CHEST

Original Research

OCCUPATIONAL AND ENVIRONMENTAL LUNG DISEASES

Longitudinal Pulmonary Function in Newly Hired, Non-World Trade Center-Exposed Fire Department City of New York Firefighters

The First 5 Years

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Background: **Few longitudinal studies characterize firefighters' pulmonary function. We sought to determine whether firefighters have excessive FEV_1 decline rates compared with control subjects.**

Methods: **We examined serial measurements of FEV_1 from about 6 months prehire to about 5 years posthire in newly hired male, never smoking, non-Hispanic black and white firefighters, hired between 2003 and 2006, without prior respiratory disease or World Trade Center exposure. Similarly defined Emergency Medical Service (EMS) workers served as control subjects.**

Results: **Through June 30, 2011, 940 firefighters (82%) and 97 EMS workers (72%) who met study criteria had four or more acceptable posthire spirometries. Prehire FEV_1% averaged higher for firefighters than EMS workers (99% vs 95%), reflecting more stringent job entry criteria. FEV_1 (adjusted for baseline age and height) declined by an average of 45 mL/y both for firefighters and EMS workers, with Fire − EMS decline rate differences averaging 0.2 mL/y (CI, −9.2 to 9.6). Four percent of each group had FEV_1 less than the lower limit of normal before hire, increasing to 7% for firefighters and 17.5% for EMS workers, but similar percentages of both groups had adjusted FEV_1 decline rates ≥ 10%. Mixed effects modeling showed a significant influence of weight gain but not baseline weight: FEV_1 declined by about 8 mL/kg gained for both groups. Adjusting for weight change, FEV_1 decline averaged 38 mL/y for firefighters and 34 mL/y for EMS workers.**

Conclusions: **During the first 5 years of duty, firefighters do not show greater longitudinal FEV_1 decline than EMS control subjects, and fewer of them develop abnormal lung function. Weight gain is associated with a small loss of lung function, of questionable clinical relevance in this fit and active population.**

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Abbreviations: EMS = Emergency Medical Service; FDNY = Fire Department City of New York; LLN = lower limit of normal (lowest 5% of values among a population); NHANES = National Health and Nutrition Examination Survey; WTC = World Trade Center

Previous longitudinal studies in firefighters have not established whether firefighters are at unusual risk of accelerated lung function decline.[1] Most studies were uncontrolled and limited by small sample sizes, only two data points per individual, longitudinal dropout, inclusion of smokers, and inclusion of firefighters not required to wear respiratory protection throughout their careers.[2-8] None analyzed the effect of weight gain. Our prior longitudinal study of firefighters at the World Trade Center (WTC)[9] examined exposures not characteristic of those encountered by most firefighters.

We sought to determine whether non-WTC-exposed firefighters are at increased risk of accelerated pulmonary function decline, using multiple spirometric measurements per individual, over about 5 years of

duty in a large cohort of newly hired Fire Department City of New York (FDNY) firefighters. Newly hired FDNY Emergency Medical Service (EMS) workers served as control subjects.

Materials and Methods

Study Population

The study population included all male FDNY firefighters and EMS workers hired between January 1, 2003, and December 31, 2006, without WTC exposure or prehire respiratory disease (except resolved childhood asthma). Each had spirometry performed by FDNY ≤ 18 months prehire and at least one posthire spirometry performed during wellness examinations, scheduled every 12 to 18 months.

We excluded women, because < 1% of newly hired FDNY firefighters are women. We focused on non-Hispanic black and white employees, because reliable prediction equations for other race/ethnicities are not available.[10] To facilitate comparison with other longitudinal studies, for our primary analyses, we examined only never smokers without prior history of respiratory disease. This study was approved by Montefiore's institutional review board (protocol #07-09-320). Written consent was obtained.

Spirometry

Experienced technicians collected spirometric indices (EasyOne spirometers) from three or more efforts. Efforts were automatically graded and accepted if without early terminations, variable efforts, leaks, obstructed mouthpieces, or artifacts; with back-extrapolated volume ≤ 150 mL and ≤ 5% of FVC; and if the best two FEV_1 measurements were within 150 mL (grades A or B). Technicians maintained quality grades of A or B for ≥ 85% of tests. Efforts graded C or worse were manually graded (by T. K. A); FEV_1 measurements were accepted if they met the criteria, even if FVC measurements did not. We archived the largest acceptable FEV_1. We calculated FEV_1 % predicted and whether FEV_1 was below the lower limit of normal (lowest 5% of values among a population) (LLN), using National Health and Nutrition Examination Survey (NHANES) prediction equations.[10] We graded and recorded FVC, but focused on the more reproducible FEV_1.[11]

Other Measures

Height and weight were measured at each spirometry, without shoes. Smoking status was defined as current, former, or never at each visit: workers were classified as never smokers if consistently so reported. Medical records were reviewed for prehire respiratory diagnoses.

Statistical Analyses

We used three strategies: a prospective cohort study of average FEV_1 over time, a matched pair analysis, and an analysis of binary outcomes indicating pulmonary function impairment. The prospective cohort study compared prehire and four posthire FEV_1 measurements in firefighters and EMS workers over time, using serial cross-sectional analyses and linear mixed effects modeling.[12] For the mixed effects models, we included age and weight at baseline, height, and race/ethnicity as covariates, with and without adjusting for weight gain. We included all predictors as fixed effects and used random intercepts to take into account heterogeneity across subjects and correlations of repeated observations. We performed separate analyses including firefighters and EMS workers who had any number of posthire spirometries, including ever smokers, and assessing FVC measurements.

Because statistical adjustment does not always adequately control confounding, we performed a matched-pair analysis to determine if differences in prehire characteristics between firefighters and EMS workers were adequately adjusted for in our models. We compared FEV_1 over five time periods (prehire and four posthire) in 42 pairs of never smoking firefighters and EMS workers, all without prehire histories of respiratory disease, matched for race, age (within 2 years), height (within 5 cm), baseline weight (within 4 kg), baseline FEV_1 (within 0.25 L), and weight change per year (within 3%/y). We also performed analyses using binary outcomes indicating pulmonary function impairment, determining the fraction of each group with FEV_1 < LLN at each time point, and the fraction with excessive decline in FEV_1—those whose FEV_1 fell by ≥ 10% from baseline, after adjustment for average decline rates. All analyses used SAS 9.2 (SAS Institute Inc).[13]

Results

Sixty-seven percent of firefighters and 50% of EMS workers hired between 2003 and 2006 were never smokers, compared with the 59% of male New Yorkers aged 25 to 44 years who reported being never smokers in 2004.[14] We focus our analyses on never smokers, but include data on ever smokers for comparison. Figure 1 outlines the study population.

Cohort Study

Table 1 shows cohort characteristics. Figure 2 shows average unadjusted FEV_1 measurements (cross-sectional). Baseline FEV_1 averaged lower in EMS workers, reflecting slightly older age, shorter height, and less stringent pulmonary function and fitness requirements for hire.

In serial cross-sectional analyses, decline in unadjusted FEV_1 was essentially identical for firefighters and EMS workers and generally constant over about 5 years. Mixed effects models estimated that, adjusting for race, baseline age and weight, and height,

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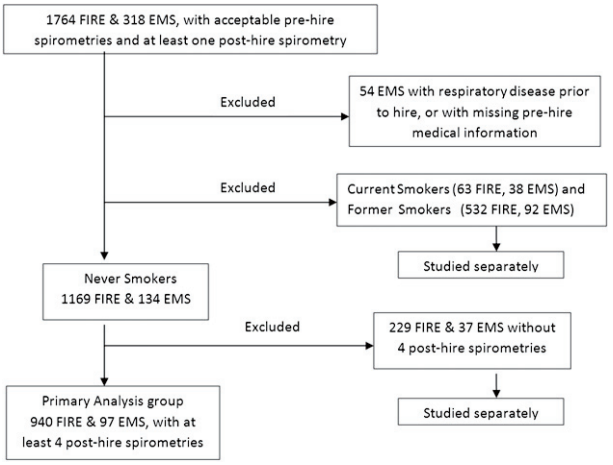

FIGURE 1. Flow diagram of the study population. Of the 1,169 never smoking firefighters and 134 never smoking EMS workers in the cohort, one firefighter and no EMS workers died; 13 firefighters (1%) and 29 EMS workers (22%) resigned, were terminated, or retired (none on respiratory disability); and 155 firefighters (13%) and five EMS workers (4%) were not yet due for their fourth posthire spirometry. Only 60 firefighters (5%) and two EMS workers (1%) were overdue for their fourth posthire spirometry. EMS = Emergency Medical Service; FIRE = firefighters.

(but not weight change), FEV_1 declined by 45 mL/y for both groups (95% CI, 42-48 for firefighters; 35-54 for EMS workers). The difference in decline rates (Fire − EMS) averaged 0.2 mL/y (95% CI, −9.2 to 9.6).

When weight change was included in the model, years of service and weight gain (but not baseline weight) were independently associated with FEV_1 decline (Table 2). Adding weight gain as a time-dependent predictor reduced the effect of service time by about 16% for firefighters and about 24% for EMS workers, implying that declines in FEV_1 are in part attributable to weight gain. Considering that average firefighter weight gain was 4.6 kg over 5.5 years, that would account for about 39 mL loss in FEV_1, equivalent to > 1 year of age-related decline. There was no significant interaction between service time and weight gain.

To assess whether regression toward the mean could help to account for FEV_1 decline, we separately analyzed four posthire FEV_1 measurements, excluding baseline spirometry. For both firefighters and EMS workers, decline rates averaged slightly but not significantly lower (35 mL/y [95% CI, 31-39], and 33 mL/y [95% CI, 22-44], respectively).

We also developed mixed effects models using prehire and any number of posthire spirometries (n = 1,169 firefighters, 134 EMS workers), instead of requiring four posthire spirometries. Adjusting for weight gain, decline rates were very similar (36 mL/y [CI, 31-38] for firefighters, 33 mL/y [22-44] for EMS workers) to those observed in the primary cohort.

We assessed the influence of smoking, using mixed effects models for ever smokers. Adjusting for weight gain, decline rates (36 mL/y [CI, 32-41] for firefighters [n = 595] and 29 mL/y [19-38] for EMS workers

Table 1—*Characteristics of Firefighters and EMS Workers With at Least Five Spirometries*

Characteristic	Firefighters (n = 940)	EMS (n = 97)
Race, No. (%)[a]		
Black	53 (6)	50 (52)
White	887 (94)	47 (48)
Duty status, No. (%)[a,b]		
Active	936 (100)	94 (97)
Retired	4 (0)	3 (3)
Demographics, mean (SD) (min, max)		
Age baseline, y	26.1 (3.3) (20.4, 38.5)	27.6 (7.0) (19.1, 47.6)
Height, cm	177.2 (6.6) (157.0, 198.0)	176.2 (7.3) (159.0, 196.0)
Weight, kg	84.7 (11.3) (55.8, 131.0)	85.2 (13.9) (52.2, 132.8)
BMI	27.2 (3.2) (18.6, 39.4)	27.7 (4.4) (18.2, 40.2)
Weight gain, kg	4.6 (6.1) (−23.4, 32.0)	5.9 (7.3) (−5.4, 26.1)
Average % weight gain/y[c]	1.1 (1.4) (−3.8, 8.9)	1.6 (2.0) (−1.5, 6.6)
Baseline PFT, mean (SD) (min, max)		
FEV_1 actual,[a] L	4.4 (0.6) (2.7, 6.4)	3.9 (0.7) (2.5, 6.0)
FEV_1% predicted[a]	98.8 (9.9) (70, 129.0)	94.9 (9.8) (66, 118.0)
FVC actual,[a,d] L	5.3 (0.7) (3.2, 7.5)	4.8 (0.8) (3.5, 6.9)
FVC% predicted[d]	98.2 (9.4) (71.0, 127.0)	96.2 (9.3) (74.0, 116.0)
FEV_1/FVC[d]	0.83 (0.05) (0.63, 0.96)	0.82 (0.05) (0.64, 0.94)
FEV_1 < LLN, No.(%)	40 (4)	4 (4)
FVC < LLN, No. (%)[d]	29 (4)	4 (5)

Subjects were male, white or black, never smokers, with no prehire respiratory conditions. EMS = Emergency Medical Service; LLN = lower limit of normal; max = maximum; min = minimum; PFT = pulmonary function test.

[a]*P* value < .05 when comparing the difference between firefighters and EMS workers.

[b]Retired at any time before end of the study.

[c]The annualized percentage of weight gain from the fourth posthire to the prehire in terms of the baseline weight.

[d]For FVC analysis, 740 firefighters and 86 EMS workers with at least four PFTs had acceptable FVC at baseline.

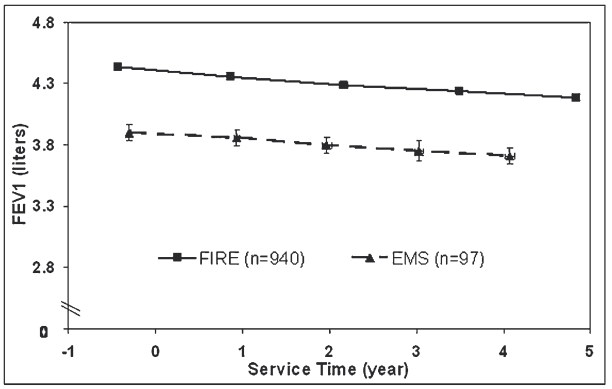

FIGURE 2. Average unadjusted FEV_1 by visit for firefighters and EMS workers. Data are mean ± SEM for the same 940 firefighters and 97 EMS workers at each time point. Mean data and SEMs are also shown for time relative to the date of hire. (SEMs are too small to be separable from the means for firefighters). See Figure 1 legend for expansion of abbreviations.

[n = 130]) did not differ from those observed in never smokers.

Finally, we assessed longitudinal changes in FVC and FEV_1/FVC in 733 firefighters and 86 EMS workers who had five adequate FVCs: one prehire and four posthire. Using mixed linear models adjusting for race, baseline weight and age, height, and weight gain, FVC decline rates did not differ significantly: 19 mL/y (95% CI, 14-23) for firefighters, 25 mL/y (95% CI, 12-38) for EMS workers ($P = .34$). FEV_1/FVC declined by a small but statistically significant amount in both groups: 0.43% (95% CI, 0.39%-0.47%) for firefighters, 0.21% (95% CI, 0.005%-0.37%) for EMS workers ($P = .001$), but averages remained well within normal limits.

Matched Pair Analysis

To examine whether our mixed linear models adequately adjusted for differences in race, height, and baseline FEV_1, we analyzed 42 pairs of firefighters and EMS workers, matched for race, age (within 2 years), height (within 5 cm), baseline weight (within 4 kg), weight change (within 3% per year), and baseline FEV_1 (within 0.25 L). FEV_1 measurements did not significantly differ at any time (Fig 3). FEV_1 decline rates (37.2 mL/y [26.6-47.9] for firefighters, 35.8 mL/y [22.0-49.6] for EMS workers) did not differ as assessed by mixed linear models with nested design ($P = .86$).

LLN and Excessive Decline Analyses

In serial cross-sectional studies, at baseline, 4.3% of firefighters and 4.1% of EMS workers had FEV_1 measurements less than LLN (Fig 4A); by its definition, one would expect 5% < LLN in a healthy population. The percentage of firefighters with FEV_1 less than LLN increased after hire, stabilizing at about 7% by study's end. In contrast, the cumulative percentage increased with each year of service for EMS workers, reaching 17.5% at the fourth posthire spirometry, significantly higher than for firefighters ($P = .001$).

Because at baseline EMS workers' FEV_1 % predicted measurements averaged lower than did firefighters'—closer to their LLNs—EMS workers were more susceptible than firefighters to falling below LLN with little change in FEV_1. For that reason, at each posthire time point we analyzed the fraction of each group whose FEV_1 had fallen ≥ 10% from baseline, after adjusting for average decline rates. We found no significant differences between the two groups (Fig 4B).

DISCUSSION

In this, the largest reported longitudinal study of pulmonary function in firefighters to our knowledge, we

Table 2—*Mixed Linear Model for FEV_1 in mL (95% CI)*

	Not Adjusting for Weight Gain, 5 Visits			Adjusting for Weight Gain, 5 Visits		
Variable	Firefighters	EMS	Firefighters − EMS Difference	Firefighters	EMS	Firefighters − EMS Difference
Service time, y	−44.8	−44.6	−0.2	−37.6	−33.8	−3.9
	(−47.33, −42.26)	(−53.7, −35.5)	(−9.6, 9.2)	(−40.4, −34.8)	(−43.7, −23.8)	(−14.2, 6.4)
Age at baseline, y	−19.9	−15.41	…	−19.6	−16.4	…
	(−28.13, −11.62)	(−27.9, −2.9)	…	(−27.9, −11.3)	(−28.9, −3.9)	…
Race, black vs white	−598.2	−666.9	…	−595.4	−663.8	…
	(−714.7, −481.8)	(−841.8, −492.0)	…	(−712.5, −478.3)	(−838.7, −489.0)	…
Height, cm	43.1	56.8	…	44	57.3	…
	(38.4, 47.8)	(44.3, 69.4)	…	(39.3, 48.7)	(44.8, 69.9)	…
Weight baseline, kg	1.1	−3.6	…	0.2	−3.4	…
	(−1.6, 3.9)	(−10.4, 3.1)	…	(−2.5, 3.0)	(−10.1, 3.3)	…
Weight gain, kg	…	…	…	−8.5	−8	…
				(−10.0, −7.0)	(−11.3, −4.7)	…

The only fixed effect that differed significantly (firefighters vs EMS) was height ($P = .049$). See Table 1 legend for expansion of abbreviation.

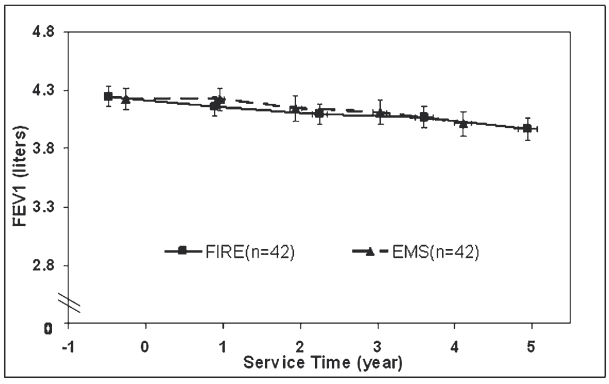

FIGURE 3. Matched pair analysis for 42 firefighters and 42 EMS workers, matched by age, race, height, baseline FEV_1, baseline weight, and average percentage of weight change per year. Data are mean ± SEM. See Figure 1 legend for expansion of abbreviations.

found no meaningful differences in the rates of decline of lung function in newly hired FDNY firefighters, as compared with a control group of newly hired FDNY EMS workers, over about the first 5 years of employment. At hire, firefighters had higher average FEV_1 and FEV_1 % predicted than did EMS workers, reflecting a slightly younger and taller population and more stringent fitness and pulmonary function hiring criteria. Specifically, firefighters are required to have $FEV_1 \geq 80\%$ predicted to qualify for hire, whereas EMS workers' FEV_1 measurements must be $\geq 70\%$ predicted. Decline rates over the subsequent 5 years, however, were nearly identical. An examination of matched pairs of firefighters and EMS workers found no significant differences in decline.

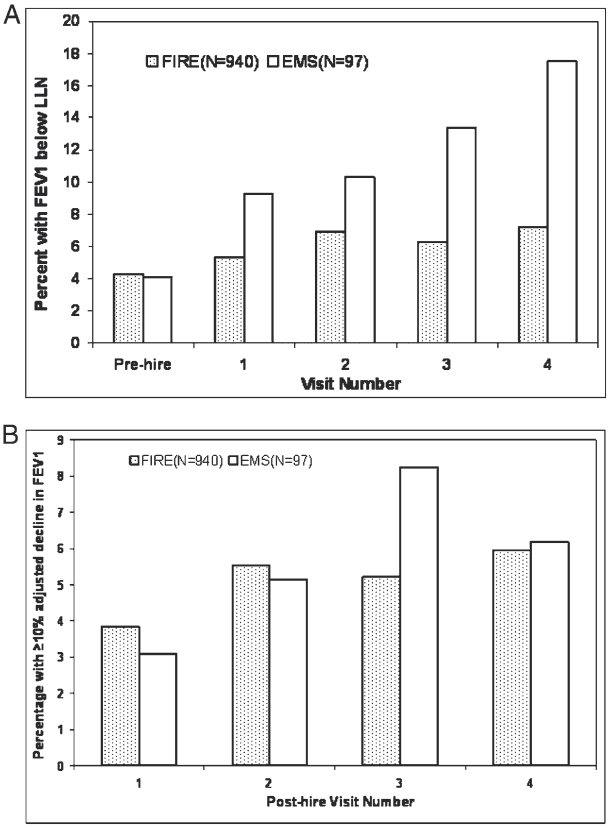

FIGURE 4. A, The percentage of each group (firefighters and EMS workers) whose FEV_1 fell below the LLN. B, Percentage of firefighters and EMS workers who showed excessive decline in FEV_1 ($\geq 10\%$ decline in FEV_1 vs baseline, after correction for the average decline of FEV_1 for EMS workers cohort and firefighters cohort). LLN = lower limit of normal. See Figure 1 legend for expansion of other abbreviations.

We observed a small decline in firefighters' FEV_1 to FVC ratios, averaging 0.4% per year, slightly higher than both the 0.2% in EMS and the expected 0.24%.[10] This result might suggest an emerging subclinical tendency toward airways obstruction. Further follow-up will be required to confirm or refute that possibility.

At hire, similar small percentages (4%) of both firefighter and EMS recruits had FEV_1 below the LLN—slightly less than the expected 5% for a normal healthy population. The percentage below LLN increased sharply over the subsequent 4 years among EMS workers but only minimally among firefighters, because EMS workers started, on average, closer to the LLN than did firefighters. The percentages with excessive FEV_1 decline ($\geq 10\%$ of baseline), irrespective of LLN, showed no meaningful differences.

We found no difference in FEV_1 decline rates among ever and never smokers. The duration of follow-up was likely too short to demonstrate such an effect. Perhaps more importantly, although we do not have accurate pack-year data, the low prevalence of current smokers (3.5%) and the young average age of our population indicate that smoking exposures were, on average, quite low.

Previous longitudinal studies specifically in firefighters have suggested average FEV_1 decline rates about 30 mL/y[2] or 63 mL/y[6] in active firefighters and about 50 mL/y in retirees.[3] However, none of the studies was well powered, and only one[6] included a non-firefighter control group. Only one[6] examined smokers and nonsmokers separately, all were done prior to the routine use of self-contained breathing apparatus, and none adjusted for weight change. Our own prior study of WTC-related FEV_1 decline[8,9] focused on post-September 11, 2011, pulmonary function changes but included longitudinal measurements before September 11, 2011, in 7,653 FDNY employees, almost all active firefighters, finding an adjusted average decline rate of 31 mL/y before September 11, 2011, FEV_1.[8] Although this was by far the largest longitudinal study in firefighters, it suffered from similar limitations: few data points per subject, inclusion of firefighters who did not wear self-contained breathing apparatus for their entire careers, longitudinal dropout, no control group, and no adjustment for weight gain.

As in prior longitudinal studies of nonfirefighters,[15-17] in our current study, we found that weight gain independently influenced FEV_1 decline beyond effects attributable to FDNY service time. Weight gain also had a strong association with risk of both falling below LLN and showing accelerated FEV_1 decline. This important finding identifies weight gain as a potentially modifiable risk factor in this nonsmoking population and a target for interventions to prevent worsening pulmonary function.

Expected rates of FEV_1 decline for an initially healthy urban cohort of young adults are not clearly established. In a large population in Boston, followed from childhood in the 1970s to 1980s, analyzed by curve-fitting of a mix of longitudinal and cross-sectional data, Tager et al[18] estimated flat FEV_1 over time for nonsmoking men aged 20 to 35 years, followed by an average decline rate of 25 mL/y for the next few years, increasing to 35 mL/y after age 40. Cross-sectional data from the NHANES study and the estimating equations derived from those data also predict accelerating decline rates over time (for white men but not for black men), but with somewhat higher rates than estimated by Tager et al[18] in the younger age groups. Nonetheless, for 26- to 31-year-old men, NHANES predictions show nearly linear association with age for whites and absolutely linear associations for blacks, both at −23 mL/y.[10]

Cross-sectional studies of the influence of age, such as the estimates obtained from NHANES, may not accurately reflect longitudinal decline in FEV_1 in cohorts for many reasons, including survivor effects (weighting toward healthy people), cohort effects (nutritional, environmental, and other factors), and period effects (eg, improvements in performance with repeated studies).[19] Longitudinal studies have provided widely varying estimates of FEV_1 decline rates in initially healthy, never smoking men 20 to 55 years old: 21 mL/y in Copenhagen during the 1980s[20]; 36 mL/y in London during the 1960s[21]; and 48.5 mL/y in California during the 1980s.[22] Environmental factors may have major influences on FEV_1 decline rates. In never smoking 25- to 64-year-old men, FEV_1 decline rates averaged about 38 mL/y in rural Lancaster, California vs about 68 mL/y in urban Long Beach, California.[22]

None of the earlier studies assessed the possible role of weight change. None of the earlier studies reported results specifically in men in their 20s and early 30s, when relatively low FEV_1 decline rates would be expected, so the longitudinal estimates may well overestimate the expected rate of decline for our cohort, with average age 26 to 31 years.

One might argue that our relatively small EMS worker sample size limited the power of our study to detect differences in FEV_1 decline. However, the 95% CI of the Fire − EMS differences was (−9.6, 9.2) indicating that we can estimate with 95% confidence that a true population excess risk for firefighters, if any, would not be >10 mL/y, not a clinically meaningful amount.

Strengths of our study are large sample size, absence of longitudinal dropout, highly experienced technicians, identical equipment throughout the study, multiple FEV_1 measurements per subject, adjustment for weight gain, and comparison with a concurrent control population. The longitudinal, prospective nature of our study is a major strength, but its 5-year duration is a limitation. However, although 5 years represents only 6% of an average New York man's 80-year lifespan, it represents a substantial portion, 23%, of an average FDNY male firefighter's 22-year career span.

In conclusion, the occupational hazards of firefighting in an urban environment, with modern protocols and equipment for respiratory protection, do not result, on average, over the first 5 years of employment, in a measurably faster decline in lung function than a comparable nonfirefighter population or in a greater increase in percentage with abnormal spirometry. Although decline rates for both firefighter and control groups were slightly higher than would be predicted from NHANES cross-sectional data, neither is out of the range of prior longitudinal studies of young urban nonsmokers. A secondary finding is that weight gain, a potentially modifiable factor, contributes to the decline in FEV_1 and the development of abnormal spirometry even in a young, healthy firefighter population with relatively high physical fitness and work requirements.

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Dr Aldrich: contributed to conceiving and designing the study, acquiring data for the study, analyzing and interpreting data, writing the first drafts of the manuscript, and the final version of the manuscript.

Ms Ye: contributed to acquiring data for the study, analyzing and interpreting data, writing the first drafts of the manuscript, and the final version of the manuscript.

Dr Hall: contributed to conceiving and designing the study, analyzing and interpreting data, editing and revising the manuscript, and the final version of the manuscript.

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