Symptoms, Respirator Use, and Pulmonary Function Changes Among New York City Firefighters Responding to the World Trade Center Disaster*

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Context: **New York City firefighters responding to the World Trade Center (WTC) disaster on September 11, 2001, were exposed to numerous hazards. A medical screening program was conducted 3 weeks after the disaster on a sample of firefighters.**
Objectives: **To determine whether arrival time at the WTC and other exposure variables (including respirator use) were associated with symptoms and changes in pulmonary function (after exposure − before exposure).**
Design: **A cross-sectional comparison of firefighters representing the following groups: (1) firefighters who arrived before/during the WTC collapse, (2) firefighters who arrived 1 to 2 days after the collapse, (3) firefighters who arrived 3 to 7 days after the collapse, and (4) unexposed firefighters.**
Setting: **Fire Department of New York City (FDNY) Bureau of Health Services on October 1 to 5, 2001.**
Population: **A stratified random sample of 362 of 398 recruited working firefighters (91%). Of these, 149 firefighters (41%) were present at the WTC collapse, 142 firefighters (39%) arrived after the collapse but within 48 h, 28 firefighters (8%) arrived 3 to 7 days after the collapse, and 43 firefighters (12%) were unexposed.**
Main outcome measures: **New/worsening symptoms involving the eyes, skin, respiratory system, and nose and throat (NT), and changes in spirometry from before to after exposure.**
Results: **During the first 2 weeks at the WTC site, 19% of study firefighters reported not using a respirator; 50% reported using a respirator but only rarely. Prevalence ratios (PRs) for skin, eye, respiratory, and NT symptoms showed a dose-response pattern between exposure groups based on time of arrival at the WTC site, with PRs between 2.6 and 11.4 with 95% confidence intervals (CIs) excluding 1.0 for all but skin symptoms. For those spending > 7 days at the site, the PR for respiratory symptoms was 1.32 (95% CI, 1.13 to 1.55), compared with those who were exposed for < 7 days. Mean spirometry results before and after exposure were within normal limits. The change in spirometry findings (after exposure − before exposure) showed near-equal reductions for FVC and FEV_1. These reductions were greater than the annual reductions measured in a referent population of incumbent FDNY firefighters prior to September 11 ($p \leq 0.05$). There was a 60% increased risk of a decline of ≥ 450 mL in FEV_1 in those arriving during the first 48 h compared to the referent ($p \leq 0.05$).**
Conclusions: **The symptoms and pulmonary function changes following exposure at the WTC demonstrate the need for improvements in respirators and their use, as well as long-term medical monitoring of rescue workers.** ***(CHEST 2004; 125:1256–1264)***

Key words: disaster; firefighters; occupational exposure; pulmonary function; World Trade Center

Abbreviations: ATS = American Thoracic Society; BHS = Bureau of Health Services; CI = confidence interval; EPA = Environmental Protection Agency; FDNY = Fire Department of New York City; NIOSH = National Institute for Occupational Safety and Health; NT = nose and throat; PR = prevalence ratio; SCBA = self-contained breathing apparatus; SOC = special operations command; WTC = World Trade Center

The terrorist events of September 11, 2001, created a health and safety challenge for thousands of firefighters from the Fire Department of New York City (FDNY) and other rescue workers responding to the World Trade Center (WTC) disaster. In the immediate aftermath of the attack, 343

FDNY firefighters and 60 police officers were fatally injured. Immediate hazards for survivors included explosions, fire, falling debris, and the "WTC dust cloud" containing particulate matter composed of pulverized building materials. Ongoing risks throughout the rescue and recovery period included lingering airborne particulate matter and combustion products from initial and persistent fires beneath the rubble pile.[1,2]

In order to better define the potential health effects of exposures to firefighters responding to the WTC disaster, a collaborative effort between the FDNY Bureau of Health Services (BHS) and the National Institute for Occupational Safety and Health (NIOSH) was organized to evaluate health symptoms, pulmonary function, and use of personal protective equipment. Initial study objectives were to determine whether arrival time, days worked, work activities, and respiratory protection used during the first 2 weeks after the WTC disaster were associated with irritant-related physical symptoms (skin, eye, nose and throat [NT], respiratory), and changes in respiratory function (comparison of spirometry findings before and after exposure). Biomonitoring results have already been reported.[3]

Prezant and coworkers[4] reported the occurrence of "WTC cough" in 332 FDNY firefighters in the first 6 months after the September 11 attack, using a case definition of a new/worsening persistent cough after WTC exposure, accompanied by respiratory symptoms severe enough to require at least 4 consecutive weeks of medical leave. This study provides additional information on symptoms and changes in pulmonary function approximately 3 weeks following the collapse in a random sample of all firefighters (not on medical leave) who were working at the WTC site.

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Supported by grants from CDC U1Q/CCU221158 and NIOSH RO1-OH07350.
Manuscript received July 29, 2003; revision accepted October 30, 2003.
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Materials and Methods

Study Design

The study was conducted from October 1 to 5 at FDNY-BHS and included a self-administered questionnaire, medical evaluation by FDNY-BHS staff, chest radiography, spirometry, and blood/urine collection for biomonitoring assays (previously reported[3]). The questionnaire was self-administered on touch-screen computers with trained personnel available to answer participant questions. The questionnaire addressed arrival time, number of days working at the WTC site, specific work activities at the WTC site, use of personal protective equipment including respirators, and current health-related symptoms. The questionnaire asked whether firefighters were present at the WTC site, as well as which job tasks they engaged in during each day of the first week and the entire second week. Activity categories were as follows: fire suppression, rescue/recovery, digging, direct supervision, and welding. There was no limit to the number of categories chosen by each firefighter for each of the time periods. During all time periods, most firefighters indicated they were involved in multiple activities at the WTC (*eg*, 100% reported engagement in rescue/recovery, but 30% were also engaged in welding at the WTC). From the questionnaire data, we also calculated the total numbers of days working at the WTC during the first 2 weeks. The FDNY-BHS required that the firefighters undergo a medical evaluation. However, participation in this study required written informed consent approved by the Montefiore Medical Center Research Review Board.

The study design was a cross-sectional stratified random sample of the nearly 11,000 FDNY firefighters who responded to the WTC during the first week. From FDNY response records, FDNY-BHS selected a random sample of FDNY units to represent three exposure groups based on arrival time at the WTC: those who arrived the morning of day 1 (September 11, 2001) and were present during the collapse, those arriving in the first 48 h but after the collapse, and those arriving days 3 to 7 after the collapse. A comparison group was also chosen of firefighters who, due to prior injuries/illnesses (other than respiratory), were assigned office duties and did not work in rescue, recovery, or fire-suppression activities at the WTC site. Arrival time was characterized using both FDNY dispatch records and questionnaire data. The latter was the final determinant of arrival time because it was impossible for official records to reflect self-deployment and/or respondents to the citywide recall (radio/television announcements calling for assistance).

Work Activities, Number of Exposure Days, and Other Assignments

The FDNY personnel database provided age, race, gender, seniority (work years), and type of unit assignment. For our purposes, unit assignments are in two groups: regular firefighter units (ladder or engine), or special operations command (SOC) units (rescue, squad, and marine). Although all firefighters are exposed to fires, SOC firefighters more often respond to serious fires. As a result, SOC firefighter job tasks put them at risk for greater exposure to combustion products both before and during the WTC rescue/recovery effort.

Respirator Use

Firefighters were asked to recall respirator use for each of the five following time periods: during the collapse, day 1 after the collapse, day 2, days 3 to 7, and week 2. The number of firefighters present each day was calculated and used to generate

rates of respirator use for each time period by respirator type. We evaluated use of the following respirator types: (1) full face mask self-contained breathing apparatus (SCBA), (2) N95 filtering face mask, (3) half-face elastomeric respirator with combination P-100 and organic vapor/acid gas cartridges, and (4) hardware store-type disposable dust/paint masks that may or may not have been a NIOSH-certified respirator and were not fit tested or fit checked. Although the half-face elastomeric respirators were recommended by NIOSH, FDNY-BHS, and other agencies for WTC rescue/recovery personnel, they were not routinely available for at least the first 48 h.

Based on participant responses to the questionnaire, a summary score for the level of respiratory protection for each firefighter over the course of the first 2 weeks was created. In addition to indicating if they used a respirator, firefighters were asked if they wore that respirator "mostly" or "rarely" during work time. For each of the five time periods, a firefighter was given a score of 0 if he was present and wore no respirator, a score of 1 if he wore a respirator rarely, a score of 2 if he wore it mostly, and a score of 3 if he was not present at the site. A mean score was then calculated for overall respirator use.

Sign/Symptom Reporting

This study concentrated on skin, eye, NT, and respiratory symptoms. Firefighters were asked, "Since the disaster, have you had any new/worsening of the following symptoms" for each organ system. Table 1 shows sign/symptom list. An affirmative response to one or more symptom within an organ system was categorized as symptomatic.

Pulmonary Studies (Spirometry and Chest Radiograph)

Each participant was offered pulmonary function testing (Model Portascreen; S&M Instruments; Doylestown, PA) as part of FDNY-BHS WTC medical monitoring using American Thoracic Society (ATS) guidelines.[5] FVC and FEV_1 were expressed as absolute values and percentage of predicted.[6] Post-WTC exposure spirometry results were compared with spirometry results obtained during the most recent FDNY-BHS pre-WTC exposure annual medical examination (within 1 to 3 years). All spirograms were assessed for ATS quality guidelines independently by two board-certified pulmonologists who were blinded to the exposure groups. Disagreements (n = 16) were resolved by conference; for 3 disagreements, the postexposure FVC was rejected, and in 13 disagreements there were expiratory flow abnormalities that could have been due to effort or upper airway disease. Not wanting to eliminate possible exposure dependent results, we did not reject these data. We did, however, compare the mean values for FEV_1 and FVC by exposure group with and without these 13 observations and found no effect. When post-WTC exposure values failed to meet ATS guidelines, no values for post-WTC exposure FVC or FEV_1 were entered into the database (9 of 358 cases [3%]). When pre-WTC exposure spirometry results failed to meet ATS guidelines, the next most recent pre-WTC exposure spirometry finding meeting ATS guidelines was chosen (32 of 323 cases [10%]).

A referent group of firefighters was selected to compare the change in spirometry following exposure at the WTC with the annual change in spirometry before September 11. The referent group consisted of 735 randomly selected FDNY firefighters chosen to match the age distribution of FDNY active firefighters who underwent two annual spirographic evaluations prior to September 11. The random selection was from incumbent firefighters who were not in our study population. The procedures and equipment used for spirometric testing were the same for all groups. To account for different time intervals between spirometry readings, those subjects with an interval of > 1 year between tests had an adjustment factor applied by multiplying their change by 365 divided by the number of days between the tests. Chest radiographs (posteroanterior view) were obtained for all subjects, and compared to their most recent pre-WTC exposure radiographs.

Table 1—*Prevalence of New/Worsening Signs/Symptoms in 319 WTC-Exposed FDNY Firefighters, October 1–5, 2001*

Signs/Symptoms	%
Eye	
Any symptom	69
Irritation	65
Worsening vision	17
Blurry vision	10
Corneal abrasion	4
Skin	
Any symptom	41
Irritation	30
Burns	17
Rash	14
Cuts/abrasions	3
Nose/throat	
Any symptom	78
Sore throat	54
Congestion	40
Hoarseness	34
Nasal drip	27
Difficulty swallowing	22
Respiratory	
Any symptom	73
Daily cough	53
Short of breath	29
Chest pain	24
Disturbed sleep	24
Wheeze	21

WTC Cough

Firefighters in our study population in whom WTC cough was subsequently diagnosed were identified. The prevalence of WTC cough was calculated for each arrival group and then compared to the prevalence in the entire FDNY firefighter population.

Statistical Methods

To evaluate the relationship between dichotomous outcomes and categorical variables, contingency tables were constructed, and prevalence ratios (PRs) with their associated 95% confidence intervals (CIs) were calculated. For continuous variables, the Student *t* test was used. For respiratory and NT symptoms, multivariable methods were used to generate adjusted PRs and 95% CIs after controlling for the potential confounders of tobacco use and age. When comparing the exposed to the unexposed firefighters, models included the three arrival groups with the unexposed as the referent group. Additional multivariable modeling was completed on the exposed firefighters to evaluate other exposure measures, including number of days working at the WTC, level of respiratory protection, welding, and SOC assignment. The modeling strategy included the three arrival groups using the day 3 to 7 group as the referent, and age and current tobacco use as potential confounders. The nonparametric Wilcoxon two-sample test was used to determine whether the pulmonary function measures differed between firefighters

who reported respiratory symptoms and those who did not; $p \leq 0.05$ was considered statistically significant. The data were analyzed using SAS software (version 8.2; SAS Institute; Cary, NC).

Results

Demographics

Our participants were 100% male and 91% white, consistent with FDNY demographics. Mean age and work years were not significantly different between the exposed groups. However, mean age and work years for the unexposed group were slightly higher. Overall, mean years worked was 15 years (range, <1 to 38 years), and mean age was 42 years (range, 24 to 60 years). The rate of current tobacco use was 11% in all exposure groups.

Three hundred sixty-two of 398 firefighters (91% of those recruited) participated in the screening program. One hundred forty-nine firefighters (41%) were present at the collapse of either WTC tower, 142 firefighters (39%) arrived within the first 48 h but after the towers collapsed, 28 firefighters (8%) arrived between days 3 to 7, and 43 firefighters (12%) were in the unexposed comparison group. Data from the entire firefighter population, which the FDNY collected using the same questionnaire, show the actual distribution of these groups in the target population: 1,636 firefighters (16%) were present at the collapse, 6,958 firefighters (69%) arrived during the first 48 h but after the collapse, 1,320 firefighters (13%) arrived 3 to 7 days after the collapse, and 202 firefighters (2%) were unexposed.

Respirator Use

Figure 1 shows respirator use during five time periods: during the collapse, day 1 after the collapse, day 2, days 3 to 7, and week 2. Among the 319 firefighters exposed at the WTC, 149 firefighters reported being present during the collapse, and an additional 118 firefighters arrived later that day after the collapse; 223 firefighters were present on day 2; 284 firefighters were present at least 1 day during days 3 to 7; and 231 firefighters were present during week 2. Of those present during the WTC collapse, 67 firefighters (45%) reported not wearing a respirator; similarly, 41 of those arriving later (35%) that day wore no respirator. Of those who reported wearing respiratory protection sometime during the first day, only 26% reported using it during most of their work time. The most common respirator used during day 1 was the disposable paint/dust mask. Of the 131 firefighters present on day 1 (either during or after the collapse) who reported wearing a respirator, 77 firefighters (59%) reported using the dis-

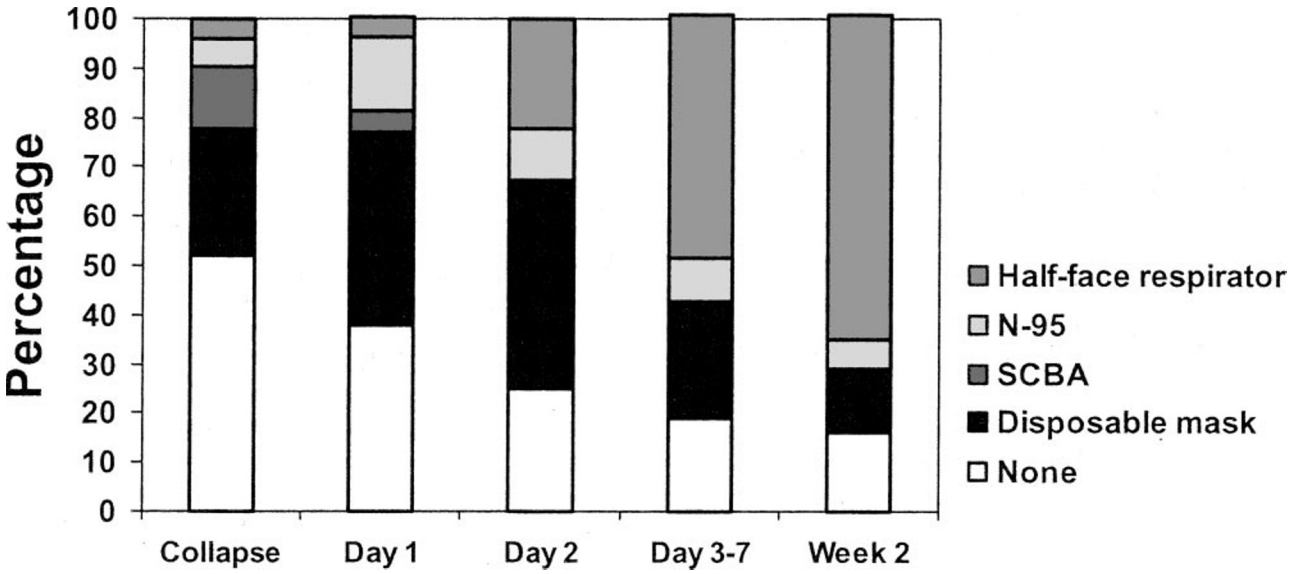

Figure 1. Respirator use during five time periods: during the WTC collapse, day 1 after the WTC collapse, day 2, days 3 to 7, and week 2. Among the 319 firefighters exposed, 149 firefighters reported being present during the collapse, and an additional 118 arrived later that day after the collapse; 223 firefighters were present on day 2; 284 firefighters were present at least 1 day during days 3 to 7; and 231 firefighters were present during week 2. Of those present during the WTC collapse, 67 firefighters (45%) reported not wearing a respirator; similarly, 41 firefighters (35%) of those arriving later that day wore no respirator. During the initial 2-week period, use of the more protective, half-face elastomeric respirator increased from 4% of responders on day 1 to 57% of responders during week 2. However, during week 2 only 53% of those using the half-face respirator reported using it during most of their work time (not shown).

posable mask. During the initial 2-week period, use of the more protective, half-face elastomeric respirator increased from 4% of responders on day 1 to 57% of responders during week 2. However, during week 2 only 53% of those using the half-face respirator reported using it during most of their work time. Using a summary score that averaged respirator use over the first 2 weeks, we found that 19% did not use any respirator and 50% reported using a respirator but wearing it rarely during work time.

Symptom Reporting

The frequency of reports of skin, eye, NT, and respiratory systems are shown in Table 1. PRs were calculated to compare rates of reporting of any skin, eye, NT, and respiratory symptoms among exposure groups (Table 2). A dose-response pattern was present with those arriving closer to the time of the collapse having the higher symptom rates. NT and respiratory symptoms were controlled for age and tobacco use. Statistically significant PRs ranged between 4.7 and 11.4.

Further statistical analysis was completed on the 319 firefighters responding to the WTC to examine potential associations between respiratory and NT symptoms and specific indicators of exposure including respirator use, welding, SOC membership, and the number of days of exposure. The number of days of exposure was the only significant predictor of both respiratory and NT symptoms in the exposed firefighters in multivariable models that included arrival time and controlled for age and smoking. When exposure days were dichotomized into > 7 days or < 7 days at the WTC site during the first 2 weeks, the PR for respiratory symptoms was 1.32 (95% CI, 1.13 to 1.55), and the PR for NT symptoms was 1.24 (95% CI, 1.08 to 1.42).

Chest Radiographs

Pre-WTC exposure and post-WTC exposure chest radiographs were available for 96% of exposed firefighters (307 of 319 subjects) and 81% of unexposed firefighters (34 of 42 subjects). No significant changes were observed from the pre-WTC exposure baseline for all firefighters for whom a comparison could be made.

Spirometry

Spirometry results were analyzed for 337 firefighters before WTC exposure and 353 firefighters after WTC exposure. Mean FVC and FEV_1 were within normal limits both before WTC exposure and after WTC exposure (Table 3) for all groups. FVC was $< 65\%$ of predicted in 1% of firefighters before WTC exposure and 2% after WTC exposure. FEV_1 was $< 65\%$ of predicted in 1% and 2.5% of firefighters before and after exposure, respectively. The FEV_1/FVC ratio was < 0.75 in 4.5% of firefighters before exposure and 6% after exposure.

Both pre-WTC and post-WTC exposure spirometry measurements were available for comparison in 323 of the firefighters studied: 91% of exposed (289 of 319 subjects) and 79% unexposed (34 of 43 subjects). The median number of days between the pre-WTC exposure and post-WTC exposure spirometry was 351 (range, 26 to 1,686 days), with no statistical difference between the exposed and unexposed firefighters. A referent group consisted of 735

Table 2—*PRs for New/Worsening Signs/Symptoms in FDNY Firefighters by Arrival Exposure Group, October 1–5, 2001**

	Arrival Exposure Group			
Symptoms	Collapse (n = 149)*	Days 1–2 (n = 142)	Days 3–7 (n = 28)	Unexposed (n = 43)
Skin				
Prevalence, %	47	40	18	7
PR (95% CI)	6.7 (2.7–26.6)	5.8 (2.3–22.8)	2.6 (0.7–11.7)	1.0
Eye				
Prevalence, %	78	63	46	7
PR (95% CI)	11.2 (3.8–34.2)	9.1 (3.7–35.7)	6.7 (2.4–27.2)	1.0
NT†				
Prevalence, %	79	79	64	9
PR (95% CI)	8.1 (3.2–20.5)	8.1 (3.2–20.5)	6.5 (2.5–17.1)	1.0
Respiratory†				
Prevalence, %	77	73	46	9
PR (95% CI)	8.1 (3.2–20.6)	7.3 (2.9–18.7)	4.7 (1.7–12.8)	1.0

*Compared to unexposed group.
†Controlling for current tobacco use and age.

Table 3—*Pulmonary Functions Before WTC Exposure and After WTC Exposure in FDNY Firefighters by Arrival Exposure Group*

	Before Exposure (n = 358)			After Exposure (n = 323)		
		% of Predicted			% of Predicted	
Functions	L, Mean ± SD	Mean ± SD	Range	L, Mean ± SD	Mean ± SD	Range
FVC						
Arrival at collapse	5.00 ± 0.91	99 ± 14	62–137	4.65 ± 0.86	93 ± 15	48–134
Arrival day 1–2	5.31 ± 0.77	102 ± 12	74–132	4.97 ± 0.75	95 ± 12	58–131
Arrival day 3–7	4.90 ± 0.77	96 ± 11	79–118	4.57 ± 0.77	94 ± 12	73–126
Unexposed control	4.67 ± 0.85	97 ± 14	57–128	4.57 ± 0.77	96 ± 14	47–128
FEV_1						
Arrival at collapse	4.23 ± 0.77	102 ± 15	52–144	3.91 ± 0.74	96 ± 18	46–177
Arrival day 1–2	4.50 ± 0.63	104 ± 13	72–133	4.16 ± 0.61	97 ± 12	60–126
Arrival day 3–7	4.14 ± 0.65	98 ± 10	78–123	3.93 ± 0.60	95 ± 14	64–132
Unexposed control	4.04 ± 0.76	103 ± 15	60–132	3.83 ± 0.68	99 ± 16	55–130
FEV_1/FVC						
Arrival at collapse	0.85 ± 0.05			0.84 ± 0.06		
Arrival day 1–2	0.85 ± 0.05			0.84 ± 0.05		
Arrival day 3–7	0.85 ± 0.05			0.84 ± 0.05		
Unexposed control	0.86 ± 0.05			0.84 ± 0.06		

FDNY firefighters with two spirograms prior to September 11. The mean age of the referent group was similar to the study population (39 years), and the rate of current smokers was higher (25%). The median days between tests for the referent group was 390 (range, 12 to 712 days). Similar quality control checks were applied to the referent spirograms as the study spirograms, which resulted in rejection of 7% of the FEV_1 and 15% of the FVC tracings. After adjusting for those with > 365 days between tests, the mean declines in FVC in the exposed, unexposed, and referent groups were 268 mL, 32 mL, and 179 mL, respectively; for FEV_1 declines were 264 mL, 85 mL, and 147 mL. After controlling for current tobacco use, the mean declines in both FEV_1 and FVC were greater for the exposed firefighters compared to the referent group ($p \leq 0.01$), while there was no difference between the unexposed firefighters and the referent group. Figure 2 shows the mean decline by arrival exposure group as compared to the referent group after controlling for current tobacco use. Greater declines in FEV_1 were seen in those arriving at the collapse and on day 1 or 2, and greater declines in FVC were seen for those arriving at the collapse compared to the referent group ($p \leq 0.05$). Twenty percent of the referent population had a decline in FEV_1 of ≥ 450 mL. Logistic regression analysis controlling for smoking status using this level of decline in FEV_1 as a threshold, showed an odds ratio of 1.67 (95% CI, 1.09 to 2.55) among those arriving at the collapse and 1.59 (95% CI, 1.04 to 2.42) among those arriving during days 1 and 2 compared to the referent group. Additional analyses looking at respirator use, days of exposure, and unit assignment among the 289 exposed firefighters with pre-WTC exposure and post-WTC exposure spirometry measurements did not further explain the variability in change in FEV_1 or FVC.

Association of Respiratory Symptoms and Spirometry

For the 289 exposed firefighters who underwent pre-WTC exposure and post-WTC exposure spirometry, we compared the median change (before exposure − after exposure) in FVC and FEV_1 for those reporting each of the respiratory symptoms to those without respiratory symptoms. The median decreases in FVC and FEV_1 for those reporting respiratory symptoms were greater than for those without symptoms (Table 4).

WTC Cough

Among the 319 firefighters in our study who responded to the WTC disaster, WTC cough was subsequently diagnosed by FDNY-BHS in 12 firefighters. This condition was reported by 6% of those who were present at the collapse and by 2% of those who arrived on days 1 or 2. There were no cases diagnosed among those who arrived on days 3 to 7. These results are comparable to those reported by Prezant et al[4] for the same exposure groups from the entire FDNY population: 8%, 3%, and 1%, respectively.

Discussion

We describe symptoms and pulmonary function changes in a random sample of FDNY rescue work-

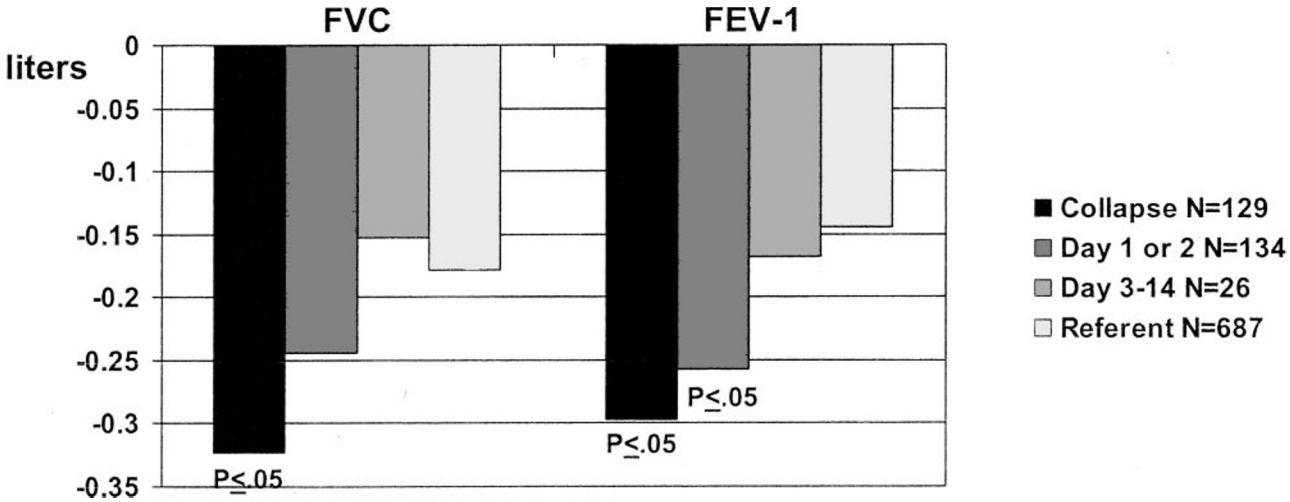

FIGURE 2. The mean decline in FEV_1 by arrival exposure group as compared to the referent group after controlling for current tobacco use. Greater declines in FEV_1 were seen in those arriving at the collapse and on day 1 or day 2, and greater declines in FVC were seen for those arriving at the collapse compared to the referent group ($p \leq 0.05$). Twenty percent of the referent population had a decline in FEV_1 of at least 450 mL. Logistic regression analysis controlling for smoking status using this level of decline in FEV_1 as a threshold showed an odds ratio of 1.67 (95% CI, 1.09 to 2.55) among those arriving at the collapse and 1.59 (95% CI, 1.04 to 2.42) among those arriving during days 1 and day 2 compared to the referent group.

ers approximately 3 weeks following their first exposure to airborne particulates and other materials from the WTC collapse. Few firefighters reported the use of respiratory protection in the first 48 h after the collapse; for those who did, most reported use of a dust/paint mask (known to provide inadequate respiratory protection), and only 26% of them reported using the dust mask most of the time. Symptom prevalence rates in exposed firefighters were elevated compared with the unexposed group. Sixty-five percent had eye irritation, 54% had sore throat, 53% had daily cough, 40% had nasal congestion, 30% reported skin irritation, and 24% had chest pain/tightness.

Arrival time at the WTC, used as an indication of exposure intensity, was associated with increased symptom reporting and greater declines in pulmonary function (FVC and FEV_1). For all organ systems (skin, eye, NT, and respiratory), there was greater symptom reporting among those present in the first 48 h when compared to those presenting on days 3 to 7. Post-WTC exposure spirometry showed near-equal reductions in FVC and FEV_1. There was a 60% increased risk for declines in FEV_1 of at least 450 mL in those arriving during the first 48 h compared to the annual declines in a referent FDNY population prior to September 11. Significantly greater declines in pulmonary function were noted in those exposed firefighters with respiratory symptoms.

We found arrival time at the site to be a more

Table 4—*Pulmonary Function Changes After WTC Exposure in FDNY Firefighters by Self-Reported New/Worsening Respiratory Symptoms*

Symptoms	Firefighters Reporting Symptom, No. (n = 289)	FVC Change After − Before Exposure		FEV_1 Change After − Before Exposure	
		Median, L	p Value Compared to No Symptoms	Median, L	p Value Compared to No Symptoms
No symptoms	75	− 0.124		− 0.138	
Cough	157	− 0.232	0.02	− 0.200	0.07
Chest tightness	91	− 0.320	< 0.01	− 0.230	0.01
Shortness of breath	72	− 0.285	< 0.01	− 0.225	0.02
Disturbed sleep	72	− 0.244	< 0.01	− 0.224	0.05
Wheeze	63	− 0.212	0.07	− 0.216	0.09
Any symptom	214	− 0.248	< 0.01	− 0.229	0.02

useful measure of exposure status than job task or respirator use because all firefighters participated in similar job tasks at the site and few reported wearing adequate respirators during at least the first week. For NT and respiratory symptom reporting, a dose-response relationship was also found based on the duration of exposure as measured by the number of days working at the WTC, showing a 32% increase in respiratory symptom reporting for firefighters working at the WTC for ≥ 7 days in the first 2 weeks compared to those working < 7 days.

There are potential limitations to this study. Self-reported data may be subject to recall bias. In this case, firefighters were asked to recall daily respirator use 3 weeks after the WTC collapse. It is possible that overreporting of symptoms in the first weeks following the event may have occurred due to heightened awareness or anxiety. However, underreporting of medical symptoms to the FDNY-BHS was documented during this same period due to concern of the firefighters that they might be removed from the rescue effort (FDNY-BHS data).

A strength of this study was having objective measures of pulmonary function in addition to symptom reporting. Since the FDNY firefighter population is selected for physical fitness without respiratory pathology, almost all firefighters had normal pre-WTC exposure and post-WTC exposure spirometry results. Our ability to show associations between arrival time, respiratory symptoms, and changes in pulmonary function was made possible by the existence of systematically collected pre-WTC exposure spirometry results by the FDNY. This provided a unique opportunity to document changes unavailable in most other WTC rescue and recovery workers. Our findings emphasize the need to provide rescue workers with spirometry at regular intervals so that declines in pulmonary function may be monitored following exposure.

Environmental monitoring at ground zero has documented high levels of particulate matter composed of construction material, soot, and glass fiber that was highly alkaline in character (pH > 11), likely due to the high cement content.[7] Because of the nature of the disaster, most air sampling by the US Environmental Protection Agency (EPA) and other researchers did not begin until several days following the collapse of the towers. Investigators also analyzed settled dust samples collected near the site in the days following the collapse to better characterize exposures. These measurements have shown that most of the dust mass was of large particle size (95% of dust particle mass was > 10 μm in diameter), which, once inhaled, would be trapped in the upper airways and due to its caustic character would likely cause significant upper airway and NT irritation.[2] EPA measurements of particulate matter in the air at the WTC perimeter exceeded the EPA daily particulate matter ($PM_{2.5}$) air quality standard of 65 $\mu g/m^3$ in 24 h during the first several days after the disaster.[8] Only a small percentage (1 to 2%) of particle mass measured ≤ 2.5 μm aerodynamic diameter, the size likely to penetrate into the lower airways, and particles of this size found in bulk samples were less caustic than the larger particles.[8] However, although the percentage of small particles was low, given the high levels of particulate matter, the airborne mass concentration of small particles was likely sufficient to have significant impact on the lower airways. Although helpful, these measurements have limitations in describing the nature of the firefighter exposures during the time periods included in our study. Settled dust samples as compared to airborne dust samples would have a particle size distribution that is enriched with larger particles. In the future, environmental monitoring capability should be developed so that during the initial stages of a disaster, airborne samples can be collected that are representative of the particle type and size distribution during the height of the exposure.

Firefighters responding to this or other disasters wear personal protective equipment consisting of a thermal protective uniform and a full face mask SCBA to protect themselves against possible airborne exposures. Theoretically, the SCBA provides the highest level of respiratory and eye protection for exposures found at structural fires or building collapses (*ie*, airborne particulates, most vapors, and typical emergency medical service tasks). However, their design limits their use to short duration activities because of their weight (> 25 lb) and air supply (< 20 min). We demonstrated in this study that once SCBA was no long available or appropriate for the response, alternative respiratory protection was lacking.

Alternative choices for personal protective equipment that provide protection from the range of exposures found at disasters of the scale, complexity, and duration of the WTC have numerous problems that must be overcome if respirators are to be used successfully.[7] Other respirators (*ie*, N95, N-100, P-100) do not provide sufficient protection for structural firefighting. All respirators, regardless of type, are uncomfortable and hinder the necessary communications between workers. Each individual using a respirator must be fit tested, but this is valid only for the specific type and manufacturer product actually tested. During the WTC rescue and recovery operation, respirators from multiple manufacturers were used, endering the pre-WTC exposure fit testing irrelevant. Time was not available to fit test workers for specific respirators as manufacturer products

changed. Although FDNY firefighters received US Occupational Safety and Health Administration-mandated training detailing the need for and use of respirators, future training should emphasize the need for initial and continued respirator and personal protective equipment use at long-duration exposures such as at the WTC disaster. This also applies to volunteers and construction workers who are not routinely involved in disaster responses and pose special challenges *eg*, assignment of responsibilities, coordination, oversight, and medical clearance/surveillance.

The numerous reports of eye irritation from airborne particulates highlight the inadequacy of currently available eye protection, which is primarily designed to prevent sharp trauma. But eye protection against small particles would require an occlusive shield or a full-face respirator that would further increase discomfort and heat stress, thereby potentially reducing compliance. Despite these barriers, personal protective equipment compliance can be improved if rapid supply and distribution is coupled with better design, supervision, enforcement, and administrative controls coordinated through an identified safety command structure responsible for all workers on-site. As personal protective equipment compliance improves, safe use at long-duration exposures requires an integrated plan between safety and operation commands that provides for adequate rest and rehydration periods to prevent potential complications such as heat stress/stroke, fatigue, or coronary ischemia.

A central question remains whether exposed firefighters will develop chronic respiratory effects as a result of responding to the WTC disaster. WTC cough has been described in 332 firefighters during the first 6 months after the WTC collapse.[7] The WTC cough group had nearly equal reductions in FVC and FEV_1 using serial spirometry, increased bronchial responsiveness (postbronchodilator studies and methacholine challenge testing), and bronchial wall thickening (high-resolution CT) Over half had persistent respiratory symptoms and dysfunction even after aggressive treatment. WTC cough was subsequently diagnosed in 4% of our sample, with a distribution by exposure group similar to that reported for the entire FDNY population. These findings suggest that exposed rescue workers will require long-term medical monitoring, which should include serial pulmonary function testing. Studies are underway in the firefighters and other exposed rescue and recovery workers to collect additional objective medical data (serial spirometry, provocative challenge testing, high-resolution chest CT, etc.), which will answer some of these questions. This study provides important findings that should help to focus future health and safety initiatives for FDNY firefighters and others at risk.

ACKNOWLEDGMENT: The authors thank Drs. Paul Enright, Thomas Aldrich, and William Rom, and Mr. Charles Mueller for review and comments.

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