HHS Public Access

Author manuscript

*Am J Ind Med*. Author manuscript; available in PMC 2017 December 07.

Published in final edited form as:

*Am J Ind Med*. 2013 August ; 56(8): 870–880. doi:10.1002/ajim.22171.

# The Respiratory Pyramid: From Symptoms to Disease in World Trade Center Exposed Firefighters

**Justin K. Niles, MA**[1], **Mayris P. Webber, DrPH, MPH**[2,3,*], **Hillel W. Cohen, DrPH**[3], **Charles B. Hall, PhD**[3], **Rachel Zeig-Owens, MPH**[2], **Fen Ye, MS**[2], **Michelle S. Glaser, MPH**[2], **Jessica Weakley, MPH**[2], **Michael D. Weiden, MD**[1,4], **Thomas K. Aldrich, MD**[2,3], **Anna Nolan, MD, MS**[1,4], **Lara Glass, MPH**[1], **Kerry J. Kelly, MD**[1], and **David J. Prezant, MD**[1,2,3]

[1]Fire Department of the City of New York, Bureau of Health Services, Brooklyn, New York

[2]Department of Medicine, Montefiore Medical Center, Bronx, New York

[3]Department of Epidemiology and Population Health, Albert Einstein College of Medicine, Bronx, New York

[4]Division of Pulmonary, Critical Care and Sleep, New York University, School of Medicine, New York, New York

## Abstract

**Background—**This study utilizes a four-level pyramid framework to understand the relationship between symptom reports and/or abnormal pulmonary function and diagnoses of airway diseases (AD), including asthma, recurrent bronchitis and COPD/emphysema in WTC-exposed firefighters. We compare the distribution of pyramid levels at two time-points: by 9/11/2005 and by 9/11/2010.

**Methods—**We studied 6,931 WTC-exposed FDNY firefighters who completed a monitoring exam during the early period and at least two additional follow-up exams 9/11/2005–9/11/2010.

**Results—**By 9/11/2005 the pyramid structure was as follows: 4,039 (58.3%) in Level 1, no respiratory evaluation or treatment; 1,608 (23.2%) in Level 2, evaluation or treatment without AD diagnosis; 1,005 (14.5%) in Level 3, a single AD diagnosis (asthma, emphysema/COPD, or recurrent bronchitis); 279 (4.0%) in Level 4, asthma and another AD. By 9/11/2010, the pyramid distribution changed considerably, with Level 1 decreasing to 2,612 (37.7% of the cohort), and Levels 3 (N = 1,530) and 4 (N = 796) increasing to 22.1% and 11.5% of the cohort, respectively. Symptoms, spirometry measurements and healthcare utilization were associated with higher pyramid levels.

**Conclusions—**Respiratory diagnoses, even four years after a major inhalation event, are not the only drivers of future healthcare utilization. Symptoms and abnormal FEV-1 values must also be considered if clinicians and healthcare administrators are to accurately anticipate future treatment needs, years after initial exposure.

*Correspondence to: Dr. Mayris P. Webber, DrPH, MPH, Department of Epidemiology and Population Health, Montefiore Medical Center/Albert Einstein College of Medicine and Director of WTC Epidemiology, Bureau of Health Services, Fire Department of the City of New York, Brooklyn, NY. mwebber@montefiore.org, webberm@fdny.nyc.gov.

Disclosure Statement: The authors report no conflicts of interests.

**Keywords**

World Trade Center; asthma; pulmonary function; treatment outcomes

## INTRODUCTION

After the September 11, 2001 (9/11) terrorist attacks on the World Trade Center (WTC), an integrated monitoring and treatment program was created for the WTC-exposed New York City Fire Department (FDNY) workforce. This program provides annual monitoring/ wellness exams and, when indicated, treatment services for WTC-related conditions at no charge to personnel. Adverse health outcomes associated with rescue and recovery exposures have been well documented in the FDNY workforce through this monitoring program and include respiratory symptoms [Webber et al., 2009; Weakley et al., 2011], airway hyper-reactivity [Prezant et al., 2002; Banauch et al., 2003; Weiden et al., 2010], substantial initial declines in pulmonary function which plateaued over the next 6 years [Prezant et al., 2002; Aldrich et al., 2010] and new onset pulmonary disease, mostly airway diseases (AD), including asthma, bronchitis and chronic obstructive pulmonary disease (COPD/ emphysema) [Weakley et al., 2011; Webber et al., 2011a]. While these and other studies have reported cross-sectional and longitudinal symptom and disease rates, the relationship between symptoms and progression to physician diagnoses has not been explored. Understanding this relationship is critical for predicting healthcare needs after a widespread inhalation exposure that could occur with any major occupational or environmental disaster.

The primary goal of this work is to examine the extent to which early post-disaster symptoms and diagnoses accurately anticipate future health care needs of a highly exposed group of workers. This study utilizes a four-level pyramid framework to understand the relationship between respiratory findings at monitoring/wellness exams (i.e., symptom reports and/or abnormal pulmonary function) and the diagnosis of respiratory diseases in WTC-exposed firefighters up to 9/11/2005, and the further evolution of this relationship by 9/11/2010. Finally, we use this pyramid framework to examine the association between AD diagnoses and treatment as estimated by physician visits and prescription medication use in the final year of this study, thereby integrating these elements into a single conceptual model of post-exposure respiratory illness.

## METHODS

The FDNY-WTC Medical Monitoring and Treatment Program (FDNY-WTC-MMTP) schedules monitoring evaluations of the FDNY active and retired workforce approximately every 12–18 months and separate visits for treatment, as required. Monitoring evaluations include self-administered questionnaires, with trained personnel available to answer participant questions. Each monitoring visit includes a physician examination. An FDNY physician “respiratory evaluation” visit was defined as any visit where the physician discussed respiratory concerns or provided respiratory testing or treatment beyond the scope of the typical monitoring visit. Respiratory evaluations could occur by physician referral or

self-referral. Study participants provided informed-consent. The study was approved by the institutional review board at Montefiore Medical Center.

### Study Participants and Study Period

The original study population consisted of 12,354 FDNY male firefighters who first arrived at the WTC site within 2 weeks of 9/11 and who were hired before the site closed in July 2002. We excluded data from 340 fire marshals due to differences in their job tasks, leaving 12,014 eligible firefighters. For inclusion in this analytic cohort, we required a minimum of three medical monitoring exams, one between 9/11/2002 and 9/10/2005 (early period) and at least two others between 9/11/2005 and the end of the study, 9/10/2010. Of the 8,103 firefighters who completed at least one exam during the early period, 7,209 (89.0%) qualified for inclusion by completing at least two others between 9/11/2005 and 9/10/2010. Finally, we included only non-Hispanic Black and White employees, because reliable pulmonary function prediction equations for other race/ethnicities were not available [Hankinson et al., 1999], resulting in an analytic cohort of 6,931 (56.1%) for this study.

### Data Sources

Demographic information was obtained from the FDNY employee databases. Monitoring questionnaire data and the FDNY electronic medical record database were used to define covariates and outcomes. Billing records from the FDNY-WTC-MMTP pharmacy benefits plan (Express Scripts Inc., available since 2007), including fill and refill dates, were used to describe the types of medications used and their costs. We did not include antibiotic prescriptions because it was difficult to reliably assign antibiotic use to bronchitis as opposed to pharyngitis or sinusitis.

### Respiratory Symptoms

Respiratory symptom(s) reported on monitoring questionnaires, were based on responses to the question, “Since your last FDNY/WTC annual medical, apart from when you had a cold or flu, did you have any of the following symptoms?” Possible responses included “None,” “wheezing or whistling in your chest,” “chest tightness,” “shortness of breath,” “frequent or usual cough (at least four times per day, 4 days per week, four consecutive weeks per year).” Except for “none,” individuals were not limited to one response. Symptoms were analyzed cumulatively and were considered to be present if they were reported on any questionnaire up to the last day of the index period (either 2005 or 2010).

### Physician Diagnoses

Physician diagnoses were either self-reported or obtained from the FDNY medical record. Self-reported physician AD diagnoses came from the following monitoring exam questions: “Since 9/11 (or since your last medical exam during follow-up monitoring exams), has a doctor or health professional told you that you have asthma, chronic bronchitis or COPD/emphysema?” FDNY physician AD diagnoses were based on medical exams and included asthma, COPD/emphysema and bronchitis. Because information was not always available on sputum production or duration, we required a patient to have had at least three visits to an FDNY physician for bronchitis (coded as acute or unspecified) or a chronic bronchitis

diagnosis to meet our study definition of recurrent bronchitis, using the date of the third bronchitis diagnosis as the diagnosis date. COPD/emphysema and recurrent bronchitis diagnoses were grouped and considered “non-asthma AD.” Diagnoses were selected by the examining physicians based on history, physical examination, spirometry, and when clinically indicated, other pulmonary function testing and chest imaging. Physician diagnoses were analyzed cumulatively and considered permanent, partly because it was difficult to differentiate between “resolved” disease and disease that was being successfully managed with medications. New diagnoses were added, when clinically indicated. Since we did not have access to records of non-FDNY physicians, we could not validate self-reports of physician diagnosis. Non-AD respiratory diagnoses (sarcoidosis, pulmonary fibrosis) previously found to be associated with WTC exposure [Izbicki et al., 2007], were not included as outcome diagnoses as they were rare and had dramatically higher healthcare costs.

### WTC Exposure Status

The FDNY-WTC Exposure Intensity Index [Prezant et al., 2002] defined four groups based on initial arrival time at the WTC site as follows: arriving morning of 9/11; arriving afternoon of 9/11; arriving 9/12, Day 2; or arriving anytime between Days 3 and 14. The duration variable was a summation of self-reported calendar months each person worked at the site, on or off duty, from September 2001 through July 2002.

### Tobacco Smoking Status

Tobacco smoking was defined as “ever” if reported as current or former on any monitoring questionnaire and as “never” if consistently reported never smoking.

### Spirometry Analyses

Even before 9/11, firefighters underwent spirometry testing, performed following American Thoracic Society criteria [Miller et al., 2005], during their medical monitoring exams [Aldrich et al., 2010]. We examined the observed decline in Forced Expiratory Volume in the first second (FEV-1) between the last pre-9/11 exam and all subsequent exams until the end of the study period. We defined abnormal FEV-1 as either a 15% decline in absolute FEV-1 from baseline or FEV-1 below the lower limits of normal (LLN) (NHANES III), which in virtually all cases in our population translated to 78% predicted or lower. We adjusted the observed decline in absolute FEV-1 for the mean age-related decline of 26 ml per year as reported in our previous lung function study [Aldrich et al., 2010]. We graded and recorded FVC, but focused our analyses on the more reproducible FEV-1.

### Pyramid Structure

Each pyramid is a cross-sectional snapshot of the study cohort during a specific time interval with four mutually exclusive levels. Level 1 includes all WTC-exposed firefighters in monitoring, without visits for respiratory evaluation or treatment to an FDNY physician. Level 2 is made up of those with at least one visit (for evaluation and/or treatment) to an FDNY physician but whose visit(s) did not result in an AD diagnosis. Levels 3 and 4 contain firefighters with an AD diagnosis from an FDNY physician or who self-reported a physician

diagnosis from a clinician outside the FDNY program. Level 3 is composed of firefighters with one AD diagnosis (either an asthma diagnosis alone or a non-asthma AD diagnosis alone) and Level 4, at the apex of the pyramid, with diagnoses of both asthma and non-asthma AD (Fig. 1). The composition of each level is cumulative to that time point.

### Statistical Analyses

Continuous data are presented as mean ± standard deviation and associations were assessed using the *t*-test, ANOVA or Spearman correlation statistics, as appropriate. Bivariate associations of categorical variables were assessed using the chi-square test with odds ratios (OR) and 95% confidence intervals (95% CI). Trends in proportions were examined using the Cochran Armitage test. We developed logistic models predicting healthcare utilization outcomes by individual firefighters in the final year of the study, using covariates from the early period. We also developed aggregate models to examine associations between factors found in the early period and increasing pyramid levels. Final models included all covariates that were significantly associated with outcomes. We excluded those without BMI measurements during the first part of the study from all models (N = 5). Those arriving at the WTC site on Days 3–14 were used as the referent exposure group. We required a two-tailed *P*-value of <0.05 for statistical significance. Data were analyzed using SAS, version 9.1 (SAS Institute, Cary, NC).

## RESULTS

### Cohort Characteristics

We compared the 6,931 firefighters in the analytic cohort to the 5,423 who did not meet inclusion criteria (Table I). The analytic cohort was younger on 9/11 (38.1 ± 6.9 years vs. 46.4 ± 9.3 years; $P < 0.01$) and included a greater proportion of individuals who worked 4 or more months at the WTC site (54.5% vs. 40.3%; $P < 0.01$). There was no significant difference in the proportion first arriving at the WTC during the morning of 9/11, (15.3% vs. 15.0%).

### Respiratory Disease Post-9/11

Figure 1 shows two snapshots of the pyramid distribution on 9/11/2005 and on 9/11/2010. For the early pyramid, Level 1 is comprised of the 4,039 (58.3%) firefighters who were not evaluated by an FDNY physician for respiratory conditions. Level 2 contains those with respiratory evaluations by an FDNY physician but whose visit(s) did not result in an AD diagnosis (N = 1,608, 23.2%). Level 3 includes the 1,005 (14.5%) firefighters with either asthma or non-asthma AD diagnoses. However, we note that since COPD/emphysema was rare in this cohort, almost all of the non-asthma AD diagnoses were recurrent bronchitis. Level 4 of the pyramid was comprised of 279 (4.0%) firefighters with both asthma and non-asthma AD diagnoses.

By 9/11/2010, the pyramid composition had changed considerably due to increases in the number of firefighters evaluated for respiratory problems and diagnosed with AD. The number with respiratory evaluations and no AD diagnoses increased to 28.8% of the cohort (Level 2), while the number with an asthma or non-asthma AD diagnosis increased by 52–

22.1% of the cohort (Level 3) and the number with both asthma and non-asthma AD diagnoses nearly tripled, increasing to 11.5% of the cohort (Level 4). This increase in diagnoses was responsible for the diminution of Level 1: those without respiratory evaluation, which declined from 58.3% to 37.7% of the cohort.

Table II shows the evolution of the pyramid structure over the study period, including the number of individuals progressing from lower to higher pyramid levels. Firefighters on Level 2 of the 9/11/2005 pyramid were significantly more likely to have at least one AD diagnosis by 9/11/2010 (OR 2.2, 95% CI 1.9–2.5) than those on Level 1. The prevalence of asthma increased from 8.3% to 18.0% and the prevalence of any AD diagnosis (including asthma) increased from 18.5% to 33.6% over the study period. 70% of self-reported asthma diagnoses also had a diagnosis of asthma by an FDNY physician.

## Characteristics by Final Pyramid Level

Table III shows selected characteristics of the cohort by pyramid levels at the end of the study period—9/11/ 2010. Those first arriving at the WTC during the morning of 9/11 were significantly more likely to end up in higher levels of the pyramid. The same was true for the proportion working 4 or more months at the WTC site and in firefighters who were ≥45 years on 9/11. Differences in BMI were statistically significant, but were too small to be of clinical significance; the proportion of cigarette smokers (ever vs. never) was similar.

## Monitoring Results by Pyramid Level

Table IV examines the relationship between pyramid levels and symptoms/abnormal FEV-1 by 9/11/2005 and the evolution of this relationship by 9/11/2010. A greater proportion of patients on higher pyramid levels reported respiratory symptoms ($P < 0.01$) compared with those on lower pyramid levels both during the initial monitoring exam (9/11/02 to 9/11/05) and cumulatively through 9/11/ 2010. There was also a statistically significant trend (Rho = 0.30, $P < 0.01$) in the median number of respiratory symptoms between pyramid levels by 9/11/2005 (Rho = 0.30, $P < 0.01$) and by 9/11/2010 (Rho = 0.42, $P < 0.01$) and in the proportion with abnormal FEV-1 at both index periods ($P < 0.01$).

## Treatment Utilization

During the final study year (9/11/2009 to 9/10/ 2010), 1,441 firefighters (20.8% of the cohort) and 803 with asthma diagnoses (64.2% of those with asthma) either self-reported recent use of bronchodilators, corticosteroids, and/or leukotriene antagonists or received them through the FDNY-WTC-MMTP pharmacy benefits plan. FDNY physicians prescribed medications for 895 (of 1,441, 62.1%) members of the cohort during the final study year. Those with non-asthma AD alone (N = 116, 10.8% of those with non-asthma AD alone) filled an average of 2.4 asthma prescriptions (1.4 types), at an average per person cost of $560. Those with a diagnosis of asthma alone (N = 172, 37.9% of those with asthma alone) filled an average of 5.5 asthma prescriptions (2.2 different types) at a mean per person cost of $1,781 in 2010. Those with both asthma and another AD diagnosis (N = 496, 62.3% of those with both) filled an average of 6.0 prescriptions (2.4 types), at a mean cost of $2,007.

The proportion of those with asthma diagnoses alone (37.2%) and of those with non-asthma AD diagnosis alone (35.9%) who utilized physician visits for respiratory healthcare in this program during the final study year were not significantly different ($P = 0.62$). However, the group with co-morbid asthma and non-asthma AD diagnoses had the largest utilization proportion (62.9%).

### Disease Models

Tables V and VI show results of multivariable models. Model 1 examines whether factors found during the early period were associated with reaching pyramid Level 4 by 9/11/2010. Earliest arrival at the WTC site (arrival group 1; OR 2.0, 95% CI 1.4–2.8) and being 45 years or older on 9/11 (OR 1.6, 95% CI 1.3–1.9) were statistically significant in this model. Reporting all four respiratory symptoms in the early period (OR 13.3, 95% CI 9.8–18.0) was very strongly associated in the model with reaching Level 4 by the end of the study. Symptom counts of three, two, and one in the early period were significant predictors as well (with zero as reference), as was having abnormal FEV-1 by Year 4 (OR 1.3, 95% CI 1.1–1.4; Table V). Model 2 compares the top two levels of the pyramid (those with at least one AD diagnosis) to the bottom two levels. Model 3 compares the top three levels of the pyramid to the bottom level. These models were similar to Model 1, although the associations were somewhat attenuated (Table V).

Model 4 examines factors associated with having at least one FDNY physician visit for respiratory evaluation or treatment during the final year of the study (9/11/2009 to 9/11/2010; Table VI). Arrival Groups 1–3 versus 4 (ORs 1.3–1.4) and being age 45 years or older on 9/11 (OR 1.4, 95% CI 1.3–1.6), were all significantly associated. Reporting four respiratory symptoms during the early period (OR 2.1, 95% CI 1.6–2.8) was also significantly associated in the model. Symptom counts of three, two and one during the early period (with zero as reference) were significantly associated with this outcome as well, as was abnormal FEV-1 by Year 4 (OR 1.2, 95% CI 1.0–1.3). Pyramid levels during the early period were all significantly associated with FDNY physician visits in the final year (Level 4, OR 4.4, 95% CI 3.4–5.7; Level 3, OR 2.4, 95% CI 2.0–2.8; Level 2, OR 1.5, 95% CI 1.3–1.8). Most of the factors associated with physician visits were also associated with filling over $1,000 worth of respiratory prescription medications during the final study year, except arrival groups (Model 5). The ORs for early diagnoses and older age were stronger in Model 5 than Model 4.

## DISCUSSION

We proposed a pyramid framework as a conceptual model for understanding the changing healthcare burden of WTC-related respiratory illness in this cohort nearly 10 years after 9/11. We found that respiratory results from the early period, particularly symptoms and an abnormal FEV-1, were strong indicators of both concurrent and future AD diagnoses. Those at the apex of the pyramid, with co-morbid physician diagnoses of asthma and non-asthma AD, reported more respiratory symptoms, had a greater likelihood of abnormal FEV-1s and earlier exposure to the WTC site. During the final year of this study, those on higher levels of the pyramid also had far greater healthcare utilization as evidenced by increased numbers

of physician visits and filled medication prescriptions for AD treatment. While those with AD diagnoses, particularly those with co-morbid AD (asthma and non-asthma), had the greatest healthcare utilization, it would be incorrect to assume that those without respiratory diagnoses did not utilize healthcare for respiratory concerns. Our data suggest that in this occupational cohort, where WTC-related healthcare is provided at no-cost, healthcare utilization is likely driven by symptoms and results from routine spirometry obtained at periodic monitoring/wellness exams, as well as by disease incidence or prevalence rates at any one point in time. We believe that the pyramid framework created for this analysis may be transferable to other occupational health settings, and could be important to healthcare administrators when long after an acute inhalation exposure incident, healthcare systems are required to transition from the delivery of acute care to the management of chronic disease.

During early stage planning for the FDNY-WTC-MMTP, many models were suggested to project future healthcare utilization. One such model proposed estimating future respiratory treatment needs based on the number diagnosed with respiratory diseases in the first four years following the disaster. Four years was chosen because for WTC-exposed cohorts other than FDNY, medical monitoring/wellness exams were not widely available early on. However, while those with AD diagnoses accounted for 81.1% of total physician visits for respiratory healthcare during the final year of this study, we also found that basing future healthcare plans only on *early* asthma or other *early* AD diagnoses would have drastically underestimated treatment needs. The 1,284 firefighters with an AD diagnosis by 9/11/2005 only accounted for 31.7% of FDNY physician visits for respiratory healthcare and 54.9% of respiratory medication costs during the final study year. Stated another way, those without respiratory evaluation or treatment by 9/11/2005 (pyramid Level 1) accounted for 42.3% of FDNY physician visits and 27.8% of respiratory medication costs during the final study year (9/11/2009 to 9/10/2010).

We categorized AD as asthma and non-asthma diagnoses for several reasons. Although we believe that nearly all of our non-asthma AD diagnoses were recurrent bronchitis, specialized tests to distinguish between recurrent bronchitis, emphysema, COPD and other non-asthma AD were generally not performed. In contrast to COPD or emphysema, abnormal FEV-1 is not a definitional requirement for the clinical diagnosis of asthma [Global Initiative for Asthma, 2010] or bronchitis [Global Initiative for Chronic Obstructive Lung Disease, 2011]. We used the term “non-asthma AD” to cover the known variability in the use of these diagnostic labels by physicians. In contrast, we had more confidence that FDNY physician diagnoses of asthma were distinguishable from non-asthma AD as we required wheezing, provocability, bronchodilator responsiveness or abnormal methacholine challenge testing (MCT) for this diagnosis. Further, the usefulness of this categorization was suggested by analyses demonstrating substantially higher healthcare utilization when these diagnoses were co-morbid.

During the second part of the study, from 9/11/2005 to 9/11/2010, the number of physician diagnoses for AD, and specifically for asthma, more than doubled—increased awareness of changes in disease rates is important for clinicians when evaluating patients and for healthcare administrators when allocating resources. The 18% firefighter asthma rate we report here is substantially higher than rates reported in non-FDNY rescue/recovery workers,

survivors, or exposed bystanders [Wheeler et al., 2007; Brackbill et al., 2009], but not as high as the cumulative incidence rate for asthma (27.6%) reported in a non-FDNY rescue/recovery worker cohort in 2010 [Wisnivesky et al., 2011]. However, the non-FDNY cohort in the latter study had a high (10.5%) rate of asthma pre-9/11 and was created after the WTC disaster, with potential for differential enrollment of symptomatic individuals. FDNY rates of new onset asthma are therefore comparable, if not higher, than any published rates to-date.

Many patients reported that their symptoms were present during the first part of our study (prior to 2005), but did not seek physician evaluation and were not diagnosed with an AD at that time. Those who sought an early evaluation but were not diagnosed with AD were twice as likely to have a diagnosis by 2010. For others, evolution of disease, delayed-reporting, new-onset disease which may or may not have been WTC-related, and/or reductions in healthcare barriers such as initiation of a free prescription medication program after 2005, may have prompted physician visits and diagnosis in the second half of this study, years after the WTC attacks. Our results demonstrate that diagnosis rates do not capture all disease, especially because symptomatic but undiagnosed disease early on may, with good access to care, result in substantial increases in both diagnoses and healthcare utilization over time.

We previously reported that the major decline in FEV-1 occurred during the first year post-9/11 [Prezant et al., 2002; Aldrich et al., 2010] and that this decline was persistent [Aldrich et al., 2010]. It is possible that the major declines in FEV-1 and subsequent lack of recovery made firefighters more likely to notice or be affected by subsequent triggers, such as inhalation exposures, allergens, irritants, respiratory infections, exercise, extremes of temperature/humidity. It is also possible that patients who knew that they had abnormal FEV-1 results (reported to them during monitoring exams) were more likely to take respiratory symptoms seriously and subsequently undergo evaluation. Public attention to this problem in the lay press/media may have also reduced barriers for reporting of symptoms. Regardless, our data are consistent with an inference that symptoms and abnormal pulmonary function drive healthcare utilization and that for many, but not all, evaluations reveal AD [Weiden et al., 2010].

There are limitations to this study. Confirmation of the onset of asthma or AD would have required performing specialized pulmonary function tests (e.g., MCT, bronchodilator responsiveness, diffusion, chest CT imaging) in all workers pre-9/11 and evaluating private non-FDNY medical records, which was not possible and is seldom required for diagnosis in community practices. We also realize that the diagnostic label “recurrent bronchitis” as used in this study does not differentiate between persistent (chronic) bronchitis and three or more cases of acute bronchitis, nor does it describe the character of the sputum (productive or non-productive). However, by requiring at least three episodes of bronchitis we believe that we avoid giving undo weight to an isolated onset of symptoms as distinct from a condition that needs chronic management. In addition, since we did not have access to records of non-FDNY physicians, we could not validate self-reported physician diagnoses. However, in another study being prepared for submission we found very good agreement between self-report and FDNY physician diagnosis ranging from 89% for non-asthma AD to 92% for

asthma. Third, we could not determine if a patient saw a non-FDNY physician for a respiratory evaluation if that visit did not result in a self-reported diagnosis, potentially affecting level 2 of the pyramid. Finally, we also could not determine the precise timing of symptom onset in relation to self-reported diagnoses; it is possible that symptoms occurred in the early time period, but after an individual's monitoring exam. It was also not possible to differentiate delays in symptom reporting from delays in symptom onset or awareness. Because timing could not be precisely determined, the increase in AD diagnoses may reflect not only disease evolution but also increased patient and physician awareness of WTC-related respiratory diseases as well as increased availability of health resources. We recognize other limitations including that the cumulative analysis of diagnoses does not take into account that some may have fully recovered during the course of follow-up. While our clinical experience suggests that this number is small, others may have partially recovered due to time or treatment.

Our healthcare utilization findings (prescription fills and physician visits) reflect a cost-free program and are therefore generalizable only to other health programs without patient fees or co-pays. Despite the cost-free FDNY treatment program, if self-reported medication use is a good indicator, we were only prescribing medications for approximately half of the users during the final year of the study. Thus, we believe that the true impact of AD on total healthcare utilization (visits and medications) is substantially higher than our estimates. Finally, this study does not address the added impact of WTC-related, comorbid, non-respiratory disease on healthcare utilization. Previous studies have shown high prevalence rates of chronic rhinosinusitis [Webber et al., 2011a], gastroesophageal reflux [Webber et al., 2011b], post-traumatic stress disorder [Chiu et al., 2011; Niles et al., 2011; Soo et al., 2011] and depression [Chiu et al., 2010] in FDNY firefighters after 9/11.

Despite the aforementioned limitations, we believe AD (including asthma) in this firefighter cohort represents new adult-onset disease for several reasons: (a) pre-hire, firefighters must meet rigorous physical requirements and are excluded from hiring if there is evidence of AD or other significant respiratory problems.; (b) firefighters did not have an AD diagnosis in FDNY's pre-9/11 post-employment medical records; and (c) significant respiratory problems would have been reported pre-9/11 due to the physical demands of the job, the availability of light duty assignments and the possibility of retirement with respiratory disability pensions.

This study also has several strengths. First, our analytic cohort was large (6,931), followed longitudinally, and, based on the comparison with those excluded, similar to the entire WTC-exposed firefighter workforce. Second, whenever possible we obtained physicians' diagnoses directly from the FDNY database, as opposed to relying exclusively on self-report to determine the rate of asthma and other respiratory diseases in this population. We also avoided using symptom data from surveys taken within the first 6 months of 9/11 as prior studies have indicated that not all early, acute symptoms were persistent [Webber et al., 2009]. By then showing how disease outcomes were associated with respiratory evaluations and medication costs, we have shown a more complete picture of the respiratory health impact of 9/11 on this highly exposed population.

## CONCLUSIONS

We developed a four-level pyramid framework to examine the association between respiratory symptoms, abnormal FEV-1, FDNY physician visits for respiratory evaluation and/or treatment, a single AD diagnosis (asthma or non-asthma), and AD diagnoses of both asthma and non-asthma to provide a single conceptual model of the detection of WTC-related respiratory illness and healthcare burden nearly 10 years after 9/11. Our model shows this evolution from 9/11/2005 to 9/10/2010. Higher pyramid levels were associated with WTC exposure intensity, more respiratory symptoms and a greater proportion of firefighters with abnormal FEV-1s. Higher pyramid levels (diagnoses) during the early period were associated with increased respiratory healthcare utilization during the final year of the study. However, to understand the full impact of a significant inhalation exposure on healthcare utilization nearly 10 years later required appreciating that respiratory diagnoses, 4 years post-disaster, were not the only drivers of future healthcare utilization. Symptoms and abnormal FEV-1s were also important as diagnoses evolved over time, despite relatively low barriers to healthcare early on. Whether this pattern will continue over the next 10 years remains to be determined but our findings clearly support the need for continued medical monitoring and treatment of this population and emphasize that after any widespread exposure, both clinicians and healthcare administrators must be prepared for the possibility of continued new diagnoses and expanding treatment utilization.

## Acknowledgments

Funding for this study came from the National Institute for Occupational Safety and Health contract numbers 200-2011-39383 and 200-2011-39378, and National Institute of Health grant numbers K23HL084191 (A.N.) and K24A1080298.

Role of Authors: Mr. Niles had full access to all of the data in the study and takes full responsibility for the integrity of all the data and the accuracy of the data analysis. Mr. Niles, Dr. Webber, and Dr. Prezant contributed to the origination of the study, analysis of data and drafting of the manuscript. Ms. Ye, Ms. Zeig-Owens, Ms. Glaser, and Ms. Weakley contributed to preparation and analysis of data, and editing the manuscript. Dr. Cohen and Dr. Hall provided statistical expertise, analysis of data and editing of the manuscript. Dr. Weiden, Dr. Aldrich, Dr. Kelly, Ms. Glass and Dr. Nolan, provided conceptual advice and edited the final manuscript.

## Abbreviations

| | |
|---|---|
| **WTC** | World Trade Center |
| **FDNY** | New York City Fire Department |
| **OAD** | obstructive airways disease |
| **FEV-1** | forced expiratory volume in the first second |
| **LLN** | lower limit of normal |

## References

Aldrich TK, Gustave J, Hall CB, Cohen HW, Webber MP, Zeig-Owens R, Cosenza K, Christodoulou V, Glass L, Al-Othman F, Weiden MD, Kelly KJ, Prezant DJ. Lung function in rescue workers at the World Trade Center after 7 years. N Engl J Med. 2010; 362(14):1263–1272. [PubMed: 20375403]

Banauch GI, Alleyne D, Sanchez R, Olender K, Cohen HW, Weiden M, Kelly KJ, Prezant DJ. Persistent hyperreactivity and reactive airway dysfunction in firefighters at the World Trade Center. Am J Respir Crit Care Med. 2003; 168(1):54–62. [PubMed: 12615613]

Brackbill RM, Hadler JL, DiGrande L, Ekenga CC, Farfel MR, Friedman S, Perlman SE, Stellman SD, Walker DJ, Wu D, Yu S, Thorpe LE. Asthma and posttraumatic stress symptoms 5 to 6 years following exposure to the World Trade Center terrorist attack. JAMA. 2009; 302(5):502–516. [PubMed: 19654385]

Chiu S, Webber MP, Zeig-Owens R, Gustave J, Lee R, Kelly KJ, Rizzotto L, Prezant DJ. Validation of the Center for Epidemiologic Studies Depression Scale in screening for major depressive disorder among retired firefighters exposed to the World Trade Center disaster. J Affect Disord. 2010; 121(3):212–219. [PubMed: 19539999]

Chiu S, Webber MP, Zeig-Owens R, Gustave J, Lee R, Kelly KJ, Rizzotto L, McWilliams R, Schorr JK, North CS, Prezant DJ. Performance characteristics of the PTSD Checklist in retired firefighters exposed to the World Trade Center disaster. Ann Clin Psychiatry. 2011; 23(2):95–104. [PubMed: 21547269]

Global Initiative for Asthma. Global strategy for asthma management and prevention. 2010. http://www.ginasthma.org

Global Initiative for Chronic Obstructive Lung Disease. Global strategy for the diagnosis, management and prevention of COPD. 2011. http://www.goldcopd.org

Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general U.S. population. Am J Respir Crit Care Med. 1999; 159:179–187. [PubMed: 9872837]

Izbicki G, Chavko R, Banauch GI, Weiden MD, Berger KI, Aldrich TK, Hall C, Kelly KJ, Prezant DJ. World Trade Center “sarcoid-like” granulomatous pulmonary disease in New York City Fire Department rescue workers. Chest. 2007; 131(5):1414–1423. [PubMed: 17400664]

Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, Crapo R, Enright P, van der Grinten CP, Gustafsson P, Jensen R, Johson DC, MacIntyre N, McKay R, Navajas D, Pedersen OF, Pellegrino R, Viegi G, Wanger J. ATS/ERS Task Force. Standardisation of spirometry. Eur Respir J. 2005; 26:319–338. [PubMed: 16055882]

Niles JK, Webber MP, Gustave J, Cohen HW, Zeig-Owens R, Kelly KJ, Glass L, Prezant DJ. Comorbid trends in World Trade Center cough syndrome and probable posttraumatic stress disorder in firefighters. Chest. 2011; 140(5):1146–1154. [PubMed: 21546435]

Prezant DJ, Weiden M, Banauch GI, McGuinness G, Rom WN, Aldrich TK, Kelly KJ. Cough and bronchial responsiveness in firefighters at the World Trade Center site. N Engl J Med. 2002; 347(11):806–815. [PubMed: 12226151]

Soo J, Webber MP, Gustave J, Lee R, Hall CB, Cohen HW, Kelly KJ, Prezant DJ. Trends in probable PTSD in firefighters exposed to the World Trade Center disaster, 2001–2010. Disaster Med Public Health Prep. 2011; 5(Suppl. 2):S197–S203. [PubMed: 21900417]

Weakley J, Webber MP, Gustave J, Kelly K, Cohen HW, Hall CB, Prezant DJ. Trends in respiratory diagnoses and symptoms of firefighters exposed to the World Trade Center disaster: 2005–2010. Prev Med. 2011; 53(6):364–369. [PubMed: 21930151]

Webber MP, Gustave J, Lee R, Niles JK, Kelly K, Cohen HW, Prezant DJ. Trends in respiratory symptoms of firefighters exposed to the world trade center disaster: 2001–2005. Environ Health Perspect. 2009; 117(6):975–980. [PubMed: 19590693]

Webber MP, Glaser MS, Weakley J, Soo J, Ye F, Zeig-Owens R, Weiden MD, Nolan A, Aldrich TK, Kelly K, Prezant D. Physician-diagnosed respiratory conditions and mental health symptoms seven to nine years following the world trade center disaster. Am J Ind Med. 2011a; 54(9):661–671. [PubMed: 21966080]

Webber MP, Lee R, Soo J, Gustave J, Hall CB, Kelly K, Prezant D. Sleep breath. Prevalence and incidence of high risk for obstructive sleep apnea in World Trade Center-exposed rescue/recovery workers. Sleep Breath. 2011b; 15(3):283–294. [PubMed: 20593281]

Weiden MD, Ferrier N, Nolan A, Rom WN, Comfort A, Gustave J, Zeig-Owens R, Zheng S, Goldring RM, Berger KI, Cosenza K, Lee R, Webber MP, Kelly KJ, Aldrich TK, Prezant DJ. Obstructive airway disease with air trapping among firefighters exposed to World Trade Center dust. Chest. 2010; 137(3):566–574. [PubMed: 19820077]

Wheeler K, McKelvey W, Thorpe L, Perrin M, Cone J, Kass D, Farfel M, Thomas P, Brackbill R. Asthma diagnosed after 11 September 2001 among rescue and recovery workers: Findings from the World Trade Center Health Registry. Environ Health Perspect. 2007; 115(11):1584–1590. [PubMed: 18007989]

Wisnivesky JP, Teitelbaum SL, Todd AC, Boffetta P, Crane M, Crowley L, de la Hoz RE, Dellenbaugh C, Harrison D, Herbert R, Kim H, Jeon Y, Kaplan J, Katz C, Levin S, Luft B, Markowitz S, Moline JM, Ozbay F, Pietrzak RH, Shapiro M, Sharma V, Skloot G, Southwick S, Stevenson LA, Udasin I, Wallenstein S, Landrigan PJ. Persistence of multiple illnesses in World Trade Center rescue and recovery workers: A cohort study. Lancet. 2011; 378(9794):888–897. [PubMed: 21890053]

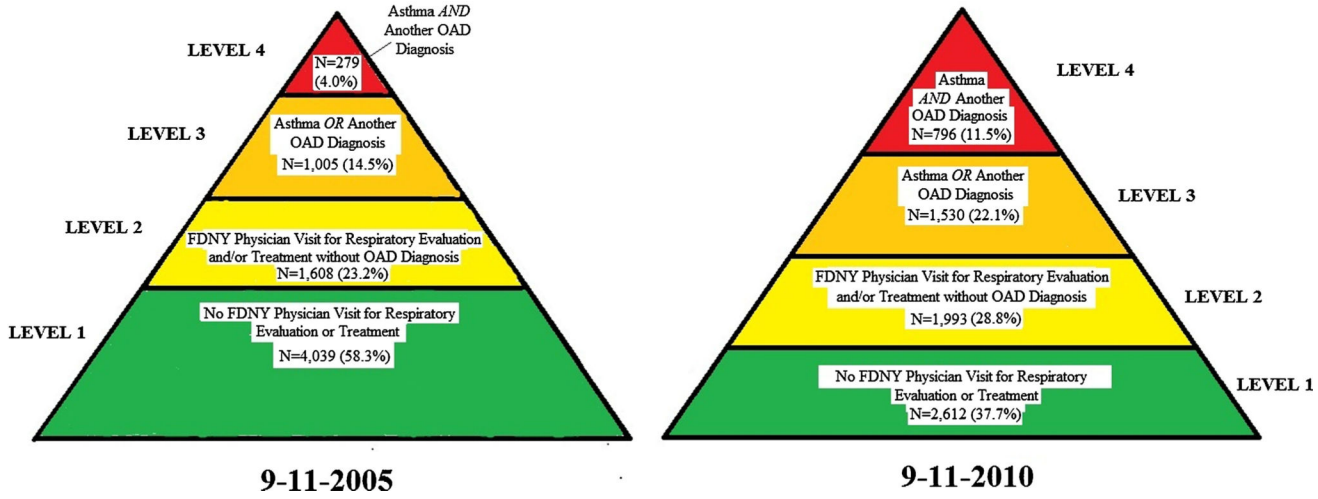


**FIGURE 1.**

The respiratory pyramid by 9/11/05 and its evolution by 9/11/10.

## TABLE I

Demographics of Cohort Members and Those Excluded

| Characteristic | Total | Excluded | Included |
|---|---|---|---|
| | 12,354 | 5,423 | 6,931 |
| Arrival group | | | |
| Day 1 AM | 15.1% | 15.0% | 15.3% |
| Day 1 PM | 49.5% | 42.7% | 54.9%* |
| Day 2 | 19.4% | 21.3% | 17.9%* |
| Days 3–14 | 16.0% | 21.1% | 12.0%* |
| Duration[a] | | | |
| 4 or more months | 50.6% | 40.3% | 54.5%* |
| Smoking status | | | |
| Ever | 36.9% | 41.9% | 33.5%* |
| Age group on 9/11 | | | |
| 45 or older | 33.2% | 54.1% | 16.8%* |

Seven hundred seventy-one did not have smoking data.

[a]Number of calendar months worked at WTC site. 2,985 did not have duration responses.

*Chi-square Sig $P < 0.05$.

## TABLE II

Pyramid Evolution

| | Pyramid Level 9/11/2010 | | | |
|---|---|---|---|---|
| | **4** | **3** | **2** | **1** |
| Pyramid Level 9/11/2005 | | | | |
| 4 | 279 | — | — | — |
| 3 | 275 | 730 | — | — |
| 2 | 101 | 343 | 1,163 | — |
| 1 | 140 | 457 | 831 | 2,612 |

* Diagnosis rates indicated here should be considered cumulative.

## TABLE III

Pyramid Levels by 9/11/2010

| Characteristic | Total | Level 4 Asthma Dx and another OAD Dx | Level 3 Single OA DDX | Level 2 Physician evaluation, no OAD Dx | Level 1 No physician evaluation |
|---|---|---|---|---|---|
| N = | 6,932 | 796 | 1,530 | 1,993 | 2,612 |
| Arrival group | | | | | |
| Day 1 AM | 15.4% | 22.2% | 18.2% | 14.8% | 11.8% * |
| Day 1 PM | 54.6% | 54.4% | 55.7% | 52.2% | 56.6% |
| Day 2 | 17.9% | 17.3% | 15.7% | 19.9% | 17.8% |
| Days 3–14 | 12.1% | 6.0% | 10.5% | 13.1% | 13.9% * |
| Duration[a] | | | | | |
| 4 or more months | 54.5% | 60.5% | 57.4% | 53.7% | 51.6% * |
| Smoking status | | | | | |
| Ever | 33.5% | 35.9% | 34.8% | 33.0% | 32.4% * |
| Age group on 9/11 | | | | | |
| 45 or older | 16.8% | 22.7% | 17.5% | 14.8% | 16.1% * |
| Mean BMI (2002–2005)[b] | 29.2 ± 3.8 | 29.8 ± 4.3 | 29.4 ± 3.9 | 29.2 ± 3.6 | 28.9 ± 3.8 ** |

[a] Number of calendar months worked at WTC site. One hundred twelve did not have duration responses.

[b] Values are percents except BMI which is mean + Standard Deviation. Five did not have BMI measurements.

* Cochran–Armitage test Sig $P < 0.05$.

** ANOVA test Sig $P < 0.05$.

**TABLE IV**

Pyramid Levels and Monitoring Results

| | Monitoring and diagnoses by 9/11/2005 | | | | Monitoring and diagnoses by 9/11/2010 | | | |
|---|---|---|---|---|---|---|---|---|
| | Level 4 | Level 3 | Level 2 | Level 1 | Level 4 | Level 3 | Level 2 | Level 1 |
| | Asthma Dx and another OAD Dx (N = 279) | Single OAD DX (N = 1,005) | Physician evaluation, no OAD Dx (N = 1,608) | No physician evaluation (N = 4,039) | Asthma Dx and another OAD Dx (N = 796) | Single OAD DX (N = 1,530) | Physician evaluation, no OAD Dx (N = 1,993) | No physician evaluation (N = 2,612) |
| Monitoring results | | | | | | | | |
| Symptoms and abnormal FEV-1 | 149 (53.4%) | 390 (38.8%) | 423 (26.3%) | 803 (19.9%) * | 547 (68.7%) | 810 (52.9%) | 854 (42.9%) | 956 (36.6%) * |
| Symptoms without abnormal FEV-1 | 112 (40.1%) | 401 (39.9%) | 458 (28.5%) | 1,039 (25.7%) * | 236 (29.7%) | 567 (37.1%) | 706 (35.4%) | 832 (31.9%) |
| Abnormal FEV-1 without symptoms | 10 (3.6%) | 111 (11.0%) | 330 (20.5%) | 886 (21.9%) * | 9 (1.1%) | 82 (5.4%) | 231 (11.6%) | 414 (15.9%) * |
| Neither | 8 (2.9%) | 103 (10.3%) | 397 (24.7%) | 1,311 (32.5%) * | 4 (0.5%) | 71 (4.6%) | 202 (10.1%) | 410 (15.7%) * |
| Median symptom count (IQR) | 3 (2–3) | 2 (1–3) | 1 (0–2) | 0 (0–1) ** | 4 (3–4) | 3 (1–3) | 2 (1–3) | 1 (0–2) ** |

Abnormal FEV-1—15% decline in adjusted FEV-1 or below lower limit of normal.

* Cochran-Armitage test for trend $P < 0.05$.

** Spearman correlation $P < 0.05$.

**TABLE V**

Pyramid Level Models

| Characteristic | Model 1 Level 4 versus 1,2,3, OR (95%CI) | Model 2 Level 3,4 versus 1,2, OR (95%CI) | Model 3 Level 2,3,4 versus 1, OR (95%CI) |
|---|---|---|---|
| Arrival Day 1 AM | 2.0 (1.4–2.8) | 1.6 (1.3–1.9) | 1.4 (1.2–1.7) |
| Arrival Day 1 PM | 1.6 (1.1–2.1) | 1.2 (1.0–1.5) | 1.0 (0.9–1.2) |
| Arrival Day 2 | 1.8 (1.2–2.5) | 1.2 (0.9–1.4) | 1.2 (1.0–1.4) |
| Arrival Days 3–14 | 1.0 (ref) | 1.0 (ref) | 1.0 (ref) |
| BMI | 1.03 (1.01–1.05) | 1.03 (1.01–1.04) | 1.03 (1.01–1.04) |
| Age > 45 on 9/11 | 1.6 (1.3–1.9) | 1.3 (1.2–1.5) | 1.1 (0.9–1.2) |
| 4 symptoms Year 4 | 13.3 (9.8–18.0) | 9.5 (7.3–12.5) | 5.4 (3.9–7.6) |
| 3 symptoms Year 4 | 8.8 (6.8–11.3) | 6.3 (5.2–7.6) | 3.7 (3.0–4.5) |
| 2 symptoms Year 4 | 5.1 (4.1–6.4) | 3.5 (3.0–4.0) | 2.6 (2.2–3.0) |
| 1 symptom Year 4 | 2.4 (1.9–3.1) | 2.2 (1.9–2.5) | 1.6 (1.4–1.9) |
| 0 symptoms Year 4 | 1.0 (ref) | 1.0 (ref) | 1.0 (ref) |
| Abnormal FEV-1 Year 4 | 1.5 (1.3–1.7) | 1.3 (1.2–1.4) | 1.2 (1.1–1.3) |

## TABLE VI

Healthcare Utilization Models

| Characteristic | Model 4 outcome: any FDNY respiratory evaluation in final year of study OR (95%CI) | Model 5 outcome: over $1,000 in final year asthma medications costs OR (95%CI) |
|---|---|---|
| Arrival Group 1 | 1.4 (1.1–1.8) | 0.9 (0.6–1.3) |
| Arrival Group 2 | 1.3 (1.1–1.6) | 0.8 (0.6–1.2) |
| Arrival Group 3 | 1.3 (1.0–1.7) | 1.0 (0.7–1.5) |
| Arrival Group 4 | 1.0 (ref) | 1.0 (ref) |
| Age 45 or older on 9/11 | 1.3 (1.1–1.6) | 2.1 (1.7–2.6) |
| BMI | 1.02 (1.00–1.03) | 1.03 (1.00–1.05) |
| Year 4 asthma and other OAD Dx (Level 4) | 4.4 (3.4–5.7) | 8.7 (6.3–12.1) |
| Year 4 single OAD Dx (Level3) | 2.4 (2.0–2.8) | 3.5 (2.7–4.5) |
| Year 4 evaluation no OAD Dx (Level 2) | 1.5 (1.3–1.8) | 1.2 (0.9–1.6) |
| Year 4 no OAD Dx (Level1) | 1.0 (ref) | 1.0 (ref) |
| 4 respiratory symptoms Year 4 | 2.1 (1.6–2.8) | 2.6 (1.7–3.9) |
| 3 respiratory symptoms Year 4 | 1.7 (1.4–2.1) | 2.5 (1.8–3.6) |
| 2 respiratory symptoms Year 4 | 1.8 (1.5–2.2) | 2.1 (1.6–2.8) |
| 1 respiratory symptom Year 4 | 1.4 (1.2–1.6) | 1.3 (1.0–1.8) |
| Norespiratory symptoms Year 4 | 1.0 (ref) | 1.0 (ref) |
| Year 4 abnormal FEV-1 | 1.2 (1.0–1.3) | 1.6 (1.3–2.0) |