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Hospitalizations for asthma among adults exposed to the September 11, 2001 World Trade Center terrorist attack

Sara A. Miller-Archie, MPH [a], Hannah T. Jordan, MD, MPH [a], Howard Alper, PhD, MS[a], Juan P. Wisnivesky, MD, DrPH [b], James E. Cone, MD, MPH [a], Stephen M. Friedman, MD, MPH[a], and Robert M. Brackbill, PhD, MPH [a]

[a]World Trade Center Health Registry, New York City Department of Health and Mental Hygiene, New York, NY, USA; [b]Icahn School of Medicine at Mount Sinai, New York, NY, USA

ABSTRACT

Objective: We described the patterns of asthma hospitalization among persons exposed to the 2001 World Trade Center (WTC) attacks, and assessed whether 9/11-related exposures or comorbidities, including posttraumatic stress disorder (PTSD) and gastroesophageal reflux symptoms (GERS), were associated with an increased rate of hospitalization. *Methods*: Data for adult enrollees in the WTC Health Registry, a prospective cohort study, with self-reported physician-diagnosed asthma who resided in New York State on 9/11 were linked to administrative hospitalization data to identify asthma hospitalizations during September 11, 2001–December 31, 2010. Multivariable zero-inflated Poisson regression was used to examine associations among 9/11 exposures, comorbid conditions, and asthma hospitalizations. *Results*: Of 11 471 enrollees with asthma, 406 (3.5%) had ≥1 asthma hospitalization during the study period (721 total hospitalizations). Among enrollees diagnosed before 9/11 ($n = 6319$), those with PTSD or GERS had over twice the rate of hospitalization (adjusted rate ratio (ARR) = 2.5, 95% CI = 1.4–4.1; ARR = 2.1, 95% CI = 1.3–3.2, respectively) compared to those without. This association was not statistically significant in enrollees diagnosed after 9/11. Compared to higher educational attainment, completing less than college was associated with an increased hospitalization rate among participants with both pre-9/11- and post-9/11-onset asthma (ARR = 1.9, 95% CI = 1.2–2.9; ARR = 2.6, 95% CI = 1.6–4.1, respectively). Sinus symptoms, exposure to the dust cloud, and having been a WTC responder were not associated with asthma hospitalization. *Conclusions*: Among enrollees with pre-9/11 asthma, comorbid PTSD and GERS were associated with an increase in asthma hospitalizations. Management of these comorbidities may be an important factor in preventing hospitalization.

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Introduction

Extensive research has shown that exposure to dust and debris resulting from the collapse of the World Trade Center (WTC) on September 11, 2001 (9/11) was associated with asthma [1–5]. Nearly a decade after 9/11, workers involved in the rescue and recovery effort continued to experience increased rates of asthma [3,4], and over two-thirds of WTC Health Registry enrollees with self-reported asthma had poor or very poor control of their disease [6].

One factor that may contribute to the persistence and poor control of asthma in this population is the relatively high rate of comorbid gastroesophageal reflux symptoms (GERS), posttraumatic stress disorder (PTSD), and sinus symptoms among those with post-9/11-onset asthma. These conditions, which have been associated with asthma in multiple studies [7–12], have been found to be associated with 9/11 exposure and to persist over a decade after the attack [3,4,6,13,14].

The combination of high rates and persistence of asthma, multiple comorbidities that could exacerbate asthma symptoms, including PTSD, GERS, and sinus problems, and evidence that 9/11-related asthma remains poorly controlled suggests that people who were exposed to the WTC attacks may have an increased risk of hospitalization for asthma. One population-based study found that lower Manhattan residents had higher rates of asthma hospitalization during the week of September 11, 2001 compared to residents of Queens, New York, who presumably had less exposure to the attack [15]; however, there are no published studies of asthma hospitalizations among 9/11-exposed cohorts.

We therefore sought to describe patterns of hospitalization for asthma in a large, diverse cohort of

CONTACT Sara A. Miller-Archie smille12@health.nyc.gov World Trade Center Health Registry, New York City Department of Health and Mental Hygiene, 125 Worth Street, New York, NY 10013, USA.

persons exposed to the WTC attack. We aimed to identify modifiable factors associated with asthma hospitalization and subpopulations at an increased risk in order to inform planning for preventive interventions. Specifically, we assessed whether PTSD, GERS, or sinusitis were associated with an increased risk of asthma hospitalization.

Methods

Study population

The WTC Health Registry (Registry) is a prospective cohort study, comprising 71,430 persons who lived in, worked in, or were passing through lower Manhattan on September 11, 2001, or who conducted rescue, recovery, or clean-up work on 9/11 or during the months that followed. In 2003–2004, all enrollees completed a baseline survey regarding sociodemographic information, 9/11-related exposures, and physical and mental health history and symptoms primarily via a computer-assisted telephonic interview (Wave 1) [16]. Two subsequent cohort-wide surveys were administered via paper, web, and telephone to gather updated health information: Wave 2 in 2006–2007 (response rate = 68%) and Wave 3 in 2011–2012 (response rate = 63%). The Registry protocol was approved by the Centers for Disease Control and Prevention and New York City Department of Health and Mental Hygiene institutional review boards. All enrollees provided verbal informed consent.

The current study was limited to Registry enrollees aged ≥18 who resided in New York State on September 11, 2001 and who reported having been diagnosed with asthma by a health professional before January 1, 2011 on Waves 1, 2, or 3 ($N = 12{,}076$). We excluded enrollees who had withdrawn from the Registry as of August 1, 2015 ($n = 81$) or had missing information on whether they had been diagnosed with asthma before or after 9/11 ($N = 524$), leaving an analytic sample of 11,471.

Study procedures

We identified hospitalizations among enrollees via a linkage to the New York State Department of Health's Statewide Planning and Research Cooperative System (SPARCS) database. SPARCS comprises approximately 95% of hospital discharges in New York since 1991 (excluding federal and psychiatric hospitals) [17]. The Registry and SPARCS were electronically linked to identify hospital discharges which occurred from September 11, 2001 to December 31, 2010. A record was matched based on an algorithm that used parts of the name, date of birth, social security number, and address. Dates of admission and discharge, principal and secondary discharge diagnoses, length of stay, and procedures that occurred during the hospitalization, including mechanical ventilation and intubation, were obtained from SPARCS records.

Study outcome

An asthma hospitalization, identified via linkage to the SPARCS hospital discharge database, was defined as either a hospitalization with a principal discharge diagnosis of asthma (ICD-9 code 493.xx) or as a hospitalization with another respiratory condition listed as the principal discharge diagnosis (Appendix 1) and asthma listed as a secondary discharge diagnosis. An asthma hospitalization that required mechanical ventilation or intubation (ICD-9 procedure codes: 939.0, 960.4, 967.0, 967.1, and 967.2) was classified as severe.

Comorbid conditions

Probable posttraumatic stress disorder (referred to simply as "PTSD"), measured at Wave 1, was defined as a score ≥44 on a 9/11-specific PTSD Checklist (PCL), a validated, 17-item instrument which has been shown to have high diagnostic efficiency [18,19]. The PCL inquired the degree to which enrollees were bothered by PTSD symptoms in the preceding 30 days (1='not at all' to 5='extremely'). An enrollee missing one or more PCL items but whose score from the completed items could only be compatible with a total score of <44 or ≥44 was included in the appropriate PTSD category; otherwise, we considered an enrollee's PTSD status as missing [20].

Physical health comorbidities studied were GERS and sinus symptoms reported in the enrollment questionnaire (2003–2004). In this survey, enrollees were asked, "since 9/11, have you had any of the following symptoms: heartburn, indigestion or reflux (GERS); sinus problems, nose irritation, or postnasal drip (sinus symptoms)?" [21].

9/11 exposures

We defined dust cloud exposure as having been outdoors within the dust or debris cloud resulting from the collapse of the WTC Towers on September 11, 2001. We further restricted our definition to require having been caught in the dust cloud south of Chambers Street in lower Manhattan. Enrollees were classified as responders if they worked at least one shift at the WTC rescue and recovery site or at the Staten Island recovery site or on a barge transporting debris from September 11, 2001 to June 30, 2002. Responders may have worked in either a professional or volunteer capacity. Community members included persons who lived, worked, or were in transit in lower Manhattan on September 11, 2001. If an enrollee

could be categorized as both, they were classified as a responder.

Covariates

All demographic covariates were measured at Wave 1 and included the following: age at 9/11, sex, race/ethnicity, education level, and history of smoking. We included these demographic characteristics as they have been shown to be associated with poor control of asthma or hospitalization for asthma [6,22–24].

Statistical analysis

All analyses were stratified by whether an enrollee was first diagnosed with asthma before or after 9/11, due to inherent differences in these subpopulations. We calculated yearly rates of asthma hospitalization for the period September 11, 2001 through December 31, 2010. The at-risk population included persons who reported ever having been diagnosed with asthma, and rates were calculated per 1000 persons at risk of asthma hospitalization. The rate for hospitalizations which occurred in 2001 was calculated to reflect the shortened time period.

We conducted bivariate analyses using the chi-square test to compare the distribution of sociodemographic factors, 9/11 exposures, and comorbid conditions between those who were and were not hospitalized for asthma. The Wilcoxon signed-rank test was used to determine whether a significant difference existed in mean length of hospital stay between those diagnosed with asthma before and after 9/11.

Multivariable zero-inflated Poisson (ZIP) regression models were used to examine the relationship between PTSD, GERS, sinus symptoms, dust cloud exposure, responder status, and rate of post-9/11 asthma hospitalizations. We ran separate models for enrollees with pre-9/11-onset and post-9/11-onset asthma. The ZIP model was selected in order to accommodate overdispersion and the skewness of the data due to an excessive number of persons who were not hospitalized (i.e., an excess of zero counts) [25]. We calculated relative hospitalization rates, defined as the average number of hospitalizations during the study period for the sample of interest, as a function of a selected exposure or comorbid condition using the Average Predicted Value method developed by Albert et al. [26] and implemented by Weaver et al. [27]. Briefly, ZIP models were employed to calculate rates of hospitalization for exposure/comorbidity = 1 and exposure/comorbidity = 0, while adjusting for other covariates, and the bootstrap method was used to calculate 95% confidence intervals. Age (18–44 years versus ≥45 years), sex, race/ethnicity (white or Asian versus black, Hispanic, or other race/ethnicity), education (college degree or higher versus less than a college degree), and smoking status (current versus former or never) were included in all models, as were the comorbidities (PTSD, GERS, sinus symptoms) and 9/11-related exposures of interest (responder status and dust cloud exposure). For all analyses, statistical significance was set to a p-value <.05. We conducted our analyses using SAS version 9.4 (SAS Institute, Cary, NC).

Results

Linkage to hospital discharge records identified 721 asthma hospitalizations which occurred during September 11, 2001 through December 31, 2010 among 406 (3.5%) of the 11,471 enrollees with self-reported asthma (97 of whom were hospitalized more than once during the study period). Of these hospitalizations, 546 (75.7%) listed asthma as the primary diagnosis, and for 175 (24.3%), asthma was a secondary diagnosis. The most common primary diagnoses for hospitalizations that listed asthma as a secondary diagnosis were pneumonia and influenza (n = 94, 53.7%), other lower respiratory symptoms and conditions (e.g., cough, dyspnea, and painful respiration) (n = 18, 10.3%), respiratory failure (n = 15, 8.6%), and acute bronchitis (n = 13, 7.4%) (Appendix 2).

Among enrollees with pre-9/11 asthma (n = 6319), 4.2% were hospitalized, whereas 2.7% of enrollees with post-9/11 asthma (n = 5152) were hospitalized (Table 1). The median number of hospitalizations was 1 (Interquartile range (IQR): 1–2) among hospitalized enrollees with pre-9/11 asthma, and 1 (IQR = 1–1) among enrollees with post-9/11 asthma. The mean length of stay was 4.1 days [standard deviation (SD) = 4.6] for those with pre-9/11 asthma, and 3.8 days (SD = 2.8) for those with post-9/11 asthma (Wilcoxon signed-rank test, p = .7). Among those with pre-9/11 asthma, 28 (10.4%) had at least one severe hospitalization for asthma, for a total of 34 severe hospitalizations. Among those with post-9/11 asthma, seven enrollees (5.1%) were hospitalized for severe asthma for a total of eight severe hospitalizations. The number of severe hospitalizations for asthma was too small to make meaningful statistical comparisons (data not shown).

Temporal trends in asthma hospitalizations are shown in Figure 1. Hospitalization rates among enrollees with pre-9/11-onset asthma peaked in 2002 at 12.8/1000 persons at risk, and rates among enrollees with post-9/11-onset asthma peaked in 2004 at 6.2/1000 at risk. Rates among those with pre-9/11 asthma remained higher than among those with post-9/11 asthma throughout the study period.

Table 1 shows characteristics of the study sample according to the timing of asthma diagnosis. Enrollees with pre-9/11 asthma (n = 6319) were evenly distributed

Table 1. Characteristics of adult World Trade Center Health Registry enrollees residing in New York State who reported asthma, stratified by timing of asthma diagnosis, September 11, 2001–December 31, 2010.

	Pre-9/11 asthma diagnosis			Post-9/11 asthma diagnosis		
Characteristic	Total[a] N	Hospitalized %	Chi-square *p*-value	Total[a] N	Hospitalized %	Chi-square *p*-value
Total enrollees	6319	4.2		5152	2.7	
Total hospitalized	268			138		
Median number of hospitalizations among those hospitalized ≥1 (IQR)		1 (1–2)			1 (1–1)	
Mean length of stay in days (SD)[b]		4.1 (4.6)			3.8 (2.8)	
Demographics						
Age on 9/11			<.0001			0.0169
18–24	567	1.1		241	1.7	
25–44	3503	3.5		2996	2.3	
45–64	2064	5.6		1783	3.2	
65+	185	13.0		132	6.1	
Sex			0.0006			0.0048
Female	3196	5.1		2161	3.4	
Male	3123	3.4		2991	2.1	
Race/ethnicity			<.0001			<.0001
White non-Hispanic	3522	2.9		3105	2.3	
Black non-Hispanic	939	6.8		586	6.0	
Hispanic	1219	6.6		915	2.5	
Asian	354	1.7		335	1.5	
Other	285	4.9		211	2.4	
Education			<.0001			<.0001
Less than high school	303	11.6		327	4.3	
High school	1092	6.5		1157	2.7	
Some college	1551	5.4		1466	4.2	
College graduate	3294	2.3		2157	1.5	
Smoking history			0.0766			0.3666
Current smoker	1036	5.3		793	3.2	
Never or former smoker	5210	4.1		4325	2.6	
Comorbidities						
PTSD			<.0001			0.1267
Yes	1237	8.8		1455	3.2	
No	5010	3.1		3651	2.5	
GERS since 9/11			<.0001			0.2326
Yes	2332	6.4		2448	2.9	
No	1956	2.9		2663	2.4	
Sinus symptoms since 9/11			0.001			0.5391
Yes	3954	4.9		3820	2.8	
No	2323	3.1		1303	2.5	
9/11 Exposures						
Eligibility Group			0.5128			0.193
Responder	2193	4.5		2819	2.4	
Community member	4126	4.1		2333	3.0	
Caught in the dust cloud south of Chambers Street			0.5226			0.0678
In dust cloud south of Chambers Street	3083	4.4		2583	3.1	
Other location, or not at all	3206	4.1		2552	2.3	

Notes. [a]Values may not sum to total due to missing data. [b]Wilcoxon signed-ranks test, $p = .7$. IQR = interquartile range; SD = standard deviation; GERS = gastroesophageal reflux symptoms; PTSD = posttraumatic stress disorder.

by gender (49.4% males) and were primarily community members (65.3%). Among enrollees with post-9/11 asthma ($n = 5152$), 58.1% were males and 54.7% were responders. Comorbid PTSD, GERS, and sinus symptoms were more common among enrollees with post-9/11 asthma (28.2, 47.5, and 74.1%, respectively) than among those with pre-9/11 asthma (19.6, 36.9, and 62.6%, respectively).

Regardless of the timing of asthma onset, the proportions of participants who were ≥65 years of age, female, black or Hispanic, or had less than a college degree were higher among those hospitalized for asthma compared with those not hospitalized during the study period (Table 1).

Among enrollees with pre-9/11 asthma, the proportion of enrollees with PTSD who were hospitalized was nearly three times higher than among those without PTSD (8.8% versus 3.1%, $p < .001$). Higher proportions of those with GERS or sinus symptoms were hospitalized for asthma compared to participants without these symptoms (6.4% versus 2.9%, and 4.9% versus 3.1%, respectively, $p < .001$) (Table 1). The 9/11-related exposures studied, including responder status and dust cloud exposure, were not associated with asthma hospitalization in this group.

Among those with post-9/11 asthma, higher proportions of participants with comorbid PTSD, GERS, or sinus symptoms at enrollment, or who had been caught in the

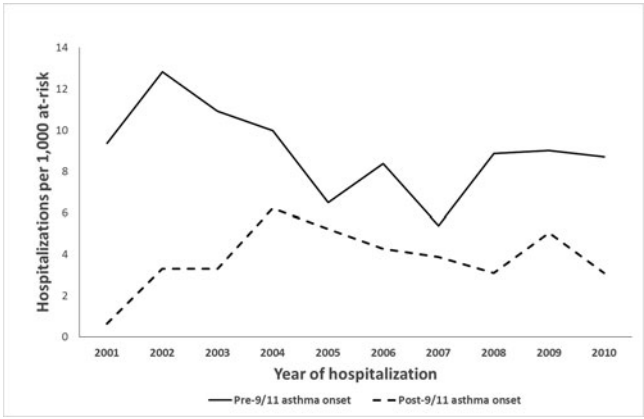

Figure 1. Asthma hospitalizations among adult World Trade Center Health Registry enrollees residing in New York State, September 11, 2001–December 31, 2010.

dust cloud, were hospitalized, although none of these met the standard definition of statistical significance (Table 1).

The results of the multivariable ZIP models are shown in Table 2. Among enrollees with pre-9/11 asthma, those aged ≥45 years on 9/11 had an elevated adjusted rate ratio (ARR) compared with those 18–44 (ARR = 2.0, 95% CI = 1.3–3.0), as did enrollees who were black, Hispanic, or multiracial (ARR = 1.9, 95% CI = 1.1–3.1) compared with white or Asian enrollees. Having less than a college degree was also significantly associated with an increase in hospitalizations (ARR = 1.9, 95% CI = 1.2–2.9). Enrollees with PTSD had an ARR for hospitalization more than two times greater (ARR = 2.5, 95% CI = 1.4–4.1) than those without PTSD, and those with GERS had twice the rate of hospitalizations (ARR = 2.1, 95% CI = 1.3–3.2) compared to those without. Sex, smoking history, sinus symptoms, responder status, and dust cloud exposure were not associated with asthma hospitalizations in this group.

Among enrollees with post-9/11 asthma, females experienced 1.8 times the rate of hospitalizations compared to males (ARR = 1.8, 95% CI = 1.1–2.8) (Table 2). Enrollees who were black, Hispanic, or multiracial had nearly twice the rate of hospitalizations than enrollees who were white or Asian (ARR = 1.8, 95% CI = 1.1–2.7). Having less than a college education was significantly associated with asthma hospitalization (ARR = 2.6, 95% CI = 1.6–4.1), Asthma hospitalization was not significantly associated with PTSD, GERS, sinus symptoms, responder status, or dust exposure in the multivariable model.

In a secondary analysis, we limited our hospitalization definition to only include asthma hospitalizations that listed asthma as a primary diagnosis. These regression models yielded similar results to those using our broader study definition (data not shown). We conducted an additional secondary analysis limiting hospitalizations to an earlier period (9/11/2001–12/31/2004) to determine whether dust exposure may have been linked to a more short-term effect on asthma hospitalization; however, we still did not observe any significant association between dust cloud exposure and asthma hospitalization (data not shown).

To address potential study participation bias, we conducted a sensitivity analysis limited to hospitalizations that occurred after Registry enrollment date (n = 498 hospitalizations). Using ZIP models that included the same covariates as those used for our primary analysis, we found similar, though slightly attenuated, measures of association (data not shown).

Table 2. Adjusted rate ratios for asthma hospitalization in New York State among adult enrollees of the World Trade Center Health Registry, September 11, 2001–December 31, 2010.[a]

	Pre-9/11 asthma diagnosis		Post-9/11 asthma diagnosis	
Characteristic	Adjusted rate ratio	95% CI	Adjusted rate ratio	95% CI
Age on 9/11				
18–44	Ref		Ref	
45+	2.0	1.3–3.0	1.4	0.8–2.3
Sex				
Female	1.1	0.7–2.0	1.8	1.1–2.8
Male	Ref		Ref	
Race				
White Non-Hispanic or Asian	Ref		Ref	
All others	1.9	1.1–3.1	1.8	1.1–2.7
Education				
Less than college	1.9	1.2–2.9	2.6	1.6–4.1
College or higher	Ref		Ref	
Smoking history				
Current	0.9	0.5–1.5	1.1	0.5–2.2
Former or never smoker	Ref		Ref	
PTSD				
Yes	2.5	1.4–4.1	1.3	0.8–2.0
No	Ref		Ref	
GERS since 9/11				
Yes	2.1	1.3–3.2	1.3	0.8–2.0
No	Ref		Ref	
Sinus symptoms since 9/11				
Yes	1.0	0.6–1.6	1.1	0.7–1.8
No	Ref			
Eligibility Group				
Responder	1.6	0.9–2.6	1.0	0.6–1.7
Community member	Ref		Ref	
Caught in the dust cloud				
In dust cloud south of Chambers Street	1.4	0.8–2.1	1.3	0.9–2.0
Other location, or not at all	Ref		Ref	

Notes. [a]Zero-inflated Poisson regression models, adjusted for the variables shown. CI = confidence interval; GERS = gastroesophageal reflux symptoms; PTSD = Posttraumatic stress disorder.

Discussion

Among Registry enrollees diagnosed with asthma before 9/11, those with PTSD or GERS at Registry enrollment (2003–2004) were more likely to be hospitalized for

asthma between September 11, 2001 and December 31, 2010 than participants without these comorbidities. While numerous studies have identified a relationship between 9/11 exposure and asthma [1–5], we found that, among persons with asthma, 9/11 dust cloud exposure was not associated with an increased risk of being hospitalized for asthma. Other factors, including sociodemographic characteristics and comorbid conditions, appear to have been more closely associated with an elevated risk of asthma hospitalization in our study, mirroring a previous finding that 9/11-related dust exposure was not associated with the level of asthma control 10 years after 9/11 [6].

Mental health conditions have been shown to increase the likelihood of poor asthma control, though this relationship may be bidirectional [28,29]. Prior Registry studies have identified relationships between PTSD and other mental health conditions and both persistent and more frequent lower respiratory symptoms and poorly controlled asthma [6,30,31]. Potential pathways that link mental health conditions to increased asthma morbidity may be biological as well as behavioral. For instance, increased inflammation and activation of stress pathways have been described in depression and PTSD; the latter mechanism may lead to the bronchoconstriction associated with an asthma exacerbation, and the former may lead to inflamed airways [32]. Similarly, mental health conditions have been linked to decreased adherence to asthma controller medications and other important self-management behaviors [29,32]. Serious mental illness has been found to predict subsequent hospitalization for asthma exacerbations and chronic obstructive pulmonary disease [33]. This indicates that psychological comorbidities may increase the complexity of treating and controlling asthma, which could lead to hospitalization.

Research suggests that GERS may lead to or exacerbate asthma and be associated with poor asthma control [34–36]. Proposed underlying mechanisms fall into two camps: reflex theory and reflux theory [35]. Reflex theory suggests that esophageal acid induces a vagally mediated reflex leading to bronchoconstriction. The reflux theory posits the direct microaspiration of gastric and duodenal contents into the lungs via the esophagus. Conversely, asthma may lead to GERS due to a resulting increase in the pressure gradient between the thorax and abdomen, relaxation of smooth muscles including the lower esophageal sphincter, and the use of certain asthma medications [35]. The co-occurrence of these two diseases is well documented [7,9,13] and adding proton pump inhibitor treatment for GERS to an asthma regimen may reduce asthma symptoms and medication use, and improve pulmonary function [37].

We found that many demographic characteristics known to be risk factors for hospitalization among persons with asthma in other studies, including being female [22,23], black or Hispanic [22–24], of older age [23], or having a lower level of education [22], were significantly associated with hospitalization in this study. These subpopulations may benefit from targeted interventions to improve asthma treatment and control. This study lacked data on health literacy and numeracy, lower levels of which have been associated with poor asthma control and hospitalizations [38,39]. Since lack of a college education was a risk factor for asthma hospitalization in our study, further research into the possible benefit of improved health education is warranted.

Our study yielded different results for enrollees who were diagnosed with asthma before 9/11 compared with those who were first diagnosed after 9/11. PTSD and GERS were associated with an increase in hospitalizations in the former group, while in the latter, elevated but not statistically significant associations were observed. While some of these findings may be due to lower statistical power in the post-9/11 group, inherent differences in these populations before 9/11 may explain some of the differences. A healthy worker effect may account for the lower rate of hospitalization in the post-9/11 asthma subpopulation, as responders comprised the majority of this group, while making up only 34.7% of the pre-9/11 asthma subpopulation.

For enrollees who were first diagnosed with asthma after 9/11, hospitalization rates steadily increased from the end of 2001 to their peak in 2004, then slowly declined in the following years. A prior study of post-9/11 incident asthma among adult Registry enrollees found the highest rates of diagnosis which occurred in 2001 (postattack) and in 2002 [2]. Among those with pre-existing asthma on 9/11, the attack and its subsequent physical and mental health effects may have contributed to disease exacerbation, which may explain the early increase in asthma hospitalization rates followed by a decline which began in 2003.

To date, only one study has examined hospitalizations for respiratory disease related to the 2001 WTC terrorist attack [15]. Using hospital discharge data from SPARCS, Lin et al. found an increase in hospitalizations the week after 9/11 for residents of lower Manhattan, but not in a less-exposed comparison population. SPARCS data have also been used to identify an elevated risk of heart disease hospitalizations among Registry enrollees with PTSD at Wave 1 [40]. To our knowledge, however, PTSD has not been studied as a predictor for asthma hospitalization in an adult WTC-exposed population.

This analysis was limited due to the lack of data on access to healthcare, asthma medication use or

adherence, medication or treatment for GERS, PTSD and sinus problems, and comorbid conditions such as obstructive sleep apnea and overweight/obesity. Subsequent Registry surveys have included these topics, though they were queried after this study's observation period. Another limitation was our inability to assess the temporal association between comorbid conditions and asthma hospitalizations, as hospitalizations occurred both before and after Wave 1 was administered, and comorbidities may have occurred anytime between September 11, 2001 and Registry enrollment in 2003–2004. We also limited our study population to enrollees who self-reported asthma and, therefore, may have missed asthma hospitalizations, either due to lower participation rates in follow-up surveys or to self-reporting errors. However, when we looked at all asthma hospitalizations in SPARCS matched to an adult Registry enrollee, regardless of their self-reported asthma status, we found that over 90% of these asthma hospitalizations were for an enrollee who reported an asthma diagnosis on one of our surveys.

A strength of this study was the use of SPARCS hospitalization data, which allowed us to examine clinically validated, objective endpoints, rather than rely on self-report. It also allowed us to look at the most severe cases of asthma among our enrollees. We also benefited from a large sample size and a follow-up period of over nine years.

This study demonstrates how data from a disaster registry can be matched to a state-wide administrative database to study factors leading to asthma hospitalization. Future Registry studies will examine emergency department admissions, though these data are only available from SPARCS beginning in 2005.

Conclusion

Comorbid conditions, including PTSD and GERS, are associated with an increase in asthma hospitalizations, as are female gender, black and Hispanic race/ethnicity and lower levels of education. Medical management of comorbid physical and mental health conditions may play an important role in preventing hospitalizations for asthma.

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Declaration of interest

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ORCID

Sara A. Miller-Archie http://orcid.org/0000-0002-4389-0029
Hannah T. Jordan http://orcid.org/0000-0003-3705-9551
Juan P. Wisnivesky http://orcid.org/0000-0003-0299-4582
James E. Cone http://orcid.org/0000-0003-2145-1348
Robert M. Brackbill http://orcid.org/0000-0003-0518-0330

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Appendix 1.

Other respiratory primary diagnoses considered, September 11, 2001–December 31, 2010.

ICD-9 code	Description
003.22	Salmonella pneumonia
020.3	Primary pneumonic plague
020.4	Secondary pneumonic plague
020.5	Pneumonic plague unspecified
021.2	Pulmonary tularemia
022.1	Pulmonary anthrax
031.0	Pulmonary diseases due to other mycobacteria
031.8	Other specified mycobacterial diseases
031.9	Unspecified diseases due to mycobacteria
032.89	Other specified diphtheria
032.9	Diphtheria unspecified
033.0	Whooping cough due to *Bordetella pertussis*
033.1	Whooping cough due to *Bordetella parapertussis*
033.8	Whooping cough due to other specified organism
033.9	Whooping cough unspecified organism
052.1	Varicella (hemorrhagic) pneumonitis
055.1	Postmeasles pneumonia
055.2	Postmeasles otitis media
073.0	Ornithosis with pneumonia
079.0	Adenovirus infection in conditions classified elsewhere and of unspecified site
079.1	Echo virus infection in conditions classified elsewhere and of unspecified site
079.2	Coxsackie virus infection in conditions classified elsewhere and of unspecified site
079.3	Rhinovirus infection in conditions classified elsewhere and of unspecified site
079.6	Respiratory syncytial virus
079.81	Hantavirus infection
114.5	Pulmonary coccidioidomycosis unspecified
114.9	Coccidioidomycosis unspecified
115.00	Infection by *Histoplasma capsulatum* without manifestation
115.05	*Histoplasma capsulatum* pneumonia
115.09	Infection by *Histoplasma capsulatum* with other manifestation
115.10	Infection by *Histoplasma duboisii* without manifestation
115.15	*Histoplasma duboisii* pneumonia
115.90	Histoplasmosis unspecified without manifestation
115.95	Histoplasmosis pneumonia unspecified
115.99	Histoplasmosis unspecified with other manifestation
116.0	Blastomycosis
116.1	Paracoccidioidomycosis
117.1	Sporotrichosis
117.3	Aspergillosis
117.5	Cryptococcosis
130.4	Pneumonitis due to toxoplasmosis
136.3	Pneumocystosis
465.9	Acute upper respiratory infections of other multiple sites
466.0	Acute bronchitis
466.11	Acute bronchiolitis due to respiratory syncytial virus
466.19	Acute bronchiolitis due to other infectious organisms
478.9	Other and unspecified diseases of upper respiratory tract
480.0	Pneumonia due to adenovirus
480.1	Pneumonia due to respiratory syncytial virus
480.8	Pneumonia due to other virus not elsewhere classified
480.9	Viral pneumonia unspecified
481	Pneumococcal pneumonia [*Streptococcus pneumoniae* pneumonia]
482	Other bacterial pneumonia
482.0	Pneumonia due to *Klebsiella pneumoniae*
482.1	Pneumonia due to pseudomonas

(*Continued on next column*)

Continued

ICD-9 code	Description
482.2	Pneumonia due to *Haemophilus influenzae* [*H. influenzae*]
482.30	Pneumonia due to streptococcus unspecified
482.31	Pneumonia due to streptococcus group a
482.32	Pneumonia due to streptococcus group b
482.39	Pneumonia due to other streptococcus
482.40	Pneumonia due to staphylococcus unspecified
482.41	Methicillin susceptible pneumonia due to *Staphylococcus aureus*
482.42	Methicillin resistant pneumonia due to *Staphylococcus aureus*
482.49	Other staphylococcus pneumonia
482.81	Pneumonia due to anaerobes
482.82	Pneumonia due to *Escherichia coli* [*E.coli*]
482.83	Pneumonia due to other gram-negative bacteria
482.84	Pneumonia due to Legionnaires' disease
482.89	Pneumonia due to other specified bacteria
482.9	Bacterial pneumonia unspecified
483.0	Pneumonia due to *Mycoplasma pneumoniae*
483.1	Pneumonia due to chlamydia
483.8	Pneumonia due to other specified organism
484.1	Pneumonia in cytomegalic inclusion disease
484.3	Pneumonia in whooping cough
484.5	Pneumonia in anthrax
484.6	Pneumonia in aspergillosis
484.7	Pneumonia in other systemic mycoses
484.8	Pneumonia in other infectious diseases classified elsewhere
485	Bronchopneumonia organism unspecified
486	Pneumonia organism unspecified
487.0	Influenza with pneumonia
487.1	Influenza with other respiratory manifestations
487.8	Influenza with other manifestations
490	Bronchitis not specified as acute or chronic
491.0	Simple chronic bronchitis
491.20	Obstructive chronic bronchitis without exacerbation
491.21	Obstructive chronic bronchitis with (acute) exacerbation
491.22	Chronic bronchitis with acute bronchitis
491.8	Other chronic bronchitis
492.0	Emphysematous bleb
492.8	Other emphysema
494.0	Bronchiectasis without acute exacerbation
494.1	Bronchiectasis with acute exacerbation
495.8	Other specified allergic alveolitis and pneumonitis
495.9	Unspecified allergic alveolitis and pneumonitis
496	Chronic airway obstruction not elsewhere classified
500	Coal workers' pneumoconiosis
506.3	Other acute and subacute respiratory conditions due to fumes and vapors
506.4	Chronic respiratory conditions due to fumes and vapors
507.0	Pneumonitis due to inhalation of food or vomitus
510.0	Empyema with fistula
510.9	Empyema without fistula
511.0	Pleurisy without effusion or current tuberculosis
511.1	Pleurisy with effusion with a bacterial cause other than tuberculosis
511.8	Other specified forms of pleural effusion except tuberculous
511.81	Malignant pleural effusion
511.89	Other specified forms of effusion, except tuberculous
511.9	Unspecified pleural effusion
512.0	Spontaneous tension pneumothorax
512.8	Other spontaneous pneumothorax
513.0	Abscess of lung
513.1	Abscess of mediastinum
514	Pulmonary congestion and hypostasis
515	Postinflammatory pulmonary fibrosis
516.3	Idiopathic fibrosing alveolitis
516.8	Other specified alveolar and parietoalveolar pneumonopathies
518.0	Pulmonary collapse
518.1	Interstitial emphysema
518.3	Pulmonary eosinophilia
518.4	Acute edema of lung unspecified

(*Continued on next page*)

ICD-9 code	Description
518.5	Pulmonary insufficiency following trauma and surgery
518.6	Allergic bronchopulmonary aspergillosis
518.81	Acute respiratory failure
518.82	Other pulmonary insufficiency not elsewhere classified
518.83	Chronic respiratory failure
518.84	Acute and chronic respiratory failure
518.89	Other diseases of lung not elsewhere classified
519.1	Other diseases of trachea and bronchus not elsewhere classified
519.11	Acute bronchospasm
519.19	Other diseases of trachea and bronchus
519.2	Mediastinitis
519.9	Unspecified disease of respiratory system
782.5	Cyanosis
786.00	Respiratory abnormality unspecified
786.05	Shortness of breath
786.06	Tachypnea
786.07	Wheezing
786.09	Respiratory abnormality other
786.1	Stridor
786.2	Cough
786.3	Hemoptysis
786.30	Hemoptysis
786.52	Painful respiration
786.7	Abnormal chest sounds
786.9	Other symptoms involving respiratory system and chest
799.02	Hypoxemia
799.1	Respiratory arrest

Appendix 2.

Most common primary discharge diagnosis categories for hospitalizations where asthma was listed as a secondary diagnosis ($N = 175$)*.

Primary diagnosis category	Frequency	Percent
Pneumonia and influenza	94	53.7
Other lower respiratory symptoms and conditions	18	10.3
Respiratory failure	15	8.6
Acute bronchitis	13	7.4
Allergic bronchopulmonary aspergillosis	9	5.1
Postinflammatory pulmonary fibrosis	7	4.0
Chronic Obstructive Pulmonary Disease exacerbation	6	3.4
Pleural effusion (unspecified)	6	3.4

Note. *Categories with fewer than five hospitalizations were not included (N = 7, 4.1%).