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## Lung Function in Rescue Workers at the World Trade Center after 7 Years

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### ABSTRACT

#### BACKGROUND

The terrorist attacks on the World Trade Center on September 11, 2001, exposed thousands of Fire Department of New York City (FDNY) rescue workers to dust, leading to substantial declines in lung function in the first year. We sought to determine the longer-term effects of exposure.

#### METHODS

Using linear mixed models, we analyzed the forced expiratory volume in 1 second (FEV<sub>1</sub>) of both active and retired FDNY rescue workers on the basis of spirometry routinely performed at intervals of 12 to 18 months from March 12, 2000, to September 11, 2008.

#### RESULTS

Of the 13,954 FDNY workers who were present at the World Trade Center between September 11, 2001, and September 24, 2001, a total of 12,781 (91.6%) participated in this study, contributing 61,746 quality-screened spirometric measurements. The median follow-up was 6.1 years for firefighters and 6.4 years for emergency-medical-services (EMS) workers. In the first year, the mean FEV<sub>1</sub> decreased significantly for all workers, more for firefighters who had never smoked (a reduction of 439 ml; 95% confidence interval [CI], 408 to 471) than for EMS workers who had never smoked (a reduction of 267 ml; 95% CI, 263 to 271) ( $P < 0.001$  for both comparisons). There was little or no recovery in FEV<sub>1</sub> during the subsequent 6 years, with a mean annualized reduction in FEV<sub>1</sub> of 25 ml per year for firefighters and 40 ml per year for EMS workers. The proportion of workers who had never smoked and who had an FEV<sub>1</sub> below the lower limit of the normal range increased during the first year, from 3% to 18% for firefighters and from 12% to 22% for EMS workers, stabilizing at about 13% for firefighters and 22% for EMS workers during the subsequent 6 years.

#### CONCLUSIONS

Exposure to World Trade Center dust led to large declines in FEV<sub>1</sub> for FDNY rescue workers during the first year. Overall, these declines were persistent, without recovery over the next 6 years, leaving a substantial proportion of workers with abnormal lung function.

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**T**HE TERRORIST ATTACK ON THE WORLD Trade Center on September 11, 2001 (hereafter referred to as 9/11), and its consequent collapse killed 2751 persons, including 343 rescue workers employed by the Fire Department of New York City (FDNY) and exposed thousands of persons to a dense, persistent dust cloud of pulverized building materials and chemical by-products of combustion or pyrolysis.<sup>1</sup> The FDNY rescue workers who responded to the World Trade Center site during the collapse or the subsequent 10-month rescue-and-recovery operations had substantial loss in pulmonary function during the first year after the event, more than 12 times the annual age-associated rate.<sup>2</sup> The largest decline was observed among workers who arrived at the site on the morning of 9/11, and there were larger declines among firefighters than among emergency medical services (EMS) workers.<sup>2</sup>

Among non-FDNY rescue workers, volunteers, and residents of lower Manhattan who were exposed to World Trade Center dust, abnormal results on spirometry were common<sup>3,4</sup> and persisted during a 3-year follow-up.<sup>3</sup> However, health records were not available before 9/11 to determine the extent of new versus preexisting abnormalities.

We investigated the longer-term consequences of exposure to World Trade Center dust by characterizing trends in pulmonary function during the 7 years after 9/11, as assessed by repeated measures of forced expiratory volume in 1 second (FEV<sub>1</sub>) among FDNY rescue workers.

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## METHODS

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### STUDY POPULATION

We included all FDNY firefighters and EMS workers who were hired before September 25, 2001; who arrived at the World Trade Center site between September 11 and September 24, 2001; and who had undergone spirometry at least once before September 11, 2008. This study was approved by the institutional review board at Montefiore Medical Center. Written informed consent was obtained from all FDNY workers.

### SPIROMETRIC MEASUREMENTS

We collected spirometric indexes from at least three measurements for FDNY personnel at routine occupational health assessments, scheduled every 12 to 18 months. FEV<sub>1</sub> measurements were

considered to be acceptable if there were no early procedural terminations, variable efforts, leaks, obstructed mouthpieces, or artifacts (e.g., cough, glottis closure); if the back-extrapolated volume was 150 ml or less and 5% or less of forced vital capacity (FVC); and if the best two measurements of FEV<sub>1</sub> were within 200 ml of each other.<sup>5</sup> We selected the largest acceptable FEV<sub>1</sub> for electronic archiving.

We calculated each participant's percent of predicted FEV<sub>1</sub> on the basis of the age at examination, height, sex, and race for white workers and black workers (since reliable prediction equations were not available for other racial or ethnic groups). We determined whether the FEV<sub>1</sub> fell below the lower limit of the normal range (i.e., the lowest 5th percentile of a reference population from the National Health and Nutrition Examination Survey<sup>6</sup>). Of 63,491 spirometric measurements, we excluded 1356 on the basis of quality grading and 389 because the measurement was performed within 60 days after the previous measurement. We graded and recorded the FVC but focused analyses on FEV<sub>1</sub> because of better reproducibility and correlation with symptoms and pulmonary function in this cohort.<sup>7</sup>

Before mid-2002, the FDNY used Portascreen spirometers (S&M Instruments). Between April 2002 and August 2002, for consistency with other federally funded medical monitoring programs associated with the World Trade Center attack, EasyOne spirometers (NDD Medical Technologies) were phased into the FDNY's monitoring program. The EasyOne device preserves numerical and graphic data from all efforts and provides automated quality grading on the basis of American Thoracic Society guidelines.<sup>5</sup> To confirm that the change in the type of spirometer did not introduce systematic bias, we compared FEV<sub>1</sub> results in 132 FDNY workers who had not been exposed to World Trade Center dust and who had undergone Portascreen spirometry, followed by at least two EasyOne measurements. The annualized mean difference (i.e., the difference in FEV<sub>1</sub> divided by the difference in years) between the Portascreen measurement and the subsequent EasyOne measurement was less than the difference between the two EasyOne measurements by 39 ml per year (95% confidence interval [CI], -25 to 102), not significantly different from zero. Results were similar when we examined the percent of the predicted FEV<sub>1</sub>.

**OTHER MEASURES**

The database for the FDNY's medical monitoring program includes birth date, sex, height, weight, body-mass index, self-reported race or ethnic group, smoking status, and arrival time at the World Trade Center on 9/11 or thereafter.<sup>2</sup> Height and weight were measured at each post-9/11 visit for spirometric measurement. Smoking status was defined as "post-9/11 ever" if reported as "current" at any post-9/11 visit, "never" if consistently reported as such, and "pre-9/11 only" if at least one entry indicated "former smoker" and no post-9/11 entry indicated current smoking. Because the FDNY's duty records were incomplete, we constructed a "duration" variable that was based entirely on self-reported calendar months that personnel worked at the World Trade Center site, on or off duty, from 9/11 through July 24, 2002; responses did not allow for more precise quantification of days worked or specific tasks (including fire suppression through December 2001 and excavation for recovery of remains through July 2002).

**STATISTICAL ANALYSIS**

We compared individual characteristics between firefighters and EMS workers, according to smoking status and arrival-time group, using Pearson's chi-square test, the Mann-Whitney test, Student's t-test, or analysis of variance, as appropriate. All reported P values are two-sided.

We used linear mixed models<sup>8-10</sup> to estimate weighted average values for FEV<sub>1</sub> and percent of the predicted FEV<sub>1</sub> for each 6-month period from March 12, 2000, to September 11, 2008, for all workers and separately for arrival-time groups and for firefighters and EMS workers. We also used the linear mixed models to assess changes during the first 6 and 12 months after 9/11, during the 7 years after 9/11, and during the 6 years between September 12, 2002, and September 11, 2008. We adjusted the FEV<sub>1</sub> for age on 9/11, sex, height, and race and adjusted both the FEV<sub>1</sub> and the percent of the predicted FEV<sub>1</sub> for weight, smoking status, arrival time, and duration of work. The models allowed for the acute decrement in spirometric measurements that was previously observed in the first year after 9/11.<sup>2</sup> We included all predictors in the models as fixed effects. We used a random intercept to take into account the heterogeneity across subjects and the correlation induced by having repeated observations on the same subjects.

We performed a similar analysis with the last FEV<sub>1</sub> value taken during the final 2 years of follow-up as the outcome but without the random effects.

For white workers and black workers, at each 6-month interval, we used marginal logistic-regression models, fit with generalized estimating equations,<sup>11</sup> to estimate the percentage of FEV<sub>1</sub> values that fell below the lower limit of the normal range and the percentage that fell below 70% of the predicted value.

Both the linear mixed models and the marginal logistic-regression models take into account that individuals could contribute unequal numbers of repeated correlated observations to the analyses over time. All data analyses were performed with the use of SAS software, version 9.1.

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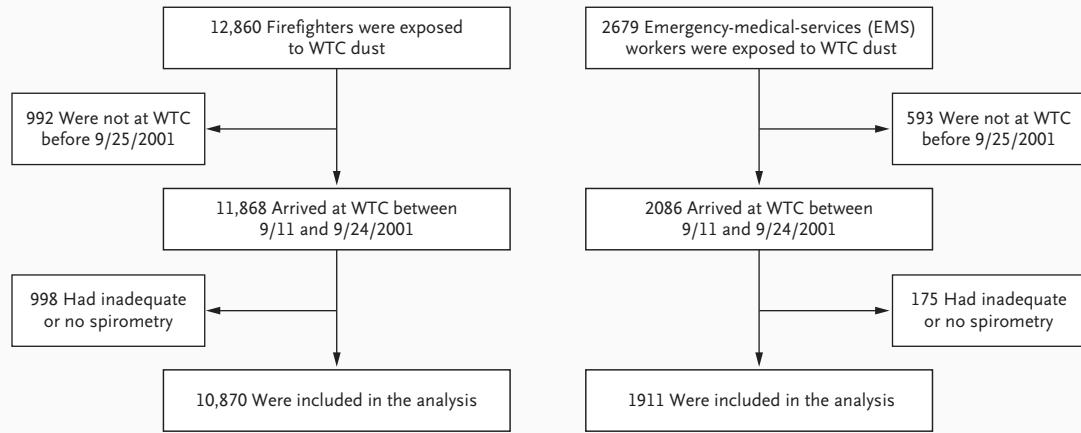
**RESULTS**

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**STUDY POPULATION**

Of the 13,954 FDNY personnel (11,868 firefighters and 2086 EMS workers) who were present at the World Trade Center site between September 11 and September 24, 2001, a total of 1173 (8.4%) were not included in this analysis because they had not undergone spirometric measurement or because the results were inadequate (Fig. 1). The workers who did not have spirometric measurements did not differ significantly from the analyzed cohort on the basis of the proportions who were male, who were firefighters versus EMS workers, or who were post-9/11 smokers. However, workers for whom data were not available, as compared with the analyzed cohort, were significantly younger (mean [±SD] age, 26.7±5.3 vs. 40.2±8.0 years), more likely to be black (8.6% vs. 5.4%) or Hispanic (15.8% vs. 6.4%), and more likely to have smoked only before 9/11 (37.6% vs. 27.3%). The percentage of workers who arrived at the World Trade Center on the morning of 9/11 was lower among those who did not have spirometric measurements than among those in the analyzed cohort (10.3% vs. 13.4%), and by the end of the study, a lower percentage of the nonanalyzed firefighters had retired (9.6% vs. 44.4%), reflecting their younger average age.

In the analysis cohort, EMS workers on average were slightly younger and heavier than firefighters (Table 1). A higher proportion of EMS workers than firefighters were women, nonwhite, or smokers (either before or after 9/11). By design, retired personnel remained in the analysis cohort,



Time Period	Active Firefighters		Retired Firefighters		Deceased Firefighters	Active EMS Workers		Retired EMS Workers		Deceased EMS Workers
	No. of persons	No. of spiro. msmts.	Cumulative no. of persons	No. of spiro. msmts.	Cumulative no. of persons	No. of persons	No. of spiro. msmts.	Cumulative no. of persons	No. of spiro. msmts.	Cumulative no. of persons
9/12/2001–9/11/2002	9694	8931	1174	20	2	1862	1830	49	0	0
9/12/2002–9/11/2003	8672	4170	2194	73	4	1803	1476	107	4	1
9/12/2003–9/11/2004	8206	5286	2654	28	10	1729	1630	179	1	3
9/12/2004–9/11/2005	7731	4266	3118	16	21	1640	1537	267	1	4
9/12/2005–9/11/2006	7236	4261	3609	1148	25	1554	1394	350	29	7
9/12/2006–9/11/2007	6743	4123	4096	1163	31	1470	1384	434	31	7
9/12/2007–9/11/2008	6347	3814	4482	2203	41	1394	1288	508	141	9

**Figure 1. Firefighters and Emergency-Medical-Services (EMS) Workers Who Participated in the World Trade Center (WTC) Study.**

Shown are the numbers of firefighters and EMS workers who were employed by the Fire Department of New York City (FDNY) on September 11, 2001; those who were present at the WTC between September 11 and September 24, 2001; those who were active, retired, or deceased during each year after September 11, 2001; and the number of spirometric measurements that were performed. The numbers of retired or deceased workers are cumulative values. The numbers of active workers include those who were employed continuously from September 11, 2001 to the end of the indicated period. Spiro. msmts. denotes spirometric measurements.

although initial participation was low (Fig. 1). Starting in 2005, outreach efforts, including the use of appointment schedulers specifically for retirees, improved the rates of participation among retirees, with 84% followed for at least 4 years. Overall, the length of follow-up was similar among retired and active firefighters (Table 1).

**MEASURES OF LUNG FUNCTION**

Figure 2 shows average FEV<sub>1</sub> values for firefighters and EMS workers before and after 9/11 and the percent of the predicted FEV<sub>1</sub> at 6-month intervals, stratified according to smoking status. FEV<sub>1</sub> values were adjusted for race (with white workers as the reference group), age on 9/11 (centered at age 40), height (centered at 179 cm), weight (centered at 200 lb), and sex (with men as the reference group). Average FEV<sub>1</sub> values were higher for

firefighters than for EMS workers (P<0.001) and tended to be highest for workers who had never smoked (P=0.06) and lowest for smokers after 9/11 (P<0.001), with a trend toward widening differences over time. The percent of the predicted FEV<sub>1</sub>, which is adjusted for an expected age-related decline, was significantly lower at year 1, a decline that persisted during the following 6 years, with a trend toward a steeper decline among workers who continued smoking after 9/11.

Figure 3 compares changes in FEV<sub>1</sub> values over time on the basis of the arrival time at the World Trade Center for workers who had never smoked. Among firefighters, we noted a large decrease in the mean adjusted FEV<sub>1</sub> (355 ml; 95% CI, 352 to 359) during the first 6 (P=0.004) months and a decrease of 439 ml (95% CI, 408 to 471) during the first year (P=0.003). The firefighters with the

**Table 1. Characteristics of the Workers, According to Arrival Time at the World Trade Center.\***

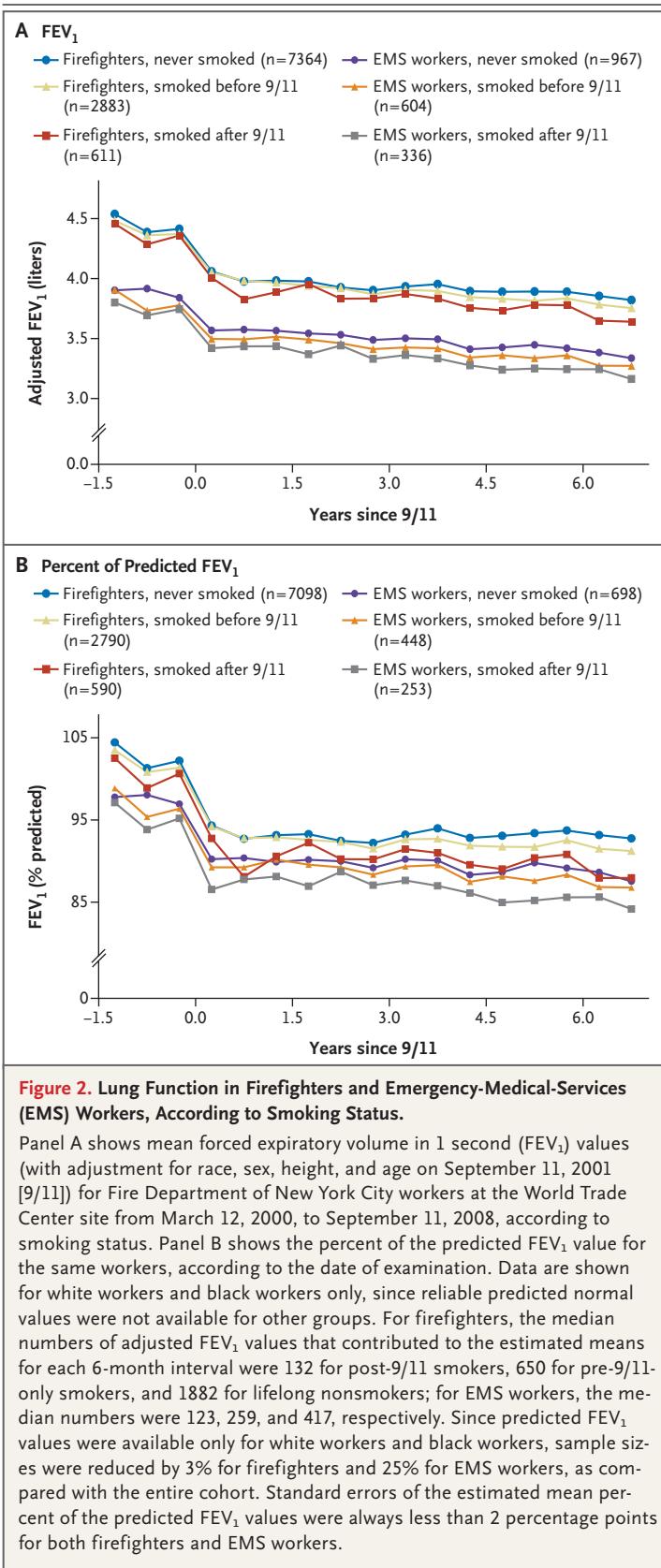
Variable	Arrival Time of Firefighters			Arrival Time of EMS Workers		
	Morning of 9/11/2001	Afternoon of 9/11 or 9/12/2001	Between 9/13 and 9/24/2001	Morning of 9/11/2001	Afternoon of 9/11 or 9/12/2001	Between 9/13 and 9/24/2001
No. of workers	1714	8174	982	385	1198	328
No. of spirometric measurements				10,870		1911
All workers	7732	37,325	3602	48,659	8240	2285
Per worker						
Median	5	5	4	5	8†	8†
Interquartile range	4-7	4-7	3-6	4-7	6-9	6-9
Male sex — %	99.7	99.8	99.6	99.8	76.5†	75.6†
Race — %‡						
White	91.7	94.6	93.4	94.0	49.8†	49.7†
Black	3.9	2.1	3.1	2.5	22.9†	22.2†
Age on 9/11 — yr						
Mean	40.2	40.4	44.9	40.8	37.1†	37.1†
95% CI	39.8-40.5	40.2-40.5	44.4-45.5	40.6-40.9	36.7-37.6	36.7-37.5
Body-mass index§						
Mean	28.1	28.0	28.1	28.0	30.1†	29.4†
95% CI	27.9-28.2	27.9-28.1	27.9-28.3	28.0-28.1	29.7-30.4	28.8-30.0
Smoker — %						
After 9/11	5.0	5.5	7.4	5.6	17.5†	17.6†
Before 9/11 only	26.1	26.0	31.8	26.6	32.2†	31.7†
Duration of work at the site after 9/11 — mo						
Mean	4.8	4.4	3.2	4.3	3.7†	3.8†
95% CI	4.6-5.0	4.3-4.4	3.0-3.4	4.3-4.4	3.5-3.9	3.7-4.0
Present at site after 9/30/2001 — no./total no. (%)	1165/1318 (88.4)	5894/6711 (87.8)	481/669 (71.9)	8660/10304 (84.1)	667/975 (68.4)†	233/313 (74.4)
Length of follow-up after 9/11 — yr						
Median	6.0	6.1	6.2	6.1	6.5†	6.4†
Interquartile range	5.1-6.5	5.2-6.6	5.2-6.6	5.2-6.6	5.9-6.7	5.9-6.7
Retired before 9/11/2008 — no. (%)	738 (43.1)	3151 (38.5)	593 (60.4)	4482 (41.2)	300 (25.0)†	508 (26.6)†
Length of follow-up for retirees — yr						
Median	5.5	6.1	6.1	6.1	4.9†	4.9†
Interquartile range	4.9-6.5	5.0-6.6	5.0-6.6	5.0-6.6	2.9-6.3	2.6-6.0

\* CI denotes confidence interval, and EMS denotes emergency medical services.

† P&lt;0.001 for the comparison between EMS workers and firefighters calculated with the use of Pearson's chi-square test, Student's t-test, or analysis of variance, as appropriate.

‡ Race was self-reported.

§ The body-mass index is the weight in kilograms divided by the square of the height in meters.



heaviest dust exposure, those arriving at the World Trade Center site on the morning of 9/11, had significantly larger declines of 371 ml (95% CI, 362 to 380) during the first 6 months and 585 ml (95% CI, 515 to 656) during the first year than did those arriving at later times. EMS workers had smaller declines, averaging 272 ml (95% CI, 268 to 276) during the first 6 months and 267 ml (95% CI, 263 to 271) during the first year, without apparent influence of arrival time. We noted similar declines in the percent of the predicted FEV<sub>1</sub> (Fig. 3B).

We saw little direct evidence of recovery during the 6 years between September 11, 2002, and September 11, 2008. During the entire 7-year period from 2001 to 2008, among workers who had never smoked, the average total decline was 592 ml (95% CI, 580 to 604) for firefighters and 504 ml (95% CI, 489 to 519) for EMS workers. After the initial decline in the first year among lifelong nonsmokers, the adjusted FEV<sub>1</sub> continued to decline, with an annualized rate of decline during the 6 years between 2002 and 2008 of 26 ml per year (95% CI, 20 to 31) for firefighters, whereas the percent of the predicted FEV<sub>1</sub> did not change significantly, with an increase of 0.01 percentage points per year (95% CI, -0.12 to 0.13). For EMS workers who had never smoked, the adjusted FEV<sub>1</sub> continued to decline by an average of 40 ml year (95% CI, 38 to 42), a value that was significantly higher than that for firefighters ( $P < 0.001$ ), and the percent of the predicted FEV<sub>1</sub> declined slightly, by 0.47 percentage points per year (95% CI, 0.46 to 0.48). We found similar results among workers who had histories as smokers.

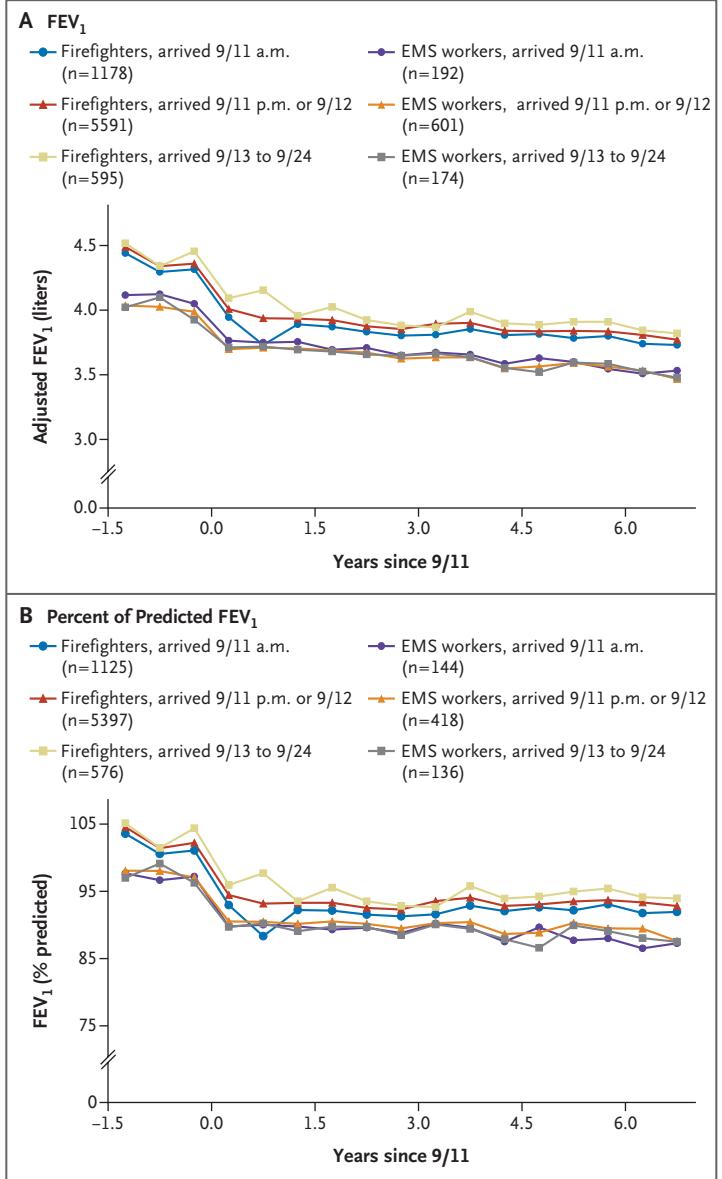
In a multivariable analysis of the last FEV<sub>1</sub> in the final 2 years for workers who had never smoked, there was a nonsignificant trend toward an association between the number of months of work at the World Trade Center site after 9/11 and the FEV<sub>1</sub> value, a decline of 4 ml per month of work ( $P = 0.07$ ). We found a significant relationship between the FEV<sub>1</sub> value and sex, calendar age, race, height, and weight but not with arrival time at the World Trade Center. For EMS workers, neither the duration of work nor arrival time was significantly associated with the FEV<sub>1</sub>.

Figure 4 shows, among firefighters and EMS workers who had never smoked and who were present at the World Trade Center site in the first 2 weeks after 9/11, the proportion whose FEV<sub>1</sub> values were below the lower limit of the normal range or below 70% of the predicted value at each

**Figure 3. Lung Function in Firefighters and Emergency-Medical-Services (EMS) Workers Who Had Never Smoked, According to Arrival Time at the World Trade Center.**

Panel A shows mean forced expiratory volume in 1 second (FEV<sub>1</sub>) values (with adjustment for race, sex, height, and age on September 11, 2001 [9/11]) for non-smoking Fire Department of New York City workers from March 12, 2000, to September 11, 2008, according to the time of their arrival at the World Trade Center. Panel B shows the percent of the predicted FEV<sub>1</sub> value for the same workers. Data are shown for white workers and black workers only, since reliable predicted normal values were not available for other groups. For firefighters, the median numbers of adjusted FEV<sub>1</sub> values that contributed to the estimated means over each 6-month interval were 289 for firefighters who arrived on the morning of 9/11, 1443 for firefighters arriving later on 9/11 or the following day, and 114 for firefighters arriving on September 13 to September 24, 2001; for EMS workers, the median numbers were 74, 263, and 73, respectively. Since predicted FEV<sub>1</sub> values were available only for white workers and black workers, sample sizes were reduced by 3% for firefighters and 25% for EMS workers, as compared with the entire cohort. Standard errors of the estimated mean FEV<sub>1</sub> data were always less than 82 ml for firefighters and less than 74 ml for EMS workers. Standard errors of the estimated mean percent of the predicted FEV<sub>1</sub> were always less than 2 percentage points for both firefighters and EMS workers.

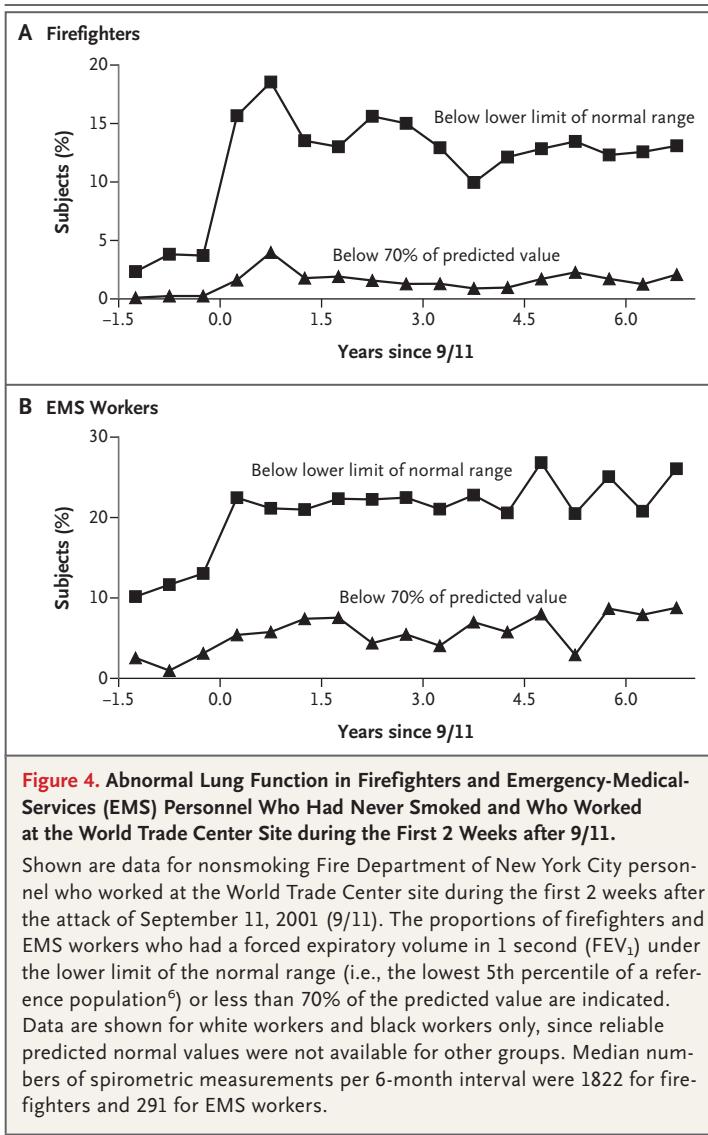
6-month interval. Before 9/11, few firefighters had abnormal results on spirometry (below the lower limit of the normal range), and almost none had values that were significantly abnormal clinically (<70% of the predicted value). After 9/11, there were immediate increases in both frequencies, with subsequent stabilization at approximately 13% of firefighters who had an FEV<sub>1</sub> value below the lower limit of the normal range and 2% who had measurements under 70% of the predicted value. For EMS workers, the baseline percentage of those with abnormal results on spirometry was much higher than for firefighters, with 11.0% of EMS workers who had an FEV<sub>1</sub> below the lower limit of the normal range and 2.5% who had an FEV<sub>1</sub> below 70% of the predicted value. Both percentages more than doubled after 9/11 and remained elevated at approximately 23.0% and 7.5%, respectively, during the subsequent 6.5 years. Among firefighters and EMS workers who had never smoked, the proportions who had at least one post-9/11 FEV<sub>1</sub> value under 70% of the predicted value — 303 of 7098 firefighters (4.3%) and 92 of 698 EMS workers (13.2%) — did not differ significantly from the proportions of



those who had normal spirometric results on the basis of age on 9/11, body-mass index, arrival time on 9/11, or work duration.

## DISCUSSION

The massive, acute exposure to dust at the World Trade Center site on 9/11 and repeated exposure to lesser amounts over the subsequent recovery operation led to significant and substantial declines in FEV<sub>1</sub> over the first year after 9/11 for the FDNY group as a whole and for both firefighters and EMS workers with no smoking history. By the nature of their work, firefighters had heavier



exposure to dust and had commensurately greater first-year declines in lung function than did EMS workers. For firefighters, decreases in FEV<sub>1</sub> values during the first year were largest for those who were present on the morning of 9/11, when the dust cloud was most intense, findings that are consistent with previous reports showing arrival-time gradients in respiratory symptoms<sup>12-15</sup> and results on spirometry.<sup>15-18</sup> However, during the entire 7-year period, there was no apparent influence of arrival time, suggesting that although the intensity of the initial exposure may have been the critical determinant of acute inflammation<sup>19</sup> and early reductions in lung function, the long-term course was more related to the population that was exposed than to the exposure.

Surprisingly, we observed little or no recovery of average lung function during the 6-year follow-up period. Indeed, from 2002 through 2008, FEV<sub>1</sub> values continued to decline, so that the overall loss in lung function from early 2001 until late 2008 averaged almost 600 ml for firefighters who had never smoked and more than 500 ml for EMS workers who had never smoked. From 2002 to 2008, FEV<sub>1</sub> values continued to decline, with an average rate of 25 ml per year for firefighters who had never smoked and 40 ml per year for EMS workers who had never smoked. Both values are within the range of 20 to 56 ml per year reported for healthy, nonsmoking men between the ages of 24 and 65 years in five longitudinal studies,<sup>20</sup> but the rate of decline among EMS workers was significantly faster than that for firefighters. A survivor effect, in which severely affected firefighters tended to drop out of the study over time, could have contributed to that finding. However, our unusually strong rate of retention (median follow-up, 6.0 years for retired firefighters and 4.9 years for retired EMS workers) should minimize any informative loss-to-follow-up effect, along with the fact that our primary analyses estimated expected FEV<sub>1</sub> separately for each 6-month interval after 9/11. A more likely explanation is that there was a small, slow trend toward partial recovery among firefighters, who had more severe initial declines than did EMS workers. Such partial recovery probably reflects the fact that lung function improved in one subgroup of workers and declined in another.

Our results underscore those of Skloot et al.,<sup>3</sup> who found high rates of abnormal spirometric measurements among non-FDNY workers at the World Trade Center site and little change during 3 years of follow-up. For non-FDNY workers, data before 9/11 were not available for comparison, so the effect of dust exposure on the initial decline in lung function after 9/11 could not be quantified. Furthermore, this population was not defined before 9/11, making potential selection bias a concern. For FDNY workers, the availability of pre-9/11 spirometry records, the essentially complete sampling, and the minimal longitudinal dropout allowed us to be confident that the post-9/11 decrease in mean FEV<sub>1</sub> and the increase in the proportion of workers who had abnormal spirometric measurements were caused by dust exposure at the World Trade Center site.

In the absence of overwhelming exposure, such as that incurred by FDNY firefighters at the World

Trade Center, smoke inhalation during firefighting causes relatively mild and reversible respiratory impairment.<sup>21-25</sup> Two studies of urban firefighters who had undergone spirometry before and within hours after heavy smoke exposure showed immediate declines in FEV<sub>1</sub> values that averaged 50 ml<sup>21</sup> and 130 ml,<sup>22</sup> despite the use of respiratory protection. Severe short-term declines in FEV<sub>1</sub> values have been documented in firefighters after a chemical fire (median decline, 490 ml)<sup>23</sup> and a woodland fire (mean decline, 200 ml),<sup>24</sup> in which most of the firefighters did not have respiratory protection. Full recovery occurred within days<sup>23</sup> or weeks.<sup>24</sup> Similarly, a case-control study of 21 firefighters who had acute hypoxemia after a chemical fire showed normal pulmonary function 1 month later and no difference between exposed firefighters and controls.<sup>25</sup>

Aside from the documented effects of 9/11, the long-term effects of firefighting on pulmonary function have also been mild. During 3 years of observation among 1146 active Boston firefighters, the annualized decline in FEV<sub>1</sub>, as calculated from two time points, averaged 30 ml per year,<sup>26</sup> a decrease similar to the normal age-related decline in U.S. men.<sup>6,20</sup> This finding suggests that short-term declines in lung function related to smoke exposure are generally followed by full recovery. However, as in most studies, firefighters who are lost to follow-up tended to have lower FEV<sub>1</sub> values than did those who were retained, suggesting a survivor effect. In support of that view, a 5-year follow-up of 109 retired Boston firefighters showed an average annualized decline of 50 ml per year in FEV<sub>1</sub>.<sup>27</sup> Nonetheless, a 250-ml decline during a 5-year period, while large, is still relatively modest in comparison to the average decline of 600 ml during a 7-year period among the FDNY firefighters who worked at the World Trade Center.

Our study has several limitations. We did not perform spirometry in the first days after 9/11,

so we cannot determine whether for some workers there was an even more severe immediate decline in FEV<sub>1</sub> and subsequent incomplete recovery. The requirement to change spirometers in 2002 could have influenced comparisons before and after the change. However, a comparison of FEV<sub>1</sub> values on both spirometers for persons who were not exposed to World Trade Center dust showed that the difference was not significant. We quantified immediate exposure according to the arrival time at the World Trade Center on 9/11 and ongoing exposure by the duration of work at the site. Although both these values are imperfect measures of the intensity of dust exposure, they have been useful predictors of respiratory and other illnesses in previous studies.<sup>12-18</sup> We could not analyze the effect of the use of masks or respirators on FEV<sub>1</sub> values, since the use of such devices was minimal during the first week after 9/11<sup>17</sup> and data on this variable thereafter did not capture the detail needed for appropriate analyses, even in aggregate. Finally, although we had near-complete sampling and excellent retention, we cannot be sure that the approximately 8% of workers who did not meet inclusion criteria did not have systematically higher or lower FEV<sub>1</sub> values than those who were analyzed.

In conclusion, in a group of FDNY workers who had immediate and sustained exposure to dust from the collapse of the World Trade Center, we observed a large decline in FEV<sub>1</sub> values at 6 months and 12 months after 9/11, followed by an overall lack of substantial recovery during the subsequent 6 years, a pattern that contrasts with reports of recovery in pulmonary function among firefighters before the 9/11 attack.

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