

Lung Function Trajectories in World Trade Center-Exposed New York City Firefighters Over 13 Years



The Roles of Smoking and Smoking Cessation

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BACKGROUND: World Trade Center (WTC)-exposed Fire Department of the City of New York firefighters lost, on average, 10% of lung function after September 11, 2001, and >10% developed new obstructive airways disease. There was little recovery (on average) over the first 6 years. Follow-up into the next decade allowed us to determine the longer-term exposure effects and the roles of cigarette smoking and cessation on lung function trajectories.

METHODS: We examined serial measurements of FEV₁ from March 11, 2000, to September 10, 2014, among 10,641 WTC-exposed Fire Department of the City of New York firefighters with known smoking and body weight histories.

RESULTS: The median number of FEV₁ measurements during follow-up was 9; 15% of firefighters arrived at the WTC during the morning of September 11, 2001; and 65% never smoked. Firefighters arriving the morning of September 11, 2001 averaged lower lung function than did lesser exposed firefighters; this difference remained significant during most of follow-up ($P < .05$). Never smokers had significantly better lung function than current smokers; former smokers fell in between, depending upon their cessation date. Those arriving the morning of September 11, 2001 were more likely to have an FEV₁ < lower limits of normal compared with those arriving between September 13, 2001, and September 24, 2001 (OR = 1.70, $P < .01$). Current smokers were more likely to have an FEV₁ < lower limits of normal compared with never smokers (OR = 2.06, $P < .01$), former smokers who quit before September 11, 2001 (OR = 1.96, $P < .01$), or those who quit between September 11, 2001 and March 10, 2008 (OR = 1.49, $P < .01$).

CONCLUSIONS: Thirteen years after September 11, 2001, most firefighters continued to show a lack of lung function recovery, with the trajectory of decline differing by WTC exposure and smoking status. Unlike the immutable effect of WTC exposure, we demonstrated the benefit on lung function of smoking cessation in this unique occupational/environmental cohort.

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KEY WORDS: firefighting; occupational lung disease; pulmonary function test; smoking; World Trade Center

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ABBREVIATIONS: FDNY = Fire Department of the City of New York; LLN = lower limit of normal; PFT = pulmonary function test; WTC = World Trade Center

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As a result of the September 11, 2001, terrorist attack on the World Trade Center (WTC) and its collapse, rescue and recovery workers suffered unprecedented exposure to aerosolized dust. Most Fire Department of the City of New York (FDNY) rescue/recovery workers had acute respiratory symptoms,¹ which persisted for years.² We have previously shown that WTC exposure led to excessive lung function decline, averaging 10% over the first year after September 11—the equivalent of 10 to 12 years of normal, age-related loss³—and that >15% of never-smoking WTC-exposed FDNY rescue/recovery workers developed new-onset obstructive airways disease.⁴ Over the next 6 years, there was little recovery

of FEV₁, on average, and only a small decrease in the percentage of workers with abnormal lung function.³

The current study, the longest serial lung function study of rescue/recovery workers before and after a major environmental disaster, focuses specifically on firefighters, extending the prior study through September 10, 2014. As before,³ we report average FEV₁ trends, and, to allow an appreciation of clinical and quality-of-life impacts, we also report prevalence of abnormal lung function. We also examine the roles of smoking and smoking cessation on both types of outcomes in this highly WTC-exposed population.

Methods

Study Population

The source population and exclusions are outlined in Figure 1 and are similar to those used in our 7-year study,³ but differing by being limited to active or retired firefighters, excluding emergency medical service workers. We also excluded those with insufficient body weight data. We restricted the population to white and African American firefighters because some analyses required percent-predicted measures, which have not been established for other racial/ethnic groups. Last, we excluded participants without at least two post-September 11 pulmonary function tests (PFTs) ≥ 1 year apart. This study was approved by the Albert Einstein College of Medicine Institutional Review Board (project #07-09-320), and all participants provided informed consent.

Spirometric Measurements

Spirometric measurements were obtained from participants' PFTs conducted during the FDNY's routine medical monitoring examinations, scheduled at 12- to 18-month intervals between March 11, 2000, and September 10, 2014. Spirometry was performed as in our 7-year study.³ Spirometric quality was defined by American Thoracic Society criteria.⁵

The main outcome was FEV₁ in liters and percent-predicted (FEV₁%).⁶ FVC was also measured. Of 93,940 PFTs, 5,623 (6%) were excluded because of improper scheduling, physiologically impossible values, or quality grades worse than "B."³

Other Measures: Demographic characteristics, including sex, race, and dates of birth and retirement were obtained from the FDNY database. Twenty-five participants with missing race were classified as white. For all analyses, age on September 11, 2001 was centered at 40 years. Height and weight, recorded at each medical monitoring examination, were used to calculate BMI. For 8,591 PFTs (9.7%) with missing concurrent weight, weight was imputed from the

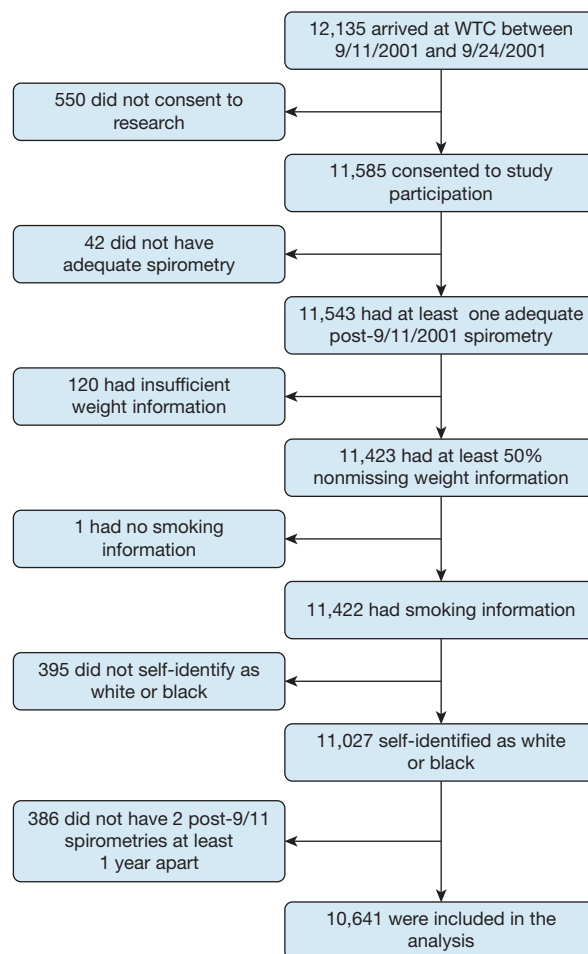


Figure 1 – Flow chart for firefighter study participation. WTC = World Trade Center.

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weight at closest PFT. In analyses, height and weight were centered at 179 cm and 200 lb, respectively.

Exposure to the WTC site was assessed from the first post-September 11 health questionnaire, starting in October 2001, and was categorized as follows: initial arrival on the morning of September 11; afternoon of September 11 or September 12, 2001; and between September 13 and September 24, 2001.^{1,3}

Cigarette smoking was based on the participants' responses to health questionnaires during medical monitoring examinations. Smoking status at study end was categorized as follows: "never," "former, quit before 9/11/2001," "former, quit between 9/11/2001 and 3/10/2008," "former, quit after 3/10/2008," and "current." Participants were classified as never smokers only if they exclusively reported never smoking cigarettes.

Statistical Analysis: Demographic characteristics were compared by analysis of variance, Fisher exact test, Kruskal-Wallis test, or Pearson χ^2 test. For multivariable analyses, we used mixed linear models with random intercepts to account for between-subject variability and repeated measures on individuals. We estimated within-subject variability using intercept-only linear mixed model variance components. Models predicting absolute FEV₁ or FVC included age on September 11, height, weight, sex (men as reference), and race (white as reference) as fixed effects. Models with FEV₁% and FVC% included age on September 11 and weight at PFT as fixed effects. All models estimated weighted average values of each outcome in 6-month increments from March 11, 2000, to September 10, 2014.

Models stratified by smoking status included the entire population, whereas those stratified by WTC arrival included only never smokers. For each 6-month time interval, *t* tests were used to determine if estimates differed significantly by arrival time or smoking status.

We categorized participants into three groups: greater-than-expected age-related decline (FEV₁ decline >64 mL/y, twice the average age-related decline, based on our previous work^{3,7,8}); those with the expected age-related decline (FEV₁ change between -64 and 0 mL/y); and those with better than expected or improved function (FEV₁ change >0 mL/y).

Additionally, lower limits of normal (LLNs) were defined according to Hankinson et al.⁶ For clinical utility, we also defined a moderately impaired group as FEV₁% < 70%. Analyses for both <LLN and <70% were stratified by smoking status. Because participants could have multiple PFTs within time periods, marginal logistic models using generalized estimating equations were used to estimate proportions with FEV₁ measurement <LLN or <70% predicted at particular times. Similar models were used to measure associations between FEV₁ < LLN or <70% predicted and arrival time or smoking status, controlling for age on September 11 and weight. We compared the population with persistent FEV₁ < LLN or <70% predicted post-September 11 (on at least two consecutive PFTs with no subsequent resolution) to the population without persistent impairment. All analyses were performed using SAS (version 9.4; SAS Institute Inc., Cary, NC). *P* values < .05 were considered statistically significant.

Results

Study Population

Selected characteristics of the firefighters are shown in Table 1. Firefighters arriving at the WTC site after September 13, 2001 were slightly more likely than those arriving earlier to be older and retired by study's end. Never smoking varied by arrival time and was most common in the earliest arrival group (*P* < .001, Table 1).

Overall, 97.0% of participants had at least one PFT after September 11, 2008, 81.9% had at least three, and 82.2% had at least one within 2 years of the study's end.

Measures of Lung Function

Average absolute FEV₁ and FEV₁% at 6-month time intervals pre- and post-September 11 are shown stratified by WTC arrival time (never smokers only; Fig 2) and smoking status (Fig 3). Before adjustments in the mixed linear models, 14.6% of the variability in FEV₁ and 17.7% of the variability in FEV₁% could be attributed to within-subject variability. Body weight at the time of the PFT was significantly associated with FEV₁ and was therefore included in all analyses. For each pound gained, FEV₁ decline averaged 3.93 mL. Because FEV₁ did not vary by retirement status, retirement status was not included.

Following the immediate post-September 11 sharp decline in lung function, FEV₁% remained relatively constant through September 10, 2014. Firefighters arriving the morning of September 11 had slightly lower average FEV₁ than lesser exposed firefighters; this difference remained significant during most of follow-up (*P* < .05 for most time intervals; Fig 2).

A total of 19.5% of WTC-exposed firefighters experienced greater-than-expected age-related FEV₁ decline between their first and last post-September PFTs, 65.5% experienced expected age-related decline, and 15.0% experienced improved function. FEV₁ change differed significantly by smoking status (*P* < .001); 32.2% of current smokers had a more than expected age-related decline compared with 17.0% of never smokers. After 2004, never smokers had significantly better FEV₁ than current smokers and former smokers who quit after September 11 (Fig 3).

During the last time interval, compared with never smokers, the average FEV₁ was 78 mL lower for former smokers quitting between September 11, 2001, and March 10, 2008; 198 mL lower for former smokers quitting after March 10, 2008; and 312 mL lower for current smokers. Although firefighters quitting before September 11 had slightly lower FEV₁ than never smokers, the difference was not significant. Firefighters

TABLE 1] Study Population Characteristics by World Trade Center Arrival Time

Characteristic	Arrival Time of Firefighters			
	Morning of 09/11/2001	Afternoon of 09/11 or 09/12/2001	Between 09/13 and 09/24/2001	Overall
No. of workers	1,601	7,545	1,495	10,641
No. of spirometric measurements				
All workers	13,399	63,288	11,630	88,317
Per worker				
Median	9	9	8	9
Interquartile range	7-10	7-10	6-10	7-10
Male sex, %	99.6	99.9	99.7	99.8
Race, % ^a				
White	96.0	97.8	96.9	97.4
Black	4.0	2.2	3.1	2.6
Age on 09/11, y				
Mean	40.5	41.0	44.2	41.4
Range	21.3-66.0	21.4-72.0	22.5-74.6	21.3-74.6
BMI (first post-09/11 BMI) ^b				
Mean	28.9	28.9	28.9	28.9
Range	19.3-45.4	14.9-52.7	18.2-49.3	14.9-52.7
Smoker, %				
Current	4.1	3.7	4.7	3.9
Former, quit after 03/10/08	5.6	5.5	5.0	5.5
Former, quit between 09/11/01 and 03/10/08	9.2	9.0	8.4	9.0
Former, quit before 09/11/01	14.0	15.8	22.6	16.5
Never smoker	67.1	65.9	59.4	65.2
Present at site after 09/30/2001, No. (%)	1,100 (68.7)	5,338 (70.8)	871 (58.3)	7,309 (68.7)
Length of follow-up after 09/11, y ^c				
Median	12.2	12.2	12.2	12.2
Interquartile range	11.5-12.6	11.6-12.6	11.6-12.6	11.6-12.6
Retired, No. (%)	993 (62.0)	4,515 (59.8)	1,046 (70.0)	6,554 (61.6)
Length of follow-up for retirees, y				
Median	12.2	12.2	12.2	12.2
Interquartile range	11.2-12.6	11.4-12.6	11.4-12.6	11.3-12.6

^aRace was self-reported and participants with a missing race variable are assumed to be white (n = 25).

^bFirst post-September 11 BMI is the weight in kilograms divided by the square of height in meters, using the first post-September 11 weight measurement after imputation.

^cLength of follow-up after September 11 was measured as the time between September 11, 2001, and the most recent pulmonary function test.

quitting smoking before March 10, 2008, had significantly better FEV₁ than current smokers during most of the post-September 11 follow-up. The effect of weight on FEV₁ varied slightly by smoking group, but was not large enough to negate the differences in FEV₁ across these groups (data not shown). Lung function findings were similar for FVC (e-Figs 1-4).

Before September 11, <4% of firefighters had FEV₁ < LLN and <1% had FEV₁ < 70% predicted (Fig 4). By study's end (2014), we found that 642 (6.0%) had

persistent FEV₁ < LLN (≥2 consecutive PFTs with FEV₁ < LLN with no subsequent resolution) and 171 (1.6%) had persistent FEV₁ < 70% predicted. By 2014, among never-smoking firefighters, those arriving the morning of September 11 were 70% more likely to have FEV₁ < LLN and 91% more likely to have FEV₁ < 70% predicted than those arriving after September 13, 2001 (P < .020 for both). In addition, never smokers arriving the afternoon of September 11 or on September 12, 2001, were significantly more likely to have FEV₁ < LLN than those arriving after September 13, 2001

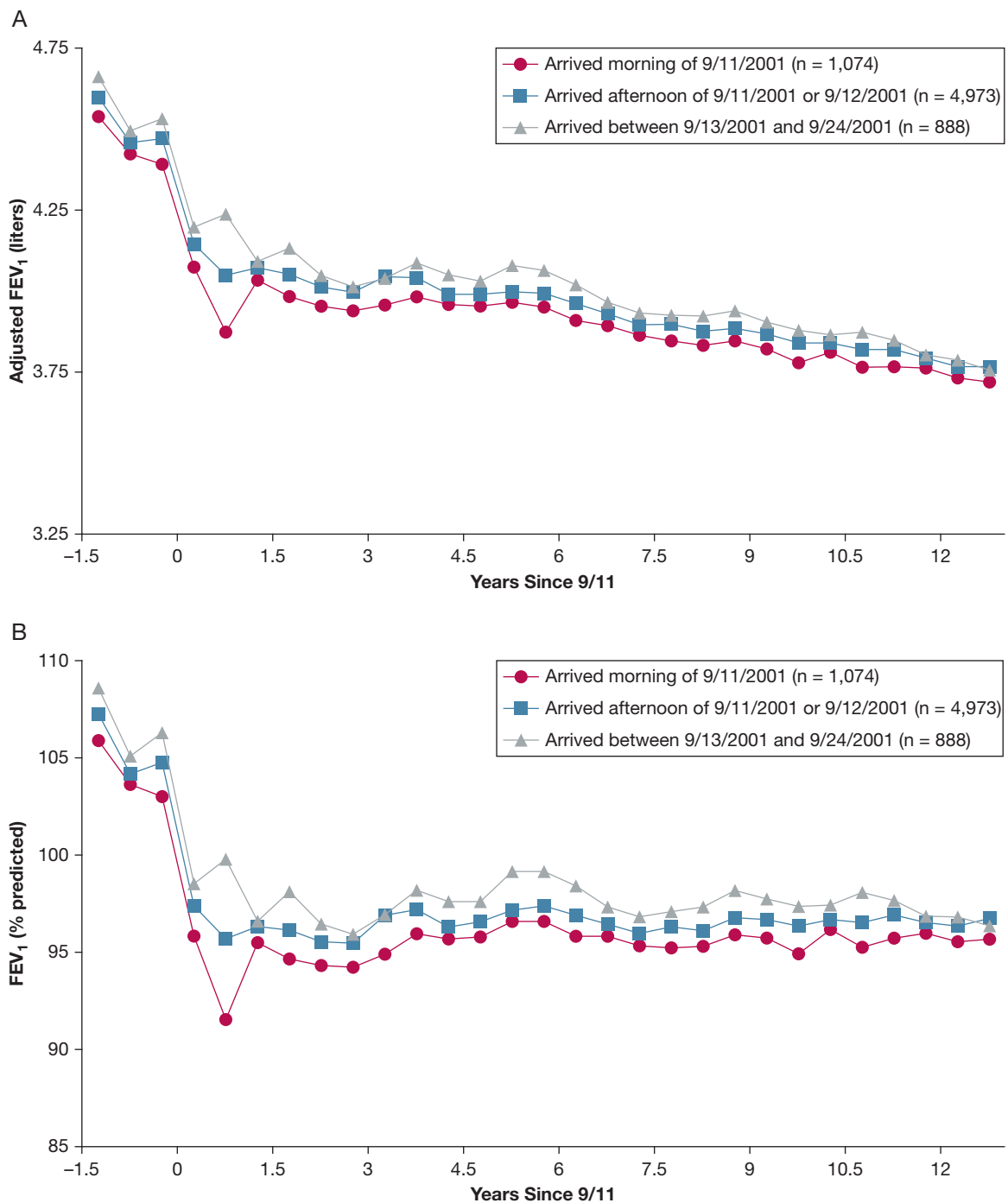


Figure 2 – Lung function by WTC arrival time. For both graphs, the population was restricted to never smokers as of the end of the study. (A) Actual FEV₁ adjusted by age on September 11, 2001 (centered at 40 years), height (centered at 179 cm), weight (centered at 200 lb), sex (men as reference), and race (whites as reference). (B) Percent predicted FEV₁ adjusted by age on September 11, 2001 (centered at 40 years), and weight (centered at 200 lb). See Figure 1 legend for expansion of abbreviation.

(OR = 1.3; $P = .022$). Both models showed significant linear trends in arrival time ($P < .015$ for both $<LLN$ and $<70\%$ predicted).

We found a pronounced impact of smoking status on the proportion of the exposed study population with

abnormal lung function. By 2014, about 9% of never smokers and pre-September 11 quitters had at least one FEV₁ $< LLN$, whereas 12% of those quitting between September 11 and March 10, 2008, and about 20% of those quitting after March 10, 2008, and current smokers had at least one FEV₁ $< LLN$ (Fig 4A). Similar patterns

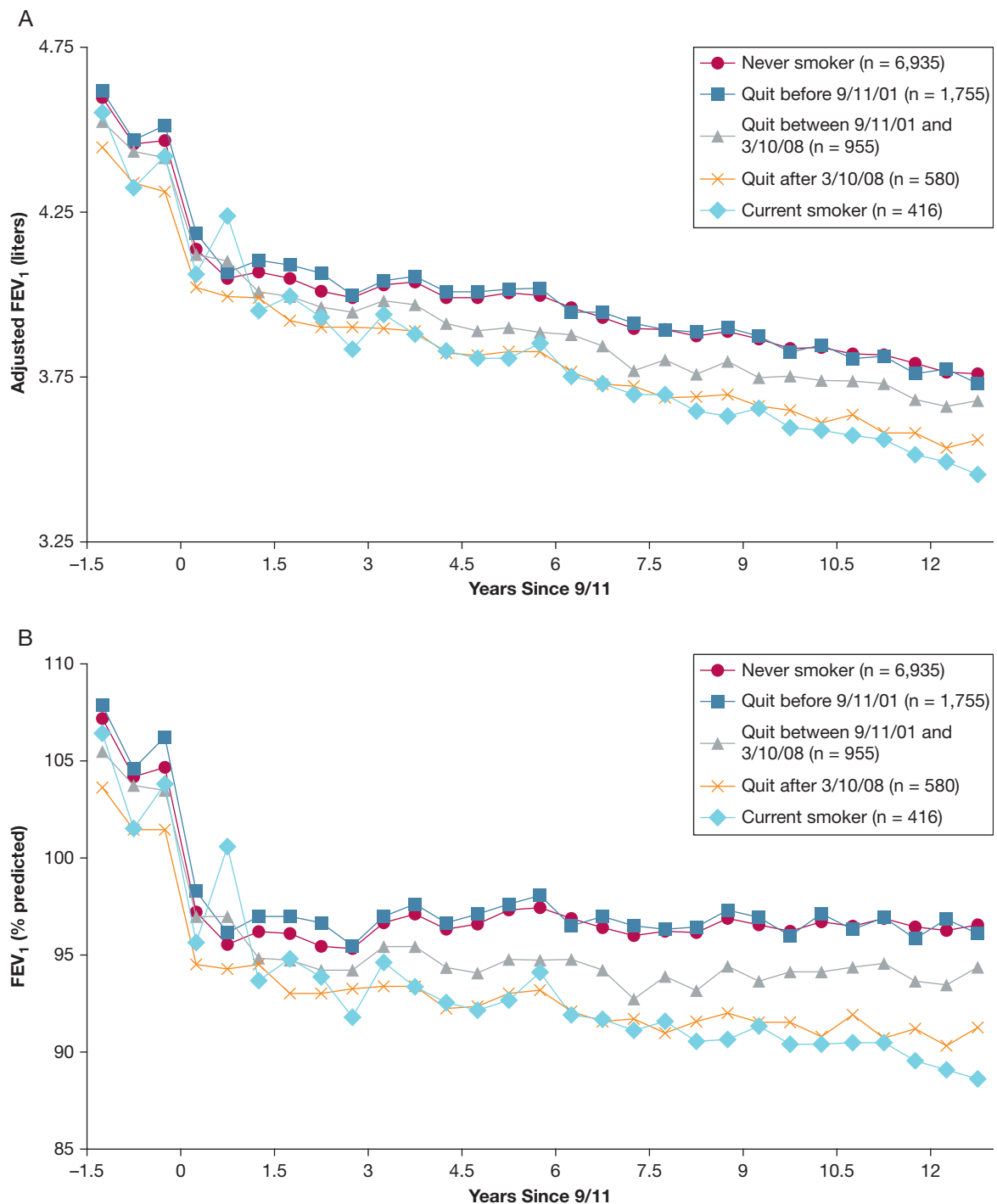


Figure 3 – Lung function by smoking status smoking status was measured as of the end of the study. (A) Actual FEV₁ adjusted by age on September 11, 2001 (centered at 40 years), height (centered at 179 cm), weight (centered at 200 lb), sex (men as reference), and race (whites as reference). (B) Percent predicted FEV₁ adjusted by age on September 11, 2001 (centered at 40 years), and weight (centered at 200 lb).

were found for at least one FEV₁ < 70% predicted, except the proportions were lower, with none >6% (Fig 4B).

When current smokers were compared with those quitting between September 11 and March 10, 2008, they were significantly more likely to have FEV₁ < LLN

(OR = 1.5; P = .002), but not FEV₁ < 70% predicted (OR = 1.5; P = .058). Linear trends were also found between smoking status and < LLN as well as < 70% predicted FEV₁ during the post-September 11 period (P < .001 for both models). With every improvement in smoking level (current smokers, former

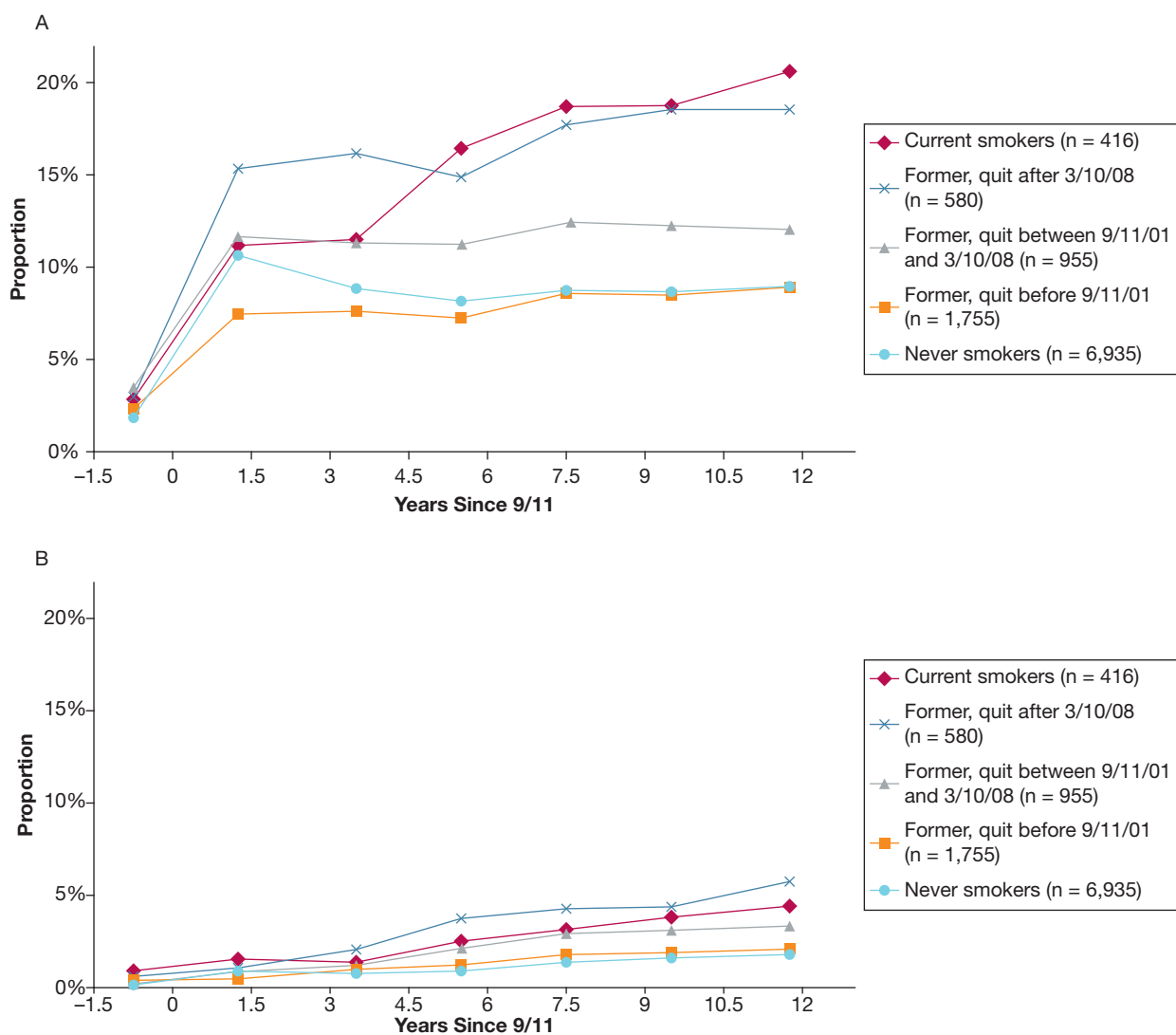


Figure 4 – Abnormal lung function by smoking status. The proportions of firefighters by smoking status, at each 1.5- to 2.5-year interval, who had an FEV₁ measurement less than the lower limit of normal (A) or less than 70% predicted (B).

smokers quitting at various times, up to never smokers), the odds of having FEV₁ < LLN was 22% lower and the odds of having FEV₁ < 70% predicted was 45% lower.

Discussion

This 13-year study represents the longest and most comprehensive study of rescue/recovery workers after a major environmental disaster. As in our original 7-year study,³ and despite 6 years of additional follow-up, we found, on average, little recovery of lung function after the very substantial (about 10%) exposure-related immediate declines. Despite considerable lung function losses following September 11 and a general absence of substantial recovery, most firefighters' lung function remained within normal limits, reflecting that their long-term course was influenced by their excellent

pre-September 11 health status and demonstrating the importance of preemployment medical screening (including lung function testing) for rescue/recovery workers such as firefighters.

For never smokers or smokers quitting before September 11, our data suggest an age- and body size-appropriate long-term lung function decline rate, superimposed on a fixed acute effect of WTC exposure. As expected, smokers fared worse, although, after the acute influence of WTC exposure, decline rates are consistent with rates reported for active smokers and for those who quit during the course of the Lung Health Study.⁹ We found that firefighters who quit smoking after September 11 had lower lung function declines than those who continued to smoke, so that, despite similar starting points, former smokers had decline rates and

end-of-study lung function intermediate between never smokers and current smokers. This beneficial effect of smoking cessation on lung function is well-known in populations without exposure to a major environmental disaster,⁹⁻¹⁴ but this is the first study demonstrating that the same benefit accrues in a highly exposed population with extensive inhalation exposure to particulates and chemicals.

Particularly for firefighters and others in physically demanding occupations, falling below the lower limit of normal FEV₁ and especially falling into the moderately severe impairment range (<70% predicted), can lead to serious lifestyle and employability changes. For that reason, our findings that 20% of current smokers and nearly 20% of those quitting after 2008 had abnormal lung function and that the prevalence of abnormal lung function continued to rise throughout the study (Fig 4A) help to demonstrate the magnitude of harm from smoking in this cohort.

We found significantly lower lung function throughout follow-up and larger percentages of abnormal lung function among those who arrived early at the WTC site the morning of September 11, when the dust cloud and chemical exposures were most intense, compared with firefighters arriving later. Both effects were much higher among active and former smokers than among never smokers. The persistence of WTC exposure gradients by arrival time confirms the importance of initial WTC exposure on early lung function decline and on the subsequent risk of abnormal lung function.³

The approximately 10% decline in average lung function and the >10% who developed abnormal FEV₁ are distinctly unusual in occupational cohorts. We have previously shown that firefighting, in the absence of WTC exposure, does not appear to be associated with unusual declines in lung function or with excess risks of developing abnormal lung function.⁷ Even coal miners with relatively high dust exposure have shown much smaller average 3-year lung function declines¹⁵ than we observed in the first 6 months after September 11, a deficit that has persisted for many years.

Last, we found a significant, albeit small, association between weight gain and lung function decline. This finding is consistent with other studies involving non-FDNY WTC rescue recovery workers¹⁶ and with our own study of non-WTC-exposed FDNY workers.⁷ Although some weight gain may have resulted from tobacco cessation,^{7,17,18} the gain did not negate the benefit associated with smoking cessation.

The strengths of this study are that it is the longest study of lung function ever undertaken in rescue/recovery workers following a major environmental disaster; exposure based on initial arrival time was known; PFTs were of high quality; preexposure spirometry was available; the first postdisaster spirometry was obtained early, usually within 6 months following the disaster; nearly all of the exposed population was included; relatively little longitudinal dropout occurred; and smoking status was available.

Our study did, however, have several limitations. PFTs could not be performed in the first days after September 11, so we cannot determine whether, for some, there was an even more severe acute decline and subsequent incomplete recovery. Quantifying immediate exposure by initial WTC arrival time has been proven to be a useful predictor of respiratory and other illnesses,^{2-4,8,19,20} but is an imperfect measure of individual exposures in composition, quantity, and duration. We could not analyze the impact of masks/respirators on FEV₁ because their use was minimal during the first week post-September 11,^{21,22} and information obtained thereafter was not sufficiently detailed. Another limitation was that, as with many studies, smoking status and quit date were self-reported and may therefore be subject to misclassification. Reliable data on treatment for obstructive airways disease, which have been shown to correlate with improvement,²³ were not available for our entire study population, and, when available, did not include information on adherence. Finally, although we had near-complete sampling and excellent retention, we cannot be sure that those not meeting inclusion criteria or not evaluated at any individual time interval were not systematically different from those who were included.

Conclusion

In this 13-year study, the longest study ever in rescue/recovery workers after a major environmental disaster, we found continued lack of lung function recovery for most FDNY WTC-exposed workers and that the trajectory of lung function varied by smoking status. Most important, we found that those who quit smoking during follow-up had better lung function than those who continued to smoke, despite weight gain, demonstrating that, despite the prevailing fatalism of that time,²⁴ that the “damage has already been done,” tobacco cessation efforts postdisaster can be successful even in a highly exposed, traumatized workforce.

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Author contributions: D. J. P. had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. T. K. A., M. V., R. Z. O., C. B. H., and D. J. P. designed the study, analyzed, and interpreted the data. T. K. A. and D. J. P. had the initial idea for the study. T. K. A., M. V., R. Z. O., and D. J. P. drafted the first manuscript with critical revisions from C. B. H., T. M. S., W. M., M. P. W., H. W. C., A. N., M. D. W., V. C., and K. J. K. All authors have approved the final manuscript.

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Additional information: The e-Figures can be found in the Supplemental Materials section of the online article.

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