The Upper Respiratory Pyramid: Early Factors and Later Treatment Utilization in World Trade Center Exposed Firefighters

Justin K. Niles, MA,[1] Mayris P. Webber, DrPH,[2,3]* Xiaoxue Liu, MS,[4] Rachel Zeig-Owens, MPH,[4] Charles B. Hall, PhD,[3] Hillel W. Cohen, DrPH,[3] Michelle S. Glaser, MPH,[4] Jessica Weakley, MPH,[4] Theresa M. Schwartz, MS,[4] Michael D. Weiden, MD,[1,5] Anna Nolan, MD, MS,[1,5] Thomas K. Aldrich, MD,[4,6] Lara Glass, MPH,[1] Kerry J. Kelly, MD,[1] and David J. Prezant, MD[1,4,6]

Background *We investigated early post 9/11 factors that could predict rhinosinusitis healthcare utilization costs up to 11 years later in 8,079 World Trade Center-exposed rescue/recovery workers.*

Methods *We used bivariate and multivariate analytic techniques to investigate utilization outcomes; we also used a pyramid framework to describe rhinosinusitis healthcare groups at early (by 9/11/2005) and late (by 9/11/2012) time points.*

Results *Multivariate models showed that pre-9/11/2005 chronic rhinosinusitis diagnoses and nasal symptoms predicted final year healthcare utilization outcomes more than a decade after WTC exposure. The relative proportion of workers on each pyramid level changed significantly during the study period.*

Conclusions *Diagnoses of chronic rhinosinusitis within 4 years of a major inhalation event only partially explain future healthcare utilization. Exposure intensity, early symptoms and other factors must also be considered when anticipating future healthcare needs.* Am. J. Ind. Med. 57:857–865, 2014. *© 2014 Wiley Periodicals, Inc.*

KEY WORDS: world trade center; firefighters; chronic rhinosinusitis; sinus symptoms; treatment outcomes

INTRODUCTION

The collapse of the World Trade Center (WTC) produced a massive exposure to caustic dust with a pH >10 and products of combustion that injured the entire aerodigestive system for many of those involved in the subsequent rescue and recovery efforts [Prezant et al., 2002]. In WTC-exposed individuals, the burden of chronic rhinosinusitis is substantial [Wisnivesky et al., 2011; Lucchini et al., 2012]. Several clinical studies have demonstrated persistent chronic rhinosinusitis, with or without seasonal exacerbation, in a large proportion of WTC-exposed patients [de la Hoz et al., 2008, 2009, 2010]. WTC-exposed firefighters have exhibited high rates of physician-diagnosed rhinosinusitis compared with the National Health Interview Survey (NHIS) estimates for demographically similar groups. In 2009, FDNY physician-diagnosed prevalence rates in the last 12 months reached 19.5% for those over age 45, and

[1]Bureau of Health Services, Fire Department of the City of New York, Brooklyn, New York
[2]Department of Epidemiology & Population Health, Montefiore Medical Center, Bronx, New York
[3]Department of Epidemiology & Population Health, Albert Einstein College of Medicine, Bronx, New York
[4]Department of Medicine, Montefiore Medical Center, Bronx, New York
[5]Division of Pulmonary, Critical Care and Sleep, New York University, School of Medicine, New York, New York
[6]Department of Medicine, Albert Einstein College of Medicine, Bronx, New York

Contract grant sponsor: National Institute for Occupational Safety and Health; Contract grant numbers: 200-2011-39383; 200-2011-39378; Contract grant sponsor: National Institute of Health; Contract grant numbers: K23HL084191; K24A1080298.
Disclosure Statement: The authors report no conflicts of interests.

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

Accepted 5 March 2014
DOI 10.1002/ajim.22326. Published online 4 June 2014 in Wiley Online Library (wileyonlinelibrary.com).

17.2% for those under 45 [Weakley et al., 2011] compared with 11.3% and 8.0% in the general population, respectively [Weakley et al., 2011]. Between 40% and 50% of WTC-exposed firefighters consistently reported current sinus symptoms since the WTC disaster [Webber et al., 2009; Weakley et al., 2011]. This was similar to results found in WTC-exposed iron workers (50/96) [Skloot et al., 2004] but higher than results found in WTC-exposed police officers, where 12.6% reported nasal symptoms [Salzman et al., 2004]. As a result, chronic rhinosinusitis has become an increasing focus of diagnostic and therapeutic resources in the WTC Health Program. A fuller understanding of how this disease evolved and impacted healthcare utilization is necessary for rational resource planning.

Chronic rhinosinusitis affects nearly 30 million adults in the United States [Schiller et al., 2012]. Causes of chronic rhinosinusitis include infections, allergy, nasal polyps, or a deviated nasal septum [Mayo ClinicMayo Clinic, 2014]. When symptoms of rhinosinusitis last longer than 8–12 weeks, a designation of chronic rhinosinusitis is given. In 2009 there were over 11.7 million visits to physicians' offices with a primary diagnosis of chronic rhinosinusitis. The national costs associated with this condition are vast, estimated at $5.8 [Ray et al., 1999]—$8.6 billion annually [Bhattacharyya, 2011], with nearly 90% of these costs attributed to ambulatory or emergency department services [Ray et al., 1999]. Endoscopic sinus surgery is particularly expensive; procedures and the subsequent 45 days of associated healthcare utilization can cost at least $15,000 (FDNY unpublished claims data). Over 600,000 persons in the U.S. undergo sinus surgery annually; these numbers have increased significantly between 2007 and 2009 [Psaltis et al., 2012].

Previous studies have reported cross-sectional and cumulative prevalence of upper respiratory symptom and disease rates [Weakley et al., 2011; Wisnivesky et al., 2011]. This study examines the extent to which early factors (e.g., WTC-exposure intensity, symptoms and diagnoses of chronic rhinosinusitis pre-9/11/2005) predict future health care needs, as estimated by FDNY physician ENT evaluations, laryngoscopies, sinus surgeries, and prescription medication use in the final year of this study (9/11/2011 to 9/10/2012). We also sought to assess whether a pyramid framework, similar to one we previously used to describe lower airways diseases [Niles et al., 2013], clarifies the observed changes between the proportion of individuals with ENT physician evaluation/treatment and diagnoses of chronic rhinosinusitis at early (9/11/2002 to 9/10/2005) and late (9/11/2005 to 9/10/2012) time points.

MATERIALS AND METHODS

The FDNY-WTC Health Program (FDNY-WTCHP) schedules monitoring evaluations of the 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. We defined an FDNY physician "ear, nose, and throat (ENT) evaluation" as any visit where the physician discussed ENT concerns or provided ENT testing or treatment beyond the scope of the typical monitoring visit. ENT evaluations could also occur by physician referral or self-referral. FDNY physicians refer firefighters to physicians outside of the FDNY-WTCHP for nasal/sinus laryngoscopy and sinus surgery, when necessary. Study participants provided informed consent. The study and right to access subjects' medical and pharmaceutical records was approved by the institutional review board at Montefiore Medical Center.

Study Participants and Study Period

The original study population consisted of 12,341 FDNY male (non-fire marshal) 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 required at least one completed monitoring exam between 9/11/2002 and 9/10/2005 for evaluation of early symptom reports, which resulted in a final analytic cohort of 8,079 (65.5%).

Data Sources

We obtained demographic information from the FDNY employee databases. Monitoring questionnaire data were used to define early symptoms, WTC arrival time, duration of work at the WTC-site (months) and smoking status. The FDNY electronic medical record database was used to obtain chronic rhinosinusitis diagnoses and ENT evaluations. We used billing records from the FDNY-WTCHP pharmacy benefits plan (Express Scripts, Inc., available since 2007), to analyze fill and refill dates and medication costs. We included decongestants, leukotriene inhibitors, nasal steroids, and sinus saline rinse kits in our analyses. We did not include antibiotic prescriptions because it was difficult to reliably assign antibiotic use to chronic rhinosinusitis as opposed to bronchitis or other respiratory conditions. Laryngoscopy and sinus surgery records were obtained from the FDNY invoice database.

Respiratory Symptoms

Upper respiratory symptom(s) reported on early monitoring questionnaires were based on responses to two separate questions, "Describe your nasal congestion or drip," and "describe your sore or hoarse throat." The following three

responses were considered as symptom presence for both questions: "Had it AFTER the disaster and it has stayed about the same," "had it AFTER the disaster and it has gotten worse," "had it AFTER the disaster and it has gotten better." The other two responses were not counted: "Have NOT had it since the disaster" and "had it AFTER the disaster and it is now gone." Symptom data were collected for the 9/11/2002 to 9/10/2005 period.

Physician Diagnoses

Physician diagnoses of chronic rhinosinusitis were obtained from the FDNY medical record. For this study, we combined "rhinitis, irritant chronic" and "sinusitis, chronic" as one diagnosis because of the high degree of agreement between these diagnoses within our database, similar symptoms, and identical therapies. Diagnoses were given by the examining physicians based on history, physical examination, and, when clinically indicated, other specialized testing. FDNY physicians received training in the evaluation and treatment of chronic rhinosinusitis but are not ENT specialists. FDNY physician diagnoses were analyzed cumulatively and considered permanent, partly because it was difficult to differentiate "resolved" disease from disease that was being successfully managed with medications. New diagnoses were added to the cumulative totals, when clinically indicated. Since we did not have access to records of non-FDNY physicians for validation purposes, we chose not to include diagnoses from self-reports.

WTC-Exposure Status

We grouped initial arrival time at the WTC-site as follows: Arriving morning of 9/11; Arriving afternoon of 9/11; Arriving 9/12, Day 2; Arriving anytime between 9/13/2001 and 9/24/2001, Days 3–14. The duration variable was a summation of self-reported calendar months each person worked at least 1 day at the WTC-site, on or off duty, from September 2001 through July 2002. Duration was divided into quartile groups for the logistic models.

Tobacco Smoking Status

Tobacco smoking was defined as "ever" if reported as current or former on the firefighter's early period monitoring questionnaire (9/11/02 to 9/10/05) and as "never" if they reported never smoking. For those who did not meet inclusion criteria, smoking status was taken from the latest date pre-9/11/2005.

Body Mass Index (BMI)

BMI was calculated using weight and height measurements taken on the same date as the firefighter's early period monitoring questionnaire for those included in the cohort. BMI was divided into groups based on the international classification definitions used by the Centers for Disease Control and the World Health Organization [Centers for Disease Control and Prevention, 2011; World Health Organization, 2013].

Pyramid Structure

Each pyramid is a cumulative, cross-sectional snapshot of the study cohort during two specific time intervals (9/11/01 to 9/10/05 and 9/11/05 to 9/10/2012) with three mutually exclusive levels. Level 1 includes all WTC-exposed firefighters in the WTC monitoring program who had no visits for ENT evaluation to an FDNY physician. Level 2 is made up of those with at least one ENT evaluation by an FDNY physician but whose visit(s) did not result in a chronic rhinosinusitis diagnosis. Level 3, at the apex of the pyramid, includes firefighters with a chronic rhinosinusitis diagnosis from an FDNY physician (Fig. 1). The composition of each level is cumulative from 9/11/2001 to that time point.

Statistical Analyses

Continuous data are presented as mean $\pm$ standard deviation; associations were assessed using the *t*-test. Bivariate associations of categorical variables were assessed using the Chi-square test with odds ratios (OR) and 95% confidence intervals (95% CI). Our first logistic model predicted a diagnosis of chronic rhinosinusitis in the post-9/11/2005 period, in relation to early symptoms and other cofactors. In addition, we developed four logistic models predicting healthcare utilization outcomes ($\geq$\$500 in sinus medications, multiple FDNY physician ENT evaluations, having a laryngoscopy, and having sinus surgery) by individual firefighters in the final study year (9/11/2011 to 9/10/2012), using covariates from the early period. Multiple FDNY physician ENT evaluations was chosen as an outcome because more than one visit is a better indication of confirmed disease requiring management or follow up. Costs of $\geq$\$500 for sinus medications was chosen because it was the first multiple of \$100 over the median cost for these medications. Final healthcare models included all covariates that were significantly associated with any early symptom. Although we do not analyze longitudinal dropout of the cohort directly, we conservatively treated those without healthcare outcome information for the final study year (N = 1,040) as having no events in that year, as the FDNY WTC Health Program incurred no costs associated with their upper respiratory conditions.

We required a two-tailed *P*-value of <0.05 for statistical significance in the models, and a one-tailed *P*-value of <0.05 for trend analyses. Goodness of fit for logistic models was

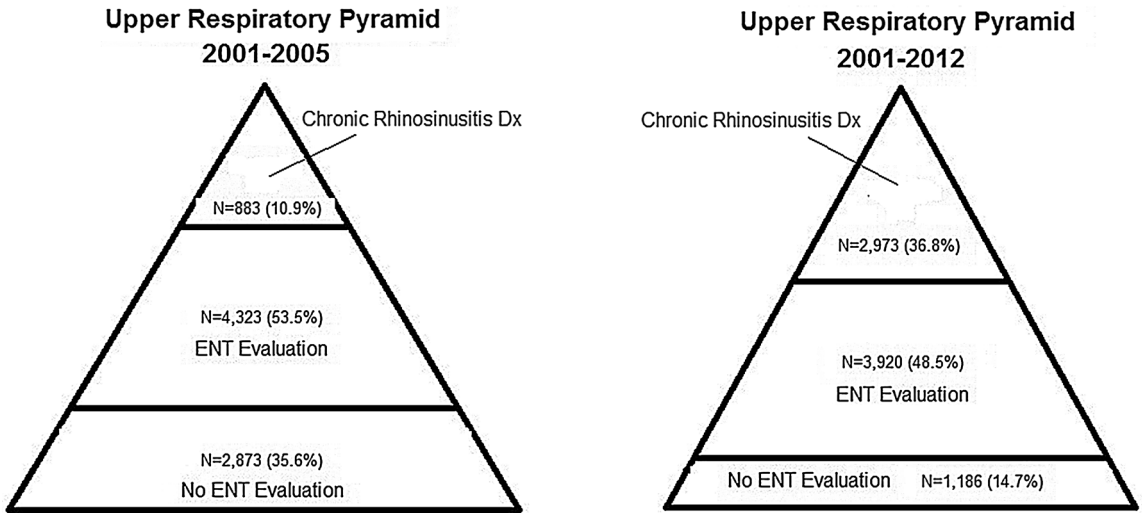

FIGURE 1. The upper respiratory pyramid structure from 2001 to 2005 and its evolution from 2001 to 2012. Please note figures are not drawn to scale.

assessed using Hosmer–Lemeshow test. Data were analyzed using SAS, version 9.3 (SAS Institute, Cary, NC).

RESULTS

Cohort Characteristics

We compared the 8,079 firefighters in the analytic cohort to the 4,262 who did not meet inclusion criteria. There were statistically significant differences in first WTC arrival times, WTC-site work duration, smoking status, and age on 9/11 between those included and excluded (Table I).

Rhinosinusitis Symptoms in the Early Period

We analyzed factors associated with reporting at least one upper respiratory symptom on the early (9/11/2002 to 9/10/2005) monitoring questionnaire. We found that: early WTC-exposure, prolonged WTC-site work duration, BMI $>40\,kg/m^2$ and age on 9/11 showed significant associations in adjusted and unadjusted models (data not shown). Therefore, we included these factors as covariates in the final year healthcare utilization models as potential confounders.

Chronic Rhinosinusitis Diagnosis in the Later Study Period

We found that in those without pre-9/11/2005 diagnoses (N = 7,196), early symptoms (nasal congestion or drip and sore or hoarse throat) were significant predictors of late (post-9/11/2005) diagnoses (Table II). In this adjusted multivariate model, firefighters on Level 2 of the early pyramid were significantly more likely to have a chronic rhinosinusitis diagnosis in the later study period 9/11/2005 to 9/10/2012 (OR 1.32, 95% CI 1.19–1.47) than those on Level 1 during the early period 9/11/2002 to 9/10/2005.

Early and Late Pyramid Levels

Figure 1 shows snapshots of the pyramid distribution by 9/11/2005 and by 9/11/2012. For the early pyramid, Level 1 is comprised of the 2,873 (35.6%) firefighters who did not receive an ENT evaluation from an FDNY physician. Level 2 contains those with ENT evaluations by an FDNY physician but whose visit(s) did not result in a chronic rhinosinusitis diagnosis (N = 4,323, 53.5%). Level 3 includes 883 (10.9%) firefighters with a chronic rhinosinusitis diagnosis. By 9/11/2012, the pyramid composition had changed considerably. Level 1 decreased to 1,186 (14.7% of the cohort). Level 2 decreased somewhat to 3,920 (48.5%), although this represented both a gain of entrants (N = 950) from Level 1, and a loss of 1,353 to Level 3, which increased to 2,973 (36.8% of the cohort).

Treatment Utilization in the Final Year

We used logistic models to examine factors found before 9/11/2005 and their associations with healthcare utilization outcomes (≥$500 in filled sinus prescriptions, multiple ENT evaluations, laryngoscopy, and sinus surgery) during the final study year (9/11/2011 to 9/10/2012). The unadjusted and adjusted models are presented in Table III. In the adjusted model, firefighters reporting nasal congestion or drip, sore or

TABLE I. Demographics of Those Included and Excluded

	Total	Excluded	Included
N=	**12,341**	**4,262**	**8,079**
First arrival time at WTC site			
Day 1, before the collapse	1,863 (15.1)	601 (14.1)	1,262 (15.6)*
Day 1, afternoon	6,119 (49.6)	1,726 (40.5)	4,393 (54.4)*
Day 2	2,398 (19.4)	956 (22.4)	1,442 (17.9)*
Days 3–14	1,961 (15.8)	979 (23.0)	982 (12.2)*
Mean age on 9/11/01 (SD)	41.8 ± 9.0	48.5 ± 8.8	38.2 ± 6.9**
Duration of work at WTC site			
7+ months	1,877 (15.2)	194 (4.6)	1,683 (20.8)*
5–6 months	1,746 (14.2)	145 (3.4)	1,601 (19.8)*
3–4 months	2,676 (21.7)	240 (5.6)	2,436 (30.2)*
1–2 months	6,042 (49.0)	3,683 (86.4)	2,359 (29.2)*
Smoking status pre-9/11/05[a]			
Ever	2,745 (26.9)	652 (30.3)	2,093 (25.9)*
Never	7,477 (73.2)	1,498 (69.7)	5,986 (74.1)
Body mass index pre-9/11/05[b]			
BMI $\geq$ 40	NT	NT	51 (0.6)
35 $\leq$ BMI $<$ 40	NT	NT	412 (5.1)
30 $\leq$ BMI $<$ 35	NT	NT	2,381 (29.5)
25 $\leq$ BMI $<$ 30	NT	NT	4,452 (55.1)
18.5 $\leq$ BMI $<$ 25	NT	NT	666 (8.2)

[a]Two thousand one hundred twelve of those excluded had no smoking data available by 9/11/05.
[b]The Majority of those excluded had no early BMI measurements and were therefore not tested.
*Statistically significant $P < 0.05$, Chi-squared test.
**Statistically significant $P < 0.05$, *t*-test.

hoarse throat, 5–6 calendar months of work at the WTC-site, chronic rhinosinusitis diagnoses, and increasing age were more likely to have $\geq$\$500 in sinus medication fills. The adjusted model predicting FDNY physician ENT evaluations showed firefighters reporting early nasal congestion or drip, sore or hoarse throat, seven or more calendar months of work at the WTC site, and chronic sinusitis diagnoses as more likely to have multiple ENT evaluations. Fewer variables remained significant in the final adjusted models predicting laryngoscopies and sinus surgeries. Firefighters reporting nasal congestion or drip, seven or more calendar months working at the WTC site, and chronic rhinosinusitis diagnoses were more likely to have a laryngoscopy. Only those firefighters reporting seven or more calendar months working at the WTC-site and chronic rhinosinusitis diagnoses were significantly more likely to have sinus surgery during the final study year.

Differences in Final Year Treatment Utilization by Early Pyramid Level

During the final study year (9/11/2011 to 9/10/2012), 1,732 firefighters (21.4% of the cohort) received \$1.26 million in sinus medications through the FDNY WTC pharmacy benefits plan. We found differences by early pyramid levels in sinus medication use during the final study year. A greater proportion of those with early chronic rhinosinusitis diagnoses (N = 325, 36.8%) used sinus medications compared with those on Level 2 (N = 857, 19.8%) or Level 1 (N = 550, 19.1%) of the Early Pyramid (by 9/11/2005). We also found differences by early pyramid levels in the proportion of firefighters with FDNY physician ENT evaluations (N = 2,725) in the final study year. Over half (50.8%) of those on Level 3 had final year ENT evaluation/treatment, compared with 34.4% of Level 2 and 27.5% of Level 1. Similarly, those on Level 3 by 9/11/2005 were more likely to have a laryngoscopy in the final study year (13.1%) than those on Level 2 (7.7%) or Level 1 (6.7%). Finally, although only a relatively few firefighters had sinus surgery (N = 69) performed during the final study year, we similarly found significant differences by early pyramid levels: 1.7% of those on Level 3 underwent sinus surgery compared to 0.8% of those on Level 2 and 0.7% of those on Level 1.

DISCUSSION

The collapse of the WTC towers produced widespread inhalation exposures to inorganic dust, products from

TABLE II. Early Factors Predicting Chronic Sinusitis Diagnosis 9/11/05 to 9/10/12

	Chronic sinusitis diagnosis 9/11/05 to 9/10/12
	Adjusted odds ratio (95% CI)
Nasal cong. or drip before 9/11/05	2.11 (1.88, 2.37)
No nasal cong. or drip before 9/11/05	Ref
Sore or hoarse throat before 9/11/05	1.21 (1.07, 1.36)
No sore or hoarse throat before 9/11/05	Ref
ENT evaluation (Tier 2)	1.32 (1.19, 1.47)
No Dx or evaluation	Ref
Age on 9/11/01	1.00 (1.00, 1.01)
Day 1 AM	1.15 (0.93, 1.41)
Day 1 PM	1.09 (0.91, 1.29)
Day 2	1.19 (0.98, 1.46)
Days 3–14	Ref
BMI $\geq$ 40	1.08 (0.56, 2.05)
35 $\leq$ BMI $<$ 40	1.12 (0.84, 1.50)
30 $\leq$ BMI $<$ 35	1.12 (0.92, 1.36)
25 $\leq$ BMI $<$ 30	1.17 (0.97, 1.41)
18.5 $\leq$ BMI $<$ 25	Ref
7+ months at site	1.18 (1.02, 1.38)
5–6 months at site	1.11 (0.95, 1.29)
3–4 months at site	1.06 (0.93, 1.22)
1–2 months at site	Ref

pyrolysis and other breathable materials [Lioy et al., 2002], particularly for workers responding near the epicenter of the site. Initially, the dust cloud overwhelmed the lungs normal protective mechanisms, including filtering of large particles by the upper airway [Fireman et al., 2004]. Not surprisingly, we and others have previously reported WTC dust exposure to be associated with several inflammatory diseases including obstructive airways disease [Prezant et al., 2002; Weiden et al., 2010] and chronic rhinosinusitis [Weakley et al., 2011; Webber et al., 2011; Nachman and Parker, 2012]. In the current analysis we examine the extent to which early post-disaster symptoms and diagnoses anticipate health care needs up to a decade later. In addition, we sought to explore whether a pyramid framework provides a conceptual model for describing the changing healthcare burden of WTC-related upper respiratory illness in this cohort.

We report that in the interval from 2005 to 2012 the prevalence of FDNY diagnosed chronic rhinosinusitis increased from 10.9% of the cohort to 36.8%. Interestingly, WTC-exposure intensity (e.g., >7 months WTC work duration) was a significant risk factor predicting the need for laryngoscopy and sinus surgery during the final study year. We also found that results from the early post-9/11 period (before 9/11/2005), particularly rhinosinusitis symptoms, were strong indicators of future healthcare utilization during the later period (before 9/11/2012) among those who did and those who did not have pre-2005 diagnoses.

During initial planning for the FDNY WTC Health Program, many paradigms were suggested to project future healthcare needs. One such model proposed estimating future treatment needs based only on the number of individuals diagnosed with respiratory diseases in the first 4 years following the disaster. In addition, 4 years was chosen because for WTC-exposed cohorts other than FDNY, medical monitoring/wellness exams were not widely available early on. Although these experiences are specific to the WTC, we feel that in future disasters a funding agency may also try to base funding projections on those diagnosed in the first few years after the event. We found that projecting healthcare services exclusively on diagnoses obtained before 9/10/2005 would have drastically underestimated treatment needs. Although they were statistically more likely to utilize healthcare than the other early pyramid levels, the 883 firefighters with a chronic rhinosinusitis diagnoses before 9/11/2005 (pyramid level 3; 10.9% of the cohort) only accounted for 17.7% of total FDNY physician ENT evaluations, 19.1% of laryngoscopies, 21.7% of sinus surgery, and 21.0% of respiratory medication costs during the final study year. Our data indicate that healthcare planners must look beyond early diagnoses for effective planning.

Many patients reported the presence of symptoms on their monitoring exams during the *early* part of our study (prior to 9/11/2005), but did not seek an ENT evaluation from an FDNY physician or were not diagnosed with chronic rhinosinusitis at that time. Early factors, including exposure intensity (WTC arrival time and work duration), BMI, age, and pyramid levels were associated with early sinus symptoms. Early sinus symptoms were strong predictors of later treatment utilization, even when adjusted for the presence of early diagnoses.

Those who sought an early ENT evaluation (pre-9/11/2005), but were not diagnosed with chronic rhinosinusitis at that time were approximately 32% more likely to have a diagnosis by 9/11/2012 than those who did not seek an ENT evaluation. For others, evolution of disease, increased patient and physician awareness of a potentially WTC-related diagnosis, delayed-reporting, new-onset disease which may or may not have been solely WTC-related, and/or reductions in healthcare barriers such as initiation of a free prescription medication program during 2007, may have prompted physician evaluations and diagnoses in the second half of this study, years after the WTC attacks. During the second part of the study, from 9/11/2005 to 9/10/2012, the number of physician diagnoses for chronic rhinosinusitis more than tripled from 883 to 2,973. The 36.8% cumulative chronic rhinosinusitis rate we report here in firefighters is comparable to the rate reported in other WTC populations in 2011 (42.3%) [Wisnivesky et al., 2011], however, the diagnosis rates we reported were obtained from the medical charts of

TABLE III. (Parts 1 and 2): Early Factors Predicting Treatment Outcomes 9/11/11 to 9/10/12

	Medications models		FDNY physician visits models	
	$500 or more in sinus meds 9/11/11 to 9/10/12		Multiple ENT evaluations 9/11/11 to 9/10/12	
	Unadjusted odds ratio (95% CI)	Adjusted odds ratio (95% CI)	Unadjusted odds ratio (95% CI)	Adjusted odds ratio (95% CI)
Part 1				
Nasal cong. or drip before 9/11/05	2.61 (2.23, 3.05)	2.04 (1.71, 2.43)	1.81 (1.62, 2.02)	1.53 (1.35, 1.74)
No nasal cong. or drip before 9/11/05	Ref	Ref	Ref	Ref
Sore or hoarse throat before 9/11/05	2.07 (1.79, 2.40)	1.37 (1.16, 1.62)	1.60 (1.43, 1.79)	1.23 (1.09, 1.40)
No sore or hoarse throat before 9/11/05	Ref	Ref	Ref	Ref
Chronic sinusitis Dx before 9/11/05 (tier 3)	2.29 (1.84, 2.84)	1.92 (1.53, 2.39)	2.27 (1.91, 2.70)	1.98 (1.66, 2.36)
ENT evaluation (tier 2)	1.04 (0.88, 1.23)	1.06 (0.90, 1.26)	1.25 (1.10, 1.41)	1.22 (1.08, 1.39)
No Dx or evaluation	Ref	Ref	Ref	Ref
Age on 9/11/01	1.04 (1.02, 1.05)	1.03 (1.02, 1.04)	0.99 (0.98, 1.00)	0.99 (0.98, 1.00)
Day 1 AM	1.37 (1.04, 1.81)	1.05 (0.79, 1.39)	1.49 (1.20, 1.85)	1.23 (0.99, 1.54)
Day 1 PM	1.05 (0.83, 1.34)	0.87 (0.68, 1.11)	1.34 (1.11, 1.61)	1.17 (0.96, 1.41)
Day 2	1.10 (0.83, 1.46)	0.96 (0.72, 1.28)	1.35 (1.09, 1.67)	1.22 (0.98, 1.52)
Days 3–14	Ref	Ref	Ref	Ref
BMI $\geq$ 40	1.45 (0.60, 3.52)	1.27 (0.52, 3.13)	1.23 (0.62, 2.46)	1.14 (0.57, 2.30)
35 $\leq$ BMI $<$ 40	1.40 (0.94, 2.08)	1.32 (0.88, 1.97)	1.22 (0.90, 1.64)	1.13 (0.84, 1.53)
30 $\leq$ BMI $<$ 35	1.31 (0.99, 1.74)	1.24 (0.93, 1.65)	1.22 (1.00, 1.50)	1.16 (0.94, 1.42)
25 $\leq$ BMI $<$ 30	1.12 (0.86, 1.47)	1.09 (0.83, 1.44)	1.07 (0.88, 1.30)	1.03 (0.85, 1.26)
18.5 $\leq$ BMI $<$ 25	Ref	Ref	Ref	Ref
7+ months at site	1.41 (1.14, 1.73)	1.18 (0.95, 1.46)	1.41 (1.20, 1.64)	1.23 (1.05, 1.44)
5–6 months at site	1.43 (1.15, 1.76)	1.29 (1.04, 1.61)	1.22 (1.04, 1.43)	1.10 (0.94, 1.30)
3–4 months at site	1.09 (0.89, 1.33)	1.07 (0.87, 1.31)	1.12 (0.97, 1.30)	1.08 (0.94, 1.26)
1–2 months at site	Ref	Ref	Ref	Ref
Hosmer–Lemeshow test statistic		H–L fit: $P > 0.65$		H–L fit: $P > 0.54$
	Laryngoscopy models		Sinus surgery models	
	Laryngoscopy 9/11/11 to 9/10/12		Sinus surgery 9/11/11 to 9/10/12	
	Unadjusted odds ratio (95% CI)	Adjusted odds ratio (95% CI)	Unadjusted odds ratio (95% CI)	Adjusted odds ratio (95% CI)
Part 2				
Nasal cong. or drip before 9/11/05	2.28 (1.93, 2.70)	1.94 (1.61, 2.35)	1.77 (1.09, 2.87)	1.48 (0.85, 2.58)
No nasal cong. or drip before 9/11/05	Ref	Ref	Ref	Ref
Sore or hoarse throat before 9/11/05	1.70 (1.45, 2.00)	1.17 (0.97, 1.40)	1.61 (1.00, 2.59)	1.25 (0.72, 2.15)
No sore or hoarse throat before 9/11/05	Ref	Ref	Ref	Ref
Chronic sinusitis Dx before 9/11/05 (tier 3)	2.11 (1.66, 2.70)	1.78 (1.39, 2.28)	2.47 (1.26, 4.84)	2.12 (1.07, 4.21)
ENT evaluation (tier 2)	1.17 (0.97, 1.41)	1.16 (0.96, 1.39)	1.13 (0.65, 1.97)	1.07 (0.61, 1.87)
No Dx or evaluation	Ref	Ref	Ref	Ref
Age on 9/11/01	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	0.97 (0.94, 1.01)	0.97 (0.93, 1.00)
Day 1 AM	1.53 (1.09, 2.15)	1.18 (0.84, 1.68)	0.78 (0.32, 1.87)	0.57 (0.23, 1.40)
Day 1 PM	1.54 (1.15, 2.07)	1.27 (0.94, 1.71)	0.78 (0.39, 1.58)	0.62 (0.30, 1.27)
Day 2	1.60 (1.15, 2.23)	1.39 (1.00, 1.94)	0.95 (0.42, 2.15)	0.80 (0.35, 1.81)
Days 3–14	Ref	Ref	Ref	Ref
BMI $\geq$ 40	1.06 (0.37, 3.06)	0.97 (0.33, 2.81)	$<$0.01 ($<$0.01, $>$999)	$<$0.01 ($<$0.01, $>$999)
35 $\leq$ BMI $<$ 40	1.09 (0.70, 1.70)	1.00 (0.64, 1.56)	3.37 (0.98, 11.57)	3.14 (0.91, 10.84)
30 $\leq$ BMI $<$ 35	1.06 (0.78, 1.44)	0.99 (0.73, 1.35)	2.23 (0.78, 6.40)	2.13 (0.74, 6.13)

(*Continued*)

TABLE III. (*Continued*)

	Laryngoscopy models		Sinus surgery models	
	Laryngoscopy 9/11/11 to 9/10/12		Sinus surgery 9/11/11 to 9/10/12	
	Unadjusted odds ratio (95% CI)	Adjusted odds ratio (95% CI)	Unadjusted odds ratio (95% CI)	Adjusted odds ratio (95% CI)
$25 \leq$ BMI < 30	1.10 (0.83, 1.47)	1.06 (0.79, 1.42)	1.37 (0.48, 3.88)	1.36 (0.48, 3.87)
$18.5 \leq$ BMI < 25	Ref	Ref	Ref	Ref
7+ months at site	1.76 (1.40, 2.22)	1.50 (1.19, 1.90)	2.70 (1.30, 5.61)	2.47 (1.17, 5.23)
5–6 months at site	1.41 (1.10, 1.79)	1.25 (0.98, 1.61)	1.88 (0.85, 4.16)	1.77 (0.79, 3.93)
3–4 months at site	1.28 (1.02, 1.60)	1.23 (0.98, 1.54)	2.03 (0.99, 4.18)	1.99 (0.97, 4.10)
1–2 months at site	Ref	Ref	Ref	Ref
Hosmer–Lemeshow test statistic		H–L fit: $P > 0.56$		H–L fit: $P > 0.17$

FDNY physicians as opposed to the self-reported diagnoses reported in other populations. Our results demonstrate that diagnosis rates even 4 years post-exposure do not capture all disease, especially because symptomatic but undiagnosed disease early on may, with good access to care, result in substantial increases in diagnoses over time.

We previously used a pyramid structure to describe lower respiratory airways disease [Niles et al., 2013]. As with the current analysis, we found that early diagnoses were not sufficient to predict the changing healthcare needs of firefighters years hence. However, we also found that the increase in diagnosed rhinosinusitis conditions over time was far more pronounced than the increase in the diagnosed lower airways disease. This may be due, in part, to the current study time period, which extended over two more years; but, it may also be due to an earlier emphasis by FDNY physicians on lower airways treatment, which was initiated soon after 9/11/2001. Regardless of these differences, the pyramid framework was useful in conceptualizing the evolution of disease and resulting healthcare needs. We believe a similar conceptual framework would be a valuable tool for healthcare system planners after any disaster (environmental, occupational, infectious disease) if they have the need to transition from acute care delivery to the management of chronic and late-emerging disease(s).

There are limitations to this study. We recognize 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, some may have recovered due to time or successful treatment. In addition, since we did not have access to records of non-FDNY physicians, we did not include those with self-reported physician diagnoses, potentially underestimating the number of patients on pyramid level 2 (evaluation) and level 3 (diagnosis). We also did not have information on allergy history, atopy, or seasonal variation, making analysis of these factors impossible.

Our healthcare utilization findings (prescription fills, physician ENT evaluations, laryngoscopies and sinus surgeries) were analyzed for the final study year because earlier data for these outcomes were not available. Also, there was a relatively small number of firefighters with sinus surgeries in the final year (N = 69), which limited our ability to draw conclusions. Finally, because patients incurred no cost to this healthcare program (no enrollment fees, co-pays, or deductibles), our findings may not be generalizable to other healthcare programs. A cost-free program like ours, however, likely reduces the utilization of non-FDNY physician and therefore the potential for underestimating evaluation and diagnosis rates and costs are also reduced. However, if non-FDNY physicians were utilized, the true impact of total healthcare utilization would be substantially higher than our estimates.

This study has several strengths. First, our analytic cohort was large (8,079), and highly exposed to the disaster. Second, we avoided using symptom data from surveys taken within the first year after 9/11/2001 as prior studies have indicated that some early, acute symptoms resolved [Webber et al., 2009]. Third, we obtained physicians' diagnoses directly from the FDNY database, as opposed to relying on self-report to determine the rate of chronic rhinosinusitis in this population. Finally, we used pharmaceutical billing records for prescriptions filled rather than prescriptions written, and paid medical claims rather than referrals, allowing us to analyze actual costs. These billing records, coupled with FDNY physician evaluation records, allowed us to analyze treatment utilization within the FDNY-WTCHP and show a more complete picture of the impact chronic rhinosinusitis in this highly exposed population post-9/11.

CONCLUSIONS

Although the highest pyramid level (chronic rhinosinusitis diagnoses) during the early period was associated with increased healthcare utilization in all final study year

outcomes, and early ENT evaluation/treatment (Level 2) was associated with multiple ENT visits during the final study year, understanding the full impact of a major inhalation exposure over a decade later required appreciating that chronic rhinosinusitis diagnoses 4 years post-disaster were not the only drivers of future healthcare utilization for related conditions. Despite the passage of time and relatively low barriers to physician visits throughout the study period, prolonged work at the WTC site and early symptoms reports remained important predictors of chronic rhinosinusitis diagnoses. Whether this pattern will continue in the years to come remains uncertain 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 disease evolution and expanding treatment utilization.

ACKNOWLEDGMENTS

The freedom to design, conduct, interpret, and publish research is not compromised by any controlling sponsor. 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.

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