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Characteristics of a Residential and Working Community With Diverse Exposure to World Trade Center Dust, Gas, and Fumes

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Learning Objectives

- Review the types of physical symptoms and signs found in local residents and workers and clean-up workers exposed to conditions at the World Trade Center (WTC) site.
- Compare and contrast the findings to those in rescue and recovery workers, and discuss possible mechanisms of the abnormalities observed.
- Discuss the implications for disaster preparedness and health monitoring after environmental disasters.

Abstract

Objective: *To describe physical symptoms in those local residents, local workers, and cleanup workers who were enrolled in a treatment program and had reported symptoms and exposure to the dust, gas, and fumes released with the destruction of the World Trade Center (WTC) on September 11, 2001.* ***Methods:*** *Symptomatic individuals underwent standardized evaluation and subsequent treatment.* ***Results:*** *One thousand eight hundred ninety-eight individuals participated in the WTC Environmental Health Center between September 2005 and May 2008. Upper and lower respiratory symptoms that began after September 11, 2001 and persisted at the time of examination were common in each exposure population. Many (31%) had spirometry measurements below the lower limit of normal.* ***Conclusions:*** *Residents and local workers as well as those with work-associated exposure to WTC dust have new and persistent respiratory symptoms with lung function abnormalities 5 or more years after the WTC destruction.* (J Occup Environ Med. *2009; 51:534–541*)

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The destruction of the World Trade Center (WTC) towers on September 11, 2001 resulted in the massive release of dust, gas, and fumes with potential environmental and occupational exposures for thousands of individuals. Adverse health effects from these exposures are well described for rescue and recovery workers with work-related exposure.[1–7] Less is known about populations with exposure to the dust, gas, and fumes from the WTC disaster who were not involved in rescue and recovery activities. These populations include those who were working in the WTC towers or in the many surrounding offices, stores, and restaurants (local workers) as well as residents of the surrounding buildings (residents). Over 360,000 local workers and over 57,000 residents south of Canal Street in lower Manhattan alone have been estimated to have had potential for dust and fume exposure.[8] Additional work-exposed populations include those involved in the cleanup of the surrounding area (cleanup workers).

For those not involved in rescue and recovery activities, exposure to the WTC dust, gas, and fumes occurred in multiple ways. The collapse of the WTC towers resulted in an initial dust cloud with estimated levels of 100,000 mcg/m^3 of pulverized dust.[9] People in the vicinity of the WTC towers in lower Manhattan and western areas of Brooklyn on September 11, 2001 had potential exposure to this initial cloud of dust (dust cloud). The particles from the collapse settled on the streets, parks, and building exteriors over southern Manhattan and Brooklyn.[10] Incompletely removed dust had potential for resuspension and the fires that burned for 4 months generated continuous particles. Local workers and residents had potential for exposure to this more chronic exposure to outside dust. Particles entered the surrounding building interiors, which were covered in millimeters to several centimeters of WTC dust.[10,11] Local workers, residents, and cleanup workers all had potential for indoor dust exposure during cleanup activities of the indoor contaminants and from resuspended indoor particles. Gases and fine particles were generated from the fires that burned in the 16-acre WTC site for the ensuing 4 months.[10] Settled dust was composed of a mix of highly alkaline materials (pH, 11) consisting of pulverized concrete, fiberglass, glass, plastics, and other building materials containing polycyclic aromatic hydrocarbons, volatile organic compounds, lead, dioxin, and furans.[12] Indoor dust was enriched for small particles.[11] All these individuals therefore had potential for complex exposures including inhalation, ingestion, and superficial contact with pulverized dust from the initial dust cloud, inhalation and contact of persistent resuspended outdoor and indoor dust, as well as inhalation of fine particulate matter, gas, and fumes from the fires that burned for months.[9]

Most local workers returned to surrounding offices 1 week after the event when southern Manhattan was officially reopened for business. Some residents closest to the site were evacuated and returned over the ensuing 3 months. Many residents remained in their apartments and were never evacuated. Although most individuals cleaned their own residence or worksite, formal cleanup of indoor and outdoor commercial and some residential sites was performed by workers hired specifically for the activity. These cleanup activities continued for months.

Adverse health effects have been well described in those involved in rescue and recovery efforts.[1–5,13–15] We, and others have previously described the presence of new onset clinical symptoms in local residents or building evacuees compared with a control population in the initial years after September 11, 2001.[8,16,17] Respiratory symptoms were associated with prolonged exposure to the dust and fumes in a dose-response model in residents.[18] There is minimal information about the presence and persistence of symptoms in local workers, residents or cleanup workers more than 5 years after the event. In 2005, in response to requests from local community groups, Bellevue Hospital, an affiliate of the New York University School of Medicine and a public hospital in New York City, began a standardized medical program to provide treatment to local workers, residents, and cleanup workers with physical symptoms thought to be associated with WTC exposures. Funding from the American Red Cross and the City of New York subsequently supported the program. We now report the baseline clinical characteristics of the initial 1898 adults enrolled in this community clinic program and exploratory analyses of the relationship of self-reported dust exposures to respiratory symptoms and lung function.

Materials and Methods

Subjects

Patients presented to the Bellevue Hospital World Trade Center Environmental Health Center (WTC EHC) in response to information about the program distributed by community-based organizations and local news reports. The Institutional Review Board of New York University School of Medicine approved the research database (NCT00404898) and only patients who signed consent were used for analysis. Initial inclusion into the program was based on an initial telephone screen to document potential exposure to WTC dust, gas, or fumes as a local worker, resident, or cleanup worker in southern Manhattan on or in the months after September 11 and the presence of any physical symptom that occurred or was exacerbated after September 11. Patients who enrolled over the 33-month period from the end of September 2005 until June 2008 were included in this analysis. Although our initial funding included treatment of individuals involved in rescue and recovery (police, construction workers etc), as federal funding became available for these workers, we focused our program on local community members who were not covered under federally funded programs.

Procedures

Patients responded to a multi-dimensional interviewer-administered questionnaire that queried demographics; confirmed and characterized exposure to WTC dust via occupation, work or residence; symptoms, including severity and temporal relationship relative to September 11, 2001; and functional status. Questionnaires were translated into Spanish, Mandarin, Cantonese, and Polish using Bellevue Hospital Center's remote, real-time translation system. Severity of dyspnea was assessed using the modified Medical Research Council (MRC) dyspnea scale, which was added after the first 823 eligible patients had enrolled in the program.[19,20] A physical examination, mental health screen, blood test, and chest x-ray (CXR) were performed.

All individuals were initially referred for spirometry, which was performed in accordance with American Thoracic Society/European Respiratory Society standards[21] on a Sensormedics spirometer (Yorba Linda, CA). Predicted values for forced vital capacity (FVC), and forced expiratory volume in one second (FEV_1) were derived from NHANES III (National Health and Nutrition Education Survey).[22] From October 2007 to March 2008, consecutive individuals with lower respiratory symptoms and normal spirometry were invited to return for methacholine challenge studies. Methacholine challenge studies were performed according to the American Thoracic Society guidelines.[23]

Data Analysis

We describe the population as a whole, and grouped by potential population exposure category defined as local worker, resident, cleanup worker, or those involved in rescue and recovery. Residents or local workers lived or worked south of 14th street on September 11, 2001 or within the year after the event. For purposes of analysis, individuals were classified as residents if they were both residents and local workers. Cleanup workers were individuals hired to clean surrounding residences, offices, churches, libraries, and schools within the year after September 11, 2001. A small group ($N = 45$) of individuals could not be classified in any of these categories and we excluded them from subsequent analyses. Symptoms were classified as "new onset" if they were reported to have started after September 11, 2001. Symptoms were considered "persistent" if they occurred more than two times each week in the month prior to entry in the treatment program.

Descriptive statistics of counts and proportions were calculated for categorical variables and means and standard deviations were calculated for continuous variables. For each individual analysis, missing values were excluded from the calculations. In the univariate analysis comparing spirometry values between smokers and nonsmokers, Wilcoxon rank-sum test, which is robust to non-normality was used. Categorical variables were analyzed using the χ^2 test or the Fisher exact test if some cell numbers were small. Odds ratio (OR) and the corresponding 95% confidence interval (CI) or *P*-values were reported. All statistical analyses were conducted using SAS, version 9.1.

TABLE 1
Characteristics of WTC EHC Population (N = 1,898)

Characteristic, *N* (%)	Total[a] (*N* = 1,898)	Local Worker (*N* = 709)	Resident (*N* = 378)	Cleanup (*N* = 566)	Rescue/ Recovery (*N* = 200)
Gender					
Male	1,005 (53)	322 (45)	194 (51)	313 (55)	156 (78)
Age, mean ± SD	48 ± 12	50 ± 11	52 ± 14	43 ± 10	47 ± 10
Race					
White	867 (46)	309 (44)	158 (42)	247 (44)	130 (65)
Black	318 (17)	227 (32)	28 (7)	25 (4)	28 (14)
Asian	217 (11)	59 (8)	146 (39)	3 (1)	7 (4)
Other	48 (2)	22 (3)	3 (1)	12 (2)	6 (3)
No answer	448 (24)	92 (13)	43 (11)	279 (49)	29 (14)
Ethnicity					
Latino	792 (42)	172 (24)	68 (18)	482 (85)	57 (29)
Income/yr					
<15 K	839 (44)	172 (24)	211 (56)	381 (67)	55 (28)
15–30 K	339 (18)	121 (17)	59 (16)	118 (21)	35 (18)
>30 K	668 (35)	400 (56)	96 (25)	54 (10)	100 (50)
No answer	52 (3)	16 (2)	12 (3)	13 (2)	10 (5)
Insurance					
Uninsured	746 (39)	133 (19)	154 (41)	383 (68)	62 (31)
Tobacco					
≥5 p-y	432 (23)[b]	182 (26)	103 (28)	74 (13)	62 (32)
Dust cloud	749 (40)	413 (60)	151 (41)	115 (21)	67 (34)

[a]Forty-five individuals could not be classified in defined population exposure categories.
[b]Fifty-two patients had missing data.

Results

Patient Characteristics

One thousand eight hundred ninety-eight patients ≥17 years of age were consecutively enrolled and signed consents between September 2005 and May 2008. The baseline demographics of the clinic population are shown in Table 1. The population included a large number of women (47%) and there was a mean age of 48 years, with little variation in age among the exposure groups. The population was racially diverse, although many individuals chose not to classify themselves into any specific race. Almost half (42%) of the population and most of the cleanup workers were self-reported Latino ethnicity and of these, many were from South America including Columbia (33%) and Ecuador (20%), with fewer from the Caribbean islands of the Dominican Republic (10%) and Puerto Rico (8%). Residents and cleanup workers tended to have low incomes and no health insurance. Most people (77%) had a <5 pack-year (p-y) tobacco history.

Population Exposure Categories

It has not been possible to measure or estimate the absolute or relative exposures of members of the population to the dust, gas, and fumes that resulted from the destruction of the WTC towers with any precision. We therefore grouped our population into exposure categories as local workers and residents with potential non-occupational exposure to WTC dust, gas, and fumes, or cleanup workers, rescue and recovery workers with work-related exposure (Table 1). Our population included local workers (37%), residents (20%) and cleanup workers (30%). We initially began as a philanthropy-funded program with a target population that included rescue and recovery workers and thus 11% of our population fit this category. A small number of individuals (2%) could not be classified in any of these exposure categories. Because of the potential for massive

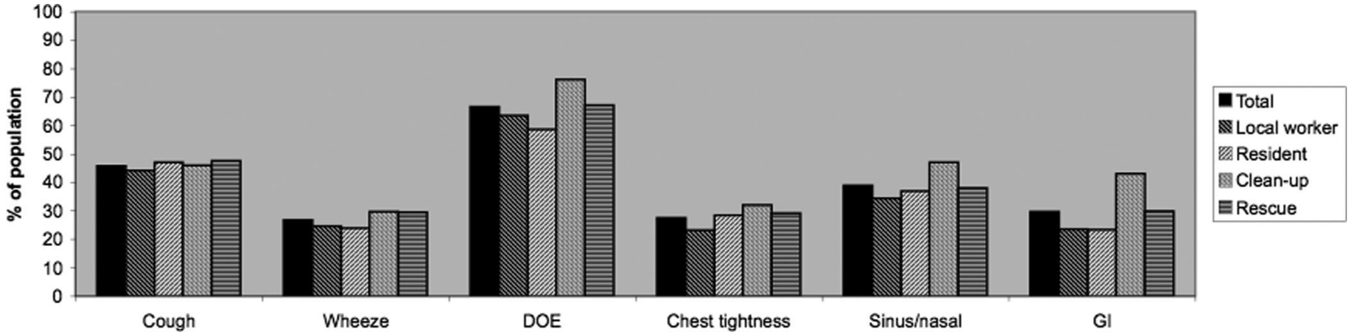

Fig. 1. Presence of new onset and persistent symptoms in WTC EHC population ($N = 1852$). New onset symptoms were defined as those with onset after September 11, 2001 and present on entry into the program. Persistent symptoms were defined as those present at a frequency of more than twice each week in the month preceding entry into the WTC EHC. Data presented for total population and for local workers, residents, cleanup workers, and rescue and recovery workers. Symptoms include cough, wheeze, DOE, chest tightness, sinus, or nasal congestion (sinus or nasal), or symptoms of acid reflux. Data missing for 46 patients.

particle inhalation and ingestion from the initial dust cloud on September 11, 2001, we also characterized our population by exposure to the dust cloud. Many local workers and residents reported exposure to this initial dust cloud.

Presence of New Onset and Persistent Symptoms

Enrollment in the WTC EHC required report of any physical symptom without a restriction as to the type of symptom. Most symptoms that patients reported, however, related to the upper and lower respiratory tract, and the distribution of the most common new onset and persistent symptoms on entry is shown in Fig. 1. Dyspnea on exertion (DOE) and cough were the most common symptoms (67% and 46%, respectively), although many described nasal or sinus congestion (39%) and less commonly wheeze (27%) and chest tightness (28%). As previously described for the rescue and recovery workers, gastrointestinal symptoms such as acid reflux were also common. The pattern of symptoms was remarkably similar across all exposure categories. Individuals with a <5 p-y tobacco history had symptoms that were similar to the population as a whole, with new onset and persistent DOE (66%), cough (47%), wheeze (26%), and sinus or nasal congestion (40%).

Severity of dyspnea was assessed using the modified MRC dyspnea scale (Table 2).[19] Forty-one percent of the total population had a dyspnea score of "3" or greater corresponding to moderate to severely disabling dyspnea.[20] Ten percent had the maximal score of "5." A significant association was noted for dust cloud exposure and new onset and persistent DOE (OR: 1.4, 95% CI: 1.1 to 1.8). Dust cloud exposure was also significantly associated with a score of "3" or more on the MRC dyspnea scale in local workers ($P = 0.01$) and in the local workers with a <5 p-y tobacco history ($P = 0.02$).

TABLE 2
Modified MRC Dyspnea Rating Scores ($N = 1{,}075^a$)

MRC Dyspnea Grade[b]	Total (%) $N = 1{,}075$	Local Worker (%) $N = 556$	Resident (%) $N = 192$	Cleanup (%) $N = 160$	Rescue/ Recovery (%) $N = 129$
Grade 0	21	22	20	17	19
Grade 1	10	11	13	9	9
Grade 2	28	30	27	24	28
Grade 3	18	19	16	19	18
Grade 4	13	10	13	19	16
Grade 5	10	9	11	12	10

[a]MRC dyspnea questionnaire added after first 823 eligible patients had enrolled.
[b]Numbers correspond to five statements about perceived breathlessness: grade 1, "I only get breathless with strenuous exercise"; grade 2, "I get short of breath when hurrying on the level or up a slight hill"; grade 3, "I walk slower than people of the same age on the level because of breathlessness or have to stop for breath when walking at my own pace on the level"; grade 4, "I stop for breath after walking 100 yards or after a few minutes on the level"; grade 5, " I am too breathless to leave the house." Patients who did not fit any of the grades were given a grade of "0."

Chest X-Ray

One thousand six hundred seventy-nine patients had CXRs performed as part of their initial evaluation. Most (90%) of these CXRs were reported as normal. Abnormalities were rare and most commonly included descriptions of flattened diaphragms (3%), single or multiple nodules (2%), increased bronchovascular markings (1%) or enlarged hilar or mediastinal nodes (1%).

Lung Function Studies

Spirometry results were available for 1475 of the patients (Table 3). Four hundred twenty-three patients did not return for spirometry ($N = 353$) or were unable to perform studies acceptable for analysis ($N = 70$). The patients with lung function studies had similar demographics and similar exposure to WTC by-products and tobacco as those in the

TABLE 3
Baseline Spirometry Values in Total Population and Population Exposure Categories ($N = 1{,}475$[a])

Spirometry[b]	Total ($N = 1{,}475$)	Local Worker ($N = 546$)	Resident ($N = 303$)	Cleanup ($N = 439$)	Rescue/ Recovery ($N = 151$)
FVC (% of predicted)	91 ± 16	91 ± 17	89 ± 18	93 ± 14	91 ± 16
<5 p-y	92 ± 16	91 ± 16	90 ± 18	93 ± 14	93 ± 15
≥5 p-y	89 ± 17*	90 ± 18	87 ± 16	92 ± 15	87 ± 17
FEV_1 (% of predicted)	90 ± 17	89 ± 18	87 ± 20	92 ± 15	88 ± 17
<5 p-y	91 ± 16	90 ± 16	89 ± 19	93 ± 14	90 ± 16
≥5 p-y	85 ± 20**	86 ± 21*	82 ± 21*	88 ± 17*	82 ± 19*
FEV_1/FVC	78 ± 8	78 ± 8	77 ± 10	80 ± 7	76 ± 9
<5 p-y	79 ± 7	79 ± 7	79 ± 8	81 ± 6	77 ± 8
≥5 p-y	74 ± 10**	74 ± 10**	72 ± 12**	76 ± 9**	74 ± 11

*$P \leq 0.04$ for <5 p-y vs ≥5 p-y.
**$P < 0.0001$ for <5 p-y vs ≥5 p-y.
[a]Four hundred twenty-three patients did not do return for spirometry or had inadequate spirometry.
[b]Data presented as mean ± SD. Percentage predicted derived from NHANES III.

TABLE 4
Patterns of Abnormal Spirometry in WTC EHC Patients With <5 p-y Tobacco Use ($N = 1{,}109$)

Spirometry Pattern *N* (%)	Total ($N = 1{,}109$)	Local Worker ($N = 397$)	Resident ($N = 214$)	Cleanup ($N = 371$)	Rescue/ Recovery ($N = 101$)
Obstructed[a]	67 (6)	28 (7)	10 (5)	15 (4)	12 (12)
Low FVC[b]	224 (20)	83 (21)	57 (27)	64 (17)	16 (16)
Obstructed and low FVC[c]	28 (3)	6 (2)	9 (4)	9 (2)	2 (2)
Any abnormality	319 (29)	117 (29)	76 (36)	88 (24)	30 (30)

[a]$FEV_1/FVC < LLN_{FEV1/FVC}$ and $FVC \geq LLN_{FVC}$.
[b]$FVC < LLN_{FVC}$ and $FEV_1/FVC \geq LLN_{FEV1/FVC}$.
[c]$FEV_1/FVC < LLN_{FEV1/FVC}$ and $FVC < LLN_{FVC}$.

total population (data not shown). The prevalence of lower respiratory symptoms did not differ significantly between patients who had completed studies and those that did not return or could not perform studies acceptable for interpretation.

Mean values of FVC, FEV_1, and the ratio of FEV_1/FVC were within normal for the total population as well as for each exposure group. As expected for tobacco use, the presence of ≥5 p-y tobacco history was significantly associated with a reduction in FEV_1 and FEV_1/FVC. Although exposure to the dust cloud was not shown to have a significant effect on lung function in the population as a whole, there was a slight but significant reduction in prebronchodilator FEV_1/FVC in residents exposed to the dust cloud compared with those not exposed (75.7 vs 78.1, respectively, $P = 0.03$).

We subsequently classified spirometry results into normal or abnormal patterns using the lower limits of normal (LLN), defined as values below the lower fifth percentile, derived from the NHANES III population. Spirometry results were classified as "normal," "obstructed" ($FEV_1/FVC < LLN_{FEV1/FVC}$ and $FVC \geq LLN_{FVC}$), "low FVC" ($FVC < LLN_{FVC}$ and $FEV_1/FVC \geq LLN_{FEV1/FVC}$), or both "obstructed and low FVC" ($FEV_1/FVC < LLN_{FEV1/FVC}$ and $FVC < LLN_{FVC}$) in a manner similar to that previously described.[4,22] Using this type of classification, 32% of the total population and 29% of the patients with a less than 5 p-y history of tobacco use had spirometry results that were below the LLN and data are shown for those with a less than 5 p-y tobacco history ($N = 1109$) (Table 4). The most common abnormality was a "low FVC" pattern, a finding similar to that previously described for individuals involved in rescue and recovery activities.[4,15] This pattern was observed in each of our exposure categories. We could not identify a clear relationship between exposure to the dust cloud and the presence of abnormal spirometry pattern when classified in this manner.

To further clarify the mechanism for respiratory symptoms in our patients with normal lung function, we sampled the population to evaluate whether these symptoms were associated with airway hyperresponsiveness. Between the months of October 2007 and March 2008 individuals with normal spirometry and any lower respiratory symptom defined as cough, shortness of breath or wheeze were consecutively referred for methacholine challenge studies. Sixty-eight individuals completed the examination. Fifty-one percent of these patients had a PC_{20} ≤4 mg/mL consistent with airway hyperreactivity.[23]

We examined whether patients with any of the abnormal spirometry patterns had improved lung function after bronchodilator and data are shown for patients with <5 p-y tobacco history ($N = 319$) (Table 5). There was significant improvement in FEV_1 in patients with the "obstructed" pattern ($P < 0.0001$) and a significant, but small improvement in FEV_1 in patients with a "low FVC" pattern ($P = 0.0003$). Both the FEV_1 and FVC improved in response to bronchodilator in the "obstructed and low FVC" group ($P < 0.0001$).

Because DOE was the most common symptom identified, we examined whether there was an association between a severity level of "3" or more in the MRC dyspnea scale and an abnormal spirometry pattern. A dyspnea score of "3" or more was associated with a "low FVC," or an

TABLE 5
Bronchodilator (bd) Response in Patients With Abnormal Pattern of Spirometry

	Pre bd	Post bd	Percentage Change
"Obstructed" (N = 67)			
FVC—L (% of predicted)	4.0 ± 1.1 (98.0 ± 12.7)	4.1 ± 1.2 (99.7 ± 14.6)	1.0
FEV_1—L (% predicted)	2.6 ± 0.7 (81.0 ± 12.9)	2.9 ± 0.8* (88.7 ± 13.6)	9.2
FEV_1/FVC	65.7 ± 5.3	70.9 ± 5.5	
"Low FVC" (N = 224)			
FVC—L (% of predicted)	2.9 ± 0.7 (72.1 ± 8.2)	2.9 ± 0.7 (72.4 ± 9.5)	1.5
FEV_1—L (% predicted)	2.4 ± 0.6 (74.6 ± 9.8)	2.4 ± 0.6* (75.8 ± 11.3)	3.7
FEV_1/FVC	82.0 ± 5.7	83.0 ± 6.7	
"Obstructed and low FVC" (N = 28)			
FVC—L (% of predicted)	2.7 ± 0.8 (68.1 ± 8.7)	2.9 ± 0.9* (74.4 ± 11.3)	10.2
FEV_1—L (% predicted)	1.6 ± 0.6 (52.5 ± 8.9)	1.9 ± 0.6* (61.1 ± 10.7)	18.7
FEV_1/FVC	61.0 ± 9.0	64.9 ± 9.3	

*$P \leq 0.0003$ compared with pre bd value.

"obstructed and low FVC" pattern in the total population ($P = 0.0001$ and $P = 0.0004$, respectively) and in the population with a <5 p-y tobacco history ($P = 0.005$ and $P = 0.05$, respectively).

Discussion

We have documented physical symptoms that developed after September 11, 2001 among local residents and local workers as well as in cleanup workers exposed to dust, gas, and fumes from the WTC destruction. These symptoms were present despite the passage of more than 5 years since exposure. Upper and lower respiratory symptoms including DOE, cough, and wheeze were particularly common. Despite the different ways in which WTC dust and fume exposure may have occurred, the symptoms described in each of the exposure categories we defined were strikingly similar to those that have been published for the occupationally exposed rescue and recovery workers.[3–5] The symptoms also were similar to those identified in the small number of rescue and recovery workers in our program. Exposure to the dust cloud appeared to increase the risk for DOE in those with non-occupational exposures. Although mean spirometry values were normal for the population as a whole, almost one third had values below the LLN with different patterns of abnormalities. More than half of a sampled population with normal spirometry was hyperresponsive to methacholine, a rate that is higher than that that described in most studies of asymptomatic individuals.[24] New-onset and persistent DOE was associated with patterns that included a reduced FVC.

We have grouped our patients by their status and potential for WTC dust, gas, and fume exposures on September 11, 2001 as a local worker, resident, cleanup worker, rescue, and recovery workers. Good exposure measurements for these groups are lacking due to the absence of systematic measurements of the airborne gases and particles, particularly during the first few days after the collapse. Exposure assessments are also limited by the few measurements of the resuspended particles, the variation in components of the substances released over the initial days and months, and differences in patterns of contact.[10] Lioy et al[10] have proposed a model of five types of environmental and occupational exposures. This model includes exposure to the initial pulverized building materials and jet fuel fires and the most intense period of the WTC plume emissions. This period would correspond to the "dust cloud" period and as expected, this exposure was most common in the local workers and was associated with dyspnea. Additional exposure periods include outdoor exposures from September 11, 2001 to the end of September due to the re-suspension of particulate mass and the massive fires at Ground Zero. Evacuated residents and local workers returning to their homes and work, as well as cleanup workers, all had potential for exposure at this time. Over the ensuing months, the fires continued and ambient particulate matter levels were noted to be elevated on particular days. Many in our exposure categories had potential for exposure during this time as well. The last category described by Lioy et al includes indoor exposures. This is the least well characterized exposure type because of non-uniformity in contamination of buildings, differences in the amounts of dust, variations in the procedures employed to clean the dust, and variations in the contact with settled WTC dust and smoke.[12] The local workers, residents, and cleanup workers all had potential for this type of exposure.

The chemical components of the toxins in the dust, gas, and fumes generated by the destruction of the WTC towers support the biologic plausibility of adverse health and particularly respiratory effects. Measurements of settled dust documented that these particles were highly alkaline (pH 11),[12] and this property alone has been shown to be associated with respiratory effects. Occupational exposure to inhaled alkaline material induces chronic cough, phlegm, and dyspnea as well as upper respiratory tract symptoms.[25] Exposure to alkaline dusts in a residential population has been described to produce similar symptoms.[26] In vitro and animal studies of settled WTC dust also suggest toxicity.[27,28]

Although lower respiratory symptoms of DOE, cough, chest tightness, and wheeze were common, these symptoms can be due to a variety of mechanisms. Airway diseases, including reactive airways dysfunction and irritant-induced asthma have been proposed in the responder and firefighter populations.[1,15] We and others have suggested involvement of peripheral or small airways in some patients using physiologic techniques and high resolution computerized tomography,[29,30] and bronchiolitis obliterans has been described in a case report.[31] Parenchymal diseases such as a sarcoid-like illnesses have also been described in firefighters. Only a small number of our patients had abnormalities consistent with obvious airway or parenchymal disease on their CXR.

Identification of lung function abnormalities may be difficult in cross-sectional studies of populations such as ours. Many of the WTC-exposed firefighters had apparently normal lung function, and only longitudinal measurements revealed a much greater than expected loss of lung function.[32] Lung function can also be normal in patients with asthma in the absence of an acute exacerbation or until significant airway remodeling has occurred, and distal airway or peripheral lung disease may not be detectable with spirometry.[29,30,33] Lung function can also be normal in early interstitial lung diseases. Although the mean spirometry values were normal in our population, one third had measurements below their expected values. We suspect that the symptoms in our population are due to heterogeneous mechanisms. The presence of positive methacholine challenge studies in a sampled population with normal spirometry suggests airway hyperreactivity consistent with irritant-induced asthma, in some, but not all of our patients. Some of the symptoms in the patients with normal spirometry may also be due to distal airway or peripheral lung disease, which would not be detectable with spirometry.[29,30,33] The patterns of spirometry in patients with abnormal lung function also suggest heterogeneity in the disease. Those with an "obstructed" pattern had some response to bronchodilator, suggesting the presence of reversible airway disease consistent with asthma. Those with the "obstructed and low FVC" pattern had the lowest spirometry values and had improvement in both FEV_1 and FVC in response to bronchodilator, raising the possibility of airway disease associated with air trapping. In contrast, those with a "low FVC" pattern had minimal improvement with bronchodilator, suggesting that this abnormality might be due to a different mechanism. Further studies are warranted for the elucidation of mechanisms of these abnormalities.

There are several potential limitations to the interpretation of our data. This was a self-referred population whose enrollment depended on the presence of any symptom and the potential for exposure to WTC dust. The prevalence and incidence of persistent symptoms that developed after September 11, 2001 remain unknown in the larger population. A recent report suggests the possibility that approximately 120,000 local residents or building occupants may have had new onset or worsening respiratory symptoms and 4100 may have newly diagnosed asthma, consistent with a 3% increase in asthma rates.[34] Our data were obtained from patients who reported exposures to WTC dust, gas, or fumes and symptoms thought to be caused by these exposures and thus do not lend themselves to formal tests of association between exposure and disease or symptoms. Because of the unexpected nature of the disaster, the causal relationship between the diverse exposures WTC dust gas and fumes and the described symptoms is difficult to determine and the absence of a specific biomarker of exposure to WTC dust, the complex mixtures of the dust gas and fumes, and the diverse potential for exposures makes biologic assessment of toxicologic effects difficult.[10] We have used a combination of the presence of exposure, the temporal pattern of the symptoms, and the consistency of findings to suggest a causal relationship as suggested for occupational health risk assessments.[35] The association of a greater risk for DOE with exposure to the dust cloud suggests a relationship to a high intensity exposure, lending further credence to causality. We do not have preexisting medical data as many of the individuals in our program sought little or only sporadic medical care before September 11, 2001 and measurements of lung function are not performed routinely. Our measures are self-reported, and thus there is a risk of recall bias. This bias may be more likely in those with potential for secondary gain, however, few in our population were eligible for monetary reimbursement and worker's compensation was only available to those with occupational WTC exposure. The resemblance of the symptoms in our population to those reported for the WTC rescue and recovery workers is consistent with a similar process of disease.

In sum, we have described new onset and persistent respiratory symptoms in populations with diverse potential for exposure to WTC dust, gas, and fumes including local workers and residents. The known chemical composition of the dust and fumes and the time sequence of occurrence of symptoms after the collapse of the WTC towers, makes an association between the symptoms and WTC toxicant exposure likely. The similarity of symptoms and lung function abnormalities in residents and local workers with those of cleanup and rescue and recovery workers supports this relationship. Abnormalities in spirometry suggest heterogeneity of disease. The presence of symptoms over 5 years after the event suggests a continued need for provision of services and medical surveillance, which will help clarify mechanisms of disease. The difficulties faced in determining disease causality and assessment underscore the need for rapid monitoring of health effects in all populations in the setting of potential environmental disasters.

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