Increased Rates of Asthma Among World Trade Center Disaster Responders

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Background *Studies have documented high rates of asthma symptoms among responders to the World Trade Center (WTC) disaster. However, whether there are increased rates of asthma among responders compared to the general population is unknown.*
Methods *The study population consisted of a prospective cohort of 20,834 responders participating in the WTC Medical Monitoring and Treatment Program between July 2002 and December 2007. We calculated prevalence and standardized morbidity ratios (SMRs) of lifetime asthma and 12-month asthma (defined as ≥1 attacks in the prior 12 months) among WTC responders. The comparison population consisted of >200,000 adults who completed the National Health Interview Survey in 2000 (for pre-9/11 comparisons) and between 2002 and 2007 (for post-9/11 comparisons).*
Results *WTC responders were on average 43 ± 9 years old, 86% male, 59% white, and 42% had an occupation in protective services. The lifetime prevalence of asthma in the general population was relatively constant at about 10% from 2000 to 2007. However, among WTC responders, lifetime prevalence increased from 3% in 2000, to 13% in 2002, and 19% in 2007. The age-adjusted overall SMR for lifetime asthma among WTC responders was 1.8 (95% CI: 1.8–1.9) for men and 2.0 (95% CI: 1.9–2.1) for women. Twelve-month asthma was also more frequent among WTC responders compared to the general population (SMR 2.4, 95% CI: 2.2–2.5) for men and 2.2 (95% CI: 2.0–2.5) for women.*
Conclusions *WTC responders are at an increased risk of asthma as measured by lifetime prevalence or active disease. Am. J. Ind. Med. 55:44–53, 2012.*
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KEY WORDS: *World Trade Center responders; asthma; NHIS*

INTRODUCTION

The collapse of the World Trade Center (WTC) towers on September 11, 2001 and associated fires killed about 3,000 people and exposed a large number of responders and nearby residents to the potential toxic effect of multiple airborne pollutants.

Multiple health problems related to exposures to the WTC disaster have been documented in the literature [Clark et al., 2001; Wheeler et al., 2007; CDC, 2002; Prezant et al., 2002; Banauch et al., 2003, 2005; McGee et al., 2003; Feldman et al., 2004; Landrigan et al., 2004; Skloot et al., 2004; Herbert et al., 2006; Farfel et al., 2008; Prezant, 2008; Brackbill et al., 2009; Aldrich et al., 2010; Weiden et al., 2010]. In particular, several studies have described a high prevalence of pulmonary conditions such as abnormal pulmonary function tests (low forced expiratory volume in 1 s and forced vital capacity), airway hyperreactivity, respiratory symptoms of cough, wheezing, and dyspnea, as well as diagnoses such as asthma and reactive airways dysfunction syndrome [Wheeler et al., 2007; CDC, 2002; Prezant et al., 2002; Banauch et al., 2003, 2005; Feldman et al., 2004; Landrigan et al., 2004; Skloot et al., 2004; Herbert et al., 2006; Farfel et al., 2008; Prezant, 2008; Brackbill et al., 2009; Aldrich et al., 2010; Weiden et al., 2010]. Moreover, a recent study showed that exposed firefighters had a large decline in FEV_1 that persisted up to 6 years following the WTC disaster [Aldrich et al., 2010]. These data suggest an increased rate of pulmonary disorders (in particular asthma) among WTC responders. However, there are no studies comparing rates of asthma in a cohort of WTC responders to those found in the general United States (US) population.

In this study, we used data from the National Health Interview Survey (NHIS), a probability sample of the US population, to assess whether WTC responders have an increase of burden of asthma compared to the general population and to describe temporal trends in the prevalence of asthma among WTC responders.

METHODS

The study cohort consisted of WTC responders who participated in the WTC Medical Monitoring and Treatment Program (MMTP) between July 16, 2002 and December 31, 2007, and consented to have their information used for research purposes. Participants underwent a comprehensive baseline interview and then were followed every 12–18 months with periodic exams. Follow-up rates in the MMTP were 71% and 42% for the first and second follow-up visits, respectively. Details regarding eligibility criteria have been published elsewhere [Herbert et al., 2006]. The NHIS, a stratified multistage probability cluster sample of US households, was used to obtain expected rates of asthma in the general US population [Pleis and Barnes, 2008]. We used NHIS data from the year 2000 to obtain data regarding pre-9/11 asthma rates and from years 2002 to 2007 to estimated asthma rates in subsequent years. NHIS has a cross-sectional design with a different sample of responders sampled in each wave. Both the WTC questionnaire and the NHIS are interviewer-administered and collect self-reports of symptoms and illnesses. The study was approved by the Mount Sinai School of Medicine's Institutional Review Board.

The items used in the WTC and NHIS survey to ascertain lifetime history of asthma or presence of 12-month asthma symptoms are shown in Table I. Briefly, both

TABLE I. Case Definitions of Lifetime Asthma and 12-Month Asthma in the National Health Interview Survey and World Trade Center Medical Monitoring and Treatment Program

Outcome	NHIS	WTC
Lifetime asthma	Have you ever been told by doctor or other health professional that you had asthma?	Has a doctor ever diagnosed you with asthma, cough variant asthma, or reactive airways dysfunction syndrome?
12-month asthma	During the past 12 months, have you had an episode of asthma or an asthma attack?	When was your last attack? (If yes to above question)
Converting WTC information to the NHIS 12-month asthma definition	Month and year of the last asthma attack collected from responders were used to match with NHIS 12-month asthma episodes definition by restricting a positive response within 12 months prior to the initial monitoring program visit. For example, if the last asthma attack was in 01/1999 and the baseline (initial) monitoring visit was 01/2004 then the responder was classified as not having active. Conversely, if the last asthma attack was in 01/2003 and the baseline (initial) monitoring visit was 01/2004 then the individual was classified as having 12-month asthma	
Calculating pre-9/11 (year 2000) prevalence of lifetime and 12-month asthma	Month and year of the last asthma attack was used to calculate lifetime prevalence by restricting a positive response before 01/2001 among responders reported "Yes" to the question "Has a doctor ever diagnosed you with asthma, cough-variant asthma, or reactive airways dysfunction syndrome (RADS)?" 12-month prevalence was calculated by limiting the last attack date between 01/2000 and 12/2000 among who reported a positive answer to the lifetime asthma	

surveys asked participants if they were ever diagnosed by a doctor as having asthma (the WTC survey also included history of reactive airways dysfunction syndrome). This information was used to determine the lifetime prevalence of asthma. Lifetime prevalence included baseline and follow-up visits data. Twelve-month asthma was ascertained based on responses to different questions in the NHIS and WTC program. As part of NHIS, participants reported whether they had an asthma attack during the prior 12 months. WTC responders reported the date of their last asthma attack only as part of the baseline questionnaire and this information was used, in combination with the date of the interview, to determine if the participant had an attack in the prior 12 months.

Age was grouped into the following categories: 18–29, 30–39, 40–49, 50–59, and >60 years of age. In the WTC sample, race and ethnicity were categorized based on the Office of Management and Budget classification [Durch and Madans, 1997]. However, in the NHIS, "Native Hawaiian/other Pacific Islander" and "American Indian/Alaskan Native" were coded in the in the "other race" category. Thus, this categorization was also applied to the WTC data. Both WTC and NHIS occupation were coded according to the 2000 Standard Occupational Classification (SOC) developed by the Bureau of Labor Statistics [2009]. Smoking status was categorized into current, former, and never smokers.

Statistical Analyses

The χ^2-test was used to compare the distribution of baseline characteristics of NHIS and WTC participants. Crude annual prevalence of lifetime and 12-month asthma were calculated using NHIS sample weighting methods [NCHS, 2008]. Age-adjusted standardized morbidity ratios (SMRs), the ratio of observed to expected counts, were calculated with a 95% confidence interval (CI) based on the Poisson distribution [Sahai and Khurshid, 1993]. Age-, gender-, and occupation-specific SMRs were calculated using an indirect standardization method to determine expected counts from NHIS [Checkoway et al., 2004]. Analyses were performed with Stata 11.0 (Stata Corp., College Station, TX) and SAS 9.1 (SAS Institute, Inc., Cary, NC).

RESULTS

Overall 20,843 WTC responders were included in the study cohort. Mean age of WTC responders was 43 (±9 years). Eight-six percent were males, 59% White, 11% Black, and 24% of Hispanic ethnicity. The most common occupations were protective services (42%) and construction (25%). Compared to NHIS participants, WTC responders were more likely to be between 30 and 49 years

of age, male, non-White, and of Hispanic ethnicity ($P \leq 0.001$ for all comparisons Table II).

Prevalence of Lifetime Asthma and 12-Month Asthma

Lifetime asthma prevalence between 2002 and 2007 in NHIS remained relatively stable (10.7%, 10.7%, and 10.9% in 2002, 2005, and 2007, respectively; Table III). Conversely, among WTC responders, the prevalence increased from 2.9% pre-9/11 (95% CI: 2.7–3.2%) to 12.8% in 2002 (95% CI: 11.5–14.1%) and 19.4% in 2007 (95% CI: 18.4–20.4%). Compared to pre-9/11, lifetime prevalence of asthma increased more than sixfold in 2007 among WTC responders (Fig. 1). These patterns were consistent across different age, race, gender, occupational group, and smoking status groups.

The average prevalence of 12-month asthma (≥ 1 attack in the prior 12 months) was 3.7% in NHIS and 6.3% in WTC, for the period 2002–2007. Rates of 12-month asthma prevalence remained stable in the NHIS population (3.8%, 3.9%, and 3.8%, for years 2002, 2005, and 2007, respectively; Table IV). However, there were large increases in 12-month asthma rates among WTC responders, from 0.2% (95% CI: 0.1–0.2%) in 2000 to 8.2% (95% CI: 6.8–9.8%) in 2005, and, a slight decrease between 2005 and 2007 (7.8%; 95% CI: 6.9–8.7% for the latter). Compared to the year 2000 (pre-9/11), 12-month asthma increased about 40-fold among WTC responders (Fig. 1).

Standardized Morbidity Ratios

The age-adjusted overall SMR for lifetime asthma prevalence (1.6, 95% CI: 1.6–1.7) was elevated among WTC responders in all years following 9/11. The age-adjusted overall SMR (1.7, 95% CI: 1.6–1.8) for 12-month asthma among WTC responders was also elevated during the 2002–2005 period and did not change thereafter. Both lifetime and 12-month asthma prevalence were considerably lower in 2000 among these WTC responders than among the NHIS participants (SMR: 0.3, 95% CI: 0.3–0.4 and 0.03, 95% CI: 0.02–0.04, respectively; Fig. 2).

Gender- and age-specific lifetime and 12-month asthma SMRs increased over time for both WTC women and men (Table V). Overall lifetime asthma SMRs were elevated in all age groups, ranging from 1.2 (95% CI: 1.1–1.3) in the 18- to 29-year-old group to 1.7 (95% CI: 1.7–1.8) in the 40- to 49-year-old group. Similarly, age-stratified 12-month asthma SMRs were increased in all groups from 1.4 (95% CI: 1.2–1.6) in 50- to 59-year-old group to 1.7 (95% CI: 1.6–1.9) in the 40- to 49-year-old group.

Occupation-specific lifetime asthma SMRs were also elevated among all groups; SMRs ranged from 1.5 (95% CI: 1.5–1.6) in protective service workers to 2.0 (95% CI:

TABLE II. Characteristics of National Health Interview Survey Population and World Trade Center Responders (Baseline Visit)

	Year												
	2000		**2002**		**2003**		**2004**		**2005**		**2006**		**2007**	
Variable	NHIS	WTC	NHIS	WTC	NHIS	WTC	NHIS	WTC	NHIS	WTC	NHIS	WTC	NHIS	WTC
Total, N	32,374	20,843[a]	31,044	2,970	30,852	5,755	31,326	3,267	31,428	1,478	24,275	3,466	23,393	3,907
Age, years (%)														
18–29	22.0	5.6	21.8	7.2	21.6	7.0	21.7	6.6	21.8	4.9	21.8	4.3	22.1	3.2
30–39	20.7	34.2	19.7	36.0	19.5	34.5	19.1	37.1	18.6	34.4	18.2	34.2	17.9	29.8
40–49	21.0	39.4	21.3	35.6	20.9	38.0	20.6	39.6	20.4	41.7	20.4	40.5	19.9	42.0
50–59	14.9	16.6	15.8	17.9	16.3	16.4	16.3	13.5	16.9	15.2	17.3	16.9	17.0	18.9
≥60	21.5	4.2	21.4	3.4	21.8	4.2	22.3	3.2	22.2	3.8	22.2	4.0	23.1	6.2
Gender (%)														
Female	52.1	14.3	52.0	11.8	52.0	13.7	51.9	13.1	51.8	15.4	51.8	16.8	51.7	15.6
Male	47.9	85.7	48.0	88.2	48.0	86.3	48.1	86.9	48.2	84.6	48.2	83.2	48.3	84.4
Race (%)														
White	81.2	59.2	80.8	62.0	83.5	56.9	83.0	60.0	82.9	58.6	81.5	58.2	81.0	61.3
Black	11.3	10.7	11.4	12.0	11.3	8.3	11.4	11.3	11.4	13.0	11.9	10.2	11.8	12.6
Asian	3.3	1.3	3.5	1.7	3.5	1.1	3.7	0.9	3.7	1.6	4.6	1.5	4.7	1.7
Other	4.3	28.3	4.2	24.4	1.8	33.8	1.9	27.9	2.0	26.9	2.1	30.2	2.5	24.4
Ethnicity (%)														
Hispanic	10.5	24.2	11.0	19.4	12.3	25.0	12.5	24.3	12.8	23.9	13.0	28.3	13.4	23.2
Non-Hispanic	89.5	57.1	89.0	66.9	87.7	55.7	87.6	56.5	87.3	63.3	87.0	52.2	86.6	54.5
Occupation (%)[b]														
Protective service	1.2	41.5	1.2	23.9	1.3	30.9	1.7	47.5	1.6	47.3	1.7	53.4	1.8	52.9
Construction and extraction	3.3	25.4	3.6	25.1	3.7	35.5	5.2	28.9	5.6	25.8	5.5	17.3	5.1	14.9
Installation, maintenance, and repair	2.2	7.2	2.3	19.5	2.4	5.8	3.4	4.0	3.0	4.9	3.3	3.8	3.3	6.4
Transportation and material moving	4.7	4.3	4.5	4.8	4.6	5.7	5.6	3.6	5.5	3.0	5.4	3.9	5.2	3.3
Other	52.4	16.9	51.0	19.1	49.3	17.1	74.0	13.3	74.4	15.5	73.3	17.4	74.8	18.0
Smoking (%)														
Current smoker	23.1	16.2	22.3	18.6	21.3	18.2	20.7	17.6	20.7	17.3	20.6	12.7	19.5	12.8
Former smoker	22.0	23.9	22.4	24.0	21.6	26.2	21.2	22.4	21.4	24.2	20.8	22.9	21.2	22.7
Never smoker	54.1	58.3	54.3	54.4	55.9	54.2	57.1	58.8	57.1	57.1	57.4	63.3	57.8	62.9

Unweighted number of participants in the National Health Interview Survey; all *P*-values for comparisons between the National Health Interview Survey participants and World Trade Center responders were <0.001; rates for the year 2001 were omitted given that exposure among World Trade Center responders occurred in September that year.
[a]Total number of World Trade Center responder population.
[b]Classified based on the 1990 Standard Occupational Classification for years 2000–2004 and the 2000 Standard Occupational Classification by Bureau of Labor Statistics for years 2005–2007.

1.8–2.2) in installation, maintenance, and repair workers. Similarly, specific acute asthma SMRs were elevated in all occupation groups, ranging from 1.6 (95% CI: 1.2–2.2) in transportation and material moving workers to 2.3 (95% CI: 1.9–2.8) in installation, maintenance, and repair workers (Table VI).

DISCUSSION

Exposure to airborne pollutants following the collapse of the WTC towers and during the recovery efforts has been linked to acute reductions in lung function, increased pulmonary symptoms, and high frequency of asthma among responders. In this study, we showed that rates of self-reported lifetime asthma and 12-month asthma were significantly increased among a large sample of WTC responders, when compared to the general US population. Most of the increased risk became evident in the early years after 9/11 and has remained elevated but relatively stable since 2005. Further studies are necessary to identify risk factors for developing asthma in this population. Appropriate planning will be important to reduce the risk of exposure-related asthma in future natural or unnatural disasters.

A study conducted using the WTC Health Registry (a large cohort of rescue and recovery workers and residents

TABLE III. Lifetime Asthma Prevalence Among World Trade Center Responders (Included Baseline and Follow-Up Visits) and National Health Interview Survey Population

	Year													
	2000		2002		2003		2004		2005		2006		2007	
Variable	NHIS 32,374	WTC 20,843[a]	NHIS 31,044	WTC 2,970	NHIS 30,852	WTC 5,755	NHIS 31,326	WTC 3,740	NHIS 31,428	WTC 4,797	NHIS 24,275	WTC 6,043	NHIS 23,393	WTC 7,620
Total (%)	9.3	2.9	10.7	12.8	9.7	11.9	9.9	14.3	10.7	17.5	11.0	17.7	10.9	19.4
Age, years (%)														
18–29	11.9	4.6	13.5	12.2	11.5	10.0	11.1	14.6	12.7	17.9	13.3	16.8	14.0	20.3
30–39	8.2	3.1	10.0	14.0	9.0	12.4	8.7	14.6	10.1	16.5	10.2	17.5	9.9	19.6
40–49	8.7	2.9	10.5	12.9	9.6	12.8	9.5	14.7	10.1	18.5	9.6	18.6	10.0	20.4
50–59	8.9	2.5	10.8	10.2	9.8	10.6	10.0	13.1	10.5	16.3	10.8	16.7	9.5	18.1
≥60	8.5	1.8	8.5	14.0	8.6	7.9	10.0	12.2	10.1	19.9	10.9	14.5	10.6	14.7
Gender (%)														
Female	10.5	2.8	11.9	21.1	11.2	15.5	11.2	23.5	12.6	24.7	12.4	23.2	12.2	28.6
Male	8.0	3.0	9.3	11.7	8.1	11.3	8.5	13.0	8.7	16.3	9.5	16.7	9.6	17.9
Race (%)														
White only	9.3	2.6	10.5	12.4	9.6	12.6	9.7	13.9	10.6	18.2	10.9	17.8	11.1	18.3
Black/African American only	9.2	4.5	12.1	14.3	10.8	13.3	11.2	14.8	11.7	16.8	11.9	20.6	10.2	19.4
Asian only	6.2	1.8	7.9	6.1	5.9	6.6	6.9	15.4	7.7	15.1	8.3	15.6	8.1	19.0
Other	10.8	3.2	11.5	13.3	14.0	10.6	15.0	14.9	14.7	16.2	18.2	16.7	15.5	22.2
Ethnicity (%)														
Hispanic	7.2	3.7	7.3	15.8	7.3	10.4	7.5	16.1	7.6	17.4	8.2	16.8	9.0	23.2
Non-Hispanic	9.5	2.9	11.1	12.6	10.1	12.6	10.2	13.9	11.2	18.0	11.4	18.4	11.2	19.0
Occupation (%)[b]														
Protective service	9.9	3.5	11.5	14.8	8.4	16.1	8.8	15.5	11.1	20.3	14.0	19.0	16.6	19.7
Construction and extraction	6.7	2.2	7.6	10.2	5.7	7.8	8.1	9.0	7.5	13.5	7.2	13.7	8.8	16.5
Installation, maintenance, and repair	5.4	3.2	8.1	13.6	7.3	13.0	7.4	15.0	7.4	15.6	11.3	20.7	8.5	20.3
Transportation and material moving	6.8	3.1	8.4	11.4	9.2	10.7	9.7	14.8	9.6	17.5	11.7	12.3	9.2	21.2
Other	9.4	2.6	10.6	13.9	9.4	13.4	10.6	20.2	11.5	19.2	11.6	20.2	11.6	22.3
Smoking (%)														
Current smoker	10.2	3.2	12.6	11.8	11.4	10.4	10.8	11.9	12.2	16.1	13.1	14.9	12.7	17.6
Former smoker	10.8	2.8	11.3	12.5	11.2	12.4	12.3	15.6	11.1	18.8	11.9	18.6	12.4	20.5
Never smoker	8.3	3.0	9.7	13.2	8.7	12.2	8.8	14.5	10.1	17.2	10.0	18.0	9.9	19.4

Unweighted number of participants in the National Health Interview Survey; all *P*-values for comparisons between the National Health Interview Survey participants and World Trade Center responders were <0.001; rates for the year 2001 were omitted given that exposure among World Trade Center responders occurred in September that year.
[a]Total number of World Trade Center responder population.
[b]Classified based on the 1990 Standard Occupational Classification for years 2000–2004 and the 2000 Standard Occupational Classification by Bureau of Labor Statistics for years 2005–2007.

in lower Manhattan on 9/11), reported high rates of new onset asthma [Brackbill et al., 2009]. In that study, new onset asthma was as high as 10% among participants with no prior history of asthma 5–6 years after 9/11. Self-reported newly diagnosed asthma was positively associated with higher exposure to the WTC site and decreased with use of a mask or a respirator [Wheeler et al., 2007; Feldman et al., 2004]. Similarly, studies of firefighters found large declines in FEV_1 [Prezant et al., 2002] and high prevalence of obstructive disease among WTC responders [Weiden et al., 2010]. Our study extends these results by showing that the rates of asthma as well as active disease are increased among WTC responders when compared with those expected in the general population, and that this increased risk persists several years after exposure.

Our results suggest that the increased risk of both prevalent and acute asthma is present across the different age, sex, and most occupation categories. Additional studies are necessary to further define the groups and type of
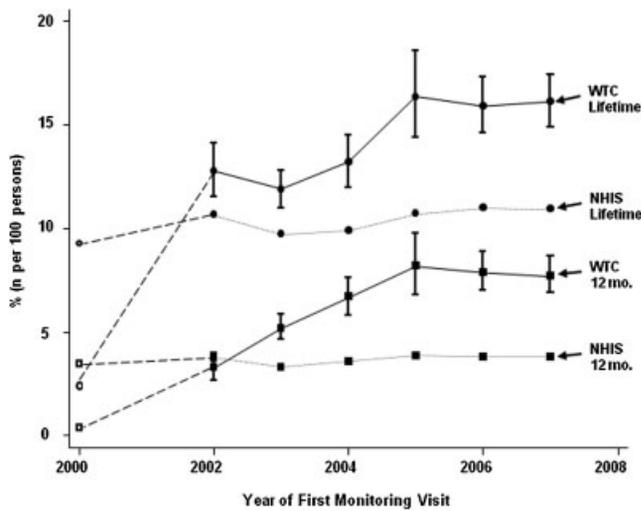
FIGURE 1. Crude prevalence of lifetime and 12-month asthma in the National Health Interview Survey and World Trade Center Medical Monitoring and Treatment Program.

WTC exposures associated with higher risk of new onset asthma. We also found that rates of lifetime and acute asthma were significantly lower among WTC responders than the general population in 2000. This finding is likely due to a healthy worker effect and suggests that our findings of increased rates in subsequent years are probably a conservative estimate of the risk of asthma among WTC responders.

The collapse of the WTC towers generated a complex mixture of airborne pollutants including pulverized building materials and products of combustion [McGee et al., 2003]. Following the initial collapse, structural fires continued for several weeks, releasing products of combustion and pyrolysis. Moreover, the use of gasoline- and diesel-powered machinery that was necessary for the removal of debris in subsequent weeks, contributed additional products of combustion. Many WTC responders were exposed to these pollutants [Clark et al., 2001] with little or no respiratory protection given the difficult working conditions in the first days after the disaster [Feldman et al., 2004]. These exposures likely lead to inflammation of the nasal passages, throat, and lower airways yielding irritant-induced rhinosinusitis, pharyngitis, reactive airways disease syndrome (RADS) [Henneberger et al., 2003], and asthma [Banauch et al., 2003, 2005]. Prior data shows that comparable levels of exposure to airborne pollutants in occupational settings has been associated with development of RADS [Brooks et al., 1985; Lombardo and Balmes, 2000]. Moreover, experimental studies using mice have shown that exposure to high levels of fine particulate matter from the WTC site led to the development of mild-to-moderate pulmonary inflammation and increases in airway hyper-responsiveness [Gavett et al., 2003].

There are several strengths and limitations of this study. Our study population consisted of a large cohort of WTC responders representing many different types of workers who participated in the WTC rescue and recovery effort. The comparison group was drawn from the NHIS, a probability sample of the entire US population. Thus, the generalizability of our findings should be strong. Although another population based survey, the Behavioral Risk Factor Surveillance System (BRFSS), showed about a 4% higher lifetime asthma prevalence in New York State (10.7% in 2000, 11.1% in 2001, 11.5% in 2002, 11.7% in 2003, 14.2% in 2004, 13.8% in 2005, 13.1% in 2006, and 14.0% in 2007) than the NHIS (US total prevalence), the rate was still lower than among responders. Although there was a smaller difference of lifetime asthma prevalence with the BRFSS data, what would remain is the increased trend in asthma among responders that occurred over time after September 11, as compared to the BRFSS asthma trend at the same period. The BRFSS measures current asthma prevalence rather than a 12-month asthma attack or episode, which we measured in this study. Thus, only lifetime asthma prevalence was comparable. Asthma prevalence was ascertained by self-report, which might be subject to reporting bias. However, both the WTC program and the NHIS collected self-reported diagnosis of asthma and presence of acute asthma episodes were evaluated using similar items. Thus, reporting bias, if present, should be comparable in both groups and therefore unlikely to explain our results. WTC responders in the MMTP undergo periodic health exams and are referred for medical evaluation if abnormalities are identified. This greater contact with healthcare providers may increase the probability that WTC responders are diagnosed more often with asthma when compared to the general population, a factor that may partially explain our findings. Increased rates of self-reported asthma among WTC responders may be also due to selection bias. Responders with asthma or other health problems are probably more likely to enroll in the MMTP and return for the follow-up exams. However, in the baseline visits SMR trends by visit year showed that individuals who enrolled in the early years of the program also had an increased risk for lifetime and 12-month asthma. Moreover, asthma rates in the New York City Fire Department's MMTP, a prospective cohort of all firefighters exposed to the WTC site, were similar to those observed in our population [Prezant et al., 2002; Banauch et al., 2003; Prezant, 2008].

Another potential limitation is related to differences in the wording of items assessing asthma prevalence in the WTC questionnaire and the NIHS (Table I). Twelve-month asthma in particular, was estimated among WTC responders by combining information from different questions, a factor that might affect comparability across studies. However, 23% of the WTC responders diagnosed with asthma

TABLE IV. Prevalence of 12-Month Asthma Among World Trade Center Responders (Baseline Visit Only) and National Health Interview Survey Population

| | Year | | | | | | | | | | | | |
| | **2000** | | **2002** | | **2003** | | **2004** | | **2005** | | **2006** | | **2007** | |
Variable	NHIS 32,374	WTC 20,843[a]	NHIS 31,044	WTC 2,970	NHIS 30,852	WTC 5,755	NHIS 31,326	WTC 3,267	NHIS 31,428	WTC 1,478	NHIS 24,275	WTC 3,466	NHIS 23,393	WTC 3,907
Total (%)	3.5	0.2	3.8	3.3	3.3	5.2	3.6	6.7	3.9	8.2	3.8	7.9	3.8	7.8
Age, years (%)														
18–29	3.8	0.2	4.2	3.7	3.5	3.3	3.5	4.2	3.9	11.0	3.6	9.3	4.0	10.6
30–39	3.2	0.2	3.8	3.9	3.3	5.4	3.3	6.6	4.0	7.9	3.9	7.9	3.7	7.3
40–49	3.8	0.2	4.0	3.5	3.6	5.8	3.7	7.6	4.3	8.3	4.0	8.1	4.2	8.2
50–59	3.4	0.1	3.8	1.7	3.8	5.0	4.1	5.9	3.9	7.6	4.7	7.5	3.6	6.9
≥60	3.0	0.2	3.0	1.0	2.6	2.9	3.4	4.8	3.3	8.9	3.2	5.7	3.5	7.9
Gender (%)														
Female	4.6	0.2	5.0	7.1	4.5	8.9	4.5	12.6	5.2	14.5	5.1	11.5	5.0	14.6
Male	2.2	0.2	2.4	2.8	2.1	4.7	2.6	5.8	2.5	7.0	2.4	7.2	2.6	6.5
Race (%)														
White	3.5	0.2	3.7	3.4	3.3	5.6	3.5	6.9	3.9	7.9	3.8	7.9	3.8	7.0
Black	3.3	0.3	4.3	3.4	3.8	5.7	4.3	6.2	3.8	10.4	3.6	9.9	3.9	8.1
Asian	1.8	0.0	2.5	0.0	1.1	4.9	1.7	0.0	2.8	8.7	2.4	7.7	2.4	10.5
Other	4.2	0.2	4.5	3.0	5.2	4.5	5.2	6.6	6.9	7.8	7.5	7.3	5.1	9.2
Ethnicity (%)														
Hispanic	2.8	0.1	2.3	3.8	2.7	4.2	2.5	6.4	2.9	8.8	2.9	7.7	3.2	10.0
Non-Hispanic	3.5	0.2	3.9	3.1	3.4	5.6	3.7	6.1	4.0	7.9	3.9	8.6	3.9	7.3
Occupation (%)[b]														
Protective service	2.7	0.2	3.3	4.2	3.1	7.5	2.5	7.7	3.8	9.3	4.6	8.1	5.6	7.3
Construction and extraction	1.7	0.1	1.2	2.0	1.5	3.0	2.6	3.5	2.0	4.5	2.4	5.3	2.3	5.0
Installation, maintenance, and repair	1.6	0.3	2.1	3.6	1.9	5.1	1.9	6.2	2.9	12.5	3.3	10.6	3.3	8.5
Transportation and material moving	2.0	0.2	1.9	0.7	1.8	3.4	3.6	9.5	3.0	6.7	3.8	5.2	3.5	8.5
Other	3.4	0.2	3.8	4.2	3.3	6.7	3.9	9.7	4.1	9.2	4.0	9.9	4.1	11.3
Smoking (%)														
Current smoker	3.7	0.2	4.7	2.4	4.1	4.4	4.2	4.2	4.4	6.3	4.7	5.9	4.2	6.4
Former smoker	3.9	0.1	3.9	3.6	3.9	5.3	4.4	8.2	4.0	10.3	4.1	8.4	4.3	8.1
Never smoker	3.2	0.2	3.3	3.5	2.9	5.5	3.1	6.8	3.6	8.1	3.4	8.1	3.5	8.0

Unweighted number of participants in the National Health Interview Survey; all P-values for comparisons between the National Health Interview Survey participants and World Trade Center responders were <0.001; rates for the year 2001 were omitted given that exposure among World Trade Center responders occurred in September that year.
[a]Total number of World Trade Center responder population.
[b]Classified based on the 1990 Standard Occupational Classification for years 2000–2004 and the 2000 Standard Occupational Classification by Bureau of Labor Statistics for years 2005–2007.

did not provide the date of their last asthma attack. These individuals were classified as not having 12-month asthma and thus, contributed only to the denominator when estimating 12-month asthma rates, likely making our results conservative.

Also we did not survey WTC workers before 9/11/01, so recall bias may have affected their reports of asthma in the year 2000 and earlier years. To check this recall bias, the percentage of those reporting lifetime or 12-month asthma attack by year of monitoring visit were checked and there was no significant difference between years (2002–2007). This means that it is less likely for a recall bias to play a role on such a low prevalence. In contrast with recall bias, there may be a healthy worker effect which means WTC responders and volunteers were much healthier than the general population, which may be a better explanation of such a low prevalence of lifetime asthma and episodes prior to 9/11. To control this healthy worker effect, we matched occupations between WTC and NHIS, but a still lower prevalence in WTC responders was observed within the same occupational group in 2000. This may imply that WTC responders were even healthier than other workers in the same occupational group. Race and ethnicity are also known risk factors of asthma, but these are not adjusted in this study, because we found no relationships between these factors and asthma among
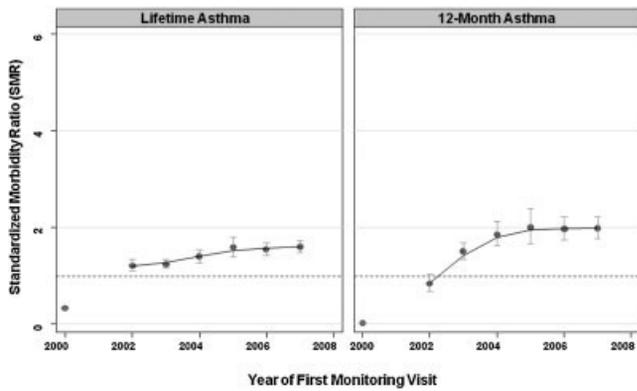
FIGURE 2. Age-adjusted standardized morbidity ratios for lifetime and 12-month asthma among World Trade Center responders compared to National Health Interview participants.

responders. However, other socioeconomic factors such as income level or household size should be investigated, but unfortunately no data has been collected to capture this information.

In summary, this study shows that WTC responders have increased rates of asthma as well as active disease when compared to the general US population. These results suggest that medical surveillance and treatment programs should be established following similar exposures in the future. Similarly, objective measures of lung function and airway responsiveness should be obtained in exposed WTC responders with respiratory symptoms. Early diagnosis and long-term monitoring are necessary to avoid irreversible lung changes among WTC responders with asthma. Further research is also needed to clarify the physiopathology of exposure-related asthma as well as to develop plans to decrease the risk of pulmonary disease among future responders to similar disasters.

TABLE V. Age and Sex Stratified Standardized Morbidity Ratio of Lifetime and 12-Month Asthma

Age by gender	2000 SMR	2000 95% CI	2002 SMR	2002 95% CI	2003 SMR	2003 95% CI	2004 SMR	2004 95% CI	2005 SMR	2005 95% CI	2006 SMR	2006 95% CI	2007 SMR	2007 95% CI
Lifetime asthma														
Male	0.4	0.4–0.5	1.3	1.2–1.5	1.5	1.4–1.6	1.7	1.5–1.8	2.0	1.9–2.2	1.9	1.8–2.1	2.1	2.0–2.3
18–29	0.4	0.3–0.6	0.8	0.5–1.2	0.9	0.6–1.3	1.3	0.9–1.9	1.4	1.0–2.0	1.3	0.9–1.8	1.3	1.0–1.7
30–39	0.4	0.4–0.5	1.6	1.3–1.9	1.5	1.3–1.7	1.8	1.5–2.1	2.0	1.7–2.3	2.1	1.8–2.3	2.4	2.2–2.7
40–49	0.5	0.4–0.5	1.4	1.2–1.7	1.6	1.4–1.8	1.7	1.4–2.0	2.3	2.0–2.5	2.1	1.9–2.3	2.1	1.9–2.3
50–59	0.3	0.3–0.4	1.0	0.8–1.4	1.5	1.3–2.0	1.6	1.2–2.0	1.9	1.6–2.3	1.7	1.4–2.0	2.2	1.9–2.5
≥60	0.2	0.1–0.4	1.8	0.9–3.2	1.0	0.6–1.7	1.2	0.7–2.1	2.0	1.3–2.8	1.3	0.8–1.9	1.6	1.2–2.1
Female	0.3	0.2–0.3	1.7	1.4–2.2	1.4	1.1–1.6	2.1	1.8–2.6	2.0	1.7–2.3	2.0	1.7–2.2	2.4	2.2–2.7
18–29	0.3	0.1–0.6	1.7	0.7–3.3	0.9	0.4–1.7	1.5	0.6–3.1	1.7	0.9–3.1	1.4	0.8–2.3	2.1	1.2–3.5
30–39	0.3	0.2–0.4	1.9	1.3–2.8	1.5	1.1–2.0	2.4	1.7–3.3	1.7	1.2–2.3	1.8	1.4–2.3	2.3	1.9–2.8
40–49	0.2	0.2–0.3	1.7	1.1–2.4	1.5	1.2–2.0	2.2	1.6–2.9	2.1	1.6–2.6	2.2	1.8–2.7	2.8	2.4–3.3
50–59	0.3	0.2–0.5	1.4	0.7–2.6	0.9	0.5–1.6	1.9	1.0–3.1	1.8	1.2–2.7	1.9	1.4–2.7	2.1	1.5–2.8
≥60	0.4	0.1–1.0	2.8	0.6–8.3	1.6	0.5–3.8	2.3	0.5–6.6	3.6	2.0–6.1	3.0	1.3–5.9	1.9	1.0–3.2
12-month asthma														
Male	0.1	0.1–0.1	1.2	0.9–1.5	2.4	2.1–2.7	2.5	2.1–2.9	2.6	2.1–3.3	2.1	0.8–4.6	2.5	2.2–2.9
18–29	0.1	0.0–0.3	0.6	0.1–1.7	1.1	0.5–2.1	1.1	0.4–2.3	1.5	0.2–5.5	4.1	1.9–7.8	3.6	1.8–6.4
30–39	0.1	0.0–0.1	1.4	1.0–2.0	2.4	1.9–3.0	2.7	2.1–3.5	2.7	1.8–3.7	3.3	2.6–4.1	3.3	2.5–4.2
40–49	0.1	0.1–0.2	1.5	1.0–2.1	2.6	2.1–3.2	2.8	2.2–3.6	2.8	2.0–3.9	2.5	2.0–3.2	2.1	1.7–2.5
50–59	0.1	0.0–0.2	0.7	0.3–1.4	2.5	1.8–3.5	1.8	1.1–2.9	2.2	1.1–4.1	2.9	2.3–3.6	2.9	2.0–4.1
≥60	0.1	0.0–0.4	0.6	0.0–3.1	1.5	0.5–3.4	2.0	0.6–4.6	3.1	0.6–9.0	2.2	1.5–3.1	2.3	1.2–4.0
Female	0.0	0.1–0.1	1.3	0.9–2.0	1.8	1.4–2.3	2.7	2.0–3.5	2.7	1.8–3.7	2.1	1.6–2.7	2.8	2.3–3.5
18–29	—	—	2.6	0.9–6.1	0.9	0.2–2.7	2.1	0.4–6.1	6.9	2.5–15.0	2.3	0.7–5.3	2.0	0.2–7.3
30–39	0.1	0.0–0.3	1.6	0.8–3.0	1.9	1.2–2.9	2.8	1.7–4.3	2.0	0.8–4.1	1.9	1.2–3.0	2.3	1.4–3.4
40–49	0.0	0.0–0.1	1.2	0.6–2.3	2.2	1.5–3.0	2.7	1.8–4.1	2.0	1.0–3.5	2.4	1.6–3.4	3.2	2.3–4.3
50–59	—[a]	—	0.4	0.0–1.9	1.2	0.5–2.5	2.7	1.2–5.3	3.7	1.5–7.5	1.8	0.9–3.2	2.9	1.7–4.5
≥60	—	—	—	—	1.9	0.2–7.0	—	—	4.0	0.5–14.5	2.9	0.4–10.5	4.1	1.5–9.0

CI, confidence interval; SMR, standardized morbidity ratio.
[a]Not reported given low number of observations.

TABLE VI. Standardized Morbidity Ratio for Lifetime and 12-Month Asthma by Gender and Occupation

Occupation by gender	2000		2002		2003		2004		2005		2006		2007	
	SMR	95% CI	SMR	95% CI	SMR	95% CI	SMR	95% CI	SMR	95% CI	SMR	95% CI	SMR	95% CI
Lifetime asthma														
Male	0.4	0.4–0.5	1.3	1.2–1.5	1.5	1.4–1.6	1.7	1.5–1.8	2.0	1.9–2.2	1.9	1.8–2.1	2.4	2.2–2.7
Protective service	0.3	0.3–0.4	1.2	0.9–1.5	2.4	2.1–2.7	2.0	0.1–2.3	4.7	0.3–5.3	2.4	0.1–2.6	2.0	0.1–2.2
Construction and extraction	0.3	0.3–0.4	1.4	1.1–1.8	1.5	1.2–1.7	1.2	0.1–1.5	6.6	0.5–7.6	4.8	0.4–5.6	4.9	0.3–5.5
Installation, maintenance, and repair	0.6	0.5–0.8	1.6	1.3–2.1	1.9	1.4–2.6	4.1	0.7–5.8	1.6	0.6–3.1	4.0	0.5–5.2	6.0	0.6–7.3
Transportation and material moving	0.5	0.3–0.7	1.1	0.6–1.9	1.2	0.8–1.6	1.7	0.4–2.8	8.4	1.5–12.0	1.8	0.4–2.6	6.5	0.9–8.5
Other	0.3	0.3–0.4	1.4	1.1–1.8	1.4	1.1–1.8	2.3	0.3–2.9	7.1	0.7–8.7	3.0	0.3–3.6	3.6	0.3–4.1
Female	0.3	0.2–0.3	1.7	1.4–2.2	1.4	1.1–1.6	2.1	1.8–2.6	2.0	1.7–2.3	2.0	1.7–2.2	2.4	2.2–2.7
Protective service	0.6	0.4–0.8	2.0	1.3–2.9	1.6	1.2–2.1	1.8	0.2–2.3	3.6	0.5–4.7	1.4	0.2–1.7	1.9	0.2–2.2
Construction and extraction	0		0.4	0.1–1.6	0.3	0.1–0.8	1.5	0.7–3.5	5.6	1.5–9.4	2.2	0.6–3.6	10.4	2.3–16.0
Installation, maintenance, and repair	0.5	0.1–1.3	2.1	1.0–4.0	0		1.8	1.1–5.3	29.2	11.0–60.1	5.5	2.7–14.0	5.2	1.7–9.6
Transportation and material moving	0.8	0.1–3.0	6.6	1.8–16.8	2.0	0.2–7.1	2.8	1.6–8.2			6.3	4.4–22.6	6.1	2.0–11.5
Other	0.3	0.2–0.4	1.4	0.9–2.1	1.7	1.3–2.2	3.1	0.5–4.2	6.6	0.8–8.3	3.2	0.3–3.9	4.6	0.4–5.5
12-month asthma														
Male	0.1	0.1–0.1	1.2	0.9–1.5	2.4	2.1–2.7	2.5	2.1–2.9	2.6	2.1–3.3	2.1	0.8–4.6	2.5	2.2–2.9
Protective service	0.1	0.0–0.1	1.4	0.9–2.1	3.5	2.9–4.3	5.4	4.4–6.7	2.5	1.8–3.3	2.9	2.4–3.4	1.8	1.5–2.1
Construction and extraction	0.1	0.0–0.2	1.6	0.9–2.7	2.3	1.8–3.0	1.5	1.0–2.1	2.3	1.3–3.8	2.5	1.7–3.6	2.4	1.5–3.4
Installation, maintenance, and repair	0.2	0.1–0.6	1.8	1.1–2.8	2.9	1.7–4.6	3.5	1.4–7.2	4.0	1.7–7.9	3.5	1.9–5.9	2.8	1.6–4.4
Transportation and material moving	0.1	0.0–0.6	0.4	0.0–2.4	1.7	0.8–3.1	3.4	1.6–6.3	2.8	0.6–8.2	1.8	0.7–3.7	2.9	1.2–5.7
Other	0.1	0.0–0.2	1.5	0.8–2.4	2.4	1.7–3.4	2.6	1.6–4.0	2.7	1.3–5.0	3.2	2.2–4.7	3.4	2.5–4.6
Female	0.0	0.0–0.1	1.3	0.9–2.0	1.8	1.4–2.3	2.7	2.0–3.5	2.7	1.8–3.7	2.1	1.6–2.7	2.8	2.3–3.5
Protective service	0.1	0.0–0.2	1.4	0.6–2.6	2.0	1.3–2.8	2.1	1.4–3.1	2.9	1.7–4.5	0.8	0.6–1.2	1.1	0.8–1.5
Construction and extraction	—	—[a]	—	—	0.5	0.1–1.3	0.7	0.1–2.6	0.7	0.0–3.8	0.6	0.1–1.9	1.5	0.3–4.4
Installation, maintenance, and repair	—	—	1.3	0.3–3.8	—	—	3.1	0.9–17.4	25.0	0.6–139.3	—	—	1.9	0.2–7.0
Transportation and material moving	—	—	—	—	11.1	0.3–61.9	2.0	0.1–10.9	—	—	—	—	4.8	1.0–13.9
Other	0.1	0.0–0.2	1.3	0.6–2.4	2.4	1.7–3.5	4.2	2.5–6.2	2.7	1.4–4.8	2.6	1.8–3.7	3.6	2.6–5.0

CI, confidence interval; SMR, standardized morbidity ratio.
[a]Not reported given low number of observations.

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