Pulmonary Function after Exposure to the World Trade Center Collapse in the New York City Fire Department

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Rationale: On September 11, 2001, the World Trade Center collapse created an enormous urban disaster site with high levels of airborne pollutants. First responders, rescue and recovery workers, and residents have since reported respiratory symptoms and developed pulmonary function abnormalities.

Objectives: To quantify respiratory health effects of World Trade Center exposure in the New York City Fire Department.

Measurements: Longitudinal study of pulmonary function in 12,079 New York City Fire Department rescue workers employed on or before 09/11/2001. Between 01/01/1997 and 09/11/2002, 31,994 spirometries were obtained and the FEV_1 and FVC were analyzed for differences according to estimated World Trade Center exposure intensity. Adjusted average FEV_1 during the first year after 09/11/2001 was compared with the 5 yr before 09/11/2001. Median time between 09/11/2001 and a worker's first spirometry afterwards was 3 mo; 90% were assessed within 5 mo.

Main Results: World Trade Center–exposed workers experienced a substantial reduction in adjusted average FEV_1 during the year after 09/11/2001 (372 ml; 95% confidence interval, 364–381 ml; $p < 0.001$) This exposure-related FEV_1 decrement equaled 12 yr of aging-related FEV_1 decline. Moreover, exposure intensity assessed by initial arrival time at the World Trade Center site correlated linearly with FEV_1 reduction in an exposure intensity–response gradient ($p = 0.048$). Respiratory symptoms also predicted a further FEV_1 decrease ($p < 0.001$). Similar findings were observed for adjusted average FVC.

Conclusions: World Trade Center exposure produced a substantial reduction in pulmonary function in New York City Fire Department rescue workers during the first year after 09/11/2001.

Keywords: building collapse; FEV_1 decline; rescue worker; respiratory health consequences of 09/11/2001

After September 11, 2001, the dust and smoke clouds produced during and after the World Trade Center (WTC) collapse raised serious health concerns among rescue workers and residents. Throughout the rescue and recovery effort, survivors were exposed to WTC-derived airborne pollutants, including particulate matter composed of pulverized building materials and combustion products (1, 2). Almost 12,000 of the approximately 14,000 Fire Department of New York City (FDNY) workforce (approximately 11,500 fire and approximately 2,500 emergency medical

service [EMS] workers) were present at the WTC site within the first week after 09/11/2001 and reported extensive exposures. Appropriate respiratory protection was initially not readily available; later, compliance was suboptimal (3). WTC exposure has since been implicated in "WTC cough," and upper and lower airway inflammation with airway obstruction and bronchial hyperreactivity (4–12).

In a previous cross-sectional stratified random sample of 319 WTC-exposed FDNY rescue workers 3 wk after 09/11/2001, we described pulmonary function declines that correlated with WTC dust exposure intensity (3). To define better the respiratory consequences of WTC exposure, we now report our analysis of longitudinal pulmonary function course from 1997 to 2002 in the entire FDNY WTC medical screening cohort (n = 12,079). Study objectives were to determine whether pulmonary function changed after 09/11/2001, and whether WTC exposure intensity affected pulmonary function and respiratory symptoms in an exposure intensity–response pattern after 09/11/2001. Some of the results of this study have previously been reported in the form of an abstract (13).

METHODS

The FDNY Bureau of Health Services performs periodic medical evaluations on all FDNY rescue workers approximately every 18 mo. Since 1997, these evaluations have included spirometry and a respiratory questionnaire. On 10/01/2001, the FDNY Bureau of Health Services started the FDNY WTC Medical Screening Program, which included spirometry and a self-administered questionnaire detailing WTC exposure and respiratory symptoms. Compliance was 85% among incumbent FDNY rescue workers. Participation in this study required written, informed consent approved by Montefiore Medical Center's Institutional Review Board.

Total and WTC-exposed Cohort

The cohort studied consisted of all FDNY rescue workers employed on or before 09/11/2001 who had at least one spirometric measurement (FVC or FEV_1) from a testing session between 01/01/1997 and 09/11/2002 that met 1994 American Thoracic Society (ATS) guidelines (FDNY cohort, n = 12,079) (14). Within the FDNY cohort, 313 rescue workers (2.6%) reported no presence at the WTC site at all during the entire rescue, recovery, and cleanup operation from 09/11/2001 to 06/30/2002. Demographics for this nonexposed group differed significantly from those of the WTC-exposed workers. To eliminate nonlinear demographic confounders, we therefore modeled FEV_1 change from before to after 09/11/2001 both in the FDNY cohort (n = 12,079; 31,994 spirometries) and the WTC-exposed FDNY subcohort (n = 11,766; 31,203 spirometries; Figure 1).

Spirometry

Before and after 09/11/2001, spirometry (Portascreen; S&M Instruments, Doylestown, PA) was administered using ATS guidelines (14). The same spirometers were used before 09/11/2001 and during the first year after 09/11/2001. Each spirometer was calibrated daily; calibrations were considered acceptable if three volumetric measurements were within 3% of each other. Before and after 09/11/2001, spirograms were considered acceptable
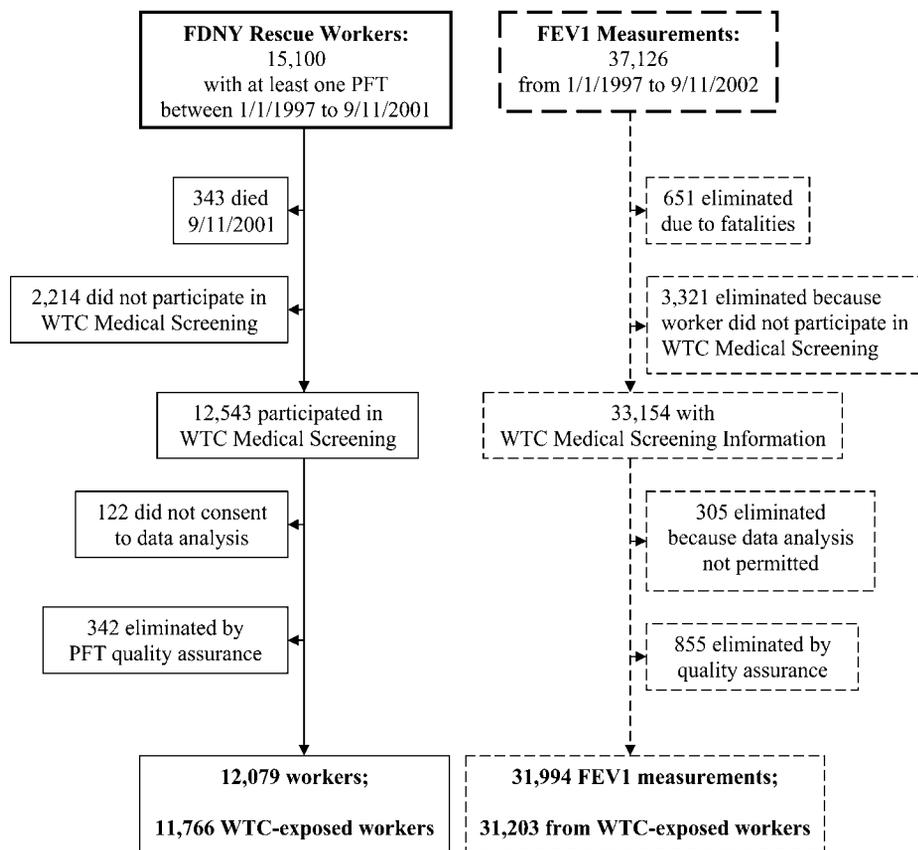
Figure 1. Study cohort derivation. FDNY = Fire Department of New York City; PFT = pulmonary function test; WTC = World Trade Center.

if they met ATS criteria (14). The largest FVC and FEV_1 from among all acceptable spirometric measurements were selected for electronic archiving. FVC and FEV_1 were expressed in absolute values (liters), as percent predicted, and classified as above or equal to versus below the lower limit of normal (NHANES III [Third National Health and Nutrition Examination Survey]) (15). For this cohort study, spirometric measurements for all FDNY rescue workers employed on or prior to 09/11/2001 who consented to data analysis were extracted from the database (Figure 1). Among WTC-exposed workers, FEV_1 measurements from at least one testing session met ATS criteria in 95% before 09/11/2001 and in 90% after 09/11/2001. Most (n = 7,653; 65% of exposed cohort) had FEV_1 measurements that met ATS criteria from at least two testing sessions before 09/11/2001, and 92% had two or more FEV_1 measurements (before or after 09/11/2001) that met ATS criteria. During additional quality assurance, paper spirogram recordings were independently reviewed (blinded to identity, WTC arrival time, work assignment, and symptoms; and regardless of whether the spirogram was obtained before or after 09/11/2001) if the values met any of the following criteria: (*1*) values < 70% or > 135% predicted, (*2*) marked variability of serial values, (*3*) change rates at the upper or lower 1.5% extreme, and (*4*) a random sample comprising 10% of the remaining database. Rejected spirometric measurements totaled 855 (2.6% of 32,849; Figure 1).

Demographics and Exposure Questionnaire

The FDNY's database includes birth date, height, race, sex, FDNY tenure, and work assignment. WTC exposure intensity was categorized either according to initial arrival time at the WTC site from the self-administered exposure questionnaire or according to work assignment on the self-reported arrival day. Self-report was preferred because FDNY records did not reflect the large-scale recall during Week 1 and the frequent self-deployment throughout the rescue and recovery effort. For the arrival time–based categorization of WTC exposure intensity, FDNY rescue workers had (*1*) early, high-intensity exposure if they arrived during the morning of 09/11/2001 (Day 1) and were present during the collapse of North or South tower; (*2*) intermediate-intensity

exposure if they arrived on Day 1 after the WTC collapse or during Day 2; (*3*) late, low-intensity exposure if they arrived on or after Day 3; and (*4*) no exposure if they reported no presence at the WTC site between 09/11/2001 and 06/30/2002. For the work assignment–based categorization of WTC exposure intensity, work assignment on the arrival day was categorized as Special Operations Command (an elite assignment responsible for the most complicated and lengthy rescue and recovery tasks) versus other non–Special Operations Command fire units versus EMS units. For assessment of respiratory protection, FDNY rescue workers were considered protected if they reported frequent use of any mask type (disposable hardware store–type dust mask, N95 mask, half-face respirator) during their arrival day, and unprotected otherwise. Nonexposed FDNY rescue workers were considered protected when they were included in the model.

Respiratory Health

The FDNY WTC Medical Screening Program self-administered questionnaire assessed tobacco use (current, ex-smoker, or never smoker) and respiratory symptoms, including "Since the disaster . . . any new/worsening . . . respiratory symptoms" ('daily cough,' 'nearly constant cough,' 'wheeze,' 'shortness of breath,' 'chest tightness,' or 'sleep disturbance caused by any of the above')." An affirmative response to any of these respiratory symptoms was categorized as symptomatic. Symptom severity analyses were based on a nonweighted summation score providing one point per symptom.

Statistical Analysis

Data analysis was performed using SPSS version 12.0 (SPSS, Inc., Chicago, IL).

Cross-sectional analyses. The authors compared age, FDNY tenure (one-way analysis of variance [ANOVA], independent samples *t* test), white race, and sex (χ^2) (*1*) between workers who did and those who did not participate in the WTC Medical Screening Program, (*2*) among arrival time–based WTC exposure groups, and (*3*) between EMS workers and firefighters. Height (one-way ANOVA, independent samples

t test), ever smoking, work assignment on 09/11/2001, symptom presence (χ^2), and symptom severity (Kruskal-Wallis H, Mann-Whitney U) were compared among arrival time–based WTC exposure groups and between EMS workers and firefighters. Spirometric means and time difference between last spirometric measurement before and first spirometric measurement after 09/11/2001 were compared between arrival time–based exposure groups (one-way ANOVA); the proportion of workers with measurements below the lower limit of normal, mask use frequency, and proportions of workers with respiratory symptoms was compared among arrival time–based exposure groups (χ^2).

Longitudinal analyses. Within arrival time–based exposure groups, changes in spirometric means from the last measurement before to the first measurement after 09/11/2001 were compared (paired *t* test).

The preferred statistical approach to longitudinal spirometric analysis is mixed linear random-effects modeling (16, 17), because subjects can have unequal numbers of observations at differing times and effect estimates are modified for the correlation between repeated measures in the same subject (18). Other recent epidemiologic pulmonary investigations have also relied on this method (19, 20). We analyzed difference in average spirometric measurements (FVC or FEV_1) from the 5 yr before 09/11/2001 to the first year after 09/11/2001, and whether WTC exposure intensity influenced spirometric changes in an exposure intensity–response gradient during the first year after 09/11/2001 using mixed linear random-effects modeling.

Separate models were run for FEV_1 and FVC as dependent variables. Subjects contributed from one to seven observations to the analysis. The primary predictors of interest were the contrast between average FEV_1 or FVC in the 5 yr before 9/11/2001 and in the first year after 09/11/2001 (modeled with indicator variables), and the interaction with WTC exposure intensity. WTC exposure intensity was measured in two ways: initial arrival time at the WTC site (three categories), and job assignment on the arrival day (two categories). The authors modeled initial WTC arrival time both as a nominal predictor variable and as an ordinal predictor variable (to test for linear trend) in separate models. Additional predictors were included as possible confounders: sex, race, height, smoking status, and age as of 9/11/2001. All these predictors were included in the models as fixed effects. A random intercept was used to take into account the heterogeneity across subjects and the correlation induced by having repeated observations on the same subjects. To explore associations between respiratory symptoms at the time of the FDNY WTC Medical Screening Program and spirometric measurements, additional interactions between average pulmonary function and respiratory symptoms were included in some models.

RESULTS

Demographics

Cohort derivation is shown in Figure 1, and key demographics are shown in Table 1. Between 10/1/2001 and 09/11/2002, 12,543 FDNY rescue workers participated in the FDNY WTC Medical Screening Program (85% compliance); 12,063 were incumbent and 480 were retired FDNY rescue worker volunteers. The final analysis included 12,079 FDNY rescue workers (83% of those eligible for the FDNY WTC Medical Screening Program). The 17% of workers who did not participate in the screening examination were significantly older, and more often nonwhite, female, and with EMS assignment and longer FDNY tenure. Although only 19% of all FDNY rescue workers were EMS, 89% of nonexposed and 33% of late-exposure groups had EMS assignments (Table 1).

The nonexposed group was small and differed markedly from WTC-exposed groups in several demographic characteristics (Table 1). Thus, it was not optimally suited for reliable comparisons with the remaining majority of FDNY rescue workers who had experienced WTC exposure. To base comparisons on the most representative group within the FDNY cohort, we used the late-arrival, low-exposure group as the principal comparison and referent group because of larger size (n = 1,921; 15.9% of FDNY cohort) and because demographics did not differ as markedly from more exposed groups. This choice of referent provided a more conservative estimate of WTC exposure effects, because a group who already had experienced WTC exposure itself (albeit low-intensity exposure) served as the comparison group.

Spirometry in WTC-exposed FDNY Workers

An FEV_1 of less than 60% predicted was found in 45 WTC-exposed FDNY rescue workers (0.4% of exposed cohort) on at least one occasion during the 5 yr of occupational monitoring before 09/11/2001, and in 93 WTC-exposed FDNY rescue workers (0.8% of exposed cohort) in the first year after 09/11/2001. The median time between 09/11/2001 and a worker's first spirometry afterwards was 3 mo, and 90% of the cohort was assessed during the first 5 mo after 09/11/2001.

When adjusted average FEV_1 during the 5 yr before 09/11/2001 was compared with adjusted average FEV_1 during the first year after 09/11/2001 in WTC-exposed workers, a substantial loss of 372 ml was observed after 09/11/2001 (95% confidence interval [CI], 364–381 ml; p < 0.001). The decrement in adjusted average FEV_1 after 09/11/2001 was equal in magnitude to 12 yr of aging-related FEV_1 decline in this cohort (longitudinally computed aging-related FEV_1 decline rate before 09/11/2001 was 31 ml/yr). Similar results were obtained when the nonexposed

TABLE 1. DEMOGRAPHIC CHARACTERISTICS OF FDNY COHORT BY ARRIVAL TIME–BASED WORLD TRADE CENTER EXPOSURE

Characteristic	Early Exposure	Intermediate Exposure	Late Exposure	Nonexposed	Total
Demographics					
Number (% of FDNY cohort)	1,660 (13.7)	8,185 (67.8)	1,921 (15.9)	313 (2.6)	12,079 (100)
Age on 09/11/01, yr	40 ± 7.6	39.7 ± 7.5	40.2 ± 8.3*	40.7 ± 9†	39.7 ± 7.7
Height, cm	179.3 ± 7.6	179.6 ± 7.4	178.3 ± 8.4*	174 ± 9.1‡	178.3 ± 7.6
Sex, % male	96.7	97.1	91.9*	71.2‡	95.6
Race, % white	86.2	88.3	78.2*	55.3‡	85.6
Ever smokers, %	28.9	27.5	33.4*	39.9‡	29
Work assignment on 09/11/01, % EMS	18.1	13.8	33*	88.8‡	19.4
FDNY tenure on 09/11/01, yr	11.2 ± 7.9	11.1 ± 7.9	10.4 ± 8.3*	6.4 ± 5.3‡	10.9 ± 8.3

Definition of abbreviations: EMS = emergency medical service; FDNY = Fire Department of New York City; WTC = World Trade Center.

* p < 0.05 among early-, intermediate-, and late-exposure groups (analysis of variance for age, height, and FDNY tenure; χ^2 for sex, race, and ever smoking).

† p = 0.006 among early-, intermediate-, late-, and nonexposed groups (analysis of variance).

‡ p < 0.001 among early-, intermediate-, late-, and nonexposed groups (analysis of variance for height and FDNY tenure; χ^2 for sex, race, and ever smoking).

FDNY workers were included in the analyses, and when FVC served as outcome variable (*see* the online supplement for a complete presentation of analyses with FVC as outcome variable).

FEV$_1$ Reduction and WTC Arrival Time

Within arrival time–based exposure groups, means of the first FEV$_1$ measurement after 09/11/2001 (in liters and percent predicted) were significantly lower than those of the last measurement before 09/11/2001 ($p < 0.001$; Table 2, Figure 2). The percentage of FDNY rescue workers with FEV$_1$ measurements below the lower limit of normal increased by at least twofold within each exposure group from before to after 09/11/2001 ($p < 0.001$; Table 2).

To explore whether WTC exposure intensity affected adjusted average FEV$_1$ after 09/11/2001, we included an estimate of WTC exposure intensity based on initial arrival time at the WTC site in comparisons of adjusted average FEV$_1$ during the 5 yr before 09/11/2001 to adjusted average FEV$_1$ during the first year after 09/11/2001. We observed substantial FEV$_1$ reductions after 09/11/2001, with a significant exposure intensity–response gradient between FDNY rescue workers with increasing arrival time–based WTC exposure intensities (Figure 3A). Early-arrival, high-intensity exposure workers experienced an average reduction of 388 ml (95% CI, 370–406 ml). Intermediate-intensity exposure workers experienced an average reduction of 372 ml (95% CI, 363–381 ml). Workers with late-arrival, low-intensity exposure experienced an average decrement of 357 ml (95% CI, 339–374 ml). This linear trend in exposure intensity–response was statistically significant ($p = 0.048$, likelihood ratio test). Similar effects of arrival time on average adjusted spirometric measurements after 09/11/2001 were also observed when the nonexposed FDNY workers were included in the analyses and when FVC served as outcome variable (although not statistically significant).

FEV$_1$ Reduction and Work Assignment

To substantiate further that WTC exposure resulted in adjusted average spirometric decrements after 09/11/2001, we included another estimate of WTC exposure intensity based on work assignment in other comparisons of adjusted average FEV$_1$ during the 5 yr before 09/11/2001 to adjusted average FEV$_1$ during the first year after 09/11/2001. We again observed substantial FEV$_1$ reductions after 09/11/2001, with significant differences according to work assignment (Figure 3B; $p < 0.001$). Firefighters had an average adjusted decrement of 383 ml (95% CI, 374–393 ml), significantly larger compared with EMS workers, who experienced an average reduction of 319 ml (95% CI, 299–340 ml). We did not find significant differences between firefighters who were and who were not assigned to Special Operations Command units. Significantly lower average adjusted spirometric measurements after 09/11/2001 for fire compared with EMS workers were also found when the nonexposed workers were included in the analyses and when FVC served as outcome variable.

Respiratory Protection

Frequent use of respiratory protection was uncommon in the first days after the collapse and became more common as time progressed, with only 22% of workers who arrived early reporting frequent mask use on their arrival day, whereas 32% of workers with intermediate arrival and 50% of workers with late arrival times reported frequent mask use on arrival ($p < 0.001$). Our analyses did not identify a protective effect of mask use frequency on adjusted average FEV$_1$ or FVC after 09/11/2001.

Respiratory Symptoms

Early- and intermediate-arrival time–based WTC exposure groups had significantly more frequent and significantly more severe (i.e., greater number) respiratory symptoms than the late group ($p < 0.001$ for both; Table 3, Figure 4A). Symptoms were also more prevalent and severe in fire compared with EMS workers ($p < 0.001$ for both; Figure 4B). We compared adjusted average FEV$_1$ reduction among FDNY rescue workers with increasing symptom severity to determine whether objective spirometric measurements correlated with clinical complaints. Each added symptom was associated with a significant additional adjusted average FEV$_1$ decrease (26 ml for each symptom, 95% CI, 20–32 ml; $p < 0.001$). In further analyses, presence of any symptom was associated with an additional 48 ml adjusted average FEV$_1$ decrement after 09/11/2001 (95% CI, 30–67 ml; $p < 0.001$).

TABLE 2. FEV$_1$ CHARACTERISTICS OF WORLD TRADE CENTER–EXPOSED FDNY RESCUE WORKERS BY ARRIVAL TIME–BASED WORLD TRADE CENTER EXPOSURE

Arrival Time–based WTC Exposure	Last FEV$_1$ before 09/11/2001 (Median, Interquartile Range, and Percent)			First FEV$_1$ after 09/11/2001 (Median, Interquartile Range, and Percent)		
	Liters	Percent Predicted	Percent Below Lower Limit of Normal	Liters	Percent Predicted	Percent Below Lower Limit of Normal
Early exposure (n = 1,660)	4.21 (3.64–4.73)	101 (92–111)	7.7	3.85[†] (3.34–4.36)	93[†] (84–102)	19.2[†]
Intermediate exposure (n = 8,185)	4.32 (3.83–4.83)	101 (92–111)	6.4	3.96[†] (3.52–4.42)	93[†] (85–102)	16.3[†]
Late exposure (n = 1,921)	4.27 (3.78–4.76)	100 (91–110)	7.8*	3.87[†‡] (3.42–4.32)	92[†‡] (83–102)	17.8*[†]
Total	4.30 (3.80–4.80)	101 (92–111)	6.8	3.93 (3.47–4.40)	93 (85–102)	15.3

Definition of abbreviations: FDNY = Fire Department of New York City; WTC = World Trade Center.

Mean (± SD) time interval between last measurement before and first measurement after 09/11/2001 was 2.13 ± 0.83 yr and did not differ significantly among exposure groups.

* $p < 0.001$ among early-, intermediate-, and late-exposure groups (analysis of variance for FEV$_1$ in liters or percent predicted; χ^2 for percentage below lower limit of normal).

[†] $p < 0.001$ between last measurement before and first measurement after 09/11/2001 within exposure group (paired *t* test for FEV$_1$ in liters or percent predicted; McNemar's test for percentage below lower limit of normal).

[‡] $p < 0.05$ among early-, intermediate-, and late-exposure groups (analysis of variance for FEV$_1$ in liters or percent predicted; χ^2 for percentage below lower limit of normal).
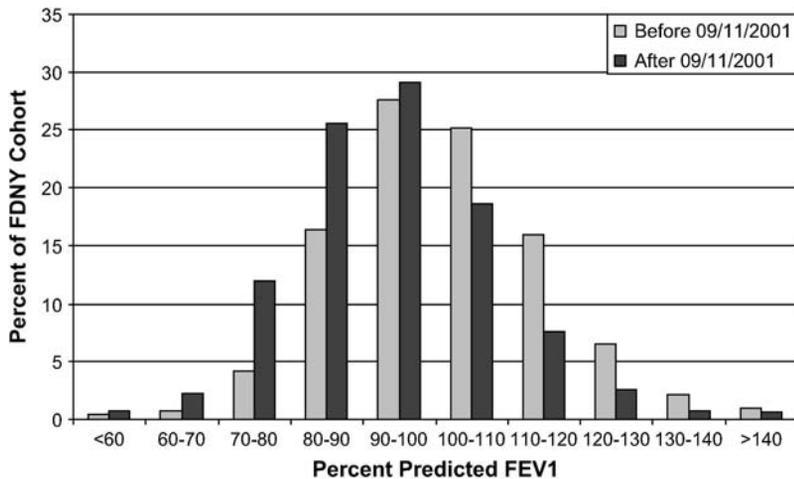
Figure 2. FEV$_1$ distribution in FDNY cohort before and after 09/11/2001. There was a leftward shift in the distribution of percent-predicted FEV$_1$ (grouped by decile) for the FDNY cohort.

DISCUSSION

The WTC collapse created a disaster site with WTC-derived pollutants that were highest during the collapse and then gradually dissipated (1, 2). Adequate respiratory protection was not immediately available (3), and many rescue workers and resi-

dents have respiratory symptoms and physiologic airway abnormalities (4–12). This study demonstrates substantial reductions in average adjusted FEV$_1$ and FVC in FDNY rescue workers during the year after 09/11/2001. In addition, WTC exposure intensity, assessed by arrival time or work assignment, predicted further pulmonary function loss and respiratory symptoms. WTC
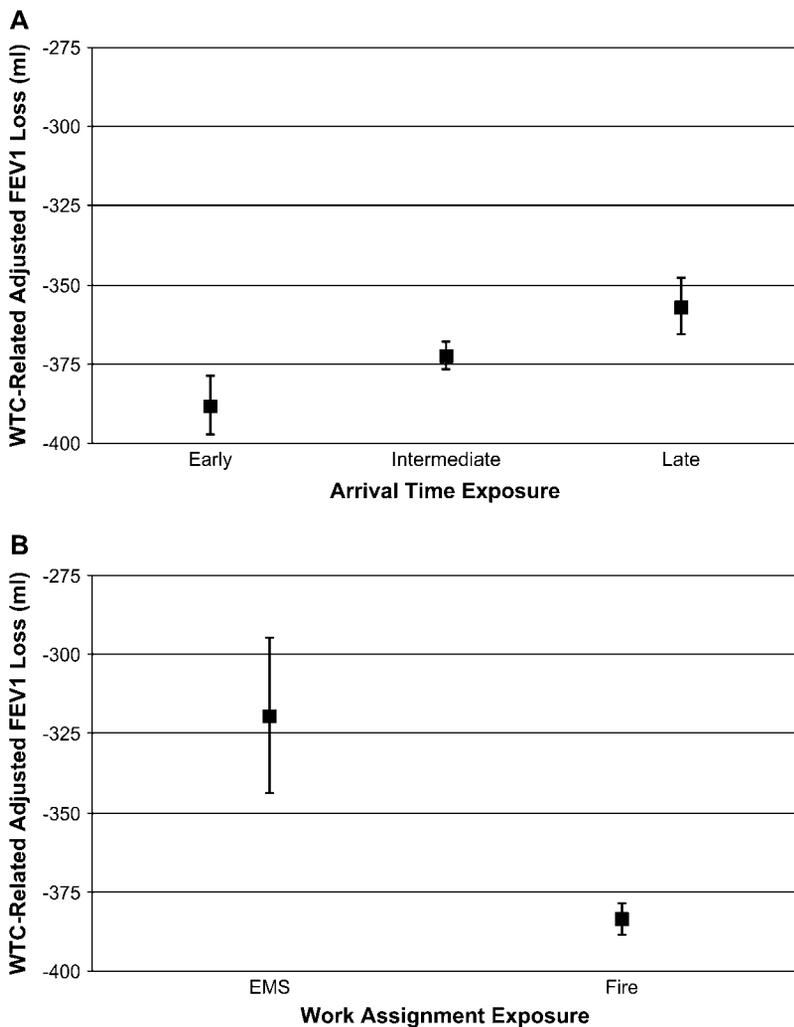

Figure 3. (*A*) WTC-related average adjusted FEV$_1$ losses during the year after 09/11/2001 by arrival time exposure category. WTC-related adjusted average FEV$_1$ losses with standard errors are depicted. We observed substantial FEV$_1$ reductions after 09/11/2001, with a significant exposure intensity–response gradient between FDNY rescue workers with increasing arrival time–based WTC exposure intensities. Early-arrival, high-intensity exposure workers experienced an average reduction of 388 ml (95% confidence interval [CI], 370–406 ml). Intermediate-intensity exposure workers experienced an average reduction of 372 ml (95% CI, 363–381 ml). Workers with late-arrival, low-intensity exposure experienced an average decrement of 357 ml (95% CI, 339–374 ml). This linear trend in exposure intensity–response was statistically significant (p = 0.048). Average FEV$_1$ losses are adjusted for sex, race, height, age, and smoking status. (*B*) WTC-related average adjusted FEV$_1$ losses during the year after 09/11/2001 by work assignment exposure category. WTC-related adjusted average FEV$_1$ losses with standard errors are depicted. We observed substantial FEV$_1$ reductions after 09/11/2001, with significant differences according to work assignment. Firefighters had an average adjusted decrement of 383 ml (95% CI, 374–393 ml), significantly larger compared with emergency medical service (EMS) workers, who experienced an average reduction of 319 ml (95% CI, 299–340 ml). We did not find significant differences between firefighters who were and who were not assigned to Special Operations Command units. Average FEV$_1$ losses are adjusted for sex, race, height, age, and smoking status.

TABLE 3. RESPIRATORY SYMPTOMS OF WORLD TRADE CENTER–EXPOSED FDNY RESCUE
WORKERS BY ARRIVAL TIME–BASED WORLD TRADE CENTER EXPOSURE

Respiratory Symptom	Early Exposure, % (n = 1,660)	Intermediate Exposure, % (n = 8,185)	Late Exposure, % (n = 1,921)	Total (%)
Cough	63.3	51.1	31.6*	49.7
Wheeze	32.9	24.9	14*	24.2
Chest pain or tightness	33.6	20.4	9.6*	20.5
Exertional dyspnea	55.9	43%	23.3*	41.6
Any lower respiratory symptom	76.5	64.1	40.5*	62

For definition of abbreviations, *see* Table 2.
 * $p < 0.001$ among early-, intermediate-, and late-exposure groups (χ^2).

exposure had clinically and statistically significant effects on pulmonary function after 09/11/2001; we observed a reduction in average adjusted FEV_1 that was equal in magnitude to 12 yr of aging-related FEV_1 decline in this cohort. The validity of these findings is strongly supported by large cohort size (n = 12,079) and availability of almost 5 yr of preexposure spirometries.

The WTC plume was most intense on Day 1 and then dissipated, with marked reduction after it rained on 09/14/2001 (1, 2). This environmental measure of airborne WTC pollutant intensity corresponds well with the arrival time–based linear exposure intensity–response gradient observed. More than 400 chemicals have been identified in WTC-derived airborne pollution

(1, 2). Induced sputum from FDNY firefighters and cellular and animal models all demonstrate inflammation (21–23). Resulting clinical (cough, wheeze, dyspnea, chest tightness, gastroesophageal reflux) and physiologic (low FEV_1 and FVC, bronchodilator response, nonspecific hyperreactivity) correlates have been reported in smaller occupational (3, 5–9, 11, 12) and community-based cohorts (4, 10, 24) during the first year after 09/11/2001.

In contrast to our current study, prior WTC-related reports (3–12) have been limited by (*1*) cross-sectional design, (*2*) small sample sizes, or (*3*) lack of objective lung function documentation before the WTC exposure. Our study analyzed spirometric measurements for 83% of all FDNY rescue workers and included
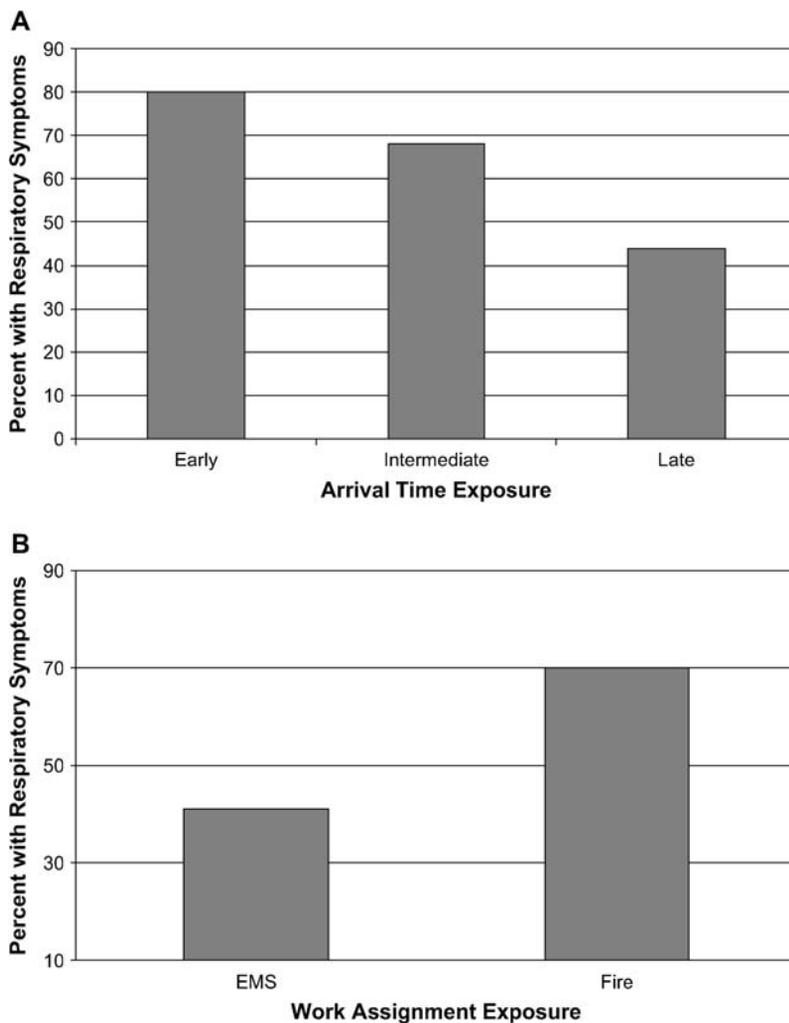

Figure 4. (*A*) Respiratory symptoms during the year after 09/11/2001 by arrival time exposure category. Rescue workers with early or intermediate exposure had significantly more respiratory symptoms compared with workers with late exposure ($p < 0.001$). (*B*) Respiratory symptoms during the year after 09/11/2001 by work assignment exposure category. Firefighters had significantly more respiratory symptoms compared with EMS workers ($p < 0.001$).

all measurements in a 6-yr longitudinal design. The 17% of workers who did not contribute spirometric measurements were significantly older, and more often nonwhite and female with longer FDNY tenure and EMS assignment. We observed a sizable spirometric loss of 372 ml when adjusted average FEV_1 during the first year after 09/11/2001 was compared with the same measure during the preceding 5 yr. Although there is evidence for abnormal spirometry (25, 26), airway inflammation (27), or hyperreactivity (28, 29) in case series and smaller cohorts after irritant exposures, there are only occasional reports that describe changes in such parameters from before to after an exposure for more than a few persons (30–32). The largest relevant non-WTC study reported FEV_1 decrements as large as 130 ml during a fire season in 52 wildland firefighters (32). In a prior stratified sample of 319 WTC-exposed FDNY firefighters, we reported a mean FEV_1 reduction of 264 ml from the last measurement before to the first measurement after 09/11/2001 (3).

In addition to the substantial loss of average adjusted FEV_1 for all WTC-exposed FDNY rescue workers, further WTC exposure intensity–related (arrival time– or work assignment–based) average adjusted FEV_1 decrements were also evident. The earlier a worker arrived at the WTC site, the greater the spirometric reduction. Although the arrival time–based exposure intensity–response gradient in our cohort was statistically significant, it was rather small. Several factors likely reduced this gradient's magnitude. Most important, the amount of WTC exposure in the late-arrival group was heterogeneous, because this group included any worker who arrived after the first 48 h. Because most FDNY rescue workers arrived within the first 48 h, and because later arrival times were more prone to recall bias, we did not further partition the arrival time–based exposure categorization. Second, there was no adjustment for cumulative exposure because official work records are incomplete, and cumulative work hours are more difficult to remember than initial arrival time. Third, even with identical arrival and cumulative work times, large individual differences in airway deposition may have existed because of physiologic variations in minute ventilation, body habitus–related differences in airway branching angles (33), and spatial and temporal heterogeneity of airborne substance concentrations (34).

Work assignment–based WTC exposure intensity was an alternative predictor of additional spirometric loss, with firefighters experiencing larger decrements than EMS workers. This was likely caused by higher intensity WTC exposure associated with fire suppression or rescue activities as opposed to emergency medical tasks. In contrast to the pronounced influence of arrival time and work assignment, respiratory protective equipment had no appreciable effect on spirometric reductions after 09/11/2001. Initial lack of adequate equipment and subsequent compliance problems (3) diminished any protective impact.

In the current study, we describe spirometric reductions in the FDNY cohort during the subacute period after 09/11/2001, with a median time of 3 mo between 09/11/2001 and a worker's first spirometry afterward, and with 90% of the cohort assessed during the first 5 mo after 09/11/2001. Potential pathogenetic mechanisms for these subacute spirometric decrements include airway inflammation and remodeling (6–8, 19, 35, 36). Our findings that hyperreactivity persisted 2 yr after 09/11/2001 in a smaller FDNY rescue worker cohort may be a sign of persistent inflammation or early remodeling (37). The current investigation does not address how long-term spirometric changes will evolve in the entire WTC-exposed FDNY cohort. Prior longitudinal investigations have shown nonlinear patterns, with slowing of spirometric decrease after cessation of inhaled irritant exposure (38) and during antiinflammatory treatment (39). Long-term spirometric patterns for the FDNY cohort will undoubtedly be influenced by genetics, new inhaled irritant exposures, and treatment.

In summary, we demonstrated significant, clinically important, detrimental effects of WTC exposure on respiratory health during the first year after 09/11/2001 in WTC-exposed FDNY rescue workers. The FDNY cohort experienced the most intense WTC exposure and is the only group with preexposure spirometry available for systematic comparison. Findings should be extrapolated with caution to other, less exposed populations, but because even our least exposed group showed spirometric reductions after 09/11/2001, continued medical monitoring is prudent for all exposed populations. In addition to future spirometric surveillance, screening for physiologic or biochemical conditions associated with accelerated spirometric decline (40–42) may help to identify subgroups with greater likelihood for airway disease development or progression in this high-risk setting.

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