Sleep Breath (2011) 15:283–294
DOI 10.1007/s11325-010-0379-7

ORIGINAL ARTICLE

Prevalence and incidence of high risk for obstructive sleep apnea in World Trade Center-exposed rescue/recovery workers

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Received: 6 November 2009 / Revised: 16 April 2010 / Accepted: 2 June 2010 / Published online: 1 July 2010

Abstract
Purpose World Trade Center (WTC)-exposed rescue/recovery workers continue to have high rates of gastroesophageal reflux disease (GERD), chronic rhinosinusitis, and posttraumatic stress disorder (PTSD) symptoms. This study examines the relationship between these WTC-related conditions and being at high risk for obstructive sleep apnea (OSA).
Materials and methods The Fire Department of the City of New York (FDNY) performs periodic health evaluations on FDNY members every 12 to 18 months. Evaluations consist of physician examinations and self-administered health questionnaires, which, since 2005, have incorporated questions about sleep problems that were adapted from the Berlin Questionnaire. The study population consisted of 11,701 male firefighters and emergency medical service personnel. Incidence analyses were limited to a cohort (n = 4,576) who did not meet the criterion for being at high risk for OSA at baseline (between September 12, 2005 and September 8, 2006) and had at least one follow-up assessment, on average, 1.4 (±0.5) years later.
Results The baseline prevalence of high risk for OSA was 36.5%. By follow-up, 16.9% of those not at high risk initially became at high risk for OSA. In multivariable logistic regression models predicting incident high risk for OSA, independent predictors included: earlier time of arrival at the WTC site, GERD, chronic rhinosinusitis, PTSD symptoms, self-assessed fair/poor health, low body mass index (BMI < 18.5 kg/m^2), and, as expected, BMI> 30 kg/m^2 and weight gain of ≥10 lb (4.5 kg).
Conclusions We found significant associations between being at high risk for OSA and common WTC-related conditions, although the responsible causative mechanisms remain unknown. Since the etiology of OSA is likely multifactorial, improvement may require successful treatment of both OSA and its comorbid conditions.

Keywords World Trade Center · Sleep disordered breathing · Obstructive sleep apnea · Firefighters · GERD · Rhinosinusitis · Snoring

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Introduction

Obstructive sleep apnea (OSA) is a chronic condition characterized by recurrent episodes of partial or complete upper airway collapse during sleep, lasting for as long as 30 to 60 s. Risk factors include male gender, aging [1], and a body mass index (BMI) > 30 kg/m^2 [2]. Reported prevalence rates vary widely, ranging from between 5% and 10% [1, 3] to higher than 26% [4], with most experts agreeing that OSA is under-diagnosed. One study estimated that only 10% of those with OSA risk factors had been adequately screened [5], and others found that fewer than 25% of all cases of severe sleep-disordered breathing had ever been diagnosed [5, 6].

OSA leads to daytime sleepiness, cognitive dysfunction, increases in motor vehicle accidents [7], impaired work performance, increased risk of work absenteeism [8], and early retirement [9]. OSA has been associated with, and may be a contributing cause of, a range of health problems including hypertension [10], cardiovascular disease [11] and stroke [12], abnormalities in glucose metabolism [13, 14], depression [15], and all-cause mortality risk [16].

Given the associations between OSA, work performance, and chronic health problems in the general population, clinicians treating the World Trade Center (WTC)-exposed workforce are particularly interested in clarifying the relationship between being at high risk for OSA and common WTC-related conditions including gastroesophageal reflux disease (GERD), chronic rhinosinusitis, and posttraumatic stress disorder (PTSD).

In our previous study of aero-digestive symptoms in WTC-exposed firefighters, we found the prevalence of GERD and chronic rhinosinusitis symptoms in 2005 to be 40% and 48%, respectively [17]. In this same population, we reported the prevalence of PTSD symptoms in 2005 to be 11% [18]. Epidemiologic evidence for associations between OSA and GERD, chronic rhinosinusitis or PTSD, alone or in combinations, is limited and complicated by the overlap between symptoms including sleep disturbance and nighttime awakening [19].

The goal of this study was to examine the relationship between being at high risk for OSA and these conditions in an effort to determine which illnesses may contribute most to OSA onset or persistence. Specifically, we had two key objectives: (1) to estimate the baseline prevalence of "high risk" for OSA in more than 11,000 WTC-exposed FDNY rescue/recovery workers and to examine prevalence in relation to WTC-related and other risk factors and (2) to identify risk factors for becoming at high risk for OSA in a cohort screened at two time points who did not meet the criterion for high risk for OSA at the time of the initial screening.

Materials and methods

The Bureau of Health Services of the Fire Department of the City of New York (BHS-FDNY) performs periodic health evaluations on FDNY members, both firefighters and emergency medical service (EMS) personnel, every 12 to 18 months. These evaluations include both physician examinations and, since 2001, self-administered health questionnaires. The questionnaires are programmed on touch screen computers with trained personnel available to answer questions. During the study, compliance of WTC-exposed firefighters and EMS with scheduled periodic evaluations, including questionnaire completion, was 86% and 93%, respectively. Participation in the study required written informed consent and was approved by the institutional review board of Montefiore Medical Center.

Study population

The study population consisted of 13,330 firefighters and EMS personnel who were hired before July 25, 2002 (date the WTC site closed) and who were present at the WTC site within the first 2 weeks of September 11, 2001 (9/11). We excluded 1,162 persons who did not complete at least one questionnaire during the study period (September 12, 2005–September 11, 2008) and 467 women due to small numbers. The final sample consisted of 11,701 men (10,342 firefighters and 1,359 EMS). For incidence analyses, we limited our population to a cohort (n = 4,576) who completed at least two questionnaires and did not meet the criterion for high risk for OSA at baseline. If persons had more than one follow-up visit during this time, we used data from the earlier questionnaire. We compared the analytic cohort to those excluded due to their being at high risk for OSA at baseline (n = 4,269, group A) and to those not high risk at baseline, but who lacked a follow-up visit (n = 2,856, group B).

Data sources

Information including demographics, weight and height, and work status, i.e., active, retired, or retired with a disability, were obtained from the FDNY employee databases. All other variables including WTC exposure status, smoking history, self-rated current health status, aero-digestive symptoms, and sleep disturbance were collected from the questionnaires.

WTC exposure

The FDNY-WTC Exposure Intensity Index [20] categorized exposure based on arrival time at the WTC site as follows:

"group 1," the most severely exposed, arrived on the morning of 9/11 and was present during the towers' collapse; "group 2" arrived during the afternoon of 9/11; "group 3" arrived the next day on September 12, 2001; and "group 4", or the least exposed, arrived any day between days 3 and 14. We also created a duration-of-exposure variable by summing information obtained from the earliest post-9/11 questionnaire, where participants reported which months they had worked at the site, from September 2001 through July 2002. Multivariable analyses used a median split of 4 months to define an extended (≥4 months) vs. short duration (<4 months) of work at the WTC site.

General health status

One question, "how do you rate your current health?" was used to measure self-perceived health (excellent, very good, good, fair, or poor) [21]. We combined the fair and poor categories due to small numbers.

Aero-digestive symptoms

Questions asked about the presence and severity of specific aero-digestive symptoms in the past 12 months including three lower respiratory symptoms (wheezing, shortness of breath, and cough), two upper respiratory symptoms (rhinosinusitis and sore throat), and GERD. For example, the question for rhinosinusitis asked: "In the past 12 months, on average, how much of a problem is your sinus or facial pain or pressure, or congestion, drip, irritation, soreness, burning, or bleeding?" The question about GERD was analogous, but asked about "your sour/acid taste, reflux/regurgitation, heartburn/indigestion, and/or nausea?" Symptom severity was scored on a six-point Likert scale from 1 = "I do not have a problem" to 6 = the problem is "as bad as it could be." Multiple responses to the same symptom were not permitted. We required that symptoms be reported as being of at least moderate severity (choices 4–6) to be considered present. We also created a numerical variable summing the number of lower and upper respiratory symptoms experienced by an individual in the last 12 months.

Elevated PTSD risk

The 17-item PTSD checklist (PCL-17) has been well studied and is often used for PTSD screening [22, 23]. Respondents rate each item for severity during the past month using a five-point Likert scale ranging from 1 = not at all to 5 = extremely. We scored the PCL-17 by summing responses using the widely accepted cut point of 44 to define "elevated PTSD risk" [24].

Sleep disturbance

In 2005, BHS-FDNY incorporated a modified form of the Berlin Questionnaire into the self-administered health questionnaires to estimate the prevalence of being at high risk for OSA. The Berlin questionnaire is a validated, ten-question, self-administered screening tool that classifies persons into high- and low-risk categories by identifying snoring behavior (category 1), daytime sleepiness (category 2), and hypertension or obesity (category 3). The criterion for being at high risk is affirmation in at least two categories [25].

The wording and content of the FDNY sleep apnea questionnaire (modified Berlin) and the original Berlin questions varied (Table 1). One difference between the versions was the specific time frame referenced, with FDNY questions referring to "in the past 12 months" and the Berlin questions without using a time frame, e.g., "do you snore?" Three Berlin questions asked about symptoms at any time, e.g., "Has your snoring ever bothered other people?" There were also differences in answer choices (binary vs. Likert or frequency), and finally, the FDNY version used BMI calculated on the day of the exam from actual measurements, while the Berlin questionnaire used self-reported height and weight measurements to categorize BMI as ≤30 or >30 kg/m^2.

Because of these differences, a reliability study was performed in 2009. FDNY employees took both the self-administered FDNY sleep questions (modified Berlin) and the original Berlin questionnaire at their routine BHS-Medical Monitoring visit. This allowed us to compare, from the same persons on the same day, the proportion meeting the criterion for "high risk" using the FDNY sleep apnea questions with the proportion meeting the criterion for "high risk" using the Berlin questions. We compared agreement using the kappa statistic.

Statistical analysis

Descriptive statistics are reported as mean (±standard deviation). Unadjusted associations between high-risk for OSA and categorical variables were tested using the Pearson chi-squared test with odds ratios (OR) and 95% confidence intervals (95% CI). Continuous variables were assessed using the *t*-test or ANOVA. The Cochran–Armitage test for trend was used to examine the association between self-assessed health status and the prevalence of being at high risk for OSA at baseline. Possible mediation effects were evaluated using logistic regression analyses to test whether GERD, rhinosinusitis, or PTSD mediated the relationship between arrival time and OSA. We also created separate models stratified by BMI>30 and ≤30 and by disability retirement (yes/no) to examine cofactors of interest in relation to being at high risk for OSA.

Table 1 Comparison of the FDNY and Berlin questionnaires

		Berlin Questionnaire			FDNY Questionnaire	
		Question	Answer	Points	Question	Answer
CATEGORY 1 SNORING	Item 1	Do you snore?	Yes	1	●IN THE PAST 12 MONTHS, have you or others noticed any of the following? —OR—	Snoring —OR—
					■IN THE PAST 12 MONTHS, apart from when you had a cold or flu, how often have you or others noticed that you snore?	Any of the following frequencies: ■Less than once per week ■1–2 days per week ■ 3–6 days per week ■Daily
		If you snore:				
	Item 2	Your snoring is	●Louder than talking ●Very loud	1	●IN THE PAST 12 MONTHS, on average how much of a problem is snoring and stopping breathing while asleep?	●Moderate problem ●Severe problem ●As bad as it could be
	Item 3	How often do you snore?	●Nearly every day ●3–4 times per week	1	●IN THE PAST 12 MONTHS, apart from when you had a cold or flu, how often have you or others noticed that you snore?	●3–6 days per week ●Daily
	Item 4	Has your snoring ever bothered other people?	Yes	1	●IN THE PAST 12 MONTHS, on average how much of a problem is snoring and stopping breathing while asleep?	●I snore or stop breathing while asleep but it's not a problem ●Very mild problem ●Mild or slight problem ●Moderate problem ●Severe problem ●As bad as it could be
	Item 5	Has anyone ever noticed that you quit breathing during your sleep?	●Nearly every day ●3–4 times per week	2	●IN THE PAST 12 MONTHS, apart from when you had a cold or flu, how often have you or others noticed that you stop breathing in while asleep?	●3–6 days per week ●Daily
CATEGORY 2 FATIGUE	Item 6	How often do you feel tired or fatigued after your sleep?	●Nearly every day ●3–4 times per week	1	●IN THE PAST 12 MONTHS, have you or others noticed any of the following?	●Persistent or unusual fatigue without physical activity
	Item 7	During your waking time, do you feel tired, fatigued or not up to par?	●Nearly every day ●3–4 times per week	1	●IN THE PAST 12 MONTHS, have you or others noticed any of the following?	●Persistent or unusual fatigue without physical activity ● Persistent or unusual fatigue AFTER physical activity
	Item 8	Have you ever nodded off or fallen asleep while driving a vehicle?	Yes	1	●IN THE PAST 12 MONTHS, on average, how much of a problem is persistent or unusual fatigue during the day?	●Moderate problem ●Severe problem ●As bad as it could be
CATEGORY 3 High Blood Pressure OR BMI	Item 9	Do you have high blood pressure?	Yes	1	●Has a doctor or health professional EVER told you that you have high blood pressure including borderline high blood pressure?	●Yes, I am being monitored without any therapy ●Yes, I am on diet/exercise ●Yes, I am on treatment/medication ●Yes, I am on diet/exercise and treatment/medication
	Item 10	BMI >30 kg/m^2	Yes	1	Weight and height measured at time of survey	

We used logistic regression analyses to determine which variables were associated with prevalent high risk for OSA at baseline and with incident high risk for OSA at follow-up, both in simple and multivariable models. Variables tested in the incidence analysis models were usually obtained from the baseline visit. These included aero-digestive symptoms, weight gain, and smoking status. Elevated risk of PTSD, however, was available primarily at follow-up as it was not regularly assessed at earlier visits. Multivariable models predicting high risk for OSA were constructed using variables that were statistically significant in unadjusted analyses or were shown to be important in prior studies, which included age at 9/11, arrival group, duration of exposure, and BMI. Variables retained in the final prevalence and incidence models were significant at $p<0.10$ or were shown to affect other variables in the model. First level interaction terms were examined; none were statistically significant. Goodness of fit was assessed using the Hosmer–Lemeshow test. Data were analyzed using SAS, version 9.1 (SAS Institute, Cary, NC, USA)

Results

Agreement Between FDNY and Berlin Questionnaires

In the group of 1,482 FDNY employees who answered the FDNY and Berlin questionnaires on the same day, the difference in the point prevalence of being at high risk for OSA was statistically significant but too small to be of clinical significance—36.4% with the FDNY vs. 38.5% with the Berlin (p = 0.02). Agreement between the questionnaires was good (κ = 77.5%), and therefore, the remainder of this study concentrates on data obtained from the FDNY sleep apnea questionnaire. In Fig. 1, we compare the proportion affirming each sleep symptom according to whether they met the high- or low-risk criterion for OSA using the FDNY or Berlin questionnaires.

Prevalence of high risk for OSA at baseline

Over the 3-year period from September 12, 2005 to September 11, 2008, 20,248 questionnaires were completed by 11,701 WTC-exposed male firefighters and EMS personnel. The prevalence of being at high risk for OSA at baseline was 36.5% (4,269/11,701); 5,117 individuals met the criterion for high risk at least once during the course of the study, resulting in an unadjusted cumulative prevalence of 43.7% (5,117/11,701). Only 828 (7.1%) participants reported a physician diagnosis of OSA since 9/11; of those who met the criterion for high risk at least once, 709 of 5,117 (13.9%) reported a physician diagnosis of OSA.

Unadjusted associations between being at high risk for OSA and other characteristics, including the number of aero-digestive symptoms, GERD, chronic rhinosinusitis, and PTSD are presented in Table 2. We found that self-perceived current health status was associated with high risk for OSA with a significant dose–response relationship ($p<0.001$). At baseline, the prevalence of being at high risk for OSA was 14.2%, 24.1%, 41.6%, and 64.8% in those reporting excellent, very good, good, and fair/poor health, respectively. In the multivariable analyses (Table 2), we found independent associations between baseline high risk

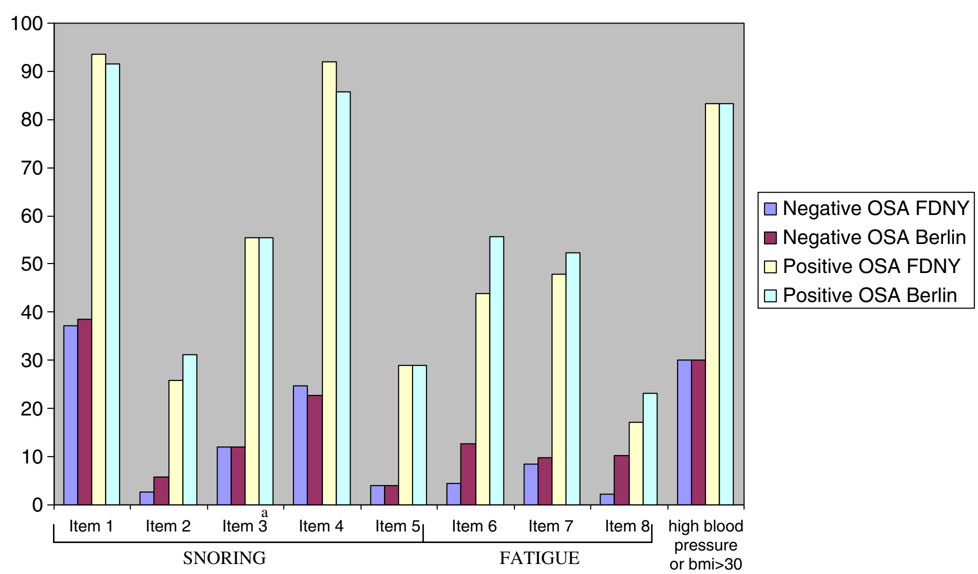

Fig. 1 Percentage scoring affirmatively in each item of the FDNY and Berlin questionnaires, grouped by their overall positive or negative score and the questionnaire taken (N = 1,482)

[a] Items 3 and 5 in snoring category use the identical question for both FDNY and Berlin versions.

Table 2 Characteristics of the group (n = 11,701) and logistic regression predicting prevalent high risk for OSA at baseline, both unadjusted and adjusted for covariates

Variable	N (%)	Odds ratio	95% Confidence interval	Adjusted odds ratio[a]	95% Confidence interval
Mean age (SD)	44.2 (8.4)years				
Age group (years)					
18–29	87 (0.7)	Ref		Ref	
30–49	7,409 (63.3)	3.18	(1.72, 5.85)	2.56	(1.30, 5.06)
50–64	3,859 (33.0)	4.52	(2.45, 8.33)	2.85	(1.43, 5.65)
65-up	346 (3.0)	4.30	(2.25, 8.20)	2.30	(1.11, 4.77)
Mean BMI (kg/m^2, SD)	29.6 (4.5)				
BMI group					
<18.5 kg/m^2 (underweight)	184 (1.6)	1.28	(0.86, 1.89)	1.80	(1.17, 2.77)
18.5<BMI<25 kg/m^2 (normal)	1,269 (10.8)	ref		ref	
25<BMI<30 kg/m^2 (overweight)	5,671 (48.5)	1.54	(1.31, 1.81)	1.54	(1.29, 1.84)
30<BMI<40 kg/m^2 (obese)	4,264 (36.4)	7.73	(6.57, 9.09)	9.14	(7.64, 10.94)
>40 kg/m^2 (morbidly obese)	313 (2.7)	10.25	(7.77, 13.54)	11.26	(8.32, 15.25)
WTC arrival group					
Arrival group 1	1,879 (16.1)	1.52	(1.31, 1.77)	1.19	(0.99, 1.43)
Arrival group 2	7,165 (61.2)	1.10	(0.96, 1.25)	1.08	(0.92, 1.26)
Arrival group 3	1,477 (12.6)	1.18	(1.01, 1.39)	1.07	(0.89, 1.30)
Arrival group 4	1,180 (10.1)	ref		ref	
Ever smoking					
Yes	4,357 (37.2)	1.17	(1.08, 1.27)		
No	7344 (62.8)	ref			
Aero-digestive symptoms					
Wheeze no	10,031 (85.7)	Ref		Ref	
Wheeze yes	1,670 (14.3)	3.15	(2.83, 3.51)	0.76	(0.61, 0.96)
Rhinosinusitis no	8,321 (71.1)	Ref		Ref	
Rhinosinusitis yes	3,380 (28.9)	2.81	(2.59, 3.05)	1.27	(1.00, 1.60)
GERD no	9,148 (78.2)	Ref		Ref	
GERD yes	2,553 (21.8)	3.29	(3.00, 3.60)	1.73	(1.54, 1.94)
Number of lower respiratory symptoms (LRS)					
LRS 0	6,760 (57.8)	Ref		Ref	
LRS 1	2,804 (24.0)	1.91	(1.74, 2.10)	1.55	(1.39, 1.73)
LRS 2	1,133 (9.7)	3.31	(2.91, 3.76)	1.93	(1.59, 2.35)
LRS 3	1,004 (8.6)	5.87	(5.09, 6.78)	2.53	(1.88, 3.41)
Number of upper respiratory symptoms (URS)					
URS 0	7,831 (66.9)	Ref		Ref	
URS 1	2,428 (20.8)	2.16	(1.97, 2.37)	1.36	(1.10, 1.70)
URS 2	1,442 (12.3)	4.53	(4.02, 5.10)	1.89	(1.42, 2.51)
Self-assessed health status[b]					
Excellent	951 (9.1)	ref		ref	
Very good	3,408 (32.7)	1.00	(0.88, 1.14)	0.96	(0.84, 1.11)
Good	4,370 (41.9)	2.25	(2.01, 2.52)	1.43	(1.26, 1.64)
Fair or poor	1,693 (16.3)	5.82	(5.06, 6.69)	2.03	(1.70, 2.42)
Race[c]					
Caucasian	10,422 (89.2)	ref		ref	
Non-Caucasian	1,261 (10.8)	0.94	(0.84, 1.07)	0.94	(0.81, 1.09)
Work duration at WTC site					
≥4 months	4,862 (41.6)	1.03	(0.95, 1.11)	1.09	(0.99, 1.19)

Table 2 (continued)

Variable	N (%)	Odds ratio	95% Confidence interval	Adjusted odds ratio[a]	95% Confidence interval
<4 months	6,839 (58.5)	Ref		Ref	
Work status[d]					
Disability retirement	2,592 (22.2)	2.62	(2.39, 2.87)	1.56	(1.38, 1.77)
Ordinary retirement	1,717 (14.7)	1.79	(1.60, 1.99)	1.57	(1.35, 1.81)
Active	7,362 (62.9)	Ref		Ref	
PTSD					
Yes	998 (8.5)	4.62	(4.01, 5.32)	1.96	(1.65, 2.34)
No	10,703 (91.5)	Ref		Ref	

[a] Model is adjusted for age group, BMI group, WTC arrival group, wheeze, rhinosinusitis, GERD, number of lower respiratory symptoms, number of upper respiratory symptoms, self-assessed health status, race, work duration at WTC, work status, and PTSD

[b] One thousand two hundred seventy-nine had missing self-assessed health status

[c] Eighteen had missing race

[d] Thirty had missing work status

for OSA and the number of aero-digestive symptoms, GERD, chronic rhinosinusitis, PTSD, and self-assessment of good or fair/poor health.

Incidence analyses

The cohort for incidence analysis represented the 39.1% of the study population (4,576 of 11,701) who did not meet the high-risk for OSA criterion at baseline and had at least one follow-up questionnaire. By the time of the first follow-up, which took place, on average, 1.4 (±0.5) years after baseline, 773 (16.9%) became at high risk for OSA. Unadjusted associations between selected characteristics of the analysis cohort and high risk for OSA are presented in Table 3.

Two groups were ineligible for inclusion in the analytic cohort. Group A met the criterion for high risk for OSA at baseline ($N = 4{,}269$); group B did not meet the high-risk for OSA criterion at baseline but lacked a follow-up visit within the designated study period ($N = 2{,}856$). We compared the analytic cohort to these groups. Members of the analytic cohort were the youngest: mean age in 2005, 42.3 years (±8.0); group A, 45.3 years (±8.5); group B, 45.5 years (±8.8). The analytic cohort was the least likely to be Caucasian: 86.3%; group A, 90.0%; group B, 93.2%; and, the least likely to have ever smoked: 35.7%; 39.6% group A; 36.2% group B. Cohort members were less likely than group A to have arrived during the collapse: 14.8%; 18.9% in group A; 13.9% in group B and had a mean BMI in 2005 that was lower than group A: cohort 28.6 (±4.1); 31.6 (±4.6) in group A and 28.1 (±3.8) in group B. Differences between the groups were statistically significant at $p<.001$.

In multivariable logistic regression models predicting incident high risk for OSA, we found that earlier time of arrival at the WTC site was a statistically significant predictor. Also, as expected, those with BMI>30 had substantially elevated odds of being at high risk for OSA, but surprisingly, those with low BMI<18.5 had 4.5 times the odds (95% CI 1.3–15.0) of becoming at high risk for OSA, all compared to individuals with BMI between 18.5 and 25 (normal BMI group). Persons with self-assessed fair/poor health were 3.2 times as likely as those with excellent health to become high risk for OSA. The presence of GERD at baseline and PTSD at any time during the study were independent predictors of becoming high risk for OSA (Table 3). Each of these symptoms was tested and found not to be a mediator of the association between arrival group and high risk for OSA. Analyses stratified by BMI ≤ 30 and >30 and by disability retirement status (yes/no) produced similar results.

Discussion

Four thousand two hundred sixty-nine (36.5%) of 11,701 male rescue/recovery workers were found to be at high risk for OSA at baseline, although only 828 (7.1%) reported having received a physician diagnosis of sleep apnea. Of those who met the high-risk for OSA criterion at least once and were therefore symptomatic, the proportion with a physician diagnosis was still low, 13.9%. As FDNY workers are required to have a WTC monitoring visit with a physician, on average every 12 to 18 months, we were surprised by the extent of potentially undiagnosed OSA. This has, however, been reported in other groups [26]. OSA has also previously been associated with low self-assessment of health status [27], although we do not know to what extent this assessment was influenced by obesity or

Table 3 Characteristics of the cohort (n = 4,576) and logistic regression predicting incident high risk for OSA at follow-up, both unadjusted and adjusted for covariates

Variable	N (%)	Odds ratio	95% Confidence interval	Adjusted odds ratio[a]	95% Confidence interval
Mean age (SD)	42.3 years (8.0)				
Age group (years)					
18–29	60 (1.3)	Ref		Ref	
30–49	3,276 (71.6)	1.31	(0.62, 2.76)	1.18	(0.53, 2.63)
50–64	1,163 (25.4)	1.40	(0.66, 2.99)	1.11	(0.49, 2.53)
65-up	77 (1.7)	1.08	(0.41, 2.89)	0.56	(0.18, 1.74)
Mean BMI (kg/m^2, SD)	28.56 (4.1)				
BMI group					
<18.5 kg/m^2 (underweight)	20 (0.4)	3.10	(1.00, 9.63)	4.49	(1.34, 14.99)
18.5<BMI<25 kg/m^2 (normal)	643 (14.1)	Ref		Ref	
25<BMI<30 kg/m^2 (overweight)	2,690 (58.8)	1.82	(1.33, 2.49)	1.70	(1.20, 2.41)
30<BMI<40 kg/m^2 (obese)	1,148 (25.1)	5.41	(3.93, 7.45)	6.14	(4.29, 8.78)
>40 kg/m^2 (morbidly obese)	75 (1.6)	7.38	(4.25, 12.83)	7.03	(3.84, 12.88)
WTC Arrival group					
Arrival group 1	676 (14.8)	2.29	(1.60, 3.27)	2.24	(1.47, 3.41)
Arrival group 2	2,949 (64.4)	1.82	(1.33, 2.51)	2.06	(1.42, 2.99)
Arrival group 3	499 (10.9)	1.76	(1.20, 2.59)	1.86	(1.19, 2.92)
Arrival group 4	452 (9.9)	Ref		Ref	
Ever smoking					
Yes	1,632 (35.7)	1.21	(1.03, 1.42)	1.13	(0.94, 1.36)
No	2,944 (64.3)	Ref		Ref	
Aero-digestive symptoms					
Wheeze no	4,145 (90.6)	Ref			
Wheeze yes	431 (9.4)	2.54	(2.04, 3.16)		
Rhinosinusitis no	3,540 (77.4)	Ref		Ref	
Rhinosinusitis yes	1,036 (22.6)	2.07	(1.75, 2.45)	1.51	(1.17, 1.94)
GERD no	3,932 (85.9)	Ref		Ref	
GERD yes	644 (14.1)	2.21	(1.82, 2.67)	1.81	(1.39, 2.37)
Number of lower respiratory symptoms (LRS)					
LRS 0	2,936 (64.2)	Ref			
LRS 1	1,106 (24.2)	2.06	(1.73, 2.47)		
LRS 2	322 (7.0)	2.70	(2.06, 3.53)		
LRS 3	212 (4.6)	4.26	(3.16, 5.75)		
Number of upper respiratory symptoms (URS)					
URS 0	3,371 (73.7)	Ref			
URS 1	865 (18.9)	1.71	(1.42, 2.07)		
URS 2	340 (7.4)	2.97	(2.32, 3.80)		
Self-assessed health status[b]					
Excellent	619 (13.9)	Ref		Ref	
Very Good	1,852 (41.4)	1.00	(0.76, 1.30)	1.01	(0.74, 1.37)
Good	1,670 (37.4)	2.10	(1.62, 2.71)	1.81	(1.35, 2.43)
Fair or Poor	329 (7.0)	4.62	(3.36, 6.36)	3.18	(2.14, 4.71)
Weight gain >10 lbs					
Yes	426(9.3)	1.71	(1.35, 2.16)	1.46	(1.12, 1.90)
No	4,150 (90.7)	ref		ref	
Race[c]					
Caucasian	3,950 (86.4)	Ref			

Table 3 (continued)

Variable	*N* (%)	Odds ratio	95% Confidence interval	Adjusted odds ratio[a]	95% Confidence interval
Non-Caucasian	623 (13.6)	0.91	(0.72, 1.14)		
Work duration at WTC					
≥4 months	2,009 (43.9)	1.18	(1.01, 1.38)	1.26	(1.05, 1.52)
<4 months	2,567 (56.1)	Ref		Ref	
Work status[d]					
Disability retirement	454 (9.9)	1.95	(1.56, 2.45)	1.67	(1.22, 2.28)
Ordinary retirement	327 (7.2)	1.14	(0.84, 1.53)	1.33	(0.91, 1.96)
Active	3,784 (82.9)	Ref		Ref	
PTSD					
Yes	189 (4.1)	3.65	(2.70, 4.93)	2.40	(1.63, 3.54)
No	4,387 (95.9)	Ref		Ref	

[a] Model is adjusted for age group, BMI group, WTC arrival group, ever smoking, rhinosinusitis, GERD, self-assessed health status, weight gain >10 lbs, work duration at WTC, work status, and PTSD

[b] One hundred six had missing self-reported health status

[c] Three had missing race

[d] Eleven had missing leave status

other factors. We found that 65% of those reporting fair/poor health on the baseline questionnaire met the high-risk for OSA criterion compared with only 14% of those reporting excellent health. The documented correlation between high risk for OSA and poor quality of life [28] has clinical relevance. One study of 7,725 middle-aged British men found that those reporting poor health had an eightfold increase in all cause mortality compared with those reporting excellent health [29].

We analyzed the cohort of workers who did not meet the high-risk for OSA criterion at baseline and who completed a follow-up questionnaire to assess characteristics of the 16.9% (773/4,576) who became high risk for OSA by follow-up. In these multivariable models, early WTC arrival time predicted new-onset high risk for OSA, which has been previously reported for other WTC-related conditions [17]. We also confirmed the role of well-known risk factors including BMI [30] and weight gain. In this cohort, however, we also identified low BMI (<18.5 kg/m^2) as conferring substantially elevated odds (OR = 4.5) of incident high risk for OSA. We believe that low BMI in this cohort may be evidence of existing illness. A recent study of all-cause mortality and BMI by others found a U-shaped association where high mortality risks were found in the highest BMI category (≥35 kg/m^2) and in the lowest (<18.5 kg/m^2) [31].

We were particularly interested in the OSA risk conferred by common WTC-related symptoms and found that GERD, chronic rhinosinusitis, and PTSD were each associated with prevalent as well as new-onset high risk for OSA. In the multivariable incidence model, these symptoms had odds ratios ranging from 1.5 to 2.4. Individuals reporting all three symptoms had 6.5-fold odds of meeting the high-risk for OSA criterion at their follow-up visit. Moreover, if participants had a BMI between 25 and 30, a common occurrence in a group where the mean BMI was 29.5, the odds were elevated more than 11-fold. Thus, in light of the frequent co-occurrence of these symptoms and conditions, the risk conferred by multiple predictors is substantial and was found even in those with a BMI ≤ 30 or who had a weight gain of under 10 lbs.

The mechanism by which WTC-related symptoms of GERD might influence the incidence of OSA is unknown. It has been suggested that extraesophageal reflux (EER), the reflux of gastric contents such as acid and pepsin into the upper aero-digestive tract, may lead to mucosal injuries in the larynx, trachea, lung, pharynx, nose, and ear [32]. Thus, EER-associated GERD could cause airway obstruction by irritation and swelling. Alternatively, apnea episodes which are accompanied by negative intrathoracic pressure could cause gastric fluid to be sucked into the esophagus, causing GERD symptoms [33]. If both of these mechanisms are operative, it could explain why previous studies have reported associations between GERD and OSA, but failed to establish a temporal sequence, i.e., GERD always preceding OSA or OSA always preceding GERD [34, 35]. Treatment for OSA, including CPAP and surgery, has generally been reported to improve GERD symptoms, and treatment of GERD, including proton pump inhibitor therapy, has also benefited symptoms of OSA [36, 37].

The association between chronic rhinosinusitis and OSA is likely due to nasal obstruction/congestion [38, 39]. Nasal congestion, which is often reported to be worse at night, reduces the internal nasal diameter, increases airway resistance to nasal airflow, and causes nasal obstruction interfering with sleep [40]. Treatment of nasal congestion, however, has not been proven to improve sleep quality. The impact of rhinosinusitis treatment on OSA has been shown to be limited [41, 42], and to date, there have been no published reports of the effect of OSA treatment on rhinosinusitis.

Proposed mechanisms to explain the association between PTSD and OSA have included biologic effects (REM sleep mechanism disturbance) [43], noradrenergic activity (hyperarousal) [44], and psychological causes (sleep-related anxiety or comorbid depression) [45, 46]. The underlying mechanism, including the temporal relationship of these conditions, however, has not been established [47]. Treatment evidence for the PTSD and OSA association has been mixed. Some pharmacological interventions that target neuroanatomical structures like the hypothalamic–pituitary–adrenal axis have resulted in reductions in both PTSD and sleep disturbances [48].

In summary, although we have shown associations between being at high risk for OSA and each of the above conditions, the responsible causative mechanisms remain to be determined. These associations may reflect causation with critical upper airway narrowing resulting from chemical trauma (acid reflux from EER or GERD), mechanical trauma (postnasal drip or cough), or PTSD-related neurological dysfunction. Or, the associations may be due to common predisposing factors such as alcohol use, obesity, and weight gain from any of the above conditions or the treatment of such conditions. Inhaled corticosteroid treatment has recently been correlated with high OSA risk [49], and mental health medications for PTSD have also been associated with sleep disorders and possible OSA [50].

We believe that our study has several strengths, including the unique opportunity to verify associations between WTC-related risk factors and OSA risk. We had a large sample size of more than 11,000 male firefighters and EMS workers who were exposed to the WTC disaster and, importantly, did not self-select for study participation. One potential study limitation, however, was that our questionnaire was designed to identify those at high risk for OSA, but not to confirm a diagnosis of OSA, which can only be done by a sleep test. In addition, our medical monitoring program adapted questions from the Berlin questionnaire which may not have the same sensitivity, specificity, and positive predictive value as the original version. We tested this concern, however, and found substantial agreement between the two versions in a subset of participants who took both versions on the same day. The Berlin questionnaire could also induce more false positive responses in our WTC cohort than in the primary care clinic population where it was validated since individuals in our cohort may be more likely to score positively on the questionnaire due to symptoms that are byproducts of other illnesses (i.e., snoring as a result of rhinosinusitis or fatigue as a result of PTSD) and not true indicators of OSA. Another potential limitation is that many variables were self-reported. Symptom reporting could have been exaggerated due to issues related to workers compensation, civil litigation, and retirement disability. However, this is unlikely as currently OSA has not been linked as a primary WTC condition for compensation, litigation, or disability. To assess the possibility of symptom exaggeration in those who retired with a disability, however, we separately examined this group ($N = 613$) and compared them to all others and found minor differences. In general, most symptom effects were smaller in the model including only disabled, the opposite of what we would expect if disability retirees were over-reporting symptoms associated with being at high risk for OSA. Finally, there were small differences between the analytic cohort and the groups that did not meet the restrictions we imposed on the analytic cohort, which could have impacted the generalizability of our findings.

While the etiology of OSA needs to be better understood, public health interventions are beginning to have an impact. Lifestyle interventions to lose weight have already been shown to reduce OSA symptoms [51]. Similarly, mental health interventions to treat PTSD, with or without comorbid depression, have also been shown to have a favorable impact on sleep quality [52]. Since the etiology of OSA is likely multifactorial, improvement may require successful treatment of both OSA and its comorbid conditions.

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