and within groups did not show any adverse effects associated with work with hazardous materials. Therefore, we also explored the hypothesis that a few hazardous materials technicians might develop significant changes in laboratory variables associated with exposure—that is, depression of haematological test values, or increases in renal or hepatic test values. Thus, we compared the proportion of hazardous materials technicians and support workers with values outside the expected range for the entire cohort. In these analyses, we identified the number of firefighters in both groups with haematological test values of more than two SDs below the mean (technicians and support workers combined), or with renal or hepatic test values of more than two SDs above the overall mean. As each hospital used a different laboratory, we used the mean (SD) for each test at each facility separately to identify the number of firefighters outside the expected ranges. Then, these numbers were summed for

Table 7 5 Year longitudinal time analysis of follow up for the team technician cohort (ANOVA time analysis)

Variable	*1993*	*1995*	*1996*	*1997*	*1998*	*ANOVA p value*
Liver function tests:						
Alkaline phosphatase (U/l)	74 (16) (n=35)	78 (16) (n=34)	77 (18) (n=34)	78 (17) (n=34)	78 (19) (n=35)	0.770
Aspartate aminotransferase (U/l)	26 (11) (n=35)	25 (13) (n=34)	29 (13) (n=34)	24 (7) (n=34)	27 (16) (n=35)	0.560
Alanine aminotransferase(U/l)	24 (8) (n=35)	26 (8) (n=34)	28 (17) (n=34)	27 (14) (n=34)	28 (14) (n=35)	0.571
Renal function tests:						
Blood urea nitrogen (mmol/l)*	6.0 (1.1) (n=35)	5.7 (1.4) (n=34)	6.0 (1.4) (n=34)	5.7 (1.4) (n=34)	6.0 (1.8) (n=35)	0.886
Creatinine (μmol/l)†	114 (8.8) (n=35)	114 (8.8) (n=34)	106 (8.8) (n=34)	106 (18) (n=34)	97 (8.8) (n=35)	0.000
Haematological variables:						
White blood cells (×10⁹/l)	7.1 (1.6) (n=35)	6.3 (1.6) (n=34)	6.7 (1.6) (n=34)	6.8 (1.5) (n=34)	6.5 (1.4) (n=35)	0.237
Packed cell volume (fraction)	0.45 (0.02) (n=35)	0.45 (0.03) (n=34)	0.45 (0.02) (n=34)	0.45 (0.02) (n=34)	0.44 (0.02) (n=35)	0.164
Platelet count (×10⁹/l)	237 (42) (n=35)	247 (54) (n=33)	242 (48) (n=34)	220 (44) (n=34)	210 (40) (n=35)	0.004

*mg/dl=2.81 (mmol/l).
†mg/dl=μmol/(88 l).

technicians and support controls for year 1 and year 3, respectively.

No differences in the proportions of technicians or support controls with test values outside the expected ranges were found with the exception that significantly more controls (7%, (5/71)) had increased creatinine values in year 1 than technicians (1%, (3/268), $p<0.012$). A detailed breakdown of technicians and support controls with values outside the expected ranges for each hospital and year is given in appendix 3.

Discussion

This study was a prospective and cross sectional evaluation of possible health effects of firefighting work with hazardous materials. No clinical health effects of work with hazardous materials were reported during the study period. This is consistent with our previous studies of incidents with hazardous materials responded to by the same six Massachusetts regional teams from 1990 to 1996.[15 16] In analyses of reports of incidents for the first 6 years of work with hazardous materials, hazardous materials team members experienced no notable chemical exposures. Minor musculoskeletal injuries were reported in a single incident. This is also consistent with findings among hazardous waste workers that few notable exposures occur because when the potential for exposure is greatest the workers are usually equipped with the highest levels of personal protective equipment.[7]

To study the possible subclinical health effects of hazardous materials firefighting, we studied liver and renal function tests and haematological indices as markers of end organ effect. Such testing has been recommended as standard or optional components in the medical examinations of hazardous materials workers[1 8 9] and firefighters.[10-12]

We found no significant differences in means for any of the effect markers studied across exposures (hazardous materials technicians versus support controls) at both year 1 and year 3. Also, no differences in the proportions of technicians or support controls with test values outside the expected ranges were found with the exception of creatinine in year 1. In this case, the result was not consistent with an adverse effect of work with hazardous materials, as more controls had increased creatinine values than technicians. Also, we found no differences in any of the variables studied between members of the teams who either left or became inactive and those who remained active to the 3rd year of the study.

Likewise, we found no clinically notable changes within the means for various subject groups over time. We found significant longitudinal changes for only two indices: creatinine and platelets. For all groups studied at two of the hospitals, creatinine decreased significantly over time, at the third hospital, mean creatinine increased non-significantly. Because mean creatinine decreased (improved) in support workers as well as technicians, and we found no differences between groups at either time point, we think that these changes are not related to exposure. The change in reference laboratory in 1998 at one of the hospitals may account for some of the variation.

In initial longitudinal analyses, we did find consistent and significant decreases in platelet values within technician groups and support workers who became technicians. In further analyses, however, the use by one of the hospitals of a new laboratory in year 3 (1998) with a lower reference interval for platelet counts seemed to be the cause. When we stratified the data by hospital, the decrease in platelets was isolated to those tested at a different laboratory in 1998, and was also found in support workers examined at the same site. Also, when platelet data for the team 1 subcohort were examined for 1992–3 to 1997 (excluding 1998 when a different laboratory was used) there was no significant change in platelets over time.

Our results are consistent with those of the study of hazardous waste workers by Favata and Gochfeld ,[13] which failed to find any differences in the same indices that we studied between workers with low and high potentials for exposure. The results are also consistent with our previous study of the team 1 cohort[14] where we found few abnormalities in these indices and none that we could link to specific exposures. Examination of the team 1 data over 5 years showed remarkable stability. This suggests that the clinically unimportant, but significant changes in some of these indices that we found from 1992–3 to 1995[14] were probably due to chance, subtle changes in specimen collection, preparation, or laboratory analyses between the two time points. As expected, over many observation points, such factors not related to exposure are unlikely to affect results in a consistent way.

The major limitation of the current study was imposed by logistical constraints. In a statewide programme, all six teams could not be examined at a single hospital. Further, the investigators could not require the examining hospitals to send all specimens to a single reference laboratory for all teams and all time points. Indeed, this study highlights the potential problems that ongoing surveillance programmes may have when hospital contractual obligations mandate changes in reference laboratories. This limitation was countered by the major strength of our study, the overall study design.

Firstly, we had an excellent control group, the support workers. Both technicians and support workers perform regular fire duty with their non-state, local fire departments. Support members are presumed to have a very limited potential for exposure compared with technicians, as they do not enter the hot or contaminated zone of an accident. Therefore, they are an ideal control group for the investigation of potential health effects limited to those arising from duty within the contaminated zone of hazmat accidents. We found some differences between technicians and control firefighters on several confounding variables, but these differences would be expected to bias the study towards finding worse results for the technicians. Despite the fact that the technicians were older, more likely to have increased blood pressure, increased cholesterol, take antihypertensive or lipid lowering medications, or have diabetes mellitus, we found no significant differences in means for any of the effect markers studied across exposures.

Secondly, the proportions of control workers examined at each of the three hospitals were similar. There were no significant differences in the proportions of technicians to controls among the three hospitals at either year 1 or year 3. This fact justified pooling the data from all three hospitals for most analyses.

Thirdly, our design allowed for multiple methods of looking for possible exposure or work related effects. These included independent, cross sectional comparisons of technicians and controls at two separate time points, comparisons of those who became inactive or left the teams with those who remained active, and prospective follow up comparisons within subjects over time. These prospective comparisons included technicians, support workers who became technicians, and a 5 year time analysis for the team 1 cohort. Although the support workers who became technicians and the team 1 cohort were small, their results support the consistency of the lack of any effect related to exposure or work. Finally, we explored the hypothesis that a few technicians might be adversely affected by examining the proportion of firefighters with results outside the expected range for the cohort as a whole. Again, we found no evidence for an adverse effect of work with hazardous materials on the test values we studied. Given the study's design, it seems unlikely that we would have missed a significant effect related to exposure on the end organ effect markers studied.

Work with hazardous materials has the potential for serious exposures and injuries due to explosions, fires, and other releases of dangerous substances. Among hazardous waste workers it has been found, however, that few significant exposures occur because those with the greatest potential for exposure are usually equipped with the highest levels of personal protective equipment.[7] This study and previous studies of surveillance[13 14] and of a hazardous materials accident database[15 16] also suggest that there are seldom health effects among hazardous materials technicians who wear appropriate personal protective equipment. Therefore, current protective equipment and procedures including decontamination seem to be effective.

Another important consideration in this discussion involves the most likely potential exposures during work with hazardous materials. Irritants and corrosives are the most commonly released hazardous materials, and respiratory exposures to irritants are the most commonly reported exposures.[16-18] Most irritant and corrosive substances would not affect haematological indices, or liver or renal function. On the other hand, common health problems and other non-occupational factors may produce abnormalities. Therefore, the hepatic, renal, and haematological tests used in our investigation cannot be expected to be either sensitive or specific markers of exposure to hazardous materials. In our experience, a further disadvantage of these markers is that firefighters under medical surveillance often misunderstand the limitations of these tests. They tend to overvalue normal results on these variables as ruling out the possibility of present and future health effects related to exposure.

Our results suggest that routine testing of the hepatic, renal, and haematological indices used in our investigation is not required on an annual basis, and that the use of these tests in detecting subclinical health effects is limited. Our current recommendations for haematological, hepatic, and renal indices in the medical surveillance of hazardous materials firefighters and other firefighters will be baseline measurements for comparison after notable exposures, illness, or other changes in clinical state. Because certain laboratory values may vary as a function of age, it seems desirable to retest at some interval. The results of the subcohort followed up over 5 years suggest that in the absence of a known exposure or other clinical indication, it is unnecessary to reassess the indices studied here more often than every 3–5 years. When comparing periodic testing with baseline results, there should also be consideration of variation not related to exposure or illness, but due to changes in laboratories, reference intervals, or testing methods.

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Appendix 1 table 1 Further analysis of alanine aminotransferase (U/l) data by hospital and year of testing

Year	*Hospital 1*	*Hospital 2**	*Hospital 3*
1996	30 (15) (n=99)	27 (14) (n=118)	50 (22) (n=120)
1997	31 (12) (n=89)	29 (14) (n=102)	60 (45) (n=21)
1998	32 (17) (n=105)	49 (16) (n=111)	48 (15) (n=115)

*Laboratory used in 1996 and 1997 was A, and in 1998 it was B.

Appendix 1 table 2 Analysis of alanine aminotransferase (U/l) data for team one subgroup

Year	*1993*	*1995*	*1996*	*1997*	*1998*
Alanine aminotransferase	24 (8) (n=35)	26 (8) (n=34)	28 (17) (n=34)	27 (14) (n=34)	48 (14) (n=35)
Hospital No	2	2	2	2	2
Laboratory used	A	A	A	A	B
Reference range	0–45	0–45	0–45	0–45	20–65

Appendix 2 Further analysis of platelet count ($\times 10^9$/l) data by hospital, position, and year of testing

Hospital	*Position*	*Year 1*	*Year 3*	*p Value*
Hospital Nos 1 and 3†	Technicians	243 (53) n=164	243 (57) n=164	0.909
	Support	257 (62) n=40	256 (55) n=40	0.828
Hospital No 2*	Technicians	236 (49) n=82	208 (41) n=82	0.000
	Support	245 (55) n=14	226 (51) n=14	0.002
Laboratory used		A	B	
Reference range (K/mm^3)		140–400	130–400	

*Laboratory used in 1996 and 1997 was A, and in 1998 it was B.
†The same laboratories were used in 1996–8.

Appendix 3 Firefighters (n (%)) with hepatic and renal test values 2 SDs above the mean, and haematological test values 2 SDs below the mean**

		Hospital 1				*Hospital 2*				*Hospital 3*				*Total firefighters*				
		Technicians		*Support*		*Technicians*		*Support*		*Technicians*		*Support*		*Technicians*		*Support*		*p Value*
White blood cells	Year 01	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0/266	(0)	0/71	(0)	NA
	Year 03	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0/269	(0)	0/63	(0)	NA
Packed cell volume	Year 01	2	(0.8)	1	(1.4)	2	(0.8)	2	(2.8)	0	(0)	1	(1.4)	4/265	(1.5)	4/71	(5.6)	0.065
	Year 03	1	(0.4)	1	(1.6)	7	(2.6)	0	(0)	1	(0.4)	0	(0)	9/269	(3.3)	1/63	(1.6)	0.694
Platelet count	Year 01	0	(0)	1	(1.4)	2	(0.8)	0	(0)	1	(0.4)	0	(0)	2/268	(0.8)	1/70	(1.4)	1.000
	Year 03	0	(0)	1	(1.6)	2	(0.8)	0	(0)	1	(0.4)	0	(0)	3/269	(1.1)	1/63	(1.6)	0.571
Blood urea nitrogen	Year 01	3	(1.1)	2	(2.8)	6	(2.2)	1	(1.4)	2	(0.8)	1	(1.4)	11/268	(4.1)	4/71	(5.6)	0.527
	Year 03	1	(0.4)	1	(1.6)	6	(2.3)	2	(3.1)	1	(0.4)	1	(1.6)	8/269	(3.0)	4/63	(6.3)	0.252
Creatinine	Year 01	1	(0.4)	1	(1.4)	2	(0.8)	4	(5.6)	0	(0)	0	(0)	3/268	(1.1)	5/71	(7.0)	0.012
	Year 03	0	(0)	1	(1.6)	5	(1.9)	2	(3.1)	1	(0.4)	0	(0)	6/269	(2.2)	3/63	(4.8)	0.380
Alkaline phosphatase	Year 01	5	(1.9)	1	(1.4)	0	(0)	0	(0)	6	(2.3)	2	(2.9)	11/266	(4.1)	3/70	(4.3)	1.000
	Year 03	3	(1.1)	1	(1.6)	2	(0.8)	0	(0)	2	(0.8)	1	(1.6)	7/269	(2.6)	2/63	(3.2)	0.681
Aspartate aminotransfe rase	Year 01	2	(0.8)	0	(0)	2	(0.8)	1	(1.4)	3	(1.1)	1	(1.4)	7/266	(2.6)	2/71	(2.8)	1.000
	Year 03	3	(1.1)	0	(0)	2	(0.8)	2	(3.1)	4	(1.5)	0	(0)	9/269	(3.3)	2/63	(3.2)	1.000
Alanine aminotransfe rase	Year 01	2	(0.8)	0	(0)	2	(0.8)	1	(1.4)	5	(1.9)	1	(1.4)	9/266	(3.4)	2/71	(2.8)	1.000
	Year 03	2	(0.8)	0	(0)	3	(1.1)	1	(1.6)	5	(1.9)	1	(1.6)	10/269	(3.7)	2/62	(3.2)	1.000

*Mean is of all subjects tested (technicians and support) at each hospital and time point.

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Firefighters' Hearing: A Comparison With Population Databases From the International Standards Organization

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We investigated firefighters' hearing relative to general population data to adjust for age-expected hearing loss. For five groups of male firefighters with increasing mean ages, we compared their hearing thresholds at the 50th and 90th percentiles with normative and age- and sex-matched hearing data from the International Standards Organization (databases A and B). At the 50th percentile, from a mean age of 28 to a mean age of 53 years, relative to databases A and B, the firefighters lost an excess of 19 to 23 dB, 20 to 23 dB, and 16 to 19 dB at 3000, 4000, and 6000 Hz, respectively. At the 90th percentile, from a mean age of 28 to a mean age of 53 years, relative to databases A and B, the firefighters lost an excess of 12 to 20 dB, 38 to 44 dB, 41 to 45 dB, and 22 to 28 dB at 2000, 3000, 4000, and 6000 Hz, respectively. The results are consistent with accelerated hearing loss in excess of age-expected loss among the firefighters, especially at or above the 90th percentile. (J Occup Environ Med. *2001;43:650–656*)

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Hearing loss is commonly reported in firefighters.[1–8] In particular, firefighters tend to exhibit hearing loss in the higher frequencies most susceptible to excessive noise exposure: 3 kHz, 4 kHz, and 6 kHz[1–6,8]. The severity of this pattern of hearing loss is strongly associated with age and the duration of firefighting service.[1,4–6,8] When the effect of presbycusis (age-related hearing loss) is adjusted for, an association between the magnitude of hearing loss and number of years of service as a firefighter remains.[2,3]

Because hearing loss is also common in the general population,[9] the question remains whether firefighters suffer from excess hearing loss relative to the general population. When normative age-matched audiometric data are compared with those of groups of firefighters, an interesting pattern seems to emerge. The youngest firefighters tend to have better hearing compared with the general population, whereas older firefighters seem to have greater hearing loss than that of the general population.[4,8] These data suggest that firefighters tend to lose hearing at an accelerated rate, especially in the frequency ranges characteristically affected by excessive noise exposure.[4,8]

Researchers have suggested that excess hearing loss among firefighters is due to occupational noise exposure.[2–6,8] Noise-induced hearing loss has long been associated with working environments that expose the person to a relatively continuous

TABLE 1
Mean Hearing Thresholds in Decibels Measured at Each Hospital

Hospital	Age Tested Mean	Age Tested n	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
1	39.6	113	25	16	7	11	14	21
2	39.7	112	10	8	10	16	22	20
3	39.2	94	6	6	7	13	19	25

level of excessive noise.[10] However, research has more recently begun to address the risk of noise-induced hearing loss because of intermittent exposure to unusually high decibel levels, such as those experienced by firefighters during emergency response situations.[1,2,4–6,11] During these emergency responses, the major sources of noise are vehicular, including horns, sirens, and engine noise.

Given the high prevalence of clinically abnormal audiometry among our cohort of firefighters, especially those over 40 years old,[7] we proposed to compare our cohort's hearing with that of the general population. Furthermore, we wanted to adjust for the effect of presbycusis by subtracting normative expected hearing losses. Therefore, we compared the hearing of our cohort of hazardous materials firefighters to the hearing of screened and unscreened populations from the International Standards Organization.[12–14]

Methods

Subjects

The study base included 340 firefighter-members of six regional hazardous materials response teams of the Commonwealth of Massachusetts who underwent state mandated medical surveillance/fitness for duty examinations. All of the firefighters also belong to municipal fire departments in addition to their hazardous materials duty with the state teams. This cohort was 99% male (336 of 340) and predominantly white. All firefighters were examined on a confidential basis. The Institutional Review Boards of the Harvard School of Public Health and The Cambridge Hospital approved review of the firefighters' medical records for research purposes.

Medical Examinations

Medical surveillance examinations for the firefighters were performed at one of three hospitals in 1996 or 1997 in the first year of a statewide surveillance program. All examinations were conducted in a similar fashion. Examinations included a medical, smoking, and environmental/occupational history tailored to emergency responders; physical examination; visual and audiometric testing; routine laboratory tests; and spirometry. Audiograms were available for 95% (319) of the 336 male subjects examined in 1996/97. Audiometry was assessed at hospital 1 in an isolated examination room using a screening audiometer (MA 19; Maico Diagnostics, Eden Prairie, MN). At hospital 2, audiometry was performed in an isolated booth using an audiometer (RA 500; Tremetrics, Austin, TX) . Audiometry at hospital 3 was assessed with a two-channel audiometer (TA 200 model 260; Teledyne Avionics, Charlottesville, VA) in a soundproof room. Table 1 shows the mean hearing thresholds over frequencies of 500 to 6000 Hz at each hospital. Right and left ear data have been averaged.

Analysis of Audiograms

Background noise can adversely affect hearing thresholds. The data in Table 1 strongly suggested that such an effect was present at 500 and 1000 Hz at hospital 1 because of a failure to sufficiently isolate the testing room. Therefore, we excluded data from hospital 1 from the calculations of firefighter thresholds at 500 and 1000 Hz. Because hospital 1 results were not dissimilar from the other two hospitals over the range 2000 to 6000 Hz, we included them in these threshold calculations. For all threshold calculations, we averaged right and left ear data.

Comparison of Firefighters' Threshold Data With Those of a Highly Screened Otologically Normal Population

Database A (American National Standards Institute 1996 and International Organization for Standardization 7029)[13,14] was developed from the hearing thresholds of a large, otologically normal population derived from several survey studies.[13] The subjects were screened specifically to study the effect of age (presbycusis) on hearing without confounding caused by otological disease, environmental noise, etc.[15] An otologically normal person is defined as a person "in a normal state of health who at the time of testing is free from excess wax in the ear canals, is without known ear pathology and who has no history of undue exposure to noise."[13] Therefore, comparisons with database A allow for the estimation of excess hearing loss caused by factors not related to age. The American National Standards Institute standard includes formulas to predict the distribution of database A hearing thresholds for any age from 18 to 70 years over frequencies between 125 and 8000 Hz, assuming that the median (50th percentile) hearing threshold for an 18-year-old person is 0 dB hearing loss.[13]

For each of the 319 firefighters, we created age-matched, male control subjects, one each at the 50th and 90th percentiles of database A. We then determined the predicted hearing thresholds of the control subjects at each frequency. Thus, at each percentile studied, the age distribution of database A control subjects matched that of the entire cohort of firefighters.

Relative Risk for High- and Broad-Frequency Hearing Loss in Firefighters Versus Otologically Normal Persons

High-frequency hearing loss was defined as an average threshold greater than 30 dB at 3000, 4000, and 6000 Hz. Broad frequency hearing loss was defined as an average threshold exceeding 20 dB across 500, 1000, 2000, and 4000 Hz. The number of firefighters exceeding these criteria for the average of the two ears was calculated.

To estimate the number of age-matched subjects from database A exceeding the high and broad frequency criterion, we stratified the firefighters by deciles of age. A mean age was calculated for each of the 10 groups. Then for each of these 10 ages, the percentiles at which database A subjects exceed the 20 dB hearing loss fence for 500, 1000, 2000, and 4000 Hz and the 30 dB hearing loss fence for 3000, 4000, and 6000 Hz were calculated. The percentage of control subjects exceeding the two criteria for each of the 10 age groups was determined and then multiplied by the total number of subjects in each age category. This yielded the number of failures in each decile. Finally, we summed the number of failures in each of the 10 age groups.

Comparison of Firefighters' Threshold Data With Those of Screened and Unscreened US Populations: Subtraction of Age-Expected Hearing Loss

For these comparisons, five subgroups of firefighters were examined. The groups were: 20 to 30 years old (mean age, 28 ± 3; n = 33); 31 to 40 years old (mean age, 36 ± 3 years old; n = 143); 41 to 45 years old (mean age, 43 ± 1 years old; n = 76); 46 to 50 years old (mean age, 48 ± 1 years old; n = 53); and greater than 50 years old (mean age, 53 ± 2 years old; n = 14).

For each of the 319 firefighters, we had two age-matched, male control subjects, one at the 50th percentile and one at the 90th percentile of database A. We then determined the predicted hearing thresholds of the control subjects at each frequency. Thus, at both percentiles, the age distribution of database A control subjects matched that of each subgroup of firefighters. The mean thresholds of hearing loss for the age-matched database A control subjects at each frequency were calculated for these percentiles. For each age group, frequency, and percentile (50th or 90th), we subtracted the database A hearing thresholds from those of the firefighters.

Subtraction of age-matched database A hearing thresholds from those of the firefighters allowed us to estimate excess hearing loss in the firefighters. With normative hearing losses eliminated, increasing age among the firefighters becomes a surrogate measure of increasing years of fire service with the presbycusis effect removed.

Database B examples 1 and 2[12–14] are derived from unscreened United States populations. The first example comes from a US Public Health Service Survey (1965).[16] Some of these subjects were assumed to have had unreported occupational or other exposure to noise. The second example comes from a survey in urban and rural North Carolina. The subjects were stratified by age, race, and sex,[17,18] and excluded only if they reported 2 or more weeks of industrial noise exposure. North Carolina subjects were not excluded for military service and nonindustrial noise exposure, including farming, hunting, and shop work. For database B example 2, we compared the male firefighters hearing with that of white, male North Carolinians[17] because the firefighter cohort was predominately white.

For examples 1 and 2 of database B, data are provided for the 10th, 50th, and 90th percentiles by age and sex for persons 30, 40, 50, and 60 years of age. Formulas are not given to interpolate between ages. To match the mean ages of the firefighter subgroups, database B data were averaged with appropriate weighting between male values for 30 and 40 years old or 40 and 50 years old, and so on. Because thresholds are quite similar for both examples of database B, these data were averaged before comparison with the firefighters. Because 20-year-old data are not provided for database B, we estimated database B values for a mean age of 28 years. We subtracted the change in thresholds in dB at the corresponding percentile from age 28 to age 30 for database A from database B values for 30-year-old persons. This method is justified because at both the 50th and 90th percentiles, the relative changes in thresholds with increasing age are quite similar for both databases A and B. Again, for each age group and frequency, the average database B hearing loss at the 50th and 90th percentile at each frequency was subtracted from that of the firefighters at the same percentiles.

Results

The average age of the 319 firefighters and the control subjects from database A was 39.5 ± 6.9 years. When results for both ears were averaged, 46 of 319 (14%) firefighters had high-frequency hearing loss (3000, 4000, and 6000 Hz) compared with 5% for a database A population with a similar age distribution. This yielded a relative risk for the firefighters of 2.9 (95% confidence interval, 1.7 to 5.1; $P < 0.001$; χ^2 =

TABLE 2
Mean Hearing Thresholds in Decibels for Firefighters by Age at the 50th and 90th Percentiles

Age Group	Age Mean ± SD	Age n	Percentile	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
20–30	28 ± 3	33	50th	5	5	5	5	5	10
31–40	36 ± 3	143	50th	5	5	5	5	10	15
41–45	43 ± 1	76	50th	10	5	5	10	15	20
46–50	48 ± 1	53	50th	10	5	10	15	21	25
>50	53 ± 2	14	50th	5	10	10	40	45	48
20–30	28 ± 3	33	90th	18	10	15	10	15	25
31–40	36 ± 3	143	90th	15	15	15	25	32	40
41–45	43 ± 1	76	90th	15	15	20	40	50	45
46–50	48 ± 1	53	90th	22	15	20	45	50	50
>50	53 ± 2	14	90th	16	16	46	72	82	76

TABLE 3
Firefighters' Hearing Loss in Decibels HL Minus Hearing Loss for Age-Matched Database A Subjects

Age Group	Age Mean ± SD	Age n	Percentile	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
20–30	28 ± 3	33	50th	5	5	4	4	3	8
31–40	36 ± 3	143	50th	4	4	3	1	5	9
41–45	43 ± 1	76	50th	8	3	1	3	5	9
46–50	48 ± 1	53	50th	7	1	4	4	7	9
>50	53 ± 2	14	50th	1	5	2	27	27	27
20–30	28 ± 3	33	90th	10	1	4	−2	1	10
31–40	36 ± 3	143	90th	5	5	2	9	13	18
41–45	43 ± 1	76	90th	4	3	4	19	23	15
46–50	48 ± 1	53	90th	9	2	1	19	16	12
>50	53 ± 2	14	90th	1	1	25	42	42	32

16.7). When both ears were averaged, 24 of 206 firefighters (12%) had broad-frequency hearing loss (500, 1000, 2000, and 4000 Hz; figures exclude hospital 1) compared with 4.0% of a database A population of similar age distribution. This yielded a relative risk for the firefighters of 2.9 (95% confidence interval, 1.5 to 5.6; $P = 0.001$, $\chi^2 = 11.4$).

Table 2 shows age-stratified hearing thresholds for the firefighters at the 50th and 90th percentiles. At the 90th percentile after age 40, there is the suggestion of a notch at 4000 Hz typical of noise-induced hearing loss.

Tables 3 and 4 show the differences between the firefighters' hearing thresholds and those predicted for persons of the same average ages from database A (Table 3) and database B (Table 4). At the 50th percentile, the oldest firefighters (>50 years old) had worse hearing relative to both comparison groups over the 3000- to 6000-Hz range. The effect was more pronounced at the 90th percentile and began earlier. Over the 3000- to 6000-Hz range, hearing generally became progressively worse with increasing age relative to the comparison groups. The group >50 years old also had worse hearing at 2000 Hz at the 90th percentile.

Table 5 shows the excess threshold shifts for the firefighters at each frequency from 28 to 53 years old at the 50th and 90th percentiles compared with databases A and B. At each of the frequencies tested, similar results were found using both databases A and B. Again, the results suggest a notch with similar or greater excess losses at 3000 and 4000 Hz than at 6000 Hz.

Discussion

In agreement with other studies of firefighters,[1–6] we found that hearing loss was common in our cohort. Whether hearing loss at high frequencies (3000, 4000, and 6000 Hz) or hearing loss over a broader frequency range (500, 1000, 2000, and 4000 Hz) was considered, 12 to 14% of the firefighters met our definitions of hearing loss for the average of both ears. This compares with a much smaller number than would be expected from an age-matched otologically normal population (database A). Because formulas for interpolation between ages or percentiles are not provided, it is unclear exactly what proportion of an age-matched, unscreened general population (database B) would be found to have hearing loss by the definitions em-

TABLE 4
Firefighters' Hearing Loss in Decibels Minus Hearing Loss for the Mean of Databases B1 and B2

Age Group	Age Mean ± SD	*n*	Percentile	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
20–30	28 ± 3	33	50th	−2	3	3	−2	−6	−6
31–40	36 ± 3	143	50th	−4	1	1	−6	−6	−7
41–45	43 ± 1	76	50th	1	0	−1	−5	−7	−8
46–50	48 ± 1	53	50th	0	−1	2	−3	−5	−7
>50	53 ± 2	14	50th	−6	3	0	17	14	10
20–30	28 ± 3	33	90th	2	−1	2	−18	−22	−20
31–40	36 ± 3	143	90th	−3	1	−2	−10	−12	−14
41–45	43 ± 1	76	90th	−5	−2	−2	−2	−2	−16
46–50	48 ± 1	53	90th	2	−3	−7	−2	−5	−14
>50	53 ± 2	14	90th	−6	−3	14	20	23	8

TABLE 5
Excess Threshold Shift for Firefighters in Decibels HL From Ages 28 to 53 Years Versus General Population Databases

Database	Percentile	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
A	50th	−4	0	−2	23	23	19
B	50th	−4	0	−3	19	20	16
A	90th	−9	−1	20	44	41	22
B	90th	−8	−2	12	38	45	28

ployed in our study. Based on the thresholds of the 90th percentile for 30- and 40-year-olds in both examples of database B, the proportions would exceed 10% and be somewhat higher for the high frequency criterion than the broad frequency criterion. Pepe et al[2] found that 18% of similarly aged firefighters (range, 21 to 59 years) failed the 30-dB high-frequency fence in both ears.

When the firefighters' data were broken down by age, the younger age groups tended to have similar or better hearing than database B, at the frequencies of 3000, 4000, and 6000 Hz at both the 50th and 90th percentiles. Again, better hearing in younger firefighters versus the general population has been observed in other samples of firefighters.[4,8] Relative to both comparison groups, as the mean age of the firefighters increased, the firefighters' hearing became worse in the high-frequency range. This effect was more pronounced at the 90th percentile and began earlier than at the 50th percentile. The excess threshold shifts from a mean age of 28 years to a mean age of 53 years were similar at each frequency whether the firefighters were compared with database A (highly screened, otologically normal subjects) or database B (unscreened general population data). At the 50th percentile, from a mean age of 28 to a mean age of 53 years old, relative to databases A and B, the firefighters lost an excess of 19 to 23 dB, 20 to 23 dB, and 16 to 19 dB at 3000, 4000, and 6000 Hz, respectively. At the 90th percentile, from a mean age of 28 years to a mean age of 53 years, relative to databases A and B, the firefighters lost an excess of 12 to 20 dB, 38 to 44 dB, 41 to 45 dB, and 22 to 28 dB at 2000, 3000, 4000, and 6000 Hz, respectively.

Therefore, the results suggest that the rate of age-related hearing loss is quite similar for databases A and B but is accelerated in the 3000- to 6000-Hz range for the firefighters, and in the 2000- to 6000-Hz range at or above the 90th percentile. Because these analyses removed the age-expected hearing losses, the threshold shift with increasing age cannot be explained by the effects of normal aging (presbycusis). In this case, age becomes a surrogate of years of service as a firefighter. Other researchers[2,3] have also found the association between the magnitude of hearing loss and number of years of service as a firefighter to remain even after the effect of presbycusis (age-related hearing loss) has been controlled for. Because the effect is much more pronounced at the 90th percentile, it suggests that a subgroup of more sensitive or susceptible individuals may exist.

Researchers have suggested that excess hearing loss among firefighters is caused by occupational noise exposure[2–6,8] Exposure assessments have consistently documented that during emergency responses, firefighters are often subject to brief periods of intense noise exceeding Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) short-term exposure limits.[2–6] The findings of high short-term exposures combined with apparent accelerated hearing loss in firefighters strongly suggest a noise-related health hazard, even though time-weighted exposures for periods of 8 to 24 hours rarely exceed OSHA and NIOSH limits.

Although an association between intermittent noise exposure and hearing loss has been found in firefighters, a causal relationship has not been established. Research has more recently begun to address the risk of noise-induced hearing loss due to intermittent exposure to high decibel levels, such as those experienced by firefighters during emergency response situations.[1,2,4–6,11] In addition, a synergistic effect between ototoxic air contaminants routinely encountered by firefighters and occupational noise has been postulated.[3] Cigarette smoking could play a similar role.[9] We could not address the role of smoking or other medical factors in this study because of the lack of smoking information or formulas for adjusting thresholds for smoking in the International Organization for Standardization comparison databases. These databases are based on studies done from the 1960s to 1980. Therefore, the prevalence of smoking in the United States would have been higher in the general population at that time than the 12% of current smokers in the firefighter cohort. We plan to study the role of smoking and other medical problems on hearing within our cohort in the near future.

The major limitation of our study was the lack of information on nonoccupational noise exposure and other historical factors that might affect hearing in the firefighters. There is also insufficient information as to the complete comparability of the reference groups to the firefighters. Although we could not completely control for these nonoccupational factors, we did use two different and independently derived sets of control hearing thresholds from a highly screened, otologically normal comparison group (database A) and an unscreened comparison group (database B examples one and two). Both examples of database B are assumed to have included subjects with exposure to noise.[16,17] In the second example, North Carolina subjects were not excluded for military service and nonindustrial noise exposure, including farming, hunting, and shop work. Nonetheless, our results for excess hearing loss in the firefighters associated with increasing age were quite similar whether we compared the firefighters with database A or B. The fact that both screened and unscreened comparison groups yielded similar results and similar rates of hearing loss with increasing age means that this finding was independent of the comparison group. The reproducibility of the results with an unscreened control group suggests that factors other than nonoccupational noise exposure are responsible for the apparent accelerated hearing loss exhibited by the firefighters.

The most important strength of our study was the ability to strictly age-match our database A control subjects. Differences in testing methods or other nonoccupational factors between the firefighters and the comparison groups would not explain the similar or better hearing of the younger firefighters compared with the control subjects, whereas older firefighters had greater than expected age-related hearing loss compared with the comparison groups. Although we could not perform exact age matching for database B, interpolation from the database A tables for age by decade for the 50th and 90th percentiles gave results almost identical to the exact age-matched ones we presented. Based on this exercise and because the rates of hearing loss with age are similar for databases A and B, we believe that the interpolated averages for database B are good estimates of what subject by subject age-matched data would have shown.

Our study and other investigations of firefighters hearing have been cross-sectional. Longitudinal investigations will be necessary to confirm that firefighters hearing loss is accelerated compared with the general population. In addition, because of numerous variables and potential confounders, none of the studies can conclusively demonstrate that firefighters' hearing loss is caused by occupational noise. Nonetheless, researchers have shown that firefighters are subject to brief intermittent periods of high levels of noise exceeding OSHA and NIOSH short-term exposure limits.[2–6] Furthermore, noise-induced hearing loss is an irreversible condition for which there is no effective medical treatment.[19] The irreversible nature of noise-induced hearing loss, the consistency of findings documenting exaggerated hearing loss in older firefighters,[1–6,8] and documented noise hazards[2–6,17] argue strongly for the widespread implementation of preventive measures. Engineering controls and personal protective equipment have been reviewed elsewhere.[3] In addition, educational interventions designed to increase the awareness of noise-induced hearing loss and promote the use of hearing protection devices have yielded positive results.[1] Therefore, although further research is still needed, sufficient information exists to confirm this hazard and to advocate prevention programs.

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Spirometric Surveillance in Hazardous Materials Firefighters: Does Hazardous Materials Duty Affect Lung Function?

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We analyzed spirometry results for 351 male hazardous materials firefighters from 1996 to 1999 who underwent one or more annual medical surveillance/fitness for duty examinations: 276 (79%) technicians and 75 (21%) support members. Support members had a very limited potential for hazardous materials exposure and served as referents. In cross-sectional comparisons, the technicians' average forced vital capacity and forced expiratory volume in 1 second were either statistically better or not significantly different from that of the support members at all four examinations. Longitudinally, no statistically significant differences were seen for forced vital capacity. The mean percent of predicted forced expiratory volume in 1 second decreased by 3% for technicians (P = 0.029), support controls (P = 0.433), and the total cohort (P = 0.014). Although respiratory irritants are the most common type of exposure in hazardous materials releases, the results suggest that hazardous materials technicians do not lose pulmonary function at a more accelerated rate than support team firefighters. (J Occup Environ Med. *2001;43:1114–1120*)

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The US Agency for Toxic Substances and Disease Registry has suggested that over 400,000 persons in the United States may be involved as first responders to hazardous materials accidents, including emergency medical technicians, firefighters, police, and others.[1] An increasing number of communities and industries have developed hazardous materials (hazmat) teams composed of specially trained individuals to respond to chemical spills, fires, and accidents. Although firefighters respond to fewer fires than in the past,[2] they have become more involved in the mitigation of hazardous materials accidents.[2–5] Respiratory exposure to irritant substances is the most common type of exposure associated with hazardous materials releases.[6–10] Therefore, the potential of hazardous materials duty to affect pulmonary function is an important question in terms of the respiratory health of firefighters and other first responders.

The US Occupational Safety and Health Administration (OSHA) standard on Hazardous Waste Workers (29 CFR 1910.120) requires medical examinations for hazardous waste workers, including members of hazardous materials response teams.[11] An identical US Environmental Protection Agency standard (40 CFR 11) applies to state and municipal employers in states without designated OSHA programs.[1,12] The OSHA standard requires preassignment examinations and periodic examinations at least every 2 years, but the content of the examinations is not specified.

Because of the potential for respiratory exposures, most medical surveillance programs include spirometry in their examination protocols.[13] This common practice is in agreement with recommendations that pulmonary function tests be considered as part of the medical examination process for hazardous waste workers[1,14,15] and for firefighters.[5,16,17] Despite the widespread use of spirometry in these medical examinations, limited information is available at present on the utility of monitoring pulmonary function testing among professional hazardous materials handlers. Because it has been estimated that over 1 million persons in the United States are involved in firefighting alone,[18] the utility of tests used to monitor health status among firefighters and other hazardous materials handlers is an important issue in the provision of preventive health services.

In a small, prospective study of 40 hazardous material firefighters, we found few spirometric abnormalities and none that could be specifically linked to exposures or accident response.[19] The current study was undertaken to evaluate further possible health effects of hazardous materials firefighting duty as measured by spirometry in a larger, statewide cohort over 3 years and in our original cohort over 6 years.

Methods

Subjects

The study population included all 351 male members of six regional hazardous materials response teams of the Commonwealth of Massachusetts who underwent one or more annual, state-mandated medical surveillance/fitness for duty examinations between 1996 and 1999. All firefighters were examined on a confidential basis. The Institutional Review Boards of the Harvard School of Public Health and The Cambridge Hospital approved review of the firefighters' medical records for research purposes.

All of the subjects were also members of municipal fire departments in addition to their hazardous materials duty with the state teams. In 1996 to 1997 (year 01 of the primary study), the initial cohort ($n = 336$) included 267 (79%) hazardous materials technicians and 69 (20%) support members. The majority of the technicians were already incumbent members of the hazardous materials teams before the start of the study. After the year 01/1996 to 1997 examination and before the end of the study period, 15 new members joined the teams and 14 firefighters (12 support members and two technicians) changed positions. Including all four examinations, data were collected for 351 firefighters: 276 (79%) technicians and 75 (21%) support members.

Hazardous Materials Duty Exposure Status

Technicians are involved with the actual assessment and mitigation of hazardous materials accidents within the "hot," or contaminated, zone of the accident. Most situations are responded to on a "level A" basis, which entails the use of vapor-tight clothing and a positive pressure self-contained breathing apparatus. Field decontamination is performed routinely after all accidents unless the hazard poses a threat only by pulmonary absorption (eg, carbon monoxide).

During hazardous materials duty, support members do not enter the hot zone of an accident and their role is limited and ancillary. Therefore, they are presumed to have a very low potential for hazardous materials exposure compared with the technicians. Both technicians and support members perform regular fire duty with their local fire departments. Because support members are not exposed in their hazardous materials duties but do serve as municipal firefighters, they are an ideal control group for the investigation of potential health effects arising from duty within the contaminated zone of hazardous materials accidents.

Baseline and Follow-Up Medical Examinations

Medical surveillance examinations for the firefighters were performed at one of three hospitals in 1996 or 1997 in year 01 of a statewide surveillance program. A smaller number ($n = 214$) were examined during the year 02 examinations in 1997. This timing was because of an administrative decision by the Commonwealth of Massachusetts in 1997 to have all teams' subsequent examinations conducted within a 2-month time period in the fall of each year. The year 01 examinations were conducted throughout 1996 and part of 1997. Because 16 months is the maximum time period allowed between examinations, some firefighters were not reexamined until fall 1998.

Forty technicians from team 1, one of the six teams, had baseline examinations conducted at hospital two, one of the three hospitals mentioned above, between November 1992 and August 1993. Thirty-seven technicians from this group had follow-up examinations performed in April and May 1995. We reported previously on the results of their 1992 to 1993 and 1995 examinations.[19] Thirty-seven technicians from this original cohort participated in the statewide year 01/1996 to 1997 examination, and 32 of the original technicians remained active through year 04 and were examined again in 1999. Therefore, this subgroup had longitudinal follow-up data over 6 years at six time points available for study.

All examinations were conducted in a similar manner. Examinations included a detailed medical, smoking, and environmental/occupational history tailored to emergency responders; physical examination; spirometry; and routine laboratory tests.

Statistical Analyses

We used the percent of the predicted forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1) to adjust for the effects of age and height. We found no significant differences in the proportions of technicians (78% to 81%) and support members (19% to 22%) examined at each of the three hospitals in year 01/1996 to 1997 (P = 0.857). Likewise, the relative proportions of technicians (76% to 86%) to support controls (14% to 24%) remained similar among the three hospitals for year 02/1997, year 03/1998, and year 04/1999 ($P = 0.207$, $P = 0.541$, and $P = 0.614$, respectively). Among firefighters tested at hospital 1 ($n = 100$), hospital 2 ($n = 117$), and hospital 3 ($n = 112$), we found no significant differences in the year 01/1996 to 1997 mean percent predicted FVC or FEV_1 ($P = 0.087$ and $P = 0.201$, respectively). Therefore, for both of these reasons, we did not adjust for examination site in our cross-sectional or longitudinal comparisons of spirometric function.

Differences between groups at a single time point were examined using independent t tests and separate variances. Differences in serial mean values within groups over time were examined using analyses of variance time analyses. Differences in proportions were compared using the chi-squared or Fisher exact test, as appropriate. The level of statistical significance for all analyses was $P < 0.05$ and was two-tailed for all tests.

Results

Table 1 summarizes the baseline characteristics of the technicians and support controls at the year 01/1996 to 1997 examination. The mean age of the technicians was significantly greater ($P < 0.001$) than the mean age of the support members. Although a larger proportion of technicians than support controls had reported various pulmonary risk factors, none of these differences was statistically significant.

Of the 336 male firefighters who were either technicians or support members in year 01/1996 to 1997, 291 (87%) remained active and were examined in year 04/1999. Among 45 firefighters who left the teams for any reason or were inactive at year 04, there was no evidence of an excess dropout rate among the technicians. The proportion of technicians (78%; 35 of 45) to support controls (22%; 10 of 45) was not significantly different from among the remaining 291 members of initial cohort ($P = 0.763$). Therefore, the proportion of technicians in the initial cohort (79%; 267 of 336) and among those who remained active through year 04 (80%; 232 of 291) was quite similar.

Table 2 compares the spirometric function at the initial year 01 examination of those who remained active through year 04 compared with those who were inactive in year 04. For the technicians, those who became inactive had a significantly lower percent predicted FEV_1 ($P = 0.039$). Among technicians who became inactive, the prevalence of any pulmonary risk factor (51%; 18 of 35) was somewhat higher than among the technicians who remained active (37%; 86 of 232), but the difference was not significant ($P = 0.136$). For the support team, there were no significant differences in baseline pulmonary function between the active and inactive members. The prevalence of any pulmonary risk factor was 30% (3 of 10) among those who became inactive and 29% (17 of 59) for those who remained active ($P = 1.000$).

Among the firefighters who were technicians in year 01/1996 to 1997 and remained active with the teams through year 04/1999, the proportion with an FVC or FEV_1 that was less than 80% predicted in 1999 was 6.6% (15 of 229). This finding is similar to the proportion of technicians with an FVC or FEV_1 that was less than 80% of predicted at the start of the study, 6.1% (16 of 264). Among the firefighters who were technicians in year 01/1996 to 1997 and had an FVC or FEV_1 that was less than 80% predicted, 25% (4 of 16) had become inactive by year 04/1999. This finding compared with 12.5% (31 of 248) of those whose FVC and FEV_1 were ≥80% predicted ($P = 0.242$).

Table 3 compares the spirometric function of technicians versus support controls at each yearly examination. After the year 01/1996 to 1997 examination before the end of the study period, 15 new members joined the teams and 14 firefighters changed positions. In Table 3, fire-

TABLE 1

Baseline Characteristics of Technicians versus Support (Year 01/1996–1997)*

Variable	Technicians (n = 267)	Support (n = 69)	P Value
Age	40.6 ± 6.4 (n = 252)	35.0 ± 7.0 (n = 68)	<0.001
BMI	29.1 ± 4.2 (n = 262)	28.3 ± 3.5 (n = 67)	0.100
Atopy (%, n)	21.3, 57 of 267	17.4, 12 of 69	0.468
Smokers (%, n)	11.9, 29 of 244	6.9, 4 of 58	0.274
Asthma (%, n)	4.1, 11 of 267	1.4, 1 of 69	0.472
MD obstruction (%, n)	1.9, 5 of 267	1.4, 1 of 69	1.000
Sinusitis (%, n)	1.1, 3 of 267	0, 0 of 69	1.000
FVC% or FEV_1% pred <80% or FEV_1/FVC <70% (%, n)	10.6, 28 of 264	7.6, 5 of 66	0.463
% FVC% or FEV_1% pred <80% (%, n)	6.1, 16 of 264	4.5, 3 of 66	0.775
FEV_1/FVC <70% (%, n)	5.7, 15 of 264	3.1, 2 of 65	0.541
Any pulmonary risk factor† (%, n)	39, 104 of 267	29, 20 of 69	0.126

* BMI, body mass index; MD, medical doctor; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; pred, predicted.

† Includes any of the following: atopy, current smoking, asthma, physician diagnosis of obstruction (MD obstruction), sinusitis, FVC% < 80%, FEV_1% < 80%, or FEV_1/FVC < 70%. In preliminary analyses, all were associated with having a lower mean FEV_1% of predicted when compared with firefighters with none of these risk factors.

TABLE 2

Comparisons of Year 01 (1996–1997) Data for Active* vs Inactive† Team Members‡

Variable	Job Type	Active	Inactive	P Value
1996–1997 FVC (% pred)	Technician	103 ± 13 (n = 228)	100 ± 14 (n = 35)	0.171
1996–1997 FEV_1 (% pred)	Technician	103 ± 13 (n = 228)	98 ± 13 (n = 35)	0.039
1996–1997 FVC (% pred)	Support	102 ± 10 (n = 58)	108 ± 8 (n = 8)	0.064
1996–1997 FEV_1 (% pred)	Support	102 ± 13 (n = 58)	105 ± 8 (n = 8)	0.458
1996–1997 FVC (% pred)	Total	103 ± 12 (n = 286)	101 ± 13 (n = 43)	0.449
1996–1997 FEV_1 (% pred)	Total	103 ± 13 (n = 286)	99 ± 12 (n = 43)	0.082

* Remained active through year 04.

† Not active in year 04.

‡ FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; pred, predicted. Independent samples t tests.

TABLE 3

Spirometric Values of Technicians vs Support Controls*

Variable/Year	Technician	Support	P Value (2-tailed)
FVC (% pred)			
1996–1997	103 ± 13 (n = 263)	102 ± 10 (n = 66)	0.719
1997	102 ± 13 (n = 169)	98 ± 10 (n = 40)	0.049
1998	103 ± 13 (n = 261)	100 ± 9 (n = 60)	0.040
1999	103 ± 12 (n = 249)	98 ± 10 (n = 52)	0.003
FEV_1 (% pred)			
1996–1997	102 ± 13 (n = 263)	103 ± 12 (n = 66)	0.998
1997	103 ± 13 (n = 169)	102 ± 12 (n = 40)	0.661
1998	101 ± 14 (n = 261)	98 ± 13 (n = 60)	0.165
1999	100 ± 13 (n = 249)	96 ± 14 (n = 52)	0.041

* FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; pred, predicted. Independent samples t tests.

fighters were classified as technicians or support members based on their designated job titles at the time of the examination. The average spirometric function of the technicians was either statistically better or not significantly different from that of the support controls at all examinations.

Table 4 shows analyses of variance values for FVC and FEV_1 as a function of time. The firefighters included in Table 4 were examined in year 01/1996 to 1997, did not change job positions, remained on the teams, and were reexamined in year 04/1999. Pooled mean values are shown for all technicians, all support controls, and the total cohort. The year 02/1997 examination is not included in these time analyses because few firefighters were examined in year 02 at hospital 3 (see Methods). For percentage of FEV_1 predicted, mean values decreased by 3% for technicians, support controls, and the total cohort. Although this change was statistically significant for the technicians (P = 0.029) and the total cohort (0.014), it did not reach statistical significance for the controls (P = 0.433) likely because of the smaller sample size.

Table 5 shows mean values by job type at each examining hospital. No statistically significant changes were observed over time in these smaller sub-cohorts. It is interesting to note that within each hospital, similar trends were observed for both technicians and support members from year to year.

Table 6 shows time analyses for the team 1 technician cohort that we have followed since 1993. At year 04/1999, 80% (32 of 40) of the technicians remained active with the team. No significant changes in spirometric function were observed.

Discussion

This study was part of a longitudinal evaluation of the possible health effects of additional duties performed by firefighters on hazardous materials teams. Overall, the results suggest that hazardous materials firefighters do not lose pulmonary function at a more accelerated rate when compared with other firefighters. Hazardous materials technicians are involved with the actual assessment and mitigation of hazardous materials accidents within the hot, or contaminated, zone of the accident. Most situations are responded to on a level A basis, which entails the use of vapor-tight clothing and a positive pressure self-contained breathing apparatus. Field decontamination is routinely performed after all accidents unless the hazard poses a threat only by pulmonary absorption (eg, carbon monoxide). Although respiratory exposures to irritants are the most common exposures among victims of hazardous materials releases,[6–10] current procedures and personal protective equipment seem to be effective.

A major strength of our study was that we addressed the question of an effect on spirometric function in three ways. First, we compared cross-sectionally firefighters who were hazardous materials technicians with support firefighters who do not perform hazardous materials duty in contaminated zones. Power calculations based on the technician and support sample sizes demonstrated a 92% power to find a 5% difference in percent predicted FEV_1 or FVC between the two groups. At each of four examinations, the average spirometric function of the technicians was either statistically better or not significantly different from that of

TABLE 4

Spirometric Values by Job Type*

Variable/Job Type	1996–1997	1998	1999	Total	ANOVA *P* Value
FVC (% pred)					
Technician	103 ± 13 (*n* = 225)	103 ± 13 (*n* = 226)	103 ± 13 (*n* = 228)	103 ± 13 (*n* = 679)	0.780
Support	100 ± 10 (*n* = 46)	99 ± 9 (*n* = 47)	98 ± 10 (*n* = 46)	99 ± 10 (*n* = 139)	0.568
Total	103 ± 12 (*n* = 271)	102 ± 12 (*n* = 273)	102 ± 12 (*n* = 274)	102 ± 12 (*n* = 818)	0.621
FEV_1 (% pred)					
Technician	103 ± 13 (*n* = 225)	101 ± 14 (*n* = 226)	100 ± 13 (*n* = 228)	101 ± 14 (*n* = 679)	0.029
Support	100 ± 12 (*n* = 46)	99 ± 13 (*n* = 47)	97 ± 13 (*n* = 46)	99 ± 12 (*n* = 139)	0.433
Total	103 ± 13 (*n* = 271)	100 ± 14 (*n* = 273)	100 ± 13 (*n* = 274)	101 ± 13 (*n* = 818)	0.014

* Analysis of variance (ANOVA) time analyses. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; pred, predicted.

TABLE 5

Mean Spirometric Values for Each Examining Hospital as a Function of Job Type*

Variable/Job Type	1996–1997	1997	1998	1999	Total	ANOVA *P* Value
FVC (% pred)						
Hospital 1						
Technician	102 ± 12 (*n* = 76)	103 ± 13 (*n* = 74)	105 ± 13 (*n* = 75)	107 ± 13 (*n* = 74)	104 ± 13 (*n* = 299)	0.113
Support	97 ± 9 (*n* = 15)	95 ± 12 (*n* = 11)	102 ± 9 (*n* = 15)	100 ± 11 (*n* = 14)	99 ± 10 (*n* = 55)	0.311
FEV_1 (% pred)						
Hospital 1						
Technician	103 ± 12 (*n* = 76)	102 ± 12 (*n* = 74)	100 ± 14 (*n* = 75)	101 ± 13 (*n* = 74)	102 ± 13 (*n* = 299)	0.644
Support	99 ± 11 (*n* = 15)	99 ± 14 (*n* = 11)	101 ± 13 (*n* = 15)	97 ± 13 (*n* = 14)	99 ± 12 (*n* = 55)	0.933
FVC (% pred)						
Hospital 2						
Technician	103 ± 11 (*n* = 77)	104 ± 12 (*n* = 68)	101 ± 11 (*n* = 76)	101 ± 11 (*n* = 78)	102 ± 11 (*n* = 299)	0.296
Support	98 ± 6 (*n* = 13)	98 ± 6 (*n* = 14)	97 ± 7 (*n* = 14)	97 ± 8 (*n* = 14)	97 ± 6 (*n* = 55)	0.958
FEV_1 (% pred)						
Hospital 2						
Technician	105 ± 13 (*n* = 77)	104 ± 12 (*n* = 68)	102 ± 12 (*n* = 76)	100 ± 13 (*n* = 78)	102 ± 12 (*n* = 299)	0.067
Support	101 ± 7 (*n* = 13)	100 ± 11 (*n* = 13)	98 ± 9 (*n* = 13)	97 ± 8 (*n* = 13)	99 ± 9 (*n* = 55)	0.793
FVC (% pred)						
Hospital 3						
Technician	105 ± 15 (*n* = 72)	94 ± 15 (*n* = 11)	102 ± 13 (*n* = 75)	100 ± 13 (*n* = 76)	102 ± 14† (*n* = 223)	0.115†
Support	105 ± 11 (*n* = 18)	84 ± 7 (*n* = 3)	99 ± 10 (*n* = 18)	97 ± 12 (*n* = 18)	100 ± 12† (*n* = 54)	0.096†
FEV_1 (% pred)						
Hospital 3						
Technician	102 ± 15 (*n* = 72)	103 ± 16 (*n* = 11)	101 ± 15 (*n* = 75)	99 ± 15 (*n* = 76)	101 ± 15† (*n* = 223)	0.400†
Support	102 ± 16 (*n* = 18)	93 ± 2 (*n* = 3)	97 ± 15 (*n* = 18)	97 ± 16 (*n* = 18)	99 ± 15† (*n* = 54)	0.527†

* Analysis of variance (ANOVA) time analyses. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; pred, predicted.
† For Hospital 3, totals and ANOVA are for 1996–1997, 1998, 1999, and do not include 1997.

the support members. Therefore, we found no evidence of an adverse effect of hazardous materials duty in cross-sectional analyses.

Second, we performed longitudinal analyses within each group of firefighters who remained active through the fourth examination and did not change job positions during the study period. We observed no significant decrements in the percent of the predicted FVC for technicians, support controls, or the entire cohort over 3 years of follow-up. There was a small, 3% decline in the percent of the predicted FEV_1 achieved for both groups and the total cohort. This change was statistically significant for the technicians and the total cohort. It did not reach statistical significance for the referents, probably because of the smaller sample size. Thus, although the results suggested a small decline in FEV_1, this trend was not isolated to those performing hazardous materials duties.

When longitudinal changes were assessed within each hospital, no statistically significant changes were seen. For the subgroups of technicians examined at each hospital, $n =$ 72 to 77, the power to detect a 5% change in percent predicted FEV_1 or FVC was estimated at 90% or slightly higher. We noted that at any given hospital, non-significant changes of a similar magnitude from year to year were seen for both technicians and support referents. These small changes may result from testing conditions themselves such as minor differences in calibration,

TABLE 6

Spirometric Values at Baseline and Follow-Up Examinations for Team 1 Technician Cohort*

Variable	1993	1995	1996	1997	1998	1999	Total	ANOVA *P* Value
FVC (% pred)	105 ± 12 (*n* = 35)	106 ± 12 (*n* = 34)	106 ± 11 (*n* = 34)	106 ± 13 (*n* = 32)	103 ± 10 (*n* = 35)	102 ± 11 (*n* = 32)	104 ± 12 (*n* = 202)	0.718
FEV_1 (% pred)	107 ± 13 (*n* = 35)	105 ± 13 (*n* = 34)	109 ± 13 (*n* = 34)	106 ± 13 (*n* = 32)	104 ± 11 (*n* = 35)	101 ± 14 (*n* = 32)	105 ± 13 (*n* = 202)	0.215

* Analysis of variance (ANOVA) time analyses. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; pred, predicted.

coaching, and technique. A 6-year time analysis of a smaller cohort of technicians showed no significant changes in spirometric function.

Third, we examined loss to follow-up, which is always a concern in longitudinal studies. We compared the firefighters who dropped out before the completion of the study with the 87% who remained active through year 04. We found no excess dropout rate among technicians who engaged in hazardous materials duty compared with support members. The technicians who dropped out, however, did have a significantly lower percent predicted FEV_1 (98%) compared with 103% for those who remained active. The technicians who dropped out also had a nonsignificantly higher prevalence of pulmonary risk factors. Among the firefighters who were technicians in year 01/1996 to 1997 and had an FVC or FEV_1 that was less than 80% predicted, 25% (4 of 16) had become inactive by year 04/1999, compared with 12.5% (31 of 248) of those with FVC and $FEV_1 \geq 80\%$ predicted (P = NS). The spirometric function and prevalence of pulmonary risk factors among the support controls that became inactive were not significantly different from among those who remained active. These results are not conclusive, but they suggest a greater dropout rate from hazardous materials duty among persons with lower pulmonary function or pulmonary risk factors. Similar self-selection effects were observed in earlier studies of Boston firefighters[20,21]; those who became inactive through job transfer or retirement in the longitudinal studies had lower levels of lung function than firefighters who remained active. Nevertheless, the question remains as to whether some firefighters self-select out of hazardous materials duty or fire suppression activities because of job-related pulmonary exposures, or whether they tolerate exertion, respirator use, and other job conditions less well than the firefighters who remain active. We are limited in our ability to answer this question because exit medical examinations are not mandatory and were not undergone by those who left the teams.

The major limitation of the current study was imposed by logistical constraints. In a statewide program, all six teams could not be examined at a single hospital. Furthermore, the investigators could not require the examining hospitals to use identical spirometers, prediction equations, and techniques for all teams and all time points. Nevertheless, we found no significant differences in the year 01/1996 to 1997 mean percent of predicted FVC or FEV_1 among the three hospitals. The proportions of referent support members examined at each of the three hospitals were also quite similar. In addition, there were no significant differences in the proportions of technicians to support members among the three hospitals at any time point. These facts justified pooling the data from all three hospitals for the majority of the analyses.

An important strength of the investigation is our control group, the support team members. Both technicians and support members perform regular fire duty with their non-state, local fire departments. Support members are presumed to have a very limited potential for exposure compared with technicians, because they do not enter the hot zone of an accident. Therefore, they are an ideal control group for the investigation of potential health effects that are limited to hazardous materials duty within the contaminated zone of accidents.

The OSHA standard on hazardous waste workers requires periodic examinations at least every 2 years, but the content of the examinations is not specified. Most medical surveillance programs have included spirometry in their examination protocols[13] as recommended for hazardous waste workers[1,14,15] and firefighters.[5,16,17] Although hazardous materials duty has the potential for serious exposures and injuries from explosions, fires, and other releases of dangerous substances, few actual overexposures may occur. In previous studies of incidents responded to by the same six Massachusetts regional teams from 1990 to 1996,[6,22] hazardous materials team members reported no significant chemical exposures to themselves. Likewise, among hazardous waste workers, few significant exposures occur, because those with the greatest potential for exposure usually are equipped with the highest levels of personal protective equipment.[13] The results of the present study are consistent with these previous observations. Nonetheless, there are several strong reasons to continue annual spirometric testing for these groups. First, among unprotected victims, inhalation is the most common route of exposure associated with hazardous materials releases[6,10] and exposure to pulmonary irritants and respiratory complaints are the most common health effects.[6–10]

Therefore, group spirometric surveillance may provide one type of objective physiologic measurement of the effectiveness of safe work practices and personal protective equipment. Given the irritant nature of the most common exposures, it is not surprising that the utility of routine biochemical and hematologic testing has been limited in both hazardous waste workers[23] and hazardous materials firefighters.[24] In the future, spirometry might be complemented by the measurement of serum proteins[25] and/or sputum analytes that are markers of lung inflammation.

Other factors that support continued annual spirometry testing and longitudinal study are the relatively short period of follow-up, the high prevalence of risk factors associated with lower baseline pulmonary function, and the small excess decline in FEV_1 for the entire cohort. Although the widespread introduction and use of respiratory protection, seems to account for the lack of chronic effects in several recent studies of pulmonary function in firefighters,[20,21,26,27] acute adverse effects from occupational smoke exposure have consistently been demonstrated.[25,28–31] Finally, this study did not consider separately those firefighters with respiratory problems or other individuals possibly susceptible to accelerated losses of pulmonary function. We believe that continued study of firefighters with and without these risk factors is warranted.

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Firefighters' Blood Pressure and Employment Status on Hazardous Materials Teams in Massachusetts: A Prospective Study

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We evaluated the association between hypertension and changes in employment status in 334 hazardous materials firefighters. Firefighters were categorized by blood pressure (BP) at baseline (1996 or 1997) and subsequent follow-up examinations (1997, 1998, and 1999). They were followed up for a maximum of 4 years for possible adverse outcomes (death, placement on "injured-on-duty" status, termination of duty, resignation, retirement, or incident cardiovascular disease). In several analytic models, we found that firefighters with stage II hypertension (BP ≥ 160/100 mm Hg) were consistently 2 to 3 times more likely to experience an adverse outcome compared with those with normal BP. Cox proportional-hazards regression was used to adjust for age, body mass index, smoking, cholesterol, and antihypertensive medication. In these models, the hazard ratio for stage II hypertension was 3.2 (95% confidence interval [CI], 1.50 to 7.04, P = 0.003) and for untreated stage II hypertension, it was 4.6 (95% CI, 2.08 to 10.11, P = 0.0002). Firefighters with a BP ≥ 160/100 mm Hg should receive further evaluation and demonstrate improved BP control before being determined fit for duty. (J Occup Environ Med. *2002;44:669–676*)

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Untreated high blood pressure is a recognized risk factor for cardiovascular disease and mortality,[1–4] with higher risks associated with increasing blood pressure.[5] Because uncontrolled hypertension poses health risks and may jeopardize public safety through sudden incapacitation, blood pressure control is a major criterion in medically determining fitness for duty in firefighters, commercial drivers, pilots, and other professions.[6–11] Although research has characterized the risk of developing hypertension and cardiovascular disease in occupational settings,[12–18] little is known about the relation between high blood pressure, occupational safety, and employment status.[19]

The National Fire Protection Association (NFPA), the US Department of Transportation (DOT), and the Commonwealth of Massachusetts Human Resources Division have established blood pressure guidelines for firefighters, commercial drivers, and policemen and firefighters, respectively. Lacking evidence from occupational cohorts, their cutoff criteria for acceptable blood pressure are based on generalizations from nonoccupational settings. Each expert panel, however, reached different conclusions. The NFPA specifies acceptable blood pressure as a systolic blood pressure (SBP) <180, a diastolic blood pressure (DBP) <100 mm Hg, and no target-organ damage.[20] The DOT stipulates that commercial drivers are medically qualified if their SBP is ≤160 mm Hg and their DBP is ≤90 mm Hg. Drivers may be provisionally qualified when 161 ≤ SBP ≤180 mm Hg and/or 91 ≤ DBP ≤ 104 mm Hg. Drivers must be disqualified when their SBP exceeds 180 mm Hg or when their DBP exceeds 104 mm Hg.[21] Meanwhile, Massachusetts' Human Resources Division defines an SBP < 160 mm Hg and a DBP < 100 mm Hg as acceptable for the initial hire of firefighters and police officers.[22]

While objective, numerical criteria may simplify the medical examiner's task by sparing subjective human judgement,[23] the impact of current blood pressure guidelines on employment status and health is unknown. In addition, the lack of evidence on occupational outcomes may reinforce examiners' reluctance to follow guidelines and exclude workers from jobs based on a single examination finding.[10,23] Finally, we do not know which guidelines, even if consistently enforced, are the most appropriate. We undertook this study to examine blood pressure and changes in employment status among firefighters and the utility of resting blood pressure as a fitness-for-duty criterion.

Methods

Subjects

The study base consisted of 340 firefighters from six regional, hazardous materials teams in Massachusetts who underwent a baseline examination in 1996 or 1997, when a statewide medical-surveillance program was initiated. The firefighters joined the hazardous materials teams on a contractual basis in addition to their primary occupational duties as municipal firefighters in local fire departments. We excluded two persons who were examined but never joined a hazardous materials team; three firefighters with inadequate follow-up information; and one firefighter already on "injured-on-duty" status at his baseline examination. The Institutional Review Boards of the Harvard School of Public Health and the Cambridge Hospital approved review of the firefighters' medical records for research purposes.

Baseline and Follow-Up Medical Examinations

Medical-surveillance examinations were performed, on a confidential basis, at one of three contracted Massachusetts hospitals. Eighty-two percent of the baseline examinations took place in 1996, and most of the firefighters (n = 214) had the first follow-up examination during 1997. The subsequent periodic examinations for all teams took place during the fall of 1998, 1999, and 2000. All examinations were performed for the dual purposes of medical surveillance and determination of fitness-for-duty status for the hazardous materials teams and were conducted in a similar fashion based on a written protocol. The physicians performing or supervising the medical examinations were board-certified or board-eligible in occupational medicine. Initially, all fitness decisions were left to the clinical discretion of the examining physicians at each hospital. Since 1998, threshold guidelines for resting blood pressure (SBP < 180 mm Hg, DBP < 100 mm Hg) and visual and acoustic acuity criteria were recommended, but the ultimate fitness-for-duty decisions remained with the attending physicians and were not subject to secondary review or audit. Examining physicians were blinded to the hypothesis of this investigation and were not informed that we were evaluating blood pressure ≧160/100 mm Hg as a threshold for increased risk. Summary results for each firefighter's examination, including the physicians' determination of fitness for duty, were transferred to a computerized medical record repository.

Blood Pressure Readings

Resting blood pressure readings were recorded routinely, in mm Hg, as part of the vital-signs evaluation and documented at every examination. For this study, the blood pressure for each examination was the single reading that was documented on each firefighter's summary sheet and sent to the central repository. Before entry into the computerized repository, blood pressure readings were rounded up to the nearest even digit. The Sixth Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC-VI)[5] was used to classify firefighters into three blood pressure categories based on the 1996 to 1999 examinations. The first category was normal blood pressure (SBP < 140 and DBP < 90 mm Hg), the second category was stage I hypertension (140 ≤SBP < 160 mm Hg and/or 90 ≤DBP < 100 mm Hg), and the third category was stage II hypertension or higher (SBP ≥ 160 mm Hg and/or DBP ≥ 100 mm Hg).

Additional Risk Factors

Prospective information on other factors was routinely collected at every examination, including the following: measured height and weight, age, gender, job type, allergies, medications, smoking history, and physical examination findings. Laboratory tests were also administered at each annual examination, including electrocardiogram (baseline only), spirometry, complete blood count, blood glucose, total cholesterol, serum triglycerides, liver enzymes, serum creatinine, and urinalysis. Since the 1996 or 1997 medical examinations, most data that were initially missing in the central data repository had been recovered from the original medical records of the examining hospital and entered into the repository.

Change in Employment Status

Changes in employment status (death, placement on injured-on-duty status, termination of duty, resignation, or retirement) were reported by the state Office of Hazardous Materials Response. Information on inci-

TABLE 1
Characteristics of the Hazardous Materials Firefighters by Blood Pressure Category ($N = 334$)

	n	Blood Pressure Categories (mm Hg): Normotensive at All Exams (SBP < 140 and DBP < 90) (*n* = 215)	Any Stage I Hypertensive Reading (140 ≤ SBP < 160 and/or 90 ≤ DBP < 100) (*n* = 93)	Any Stage II Hypertensive Reading (SBP ≥ 160 and/or DBP ≥ 100) (*n* = 26)	*P* Value
Age (mean ± SD)	334	38.0 ± 6.6	41.2 ± 7.0	43.0 ± 7.1	<0.001
SBP (mean ± SD)	334	118 ± 10	129 ± 12	142 ± 16	<0.001
DBP (mean ± SD)	334	76 ± 8	82 ± 9	91 ± 10	<0.001
BMI, (kg/m^2) [*n* (%)]	327				0.004
<25 Normal		[36 (17%)]	[6 (7%)]	[0]	
25–29 Overweight		[115 (55%)]	[46 (50%)]	[12 (48%)]	
≥30 Obese		[60 (28%)]	[39 (43%)]	[13 (52%)]	
Cholesterol [*n* (%)]	296				0.481
<200 mg/dL		[60 (31%)]	[21 (27%)]	[6 (24%)]	
200–239 mg/dL		[74 (38%)]	[27 (35%)]	[7 (28%)]	
≥240 mg/dL		[60 (31%)]	[29 (38%)]	[12 (48%)]	
Creatinine (mg/dL), (mean ± SD)	333	1.1 ± 0.2	1.1 ± 0.2	1.1 ± 0.1	0.928
Smoking [*n* (%)]	333				0.896
Nonsmoker		[193 (90%)]	[83 (89%)]	[24 (92%)]	
Current smoker		[21 (10%)]	[10 (11%)]	[2 (8%)]	

SBP, systolic blood pressure, and DBP, diastolic blood pressure, are in mm Hg. Ages are in years.

dent cardiovascular disease events (coronary heart disease or significant arrhythmia potentially interfering with duty) was collected by systematically reviewing the medical examination summaries. The following possible changes in employment status were included as a summary outcome measure: death, placement on injured-on-duty status, termination of duty, resignation, retirement, and incident cardiovascular disease events.

Statistical Analyses

Statistical analyses were performed using SAS software (version 6.12)[24] and SPSS version 9.0.[25] *T* test and chi-square tests were used to compare the differences in risk factors between the blood pressure categories. Person-years of follow-up were calculated from the baseline examination (1996) until the end of the study's follow-up period, which ended with the annual fall examination of 2000. Individual person-years subsequent to each examination were excluded if a firefighter had been found medically unfit for duty, was otherwise occupationally inactive, or on injured-on-duty status at the time of the index examination. Cox proportional-hazards regression models (adjusted for age, smoking, body mass index [BMI], total cholesterol, and blood pressure medication use) were used to evaluate the association between blood pressure and the risk of adverse employment status change.

We generated several separate models using either dichotomous measures for blood pressure (≧140/90 mm Hg or ≧160/100 mm Hg) or a three-category blood pressure variable. Effect modification was also evaluated using age, BMI, and antihypertensive medication as possible modifiers. Stratified analyses were performed for two different BMI categories and among those who were taking versus those who were not taking antihypertensive medications.

Results

The 334 firefighters included in our study were followed up for an average of 3.8 years (range, 1 to 4 years) and generated 1,262 person-years of follow-up. Their initial mean age was 39 ± 7 years (range, 20 to 58 years), and the vast majority were men ($n = 331$). At baseline, 66% had optimal or normal blood pressure (SBP < 130 mm Hg and DBP < 85 mm Hg), 17% had high-normal readings (130 ≤SBP < 140 mm Hg and/or 85 ≤DBP < 90 mm Hg), and 15% had stage I hypertension according to the JNC-VI guidelines. Only nine firefighters (2.7%) at baseline were found to have stage II hypertension (SBP ≥ 160 mm Hg and/or DBP ≥ 100 mm Hg). The highest SBP observed at any examination was 180 mm Hg, and the highest DBP was 114 mm Hg. Among the 26 firefighters with any stage II readings (1996–1999), 23% had both systolic and diastolic stage II readings, 23% had stage II systolic readings alone, and 54% had stage II diastolic readings alone.

Table 1 describes the baseline characteristics of the study population by summary blood pressure categories for all examinations from 1996 to 1999. Firefighters with higher blood pressure were significantly older ($P < 0.001$) and more obese ($P = 0.004$) compared with

TABLE 2

Employment Status Changes Between 1996 and 2000 Based on Blood Pressure Categories at 1996–1999 Examinations (N = 334)

		Blood Pressure Categories (mm Hg)			
	n	Normotensive at All Time Points (*n* = 215)	Some Stage I Hypertensive Readings (*n* = 93)	Any Stage II Hypertensive Readings (*n* = 26)	*P* Value
Total years of follow-up, 1996–2000, or prior to a change in work status	334				
1		2 (1%)	2 (2%)	2 (8%)	0.022
2		11 (5%)	2 (2%)	1 (4%)	
3		16 (7%)	9 (10%)	6 (23%)	
4		186 (87%)	80 (86%)	17 (65%)	
Adverse events	334				
No event		180 (84%)	84 (90%)	18 (69%)	0.029
Event		35 (16%)	9 (10%)	8 (31%)	
Adverse events (those on BP medication excluded)*	314				
No event		178 (85%)	75 (90%)	13 (62%)	0.005
Event		32 (15%)	8 (10%)	8 (38%)	
Adverse events (excludes BMI < 30)†	112				
No event		46 (77%)	34 (87%)	7 (54%)	
Event		14 (23%)	5 (13%)	6 (46%)	0.013
Adverse events (excludes BMI < 30 and BP medication use)	102				
No event		46 (78%)	28 (85%)	4 (40%)	
Event		13 (22%)	5 (15%)	6 (60%)	0.042

* Excludes firefighters who were receiving an antihypertensive medication in 1996.
† Excludes all firefighters with a body mass index (BMI) < 30.

those with normal blood pressure. The prevalence of elevated total cholesterol was not significantly different among the blood pressure categories; however, we observed a dose–response trend ($P = 0.093$) of increasing cholesterol by increasing blood pressure.

During 4 years of follow-up, 52 firefighters experienced adverse changes in their employment status. Twenty-five firefighters resigned at some point during the study period; 19 firefighters were placed on injured-on-duty status; three were terminated from their duties; two were removed from the hazardous materials teams; one died on duty; and two experienced cardiovascular disease events.

Table 2 summarizes years of follow-up and adverse events for the entire study period based on blood pressure categories as described in Table 1 from the 1996 to the 1999 examinations. Adverse events for the entire study period were more frequent for those with any stage II hypertension readings (31%) compared with the other two groups (10% to 16%) ($P = 0.029$). Considering only obese firefighters or those not taking antihypertensive medications further increased the risks of adverse events. When both nonobese firefighters and those taking antihypertensive medications were excluded, the rate of adverse events was 60% for obese persons with any stage II hypertension readings compared with 15% to 22% among obese subjects in stage I hypertension and normotensive groups ($P = 0.013$).

Table 3 examines the risk of an adverse event before the next follow-up examination, based on the single blood pressure recorded at the preceding examination. For firefighters with a stage II hypertension reading, the rate of events before the next examination was 10.8 per 100 person-years ($P < 0.05$) compared with those with normal and stage I hypertension readings pooled. Again, further increases in risk were observed for stage II readings among obese firefighters and those with untreated hypertension. When nonobese firefighters and persons taking antihypertensive medications were excluded, the rate of adverse events after a stage II reading was 21 events per 100 person-years. Again, this was significantly higher ($P < 0.05$) than the pooled rate for obese firefighters in the two groups with lower blood pressure.

Cox proportional-hazards regression models adjusting for age, BMI, smoking, cholesterol, and antihypertensive medication are presented in Table 4. Stage II hypertension was a significant predictor of adverse events in all models. We found that firefighters with stage II hypertension readings, at any examination, were 3.2 (95% confidence interval [CI], 1.50 to 7.04) times more likely

TABLE 3
Employment Status Changes Between 1996 and 2000 per Person-Years of Follow-Up in Different Blood Pressure Categories at Each Individual Examination 1996–1999

Adverse Events	Person-Years	Blood Pressure Categories (mm Hg)			(P Value*)
		Normotensive Readings	Stage I Hypertension Readings	Stage II or Higher Readings	
All firefighters					
Events/person-years	1,262	40/1,049	8/176	4/37	
Events/100 person-years		3.81	4.54	10.81	(<0.05)
On BP med excluded†	1,186				
Events/person-years		37/1,003	7/156	4/27	
Events/100 person-years		3.68	4.48	14.81	(<0.005)
Excludes BMI < 30‡	413				
Events/person-years		17/320	5/72	3/21	
Events/100 person-years		5.3	6.9	14.3	NS
BMI < 30‡ or on BP med excluded†	376				
Events/person-years		16/300	5/62	3/14	
Events/100 person-years		5.3	8.1	21.4	(<0.05)

* Fisher's exact tests comparing adverse events in stage II vs normal and stage I hypertension categories combined.
† Excluding firefighters who were receiving an antihypertensive medication in 1996.
‡ Excluding all firefighters with a body mass index (BMI) < 30.

TABLE 4
Multivariable-Adjusted Hazard Ratios and 95% CIs for the Association of Hypertension and Change in Employment Status in Hazardous Materials Firefighters (*N* = 334)*

	Hazard Ratios (95% CI)	*P* Value
Hypertension (model 1)†	1.4 (0.85–2.35)	0.19
Stage II Hypertension (model 2)‡	3.1 (1.47–6.60)	0.003
Firefighters with BMI ≥ 30	3.0 (1.12–8.07)	0.03
Firefighters with no medication use for BP	4.2 (1.96–8.81)	0.0002
Hypertension (model 3)§		
Stage I hypertension	0.9 (0.48–1.57)	0.6
Stage II or higher	3.2 (1.50–7.04)	0.003
Firefighters with BMI > 30		
Stage I hypertension	1.1 (0.52–2.30)	0.8
Stage II or higher	2.9 (1.06–8.09)	0.04
Firefighters with no medication use for BP		
Stage I hypertension	0.8 (0.40–1.50)	0.45
Stage II or higher	4.6 (2.08–10.11)	0.0002

* Adjusted for age (continuous), smoking (yes/no), total cholesterol (continuous), body mass index (BMI, continuous), and blood pressure (BP) medication use (yes/no).
† Hypertension was defined as a dichotomous variable with BP < 140/90 mm Hg as the reference category.
‡ Hypertension was defined as a dichotomous variable with BP < 160/100 mm Hg as the reference category.
§ Hypertension was defined as a three-category variable. Normal BP (BP < 140/90 mm Hg) was used as the reference category. Stage I hypertension (140/90 ≤ BP < 160/100 mm Hg) and stage II hypertension or higher (BP ≥ 160/100 mm Hg) were compared with the reference category to explore possible dose–response relationships.

to experience an adverse employment status change compared with those with normotensive readings. The hazard ratio increased to 4.6 (95% CI, 2.08 to 10.11) among firefighters with stage II hypertension who were not taking antihypertensive medications. This dose–response model demonstrated that only stage II hypertension readings were significantly associated with higher risks of employment status changes. Neither age (hazard ratio, 1.0; 95% CI, 0.95 to 1.02) nor the interaction of age and hypertension (hazard ratio, 1.0; 95% CI, 0.99 to 1.02) were significant predictors of adverse events in multivariable-adjusted regression.

Discussion

To our knowledge, this is the first study to prospectively examine blood pressure control and changes in employment status. Using various methods of analysis, we found that firefighters with stage II hypertension (BP ≥ 160/100 mm Hg) were consistently 2 to 3 times more likely to experience an adverse event than firefighters with normal blood pressure. This finding persisted after adjustment for a number of possible confounders. Therefore, our results provide evidence-based support for using <160/100 mm Hg as a cutoff criterion for occupationally acceptable resting blood pressure among firefighters. Only a single systolic reading exceeded the NFPA systolic guideline (SBP < 180 mm Hg) during 1262 person-years. Therefore, this particular systolic criterion lacked sensitivity and utility in our study population.

A second important finding regards two other modifiable risk factors. Among firefighters with stage II hypertension readings, adverse events were even more frequent among those not receiving antihypertensive medications and those with obesity (BMI ≥ 30). Obese firefighters with untreated stage II hypertension experienced the highest rate of adverse events. Therefore, although all firefighters with hypertension should be referred for treatment, our data suggest that certain groups warrant further consideration before receiving clearance as fit for duty, as well as more aggressive risk factor detection and management.

The overall prevalence of hypertension (defined by blood pressure readings and/or antihypertensive medication use) among our study population was relatively high (20%); however, it was lower than the prevalence in the general population (23% to 40%),[26] perhaps because of the healthy worker effort.[27] In any case, if <160/100 is used as a strict fitness-for-duty cutoff, only a small proportion of firefighters (about 3% per year) will be temporarily disqualified on this basis until improved blood pressure control is achieved. Thus, in addition to support from our study, this proposed guideline is practical to implement and reasonable public health policy.

Our investigation does have several limitations. The annual examinations and data collection processes were conducted in three different hospitals for six regional hazardous materials teams. Despite written protocols for medical surveillance, we know that not all physicians followed the same fitness determination practices.[10] Therefore, their clinical practices regarding uncontrolled hypertension may have differed also. When we adjusted for the examining hospital, however, the significantly increased risk for stage II hypertension persisted. It might also be postulated that from 1998 on, when a blood pressure guideline was recommended, some physicians might have been less likely to document a reading higher than 179 mm Hg, systolic or 99 mm Hg, diastolic to avoid disqualifying firefighters. This scenario would have misclassified some firefighters with high DBPs as <100 mm Hg. Another possible concern is differential methods of blood pressure assessment among examiners. Both misclassification scenarios, however, would be likely to drive the results toward the null hypothesis. Finally, the study subjects were classified primarily on the basis of single blood pressure readings. Single readings, however, have previously been shown to be significant predictors of cardiovascular disease outcomes.[28]

A different limitation, imposed by our relatively small sample size, was the inability to study specific outcomes (eg, on-duty incapacitation or injury). Therefore, we needed to use a broad outcome measure encompassing significant changes in employment status. Thus, the summary measure included retirement and resignation as well as health events. We believe our choice of outcomes was justified for several reasons. First, we did not consider fitness-for-duty decisions themselves because they can be directly linked to the exposure under study, uncontrolled hypertension. Second, we excluded from consideration resignations that resulted from promotions to higher rank and were unlikely to be health related. In other cases, however, there is good reason to believe that retirements and resignations in firefighters under the age of 60 may involve health issues. Likewise, termination of duty is likely to occur due to lack of compliance with the medical examination process, which again may relate to health problems. We do not have definitive evidence because the departing firefighters did not take advantage of an exit medical examination. Nonetheless, support for this ill-health hypothesis is the fact that in multivariable-adjusted models, stage II hypertension, obesity, and smoking were significant predictors of adverse events while age was not. Regarding injured-on-duty status, we lacked detailed information regarding the nature of the health problem in most reports. Injured-on-duty status usually relates to an injury occurring during the firefighter's municipal firefighting duties or a significant intervening medical illness. These injuries and illnesses resulted in sick leaves for several months to years from the hazardous materials teams and in several firefighters, to eventual retirement. In summary, the adverse employment outcomes included in the study were also likely to reflect changes in functional status that could interfere with some aspects of active duty.

It is not entirely clear why stage II blood pressure levels were associated with adverse employment status changes, since the majority of these events were not cardiovascular in nature. Stage II hypertension may be a marker of reduced fitness and other health problems, especially when untreated. In this sense, our results may be analogous to those of Cady et al,[29] who found that decreased measures of physical fitness in firefighters conveyed increased risks of injury. The majority of adverse events among hypertensive firefighters occurred in individuals who were not treated for hypertension rather than those who were prescribed medication but with inadequate blood pressure control. Therefore, their other health problems were also likely to be untreated.

Our baseline data demonstrated some cardiovascular risk factor clustering, such as increasing age, obesity, and elevated cholesterol among firefighters with hypertension. In a previous study,[30] we found that firefighters with various single and aggregate measures of possible decreased fitness tended to have worse examination results on other parameters as well. General population studies have shown that cardiovascular risk factors may cluster together in certain groups, especially hypertensives.[31–34] On the other hand, although elevated blood pressure may be a marker of other health problems, firefighters with stage II hypertension had significantly increased risks for adverse events, after adjustment for possible confounders including age and BMI. Moreover, the results were not an artifact of medication side effects because untreated hypertension was associated with higher risks.

Although we could not directly measure the impact of hypertension on cardiovascular outcomes, persons with hypertension, especially stage II hypertension, are more prone to cardiovascular disease and should receive further evaluation.[35,36] Myocardial infarctions are the most common cause of on-duty fatalities among firefighters, accounting for 45% of deaths,[37] and risk factor identification and management could reduce mortality.[38] In addition, based on our findings of increased risks of adverse employment events, firefighters with blood pressure ≥160/100 mm Hg should demonstrate improved blood pressure control before receiving medical clearance as fit for duty.

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Lipid Profile of Firefighters Over Time: Opportunities for Prevention

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Heart disease is the primary cause of on-duty deaths in firefighters, but little is known about their lipid profile. We evaluated the lipid profile in relation to other cardiovascular disease risk factors in 321 firefighters at a baseline examination. Prospective comparisons were performed for 285 firefighters, who were enrolled in a statewide medical surveillance program, and had complete follow-up data for 4 years. The average cholesterol level in firefighters declined from 224 mg/dL at baseline (1996–1997) to 214 mg/dL at the follow-up examination ($P <$ 0.0001). Conversely, both obesity (body mass index ≥ 30; 34% versus 40%, $P = 0.008$) and triglycerides (≥200 mg/dL; 27% versus 35%, $P = 0.047$) increased over time. The proportion of firefighters taking lipid-lowering medications increased from 3% at baseline to 12% at follow-up ($P < 0.0001$). Cholesterol levels declined significantly, and treatment rates for elevated cholesterol increased over time. Despite repeated examinations, a considerable number of firefighters had persistently elevated cholesterol, and only a minority were receiving adequate treatment. (J Occup Environ Med. *2002;44:840–846*)

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Cholesterol screening has long been established as a recommended preventive measure for particular groups as well as the general population. According to the recently published report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III [ATP III]), all adults 20 years of age or older should undergo a fasting lipoprotein profile test at least once every 5 years.[1,2]

Screening for cardiovascular disease risk factors in general and blood cholesterol in particular has been promoted in the context of workplace wellness programs, surveillance examinations, and fitness-for-duty evaluations.[3–7] Several studies have been conducted in occupational settings, such as airforce and commercial pilots,[8,9] office workers,[10] bus and truck drivers,[11] and other groups of workers. However, few studies have been reported on the lipid profile of firefighters.[12,13] We reported previously the cholesterol levels of hazardous-materials firefighters at a baseline examination undertaken in 1996 at the initiation of a prospective surveillance program.[14,15]

The objectives of the current report were to describe the population distribution of lipids in our occupational group according to the updated NCEP guidelines and to evaluate the longitudinal changes of the lipid profile of the hazardous-materials firefighters. In addition, we sought to explore the possible benefits of participating in an occupational surveil-

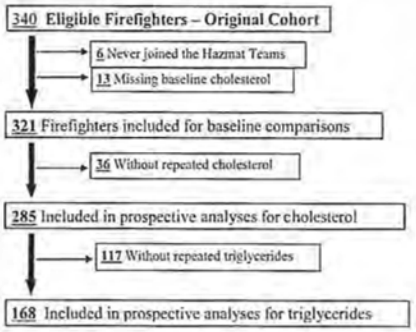

Fig. 1. Sample sizes and exclusion criteria for the different statistical comparisons.

lance program in terms of detection, evaluation, and treatment of high cholesterol.

Methods

Study Sample

The study population consisted of 340 members of six regional hazardous-materials teams in the Commonwealth of Massachusetts who underwent a baseline medical examination in 1996 or 1997 when a statewide medical surveillance program was initiated. These firefighters included 268 hazardous-materials technicians and 72 support members. The firefighters joined the hazardous-materials teams on a contractual basis in addition to their primary occupational duties as municipal firefighters in local fire departments. A total of 19 firefighters were excluded altogether from the study sample. Thirteen firefighters were excluded because they did not have baseline cholesterol values, two firefighters were excluded because they had a medical examination but never joined a hazardous-materials team, three were excluded because of inadequate follow-up information, and one firefighter who was already on "injured-on-duty" status at his baseline examination was also excluded. The breakdown of the entire study population is summarized in Fig. 1.

We evaluated the lipid profile in relation to other cardiovascular disease risk factors in 321 firefighters at a baseline examination. Thirty-six firefighters were not included in the prospective analyses. Eight firefighters did not have follow-up examination in 2000 because of injured-on-duty status. Twenty-eight firefighters either did not undergo blood cholesterol testing at follow up, their drawn blood sample was not suitable for analysis, or the results were not documented appropriately. Thus, a subsample of 285 firefighters who had cholesterol data at both the baseline and the follow-up examinations was used to make comparisons over time. For the comparison of serum triglyceride levels over time, we included 168 firefighters who had triglyceride levels at both examinations. Many firefighters had missing triglyceride levels because one of the contracted hospitals did not perform the serum triglyceride test on the participating firefighters at the baseline examination.

The Institutional Review Boards of the Harvard School of Public Health, Olympus Specialty and Rehabilitation Hospital, and the Cambridge Hospital all approved review of the medical records for research purposes. The examination and all results were confidential.

Baseline and Follow-Up Medical Examinations

Medical surveillance examinations were performed at one of three contracted Massachusetts hospitals. The baseline examinations for most of the firefighters took place in 1996 (82%) and the remainder in 1997. The subsequent medical examinations for the total study sample took place during the fall of 1998, 1999, and 2000. The examinations were done for the dual purposes of medical surveillance and for fitness-for-duty determination for the state hazardous-materials teams. All examinations were conducted in a similar fashion and followed a written protocol. Examinations included a detailed medical and occupational/environmental history, a physical examination, and routine laboratory tests, but not medical treatment. The firefighters were notified of their laboratory results at every examination and were encouraged by the examiners to consult their own primary care physicians for further evaluation and/or management of any abnormal values. Summary results for each firefighter's examination were submitted to a computerized medical record repository.

Blood Lipid Measurements

During the baseline examination in 1996 or 1997, blood cholesterol was measured for all participating subjects at all three hospitals, whereas at two hospitals subjects underwent additional testing for serum triglyceride levels. During the year 2000 examination, all subjects underwent a complete lipid profile evaluation, which included total cholesterol, serum triglycerides, and low-density and high-density lipoprotein (LDL, HDL) cholesterol. Lipid profile results for each examination were documented on each firefighter's summary sheet and sent to the medical record repository. The firefighters were assigned to the different categories of blood cholesterol levels according to the ATP III classification (normal cholesterol, <200 mg/dL; borderline-high cholesterol, ≥ 200 but <240 mg/dL; high cholesterol, ≥ 240 mg/dL).[1] The tests on blood cholesterol and serum triglycerides were random (nonfasting) because firefighters were scheduled for the annual examinations during working hours throughout the day.

Additional Risk Factors

Prospective information on several other factors was also collected routinely at every examination and entered into the computerized repository. These factors included age, sex, height, weight, allergies, medications, smoking history, and physical examination findings. A number of clinical tests, including a routine electrocardiogram, spirometry, and visual and acoustic acuity tests, were also performed. Finally, a broad range of laboratory tests were administered at each annual examination.

TABLE 1
Distribution of Cardiovascular Disease Risk Factors in Hazardous-Materials Firefighters by Total Cholesterol Level at the Baseline Examination

		Total Cholesterol		
Risk Factors	*n*	<240 mg/dL (n = 211) Percent (*n*)	≥240 mg/dL (n = 110) Percent (*n*)	*P* Value
Age ≥ 45 years	321	21.3 (45)	32.7 (36)	0.02
Smoking	321	8.1 (17)	11.8 (13)	0.27
Hypertension*	321	18.0 (38)	25.4 (28)	0.12
BMI ≥ 30 kg/m^2	321	28.9 (61)	46.4 (51)	0.002
Triglycerides ≥ 200 mg/dL	202	17.6 (23)	52.1 (37)	<0.0001
Mean blood glucose (mg/dL) (±SD)	146	96.7 (±28.2)	96.6 (±12.6)	0.97

* According to the Joint National Committee-VI guidelines. "Hypertension" includes firefighters with high blood pressure or those taking antihypertensive medications.

TABLE 2.
Comparison of Total Cholesterol and Triglycerides in Hazardous-Materials Firefighters at Baseline and Follow-Up Examinations

	n	Baseline Examination (1996–1997)	Follow-Up Examination (2000)	*P* Value
Total cholesterol (mg/dL)				
Mean (±SD)	285	224 (±39)	214 (±36)	<0.0001*
<200 (% normal)		30.5	35.8	
200–239 (% borderline-high)		36.1	42.8	
≥240 (% high)		33.3	21.4	<0.0001†
Triglycerides (mg/dL)				
Mean (±SD)	168	165 (±109)	175 (±97)	0.22*
<150 (% normal)		54.2	45.8	
150–199 (% borderline high)		18.4	19.1	
200–499 (% high)		26.8	33.9	
≥500 (% very high)		0.6	1.2	<0.0001†

* *P* value for paired *t* test.
† *P* value for chi-square test by the GENMOD procedure.

These tests included complete blood count and biochemical measurements (blood glucose, liver enzymes, serum creatinine, etc).

Statistical Analyses

Statistical analyses were performed using SAS software (version 6.12; SAS Institute, Cary, NC).[16] *t* Tests and chi-square tests were used to compare possible differences between firefighters with high versus low cholesterol in standard cardiovascular disease risk factors (age, smoking, hypertension, and body mass index [BMI]) at baseline. Comparisons between those who underwent the blood tests and those with missing data were performed to evaluate possible significant differences.

Additional comparisons were also made between the cholesterol or triglyceride levels of firefighters at baseline with the corresponding levels at the year 2000 follow-up examination (paired *t* test, McNemar's test). The GENMOD procedure was used to make comparisons for the categorical variable of cholesterol and triglycerides. The level of significance was 0.05, and all tests were two-sided.

Results

A total of 321 firefighters were included in our analyses. The mean age of the study participants at baseline was 39 years (range, 22–58 years), and almost all of them were men (n = 317). The mean total cholesterol level at the baseline examination was 224 mg/dL. The distribution of cardiovascular disease risk factors by different cholesterol categories in the firefighters at baseline is shown in Table 1. Firefighters with high cholesterol values were older and were more likely to have higher BMIs and higher serum triglyceride values when compared with those with lower cholesterol values. The prevalence of smoking and hypertension was also greater in the high-cholesterol category, but these differences did not reach statistical significance.

In Table 2 we compared the levels of total cholesterol and triglycerides between the baseline and the follow-up examinations. A sample of 285 firefighters who had no missing data was used for the prospective comparisons of total cholesterol. There were no statistically significant differences in age, BMI, and systolic or diastolic blood pressure between firefighters who were excluded because of missing values on total cholesterol and firefighters who were included in the prospective analyses. The majority of the firefighters were found to have either borderline-high (36%) or high (33%) cholesterol levels at baseline. In addition, a considerable proportion of the study population (13%) had persistently high total cholesterol values over time (baseline and follow-up examinations); however, there was a

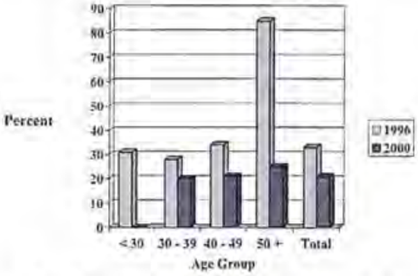

Fig. 2. The distribution of high total cholesterol (≥240 mg/dL) by age group in the study population at baseline and follow-up examinations. The light bars represent the population distribution in 1996, and the dark bars represent the distribution in 2000.

TABLE 3.
Distribution of HDL and LDL Cholesterol Levels in Hazardous-Materials Firefighters

	n	Follow-Up Examination in 2000
HDL cholesterol (mg/dL)*	285	
Mean (±SD)		47 (±12)
<40 (% low)		25.6
40–59 (% intermediate)		60.4
≥60 (% high)		14.0
HDL cholesterol <40 mg/dL by age category	285	% (*n*)
<30 years old		1.1 (3)
30–39 years old		6.3 (18)
40–49 years old		11.9 (34)
≥50 years old		6.3 (19)
Total		25.6 (73)
LDL cholesterol (mg/dL)*	275	
Mean (±SD)		133 (±31)
<100 (% optimal)		12.0
100–129 (% above optimal)		36.0
130–159 (% borderline high)		34.2
160–189 (% high)		13.8
≥190 (% very high)		4.0
LDL cholesterol ≥ 160 mg/dL by age category	275	% (*n*)
<30 years old		0 (0)
30–39 years old		5.4 (15)
40–49 years old		8.7 (24)
≥50 years old		3.6 (10)
Total		17.8 (49)

* HDL and LDL values were not available at the baseline examination in 1996–1997.

statistically significant shift of total cholesterol levels to lower values after 4 years of follow-up. The distribution of high total cholesterol by age group and examination (baseline and follow-up) is shown in Fig. 2.

In addition, we compared the levels of triglycerides over time in 168 firefighters who had complete data on both examinations. There were no statistically significant differences in age, BMI, and systolic or diastolic blood pressure when we compared firefighters with complete data on serum triglycerides with those with any missing data. Unlike the declining pattern of total cholesterol levels, the values of serum triglycerides increased over time, as shown in Table 2. A similar pattern of increasing values over time was observed for BMI as well. At baseline, 34% of firefighters had a BMI ≥ 30 kg/m^2, whereas at follow-up, the proportion of obese firefighters increased to 40% ($P = 0.008$).

The levels of LDL and HDL cholesterol for those with complete data at the follow-up examination are presented in Table 3. Values for LDL and HDL for the baseline examination were not obtained. The mean HDL cholesterol was 47 mg/dL (range, 26–96 mg/dL), and a considerable percentage of firefighters (26%) were found to be in the lowest HDL cholesterol category (HDL < 40 mg/dL). The mean LDL cholesterol value was 133 mg/dL (range, 37–236 mg/dL). A considerable proportion of firefighters (17%) was found to have high or very high LDL cholesterol values (≥160 mg/dL). In addition, there was an increase in the proportion of firefighters with low HDL and high LDL cholesterol levels with advancing age.

In Table 4 we present information on lipid-lowering medication use at the baseline and follow-up examinations. Decisions on treatment were made neither by the physicians in our research team nor by the occupational physicians performing the medical surveillance examinations. The lipid-lowering medications were prescribed by the firefighters' primary care physicians according to their own medical care practices. A significantly higher number of firefighters were taking lipid-lowering medications at follow-up compared with baseline ($P < 0.0001$). It is also notable that only a small proportion of firefighters with persistently high cholesterol levels at both examinations was taking medications at follow-up (14%). Among 49 firefighters with high or very high LDL cholesterol levels (≥160 mg/dL), only five (10%) were taking medications at follow-up. In addition, among firefighters with high cholesterol values ($n = 61$), only nine (15%) were taking lipid-lowering medications at follow-up, and among firefighters with high triglycerides ($n = 59$), only 14 (24%) were on medications at follow-up. Finally, among firefighters with high total cholesterol, high triglycerides, and high LDL cholesterol ($n = 9$), only two (22%) were found to be taking lipid-lowering medications at follow-up.

Discussion

The results of this investigation show that the majority of the hazardous-materials firefighters had abnormal levels of total cholesterol at the

TABLE 4

Lipid-Lowering Medication Use by Hazardous-Materials Firefighters at the Baseline and Follow-Up Examinations

	Baseline Examination (1996–1997) Percent (*n*)	Follow-up Examination, 2000 Percent (*n*)
Firefighters on lipid-lowering medications (*n* = 285)	2.8 (8)	12.3 (35)
Firefighters with		
Total cholesterol < 240 mg/dL	1.1 (2)	11.6 (26)
Total cholesterol ≥ 240 mg/dL	6.3 (6)	14.7 (9)
Firefighters with*		
HDL cholesterol ≥ 40 mg/dL	—	10.8 (12)
HDL cholesterol < 40 mg/dL	—	16.4 (23)
Firefighters with*		
LDL cholesterol < 160 mg/dL	—	12.7 (30)
LDL cholesterol ≥ 160 mg/dL	—	10.2 (5)
Firefighters on lipid-lowering medications (*n* = 168)	1.8 (3)	13.7 (23)
Firefighters with		
Serum triglycerides < 200 mg/dL	0	8.3 (9)
Serum triglycerides ≥ 200 mg/dL	6.5 (3)	23.7 (14)

* HDL and LDL values were not available at the baseline examination.

baseline as well as the follow-up examination. The mean total cholesterol and distribution of values, however, were found to be significantly lower after 4 years of follow-up. On the contrary, serum triglycerides had increased significantly at follow-up. This result was likely due to a parallel increase in BMI. Finally, despite an increase in the proportion of firefighters with high cholesterol who were taking medications at follow-up, the majority of firefighters for whom drug treatment was indicated based on their lipid profile (78%) were not on lipid-lowering medications.

Previous studies have shown that the levels of total cholesterol among the general population have been declining during the past decade.[17,18] This declining pattern has been attributed to a greater awareness among the general population of the adverse effects of high cholesterol, changes in diet, and lipid-lowering medication use.[19–21] We observed a similar pattern among firefighters. In addition, even after excluding firefighters who were taking medications, the mean cholesterol in the study population showed a significant decrease at follow-up compared with baseline (220 mg/dL vs 214 mg/dL, $P = 0.002$), suggesting that other health behaviors also contributed to this decline. Nevertheless, a considerable number of firefighters with abnormal lipid profiles were not taking medications even after 4 years of repeated screening.

Serum triglycerides, unlike total cholesterol, were found to be significantly increased at follow-up. The increase in triglycerides was accompanied by significant increases in BMI among the firefighters, supporting the validity of this finding. Higher levels of serum triglycerides are associated with a higher BMI.[22]

Firefighters were more likely to be on lipid-lowering medications at the follow-up compared with the baseline examination (3% vs 12%, $P < 0.0001$). This is not surprising, because the firefighters were being notified of their cholesterol levels and other laboratory results at every examination, and they were encouraged to consult their primary care physicians and take appropriate action for any abnormal values. The apparent significant increase in medication use after 4 years of follow-up could be attributed, in part, to the surveillance program itself.

Other significant findings of our study include the distributions of HDL and LDL cholesterol values among the firefighters. We found very high proportions of firefighters with abnormal HDL and LDL cholesterol levels, and the majority of these individuals had not been prescribed medications. Low HDL cholesterol is an independent risk factor for cardiovascular disease and is also known to be a modifiable risk factor.[23,24] Cardiovascular mortality is the most common cause of on-duty mortality in firefighters, being responsible for ~45% of on-duty deaths.[25] The results of our study suggest that comprehensive preventive programs are needed to address several modifiable cardiovascular disease risk factors among firefighters, including abnormal values of total, LDL, and HDL cholesterol. In addition, serum triglycerides and obesity showed an increasing pattern, which also require intervention. Recommended regular exercise would be an appropriate approach that could favorably affect several of these problems, including obesity, serum triglycerides, and HDL and total cholesterol.[26]

There are several limitations worth noting in our study. The annual examinations and data collection processes were conducted at three different hospitals for six regional hazardous-materials teams. There were no significant differences, however, in the mean total cholesterol values among the three hospitals ($P = 0.20$). Furthermore, the follow-up comparisons for paired observations were performed on firefighters who had complete data on both examinations. Another possible concern relates to the use of random (nonfasting) blood tests to measure the lipid profile of the participants. Owing to the fact that the annual surveillance examinations were performed during working hours, firefighters were not able to provide fasting blood samples. Previous studies have shown, however, that there is little difference in total cholesterol or HDL cholesterol when comparing fasting with casual values.[1] Although triglycerides are significantly influenced by fasting, and individual treatment plans cannot be based on casual measurements, population comparisons are useful to elucidate temporal trends. Possible bias because of the use of nonfasting values would most likely be random (nondifferential) and therefore, would bias the results toward the null hypothesis, ie, of no significant change of triglyceride levels over time.

In conclusion, we observed a significant decrease in total cholesterol levels among firefighters after 4 years of follow-up, partly attributable to increased lipid-lowering medication use. Serum triglycerides and BMI were increased at follow-up and require further investigation and monitoring. HDL and LDL cholesterol were found to be abnormal for a considerable proportion of firefighters, and only a small number of these cases were receiving lipid-lowering medications. Occupational and primary care physicians need to be aware of these findings because coronary heart disease continues to account for ~45% of on-duty deaths[25] and for ~36% of lifetime mortality in firefighters.[27–34] Therefore, firefighters should be managed aggressively according to current evidence-based medical standards. Certain administrative measures, such as the encouragement of exercise programs, delivery of appropriate diet schedules, and cardiovascular disease risk factor screening programs in fire departments, would also help improve the current risk factor profile of firefighters and prevent adverse health outcomes.

Acknowledgments

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DEPARTMENT OF HEALTH AND HUMAN SERVICES

Public Health Service
Centers for Disease Control
and Prevention (CDC)

Memorandum

Date: March 5, 2003

From: Lee M. Sanderson, Ph.D., Program Official Lee M Sanderson
Office of Extramural Programs, NIOSH, E-74

Subject: Final Report Submitted for Entry into NTIS for Grant 5 R01 OH003729-03.

To: William D. Bennett
Data Systems Team, Information Resources Branch, EID, NIOSH, P03/C18

The attached final report has been received from the principal investigator on the subject NIOSH grant. If this document is forwarded to the National Technical Information Service, please let us know when a document number is known so that we can inform anyone who inquires about this final report.

Any publications that are included with this report are highlighted on the list below.

Attachment
cc: Sherri Diana, EID, P03/C13

List of Publications

Soteriades ES, Kales SN, Christoudias SG, Tucker S, Liarokapis D, Christiani DC: The Lipid Profile of Firefighters Over Time: Opportunities for Prevention. J Occup Env Med 44(9):840-846, 2002

Kales SN, Soteriades ES, Christoudias SG, Tucker S, Nicolaou M, Christiani DC: Firefighters' Blood Pressure and Employment Status on Hazardous Materials Teams in Massachusetts: A Prospective Study. J Occup Env Med 44(7):669-676, 2002

Kales SN, Mendoza PJ, Hill JM, Christiani DC: Spirometric Surveillance in Hazardous Materials Firefighters: Does Hazardous Materials Duty Affect Lung Function? J Occup Environ Med 43(12):1114-1120, 2001

Kales SN, Freyman RL, Hill JM, Polyhronopoulos GN, Aldrich JM, Christiani DC: Firefighters' Hearing: A Comparison with Population Databases from the International Standards Organization. J Occup Environ Med 43(7):650-656, 2001

Kales SN, Polyhronopoulos GN, Aldrich JM, Mendoza PJ, Suh JH, Christiani DC: A Prospective Study of Hepatic, Renal, and Haematologic Surveillance in Hazardous Material Firefighters. Occup Environ Med 58:87-94, 2001

Kales SN, Christiani DC: Cardiovascular Fitness in Firefighters. J Occup Environ Med 42(5):467-468, 2000

Kales SN, Aldrich JM, Polyhrono[oulos GN, Leitao EO, Artzerounian D, Gassert T, Hu H: Correlates of Fitness for Duty in Hazardous Materials Firefighters. Am J Ind Med 36:618-629, 1999

Kales SN, Polyhronopoulos GN, Aldrich JM, Leitao ED, Christiani DC: Correlates of Body Mass Index in Hazardous Materials Firefighters. J Occup and Environ Med 41(7):589-595, 1999

Kales SN, Polyhronopoulos GN, Aldrich JM, Dimitriadis EA, Christiani DC: Interlaboratory Comparisons of Red Blood Cell Cholinesterase Activity. J Environ Med 1:19-26, 1999

Title: Evidence-Based Medical Examinations for Firefighters
Investigator: Stefanos N. Kales, MPH
Affiliation: Harvard University
City & State: Boston, MA
Telephone: (617) 498-1580
Award Number: 5 R01 OH003729-03
Start & End Date: 9/30/1998–9/29/2002
Total Project Cost: $562,193
Program Area: Health Services Research
Key Words:

Final Report Abstract:
Our study evolved from an investigation of medical surveillance for one of six Massachusetts hazardous materials teams from 1993 – 1995. The principal investigator later received a special emphasis research-career award (1996-1999) from NIOSH to investigate incident and medical surveillance in firefighters and the program included all six hazardous materials teams of Massachusetts. The current award (1998-2002) was designed to focus on medical examinations and had the following specific aims: (1) To evaluate the ability of objective fitness guidelines, and baseline health ratings to predict increased risks of injury, cardiac events or other adverse outcomes. (2) To evaluate whether firefighters with abnormal hearing are at increased risk for injury or other adverse outcome. (3) To examine the clinical utility of various examination components among firefighters. (4) To help develop evidence-based medical evaluations for firefighters. In the past five years, the firefighters have been followed on an annual basis and a computerized state repository has been maintained with data on physical examinations of firefighters and other tests including various blood tests, vision and hearing tests and electrocardiograms.

Several research projects were completed using the available information. Nine peer-reviewed articles have been published in scientific journals, and several national and regional invited presentations were given from the current award. A number of evidence-based improvements in firefighter medical evaluations have been identified. We found that significant exposures and injuries identified by medical surveillance during hazardous materials duty are infrequent and the use of biochemical testing is of limited utility, and the frequency of this testing may be reduced. With regards to respiratory exposures, we found that the hazardous materials technicians do not appear to lose pulmonary function at a faster rate than regular firefighter.

One other important consideration is the evaluation of fitness for duty in firefighters with blood pressure readings >/=160/100 mm Hg. Our research suggests that firefighters with high blood pressure readings should receive further evaluation and demonstrate improved blood pressure control prior to receiving medical clearance as "fit for duty." With respect to myocardial infarctions, the 10-year estimated CHD risk of fire fighters is similar to the general population and increases with age. Extrapolation from general population paradigms, risk assessment and stratification, previous studies and a case-control analysis of on-duty CHD fatalities, all suggest similar risk profiles for those at elevated risk for

cardiovascular disease. Our research supports that medical screening could have an important impact on reducing fire fighters' risk for adverse outcomes.

Publications

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