Respiratory Symptoms and Physiologic Assessment of Ironworkers at the World Trade Center Disaster Site*

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Study objectives: To characterize respiratory abnormalities in a convenience sample of ironworkers exposed at the World Trade Center (WTC) disaster site for varying lengths of time between September 11, 2001, and February 8, 2002.

Design: Cross-sectional study.

Setting: The Mount Sinai Medical Center, a large tertiary hospital.

Participants: Ninety-six ironworkers engaged in rescue and recovery with exposure onset between September 11, 2001, and September 15, 2001, who responded to an invitation to undergo respiratory evaluation.

Measurements: Medical and exposure history, physical examination, spirometry, forced oscillation (FO), and chest radiographs. The relationships of prevalence of respiratory symptoms and presence of obstructive physiology to smoking, exposure on September 11, duration of exposure, and type of respiratory protection were examined using univariate and linear and logistic regression analyses.

Results: Seventy-four of 96 workers (77%) had one or more respiratory symptoms (similar in smokers [49 of 63 subjects, 78%] and nonsmokers [25 of 33 subjects, 76%]). Cough was the most common symptom (62 of 96 subjects, 65%), and was associated with exposure on September 11. Chest examination and radiograph findings were abnormal in 10 subjects (10%) and 19 subjects (20%), respectively. FO revealed dysfunction in 34 of 64 subjects tested (53%), while spirometry suggested obstruction in only 11 subjects (17%). Lack of a respirator with canister was a risk factor for large airway dysfunction, and cigarette smoking was a risk factor for small airway dysfunction. No other relationships reached statistical significance.

Conclusions: Respiratory symptoms occurred in the majority of ironworkers at the WTC disaster site and were not attributable to smoking. Exposure on September 11 was associated with a greater prevalence of cough. Objective evidence of lung disease was less common. Spirometry underestimated the prevalence of lung function abnormalities in comparison to FO. Continuing evaluation of symptoms, chest radiographs, and airway dysfunction should determine whether long-term clinical sequelae will exist. *(CHEST 2004; 125:1248–1255)*

Key words: exposure; forced oscillation; ironworkers; September 11, 2001; spirometry; World Trade Center disaster

Abbreviations: AX = area of low-frequency reactance; f-d R = frequency dependence of resistance; $FEF_{25-75\%}$ = forced expiratory flow during 25% to 75% of FVC; FO = forced oscillation; IOS = Impulse Oscillation System; OR = odds ratio; R5 = respiratory resistance at 5 Hz; R5-R20 = respiratory resistance at 5 to 20 Hz; R20 = respiratory resistance at 20 Hz; WTC = World Trade Center

The catastrophic events at the World Trade Center (WTC) on September 11, 2001, exposed thousands of workers including police and firefighters, other rescue personnel, and construction crews to unusual products of combustion.[1] Many of these individuals were present at the time of maximum air pollution and for varying lengths of time thereafter.[2] Lack of appropriate respiratory protection, particularly in the initial days after the crisis, may have heightened exposure risk.[3] Acute inhalational injury in both rescue workers and nonrescue survivors was well documented.[4–7] Persistent respiratory symptoms were present in multiple groups of rescue personnel.[8–10] The purpose of this study was to characterize respiratory abnormalities in a cohort of ironworkers at the WTC site by detailed history, physical examination, and physiologic and radiographic studies. A second goal was to compare the techniques of forced oscillation (FO) and routine spirometry as screening modalities for airways dysfunction in this cohort.

MATERIALS AND METHODS

Subjects

One hundred four male ironworkers involved in rescue and recovery efforts and prolonged cleanup of the WTC site were recruited via distribution of an exposure questionnaire to union members. Subjects were > 18 years old and had spent at least 3 days at the disaster site with a start date between September 11, 2001, and September 15, 2001. Many were still working at the site at the time of this evaluation. Eight individuals were excluded due either to a shorter duration of exposure or to a start date later than September 15. Demographics and smoking history of the remaining 96 subjects who met inclusion criteria are outlined in Table 1. The study was approved by the Institutional Review Board of the Mount Sinai School of Medicine, and informed, written consent was obtained from each subject.

Protocol

The study required a single visit to the Mount Sinai Medical Center. Evaluation was conducted on February 9 and February 10, 2002, approximately 5 months after the initial exposure. Each worker provided a detailed medical and exposure history, and received a physical examination focusing predominantly on the upper and lower respiratory systems, routine spirometry, and chest radiographs (posteroanterior and left lateral). Due to time constraints, only 75 subjects underwent additional physiologic testing by FO. The large number of subjects evaluated on the same day necessitated varying the order of testing among individuals (ie, some underwent physiologic studies, including administration of a bronchodilator, prior to the medical interview and examination).

Medical and Exposure History

Medical histories were acquired using a prepared questionnaire. Prior upper and lower respiratory conditions (ie, chronic sinusitis and asthma), persistent upper and lower respiratory symptoms (ie, sinus complaints, cough, dyspnea, wheeze, and chest tightness), provocability of these symptoms (eg, in relation

Table 1—Demographics and Smoking History of 96 Ironworkers Exposed at Ground Zero*

Variables	Results
Age, yr	43 ± 10
Race	
White	80 (83)
Black	9 (9)
Other	7 (8)
Smokers, current or former	63 (65)
Pack-years	19 ± 15

*Values are expressed as mean $\pm$ SD or No. (%).

to exposure to cold weather or changes in weather, exposure to smoke, diesel exhaust, or chemicals) and smoking history were documented.

Exposure history pertaining to the disaster was obtained by trained industrial hygienists and included assessment of exposure onset (September 11, 2001, or subsequently) and total exposure duration (days). Subjects were also questioned regarding the use of a dust mask and respirator with canister. Prior occupational exposure history was not recorded.

Physical Examination

Physical examination focused on the upper and lower respiratory systems. Swollen turbinates and erythematous nasal mucosa were considered abnormal upper respiratory findings, while wheezing, rhonchi, and prolongation of expiration comprised the lower respiratory abnormalities.

Spirometry

Pulmonary function tests were performed using either a Sensormedics 6200 (SensorMedics; Yorba Linda, CA) or a Jaeger Impulse Oscillation System (IOS) spirometer (Jaeger USA; Yorba Linda, CA) according to standard protocol. The data included FEV_1, FVC, and forced expiratory flow during 25% to 75% of the FVC ($FEF_{25-75\%}$). Each spirometric maneuver was done in triplicate, and the best FEV_1 and FVC values were selected. The predicted values were those of Morris et al.[11] Adjustments were made for nonwhite individuals.[12] Airways obstruction was defined as $FEV_1/FVC \leq 0.70$ and $FEV_1 < 80\%$ predicted. Spirograms with $FEV_1/FVC \leq 0.70$ but with $FEV_1 \geq 80\%$ predicted were interpreted as showing borderline obstruction.

FO

FO was performed using a commercial instrument (IOS), calibrated with a standard 3-L syringe, and a known, fixed resistance to verify pressure calibration and frequency fidelity. Measurements (three 30-s trials) were made during tidal breathing using a mouthpiece that stabilizes tongue position to minimize oral resistance while firmly supporting the cheeks. The mouthpiece was connected to the pneumotachometer, and small pressure oscillations "forced" by a loudspeaker attached to the other end of the tube (Fig 1). The FO instrument applied pressure pulses five times per second. Respiratory resistance and reactance were calculated from oscillatory components of flow and pressure[13] at 5 to 35 Hz. Large and small airways mechanics were inferred from responses at high (20 Hz) and low (5 to 15 Hz) frequencies, respectively. Low-frequency oscillations at the mouth are transmitted to the lung periphery, while those at ≥ 20 Hz are limited to larger airways.[14,15] Four parameters were

Loudspeaker

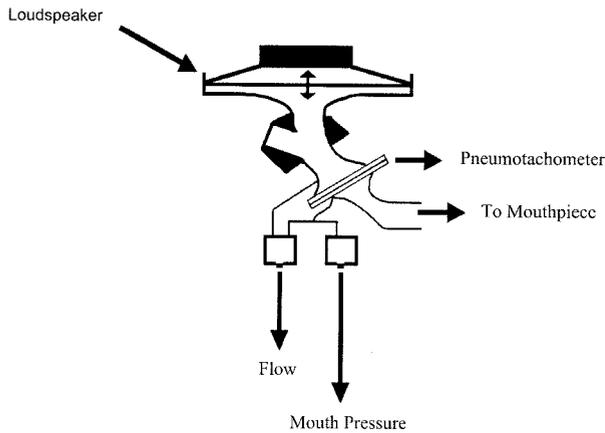Pneumotachometer

To Mouthpiece

Flow

Mouth Pressure

FIGURE 1. Schematic representation of the IOS. A loudspeaker driven by computer pushes pressure pulses into a Y-connector, one arm of which connects to a pneumotachometer, the other open through a moveable resistor to room air. During IOS measurements, the resistor is tightly in place and energy of pressure pulses is directed into the mouthpiece.

evaluated: (1) respiratory resistance at 5 Hz (R5), a global index influenced by both small and large airways; (2) respiratory resistance at 20 Hz (R20), an index of large airways resistance; (3) respiratory resistance at 5 to 20 Hz (R5-R20), an index of frequency dependence of resistance (f-d R), reflective of small airways function; and (4) an integrated area of low-frequency reactance (AX).[13,16] This parameter includes all negative values of respiratory reactance between 5 Hz and the frequency at which reactance is zero (resonant frequency). AX is an index of small airways obstruction complementary to f-d R.[13,16–21] As a reference standard for R5, we used published FO data of > 400 normal male subjects (45% of whom were smokers), of comparable age to the present cohort, and set the cutoff for the upper limit of normal equal to mean R5 + 1.65 SD.[17,18] Accordingly, R5 > 3.5 cm H_2O/L/s was defined as abnormal. FO tests were performed prior to spirometry to avoid any influence of forced expiratory maneuvers on airways function during resting breathing. Data calculations were reviewed after each test to check that correlations (coherence) among pressure and flow phase and amplitude appeared acceptable (coherence > 0.8).

Bronchodilator Administration

Subjects with baseline FEV_1 < 80% predicted or with R5 > 3.1 cm H_2O/L/s received 1.25 mg of levalbuterol via small-particle nebulizer (AeroEclipse; Monaghan Medical; Plattsburgh, NY) over 5 to 7 min. Spirometry and FO were repeated 15 min later. Significant spirometric bronchodilator response was defined by an absolute increase of 200 mL and an increase of at least 12% in either the FEV_1 or FVC.[22] Significant FO improvement was defined by an absolute decrease from mean baseline data of > 2 SD and a decrease of ≥ 15% for respiratory resistance and/or ≥ 25% for AX.

Radiologic Testing

Each subject underwent posteroanterior and left lateral chest radiography. The radiographs were reviewed independently by one pulmonologist and a National Institute for Occupational Safety and Health-certified "B" reader, and were scored using the International Labor Office 1980 schema.[23]

Statistics

Data were analyzed using a standard statistical package (Stata Statistical Software, Version 8.0; Stata Corporation; College Station, TX). Outcome variables included onset of respiratory symptoms after September 11, presence of spirometric obstruction, and FO indices. Risk factors considered were smoking, exposure on September 11, duration of exposure, and type of respiratory protection. Univariate analyses (unpaired t tests and χ^2) of the outcome variables were carried out. Multivariate analyses of the associations with the risk factors were performed using logistic regression and linear regression for dichotomous and continuous outcome variables, respectively; $p < 0.05$ was considered significant.

RESULTS

Table 2 summarizes the medical history and exposure data. Seventy-four of the 96 ironworkers had one or more respiratory complaints. The most common symptom was cough (n = 62), followed by dyspnea (n = 48) and chest tightness and wheezing (n = 44 each). Sinus complaints occurred in 50 individuals. Upper and lower respiratory symptoms were present concurrently in almost half the cohort (n = 45). Few subjects had prior self-reported asthma (n = 7) or sinus disease (n = 1). More than half of the subjects (n = 53) noted new respiratory symptoms induced by classic provocative stimuli since September 11. Only 25 subjects sought medical attention. Of these, 15 subjects were treated with a bronchodilator (n = 7) or a combination of a bronchodilator and corticosteroid (n = 8). Eight subjects received an antibiotic alone. Two subjects received no specific treatment.

Forty-two ironworkers were at Ground Zero on

Table 2—Medical and Exposure Data for 96 Ironworkers at Ground Zero*

Finding	Data
Presence of ≥ 1 respiratory symptom	74
Prior asthma history	7
Prior sinus history	1
History of provocability†	53
Sought medical attention	25
Received pulmonary medication‡	15
Duration of exposure, d	53 ± 47
Range of exposure duration, d	3–146
Exposure on September 11	42
No respiratory protection during first week	41
Dust mask only during first week	33
Respirator with canister only during first week	17

*Data are presented as No. or mean ± SD unless otherwise indicated.

†History of respiratory symptoms provoked by exposure to cold weather, changes in weather, cigarette smoke, diesel exhaust, or chemicals.

‡Bronchodilator or inhaled corticosteroid.

September 11 (Table 2). In 54 subjects, exposure began between September 12 and September 15. Exposure duration ranged from 3 to 146 days (mean ± SD, 53 ± 47 days). Forty-one subjects wore no respiratory protection during the first week. Thirty-three subjects wore a dust mask, and 17 subjects used a respirator with canister. Five subjects wore either a dust mask or respirator with canister at different times. Abnormal upper respiratory findings were documented more frequently on physical examination (n = 28) than lower respiratory abnormalities (n = 10).

Radiographic evaluation revealed abnormalities in 19 subjects who were referred for further evaluation. Parenchymal changes ≥ 1/1 according to the International Labor Office classification were found in five individuals. Seven workers had pleural abnormalities. Subcentimeter lung nodules were detected in seven subjects.

Mean pulmonary function data for spirometry and FO, stratified by smoking behavior, are shown in Table 3. The 21 subjects who did not undergo FO testing because of time limitations were not statistically different spirometrically from the remaining 75 individuals. Of the subjects who underwent FO testing, 7 subjects had technically unacceptable pulmonary function results and 4 subjects had a history of asthma, so that 64 nonasthmatics were included in the analysis.

Despite the high frequency of respiratory symptoms, FEV_1 and FVC percentage of predicted were normal in 51 subjects (80%). Four subjects manifested airways obstruction, and four subjects had borderline airways obstruction. Three additional subjects were probably obstructed in light of a markedly reduced $FEF_{25-75\%}$ (< 2.5 L in all cases), while two subjects appeared to have a restrictive pattern (FEV_1 and FVC both $< 80\%$ predicted but FEV_1/FVC normal). Seven of the eight subjects who met criteria for spirometric obstruction or borderline obstruction were current or former smokers, and 7 of the 42 subjects (17%) who received a bronchodilator manifested a significant spirometric response.

Studies of FO indices showed a higher prevalence of baseline abnormalities. Thirty-four of the 64 nonasthmatics evaluated (53%) manifested R5 above the cutoff value of 3.5 cm H_2O/L/s. Mean R5 was 4.4 cm H_2O/L/s in these subjects. In comparison, the four subjects with a history of asthma who underwent FO testing manifested a mean R5 of 5.9 cm H_2O/L/s. Response to bronchodilator was also more notable from FO data. Improvement in R5 and/or R20 occurred in 25 subjects (60%), while 3 additional subjects (7%) showed improvement in AX alone after nebulized bronchodilator.

The principal study outcomes, namely, the prevalence of respiratory symptoms, spirometric obstruction, and FO indices, were analyzed in relationship to risk factors (*ie*, smoking, exposure onset and duration, and respiratory protection). There was no significant difference in prevalence of respiratory symptoms between smokers and nonsmokers. Forty-nine of the 63 smokers (78%) and 25 of the 33 nonsmokers (76%) were symptomatic (p = 0.97). We did not find a statistically significant relationship between respiratory symptoms and duration of exposure, but the time of exposure onset significantly influenced prevalence of cough. Thirty-three of 42 ironworkers (78%) at Ground Zero on September 11 complained of cough, as opposed to 29 of 54 subjects (54%) who arrived subsequently (p = 0.02). Respiratory symptoms tended to occur less frequently in workers who wore a respirator with canister (14 of 22 subjects, 64%) than in those without this protection (60 of 74, 81%) during the first week at the site, although this relationship did not reach significance (p = 0.16).

Spirometric obstruction was found in a similar percentage of symptomatic (7 of 46 subjects, 15%) and asymptomatic (4 of 18 subjects, 22%) [p = 0.76] ironworkers, and none of the FO indices distinguished symptomatic from asymptomatic individuals. None of the lung function test results were significantly associated with either exposure onset or duration. Spirometric obstruction was not different in smokers (8 of 45 subjects, 18%) vs nonsmokers (3 of 19 subjects, 16%) [p = 0.87] for any of the indices listed in Table 3, although FEV_1/FVC approached significance (p = 0.099). In contrast, significant differences were seen in oscillometric indices reflecting small airways function, since smokers demonstrated a higher AX and R5-R20 than did nonsmokers (mean, 3.9 ± 3.2 vs 1.8 ± 0.98, p = 0.008; and mean, 0.79 ± 0.48 vs 0.46 ± 0.31, p = 0.007, re-

Table 3—Spirometric and FO Data*

Parameters	Smokers (Current and Former), n = 45	Nonsmokers, n = 19
FEV_1 % predicted	97 ± 15	99 ± 13
FVC % predicted	100 ± 14	99 ± 10
FEV_1/FVC	0.78 ± 0.08	0.82 ± 0.07†
$FEF_{25-75\%}$ predicted‡	84 ± 35	97 ± 33
R5, cm H_2O/L/s	3.93 ± 0.91	3.58 ± 0.75
R20, cm H_2O/L/s	3.14 ± 0.62	3.12 ± 0.70
R5–R20, cm H_2O/L/s	0.79 ± 0.48	0.46 ± 0.31§
AX, cm H_2O/L/s	3.85 ± 3.16	1.83 ± 0.98§

*Data are presented as mean ± SD.
†p = 0.099, smokers vs nonsmokers.
‡$FEF_{25-75\%}$ predicted correlated significantly with the following FO indices: R5 ($r = 0.39$, p = 0.002) and R20 ($r = 0.37$, p = 0.003).
§p < 0.01, smokers vs nonsmokers.

Table 4—*Logistic Regression Model of Onset of New Respiratory Symptoms After September 11*

Risk Factors	Adjusted OR (p Value)
Exposure onset on September 11	5.46 (0.007)
Exposure duration, d	1.01 (0.106)
Use of respirator with canister (with or without dust mask)	0.322 (0.052)
History of smoking	1.73 (0.330)

spectively). Additionally, FO results indicated a decreased large airways resistance in individuals who wore a respirator with canister: R20, 2.8 ± 0.48 vs 3.2 ± 0.64 (p = 0.01); R5, 3.4 ± 0.53 vs 3.9 ± 0.92 (p = 0.04).

Because the risk factors studied were not distributed entirely independently of each other, logistic and linear regression analyses of the outcomes were also performed. Analysis of respiratory symptoms revealed that only the association of exposure on September 11 was statistically significant at the conventional 0.05 level, although the association of use of a respirator with canister was close to significant (Table 4). When cough, by itself, was considered an outcome, a significant relationship with exposure on September 11 was again found (adjusted odds ratio [OR] = 3.64; 95% confidence interval, 1.35 to 9.83; p = 0.011). As with univariate analysis, the linear regression models of spirometric obstruction did not reveal any statistically significant associations with the risk factors. The model for the FO indexes (Table 5) confirmed the relationships noted in the univariate analysis and also demonstrated significant association between R5 and smoking.

Discussion

The initial goal of the present study was to characterize the extent of pulmonary disease in a convenience sample of ironworkers who responded to an invitation to undergo medical evaluation 5 months after the disaster. A second important goal was to compare the techniques of FO and routine spirometry as screening modalities for airways dysfunction in this cohort. Our results demonstrate a high prevalence of respiratory symptoms in exposed workers with fewer abnormalities on physical examination, spirometric testing, and chest radiographs. Despite the high symptom prevalence, the ironworkers evaluated were able to continue working and most did not seek medical attention. A minority of subjects had spirometric airways obstruction, and the spirometric response to bronchodilator was variable. Radiographic abnormalities were presumed secondary to prior occupational exposure rather than newly acquired disease given the expected time course for manifestation of pneumoconiosis.[24] There was a higher prevalence of cough in ironworkers at Ground Zero on September 11 as opposed to those who arrived subsequently. Use of a respirator with canister may have protected against respiratory symptoms, although this relationship did not reach significance. There was no significant association between respiratory symptoms and either smoking or exposure duration. Spirometric airways obstruction was not significantly associated with any risk factor examined.

The oscillometric data revealed a substantially higher prevalence of lung function abnormalities and bronchodilator response and several significant relationships with risk factors. Smoking was associated with evidence of small airways obstruction (R5, R5-R20, and AX). Use of a respirator with canister was protective in terms of large airways dysfunction. None of the lung function tests discussed in this report distinguished between symptomatic and asymptomatic individuals.

Other investigators have documented the presence of increased respiratory symptoms in rescue

Table 5—*Linear Regression Model of FO Indices After September 11**

Risk Factors	FO Testing Parameter			
	R5	R20	R5–R20	AX
Exposure onset on September 11	− 0.130 (0.215)	− 0.214 (0.157)	0.084 (0.116)	0.736 (0.722)
Exposure duration, days	− 0.002 (0.002)	− 0.001 (0.002)	− 0.001 (0.001)	− 0.001 (0.008)
History of smoking	0.549† (0.232)	0.246 (0.169)	0.303† (0.125)	1.875† (0.779)
Use of respirator with canister (with or without dust mask)	− 0.649† (0.250)	− 0.509‡ (0.182)	− 0.141 (0.135)	− 0.700 (0.839)
Constant	3.731‡ (0.259)	3.229‡ (0.189)	0.502‡ (0.140)	1.776† (0.871)
Observations, R^2	64 (0.16)	64 (0.16)	64 (0.10)	64 (0.10)

*Data are presented as coefficient (SE).
†Significant at 5%.
‡Significant at 1%.

workers at the WTC disaster site.[5–10] Indeed, "WTC cough" is now well described, particularly in firefighters.[8] There have also been reports of symptoms in nearby office workers.[25] The importance of early exposure has been concurrently observed by Prezant et al,[8] who showed that firefighters at Ground Zero immediately following the collapse had a higher prevalence of respiratory symptoms and bronchial hyperresponsiveness than those who arrived later the same day. In a more recent report, Banauch et al[10] showed that bronchial hyperresponsiveness persisted in this group 6 months after the disaster.

In the current study, there was a risk for both reactive airways dysfunction syndrome and irritant-induced asthma. Rescue workers present at the time of the collapse were enveloped in the cloud of debris and were more likely to develop reactive airways dysfunction syndrome.[3] Although the ironworkers were not involved early on September 11, a large number were exposed later that day when toxin levels were presumably still quite high. The majority of ironworkers participated in demolition and debris removal over weeks to months and were subject to repetitive, lower-level exposures. A variety of agents containing toxic constituents may have been inhaled, including fire and smoke, dust, and fumes. Most men were not wearing appropriate respiratory protection at the onset of exposure, which may have heightened their risk.[26] Although prior occupational exposure may have posed an additional risk for development of respiratory abnormalities after September 11, this report focused on exposures related specifically to the WTC disaster. Even though air sampling beginning on September 18 suggested that levels of toxic dusts and gases were lower than initially suspected,[27] earlier measurements[1] demonstrated significant concentrations of toxicants (eg, asbestos, glass fibers, lead, and polycyclic aromatic hydrocarbons). Sequelae of such inhalations may take years to become clinically apparent.

The high prevalence of respiratory symptoms in ironworkers was not attributable to smoking, since similar percentages of smokers and nonsmokers were symptomatic. Although Blanc et al[28,29] have shown that respiratory symptoms following irritant exposure are more common in smokers or individuals with preexisting lung disease, their subjects all encountered brief, high-intensity inhalational exposures. It is possible that the prolonged, repetitive exposures of ironworkers to toxins at the WTC disaster site overwhelmed pulmonary defense mechanisms of both smokers and nonsmokers. The role of smoking as a predisposing factor for respiratory symptoms under the unique circumstances of the WTC catastrophe has not been explored.

Early exposure following the collapse was more provocative of cough than subsequent exposure. The concentration of an inhaled irritant has been identified as a risk factor for the development of respiratory abnormalities.[30] Those individuals with earlier exposure presumably inhaled a higher concentration of toxins than those who arrived later. However, longer exposure duration was not associated with a higher prevalence of respiratory symptoms. Although use of a respirator with canister was not significantly associated with reduction in new onset of respiratory symptoms, there was a strong trend favoring protection by respiratory canister (adjusted OR, 0.32; p = 0.052).

The FO data show a substantially higher prevalence of abnormal airflow resistance in ironworkers after exposure at the WTC site than inferred from spirometric abnormalities. Similarly, bronchodilator responsiveness was substantially greater when assessed by FO. The increased sensitivity of FO over spirometry is consistent with earlier reports of subjects with either reactive airways disease or those exposed occupationally to toxic fumes or other inhalants.[31–39] Inferences of small or large airways mechanics from FO measures are based on established evidence for f-d R and compliance in patients with chronic airflow obstruction and in asymptomatic cigarette smokers.[18,31,33,40,41] Although unexposed ironworkers were not available to serve as a control group at the time of this evaluation, historical control subjects are available from other studies.[18,40,42,43] These studies constitute a much smaller normal population than is available for spirometry. While studies over a period of 4 decades using monofrequency sine waves, or multifrequency pseudorandom noise, or impulse oscillation provide similar mean values and variance, it must be appreciated that differences in techniques may allow for some uncertainty regarding an upper limit of normal in clinically healthy, unexposed individuals. With this caveat, we examined more recent IOS studies[42,43] reporting a mean of R5 in normal subjects of 2.5 to 3 cm $H_2O/L/s$ with SD of 0.5 to 0.6 cm $H_2O/L/s$. We accepted the larger of these mean values and 1.65 SD to define an upper limit of normal of 4 cm $H_2O/L/s$. This higher estimated upper limit of normal yields 24 individuals in the present study with abnormal R5, or more than twice the number showing spirometric airflow obstruction. Quite apart from attempts to define "normal" vs "abnormal" in our study population, the present work confirms earlier FO studies demonstrating significant differences in small airway behavior in ever-smokers compared with never-smokers, and reports a new finding of significant differences in large airway behavior independent of smoking history in ironworkers wearing

respiratory protection compared with those not using such protection during the first week following September 11, 2001.

FO indexes were influenced by use of a respirator with canister as well as by smoking. While FO evidence of small airways obstruction in smokers is not new and is consistent with previous reports of f-d R in asymptomatic smokers with normal spirometry but not in nonsmokers,[18,31,33–35,42] the demonstration of significantly higher AX in smokers is new. There are no published reports of f-d R and AX in normal adult subjects using an IOS, but unpublished data in 36 normal subjects in the second author's laboratory document a mean R5-R20 of 0.36 cm $H_2O/L/s$ (SD, 0.09) and mean AX of 1.5 cm H_2O/L (SD, 0.6). Results from the nonsmokers in the present study do not differ significantly from these normal indices of small airways mechanics. Perhaps the more interesting observation was that ironworkers who did not use a respirator with canister had greater large airways resistance than those who did. Increased large airways resistance in these subjects is consistent with high concentrations of large particles in the initial air pollution cloud, and the likelihood of such particles to impact in large airways rather than in the lung periphery. Effective respiratory protection would be expected to favor large airways, and it is notable that there were no significant differences in indices of small airways obstruction (f-d R, AX) related to effective respiratory protection. Because large airways resistance contributes directly to total respiratory resistance, total respiratory resistance was also greater in those who did not use the canister.

In summary, this study documents a high frequency of respiratory symptoms in a cohort of ironworkers present at the WTC disaster site with fewer abnormalities on physical examination, spirometry, and radiographic tests. Routine spirometry underestimated the prevalence of lung function abnormalities in comparison to FO testing. FO confirmed the presence of abnormal small airways function in smokers and identified lack of a respirator with canister as a risk factor for large airways dysfunction. Respiratory symptoms were not attributable to smoking or to exposure duration but were probably influenced by use of appropriate respiratory protection. None of the lung function tests distinguished between symptomatic and asymptomatic individuals. The probability exists that the abnormalities documented in this study are due to exposure at the WTC site. We cannot address this issue with certainty in the absence of baseline data (before September 11, 2001). Follow-up evaluation of symptoms and airways dysfunction should determine whether long-term clinical sequelae exist.

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