FDNY and 9/11: Clinical Services and Health Outcomes in World Trade Center-Exposed Firefighters and EMS Workers From 2001 to 2016

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Background *After the World Trade Center (WTC) attacks on September 11, 2001, the Fire Department of the City of New York (FDNY) instituted a WTC medical monitoring and treatment program and established a data center to document health outcomes in the WTC-exposed workforce of ~16,000 firefighters and EMS workers.*
Methods *FDNY schedules routine monitoring exams every 12–18 months and physical and mental health treatment appointments, as required.*
Results *FDNY research studies have consistently found that early arrival to work and/or prolonged work at the WTC-site increased the risks for adverse physical and mental health outcomes. To date, a substantial proportion has been diagnosed with obstructive airways disease, chronic rhinosinusitis, and gastroesophageal reflux disease; a quarter has two or more of these conditions.*
Conclusions *While much has been learned, the entire spectrum and trajectory of WTC-related disorders and their mechanisms of onset and persistence remain to be fully described.* Am. J. Ind. Med. © 2016 Wiley Periodicals, Inc.

KEY WORDS: September 11 terrorist attacks; world trade center; firefighters; ems workers; occupational health

INTRODUCTION

The collapse of the World Trade Center (WTC) on September 11, 2001 (9/11) resulted in the loss of 343 Fire Department of the City of New York (FDNY) rescue/recovery workers and exposed thousands more to a hazardous mix of inorganic dust, products of combustion, and respirable particulates [Prezant et al., 2002]. In response, FDNY Bureau of Health Services (FDNY-BHS) instituted a rigorous medical monitoring and treatment program for the almost 16,000 FDNY firefighters and emergency medical service (EMS) workers who performed rescue/recovery work on 9/11 and during the subsequent 10-month recovery period at the WTC-site. Concurrently, FDNY physicians and others documented the early health symptoms and conditions presented by the FDNY workforce, most notably respiratory and mental health symptoms, which were the most problematic immediately post-disaster. In 2005, the FDNY data center was established to institutionalize the collection and analysis of data on health conditions associated with WTC-exposure.

FDNY's multifaceted approach (monitoring, treatment, and research) has enabled us to document and ameliorate the health effects of 9/11. FDNY-BHS and its WTC Health Program (WTCHP) provided clinical care and referrals for services, some of which were beyond the scope of FDNY-BHS expertise, while research studies from the FDNY data center

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identified trends and risk factors for WTC-related health conditions to improve our understanding of exposure-host interactions and in so doing, to provide appropriate clinical services. In this report, we describe FDNY's post-9/11 clinical care and health interventions and provide a summary of health outcomes that we have identified between 2001 and 2016.

FDNY WTCHP

Physical Health Services

FDNY's WTC treatment program began on 9/11, as FDNY-BHS physicians were deployed to the WTC site, some prior to the collapse, to provide triage and on-site treatment. Treatment continued and 3 weeks after 9/11 formal medical monitoring began, leveraging the existing health infrastructure already in place at FDNY-BHS at the time of the disaster. This occupational health service was established well before 9/11 to provide monitoring and treatment medical exams for active FDNY firefighters and EMS workers, primarily to assess and improve their fitness to perform work-related activities. The early WTCHP incorporated FDNY-BHS routine exams that included physical examinations by FDNY physicians, self-administered health questionnaires (rapidly updated to include WTC-related questions), pulmonary function tests, chest x-rays, cardiograms, hearing tests, and the collection of blood and urine samples for testing. Since then, the WTCHP, based in Brooklyn, has added satellite locations in Queens, Staten Island, Suffolk and Orange counties to increase access to care. It has also expanded to include free treatment services and more in-depth clinical exams and physical and mental health monitoring exams.

Free treatment services for WTC-related health conditions are offered to all active and retired WTC-exposed FDNY rescue/recovery workers. FDNY-WTCHP provides on-site diagnosis and treatment of WTC-related physical health conditions such as lower- and upper-respiratory diseases and GERD, and when necessary referrals to an extensive network of specialty providers conveniently located in the New York metropolitan area. Referrals are provided for diagnostic procedures and treatment including imaging, endoscopy, biopsy, and surgery. After epidemiological findings that demonstrated a link between WTC-exposure and cancer [Zeig-Owens et al., 2011; Li et al., 2012; Solan et al., 2013], and the subsequent addition of cancers as a WTC-covered condition under the James Zadroga 9/11 Health and Compensation Act of 2010 Act [Pub. L. No. 111–347], in 2015, FDNY-WTCHP expanded to provide diagnostic evaluations for WTC-related cancers and added providers such as the Memorial Sloan Kettering Cancer Center to its external network for cancer treatment. Program expansion also included providing end of life care through hospice referrals and adding in-house healthcare personnel to provide case management for patients with cancer or other WTC-related conditions.

Mental Health Services

FDNY-WTCHP referrals also include mental health visits at FDNY's counseling service unit (FDNY-CSU), a division of the FDNY-BHS, which has been in existence since the 1970s. Before 9/11, FDNY-CSU was staffed by 11 counselors working at one Manhattan location, mostly providing counseling for family challenges, personal stress or bereavement. In response to 9/11, FDNY-CSU expanded its reach to meet the increased demand for mental health services. Staff members visited every firehouse and EMS station and provided counseling in satellite locations. To help workers cope with specific challenges, FDNY-CSU introduced post-9/11 health interventions that in addition to standard treatment modalities for post-traumatic stress disorder (PTSD), anxiety, depression, and prolonged grief, also included tobacco cessation counseling, treatment for alcohol and substance abuse, and retirement counseling. In post-9/11 questionnaires, 15% of 11,777 FDNY WTC rescue/recovery workers reported being current smokers, of whom 29% increased tobacco use after the WTC disaster [Bars et al., 2006]. Similarly, an increase in alcohol use after 9/11 was reported by 34% of the 14,228 individuals who completed a post-9/11 mental health questionnaire. Understanding that these attempts to self-medicate could have negative consequences, FDNY-CSU increased its alcohol/drug treatment programs and in 2002, FDNY initiated "Tobacco Free with FDNY," a tobacco cessation program that provided free counseling and medications to FDNY-WTC rescue/recovery workers and family members. Among 220 early program enrollees (including 164 rescue workers), the abstinence rate after 3 months of treatment was 47%; at 6 months, 36%; and at 12 months, 37% [Bars et al., 2006]. Of the 135 FDNY-WTC rescue/recovery workers followed-up in 2014–2015, more than 70% remained tobacco free (unpublished data). To date, the program continues to provide tobacco cessation counseling.

Another intervention, "Stay Connected" was designed for retired FDNY firefighters and EMS workers. In the first 4 years after 9/11, more than 3,000 FDNY responders retired from FDNY, over twice the number who retired in the 4 years before 9/11 [Alvarez et al., 2007]. The increase in retirement was attributed to challenges associated with work at the WTC including grief, physical injuries, respiratory health conditions, and psychological distress [Alvarez et al., 2007; Niles et al., 2011a]. Pension considerations might have also contributed to the increase. The "Stay Connected" initiative

provided peer counseling and, when necessary psychotherapy and psychiatric services to help those affected cope with the challenges related to WTC and retirement. Participants gave high satisfaction ratings to the program's mental health services [Alvarez et al., 2007].

Similar to "Stay Connected" is a volunteer support network staffed by retired FDNY responders to provide transport services to and from doctors' appointments for WTC-exposed firefighters and EMS workers who were diagnosed with cancer or other serious health conditions. Augmenting FDNY-WTCHP's care coordination, this network of volunteer drivers helped to increase FDNY responders' access to care by reducing barriers such as distance to care and patient fatigue, which is especially valuable for patients who require surgery, chemotherapy, or supplemental oxygen.

WTCHP Utilization

There are 15,646 FDNY WTC-exposed rescue/recovery workers enrolled in the FDNY-WTCHP. Since the inception of FDNY-WTCHP, 15,132 (97%) received at least one follow-up monitoring exam, and to date (March 31, 2016), 10,176 (65%) have received at least eight monitoring exams. Participation rates remain high: in the last 12 months, 10,870 (70%) enrolled members received an FDNY WTC monitoring exam. To date, 242 of the enrollees have died, nearly half due to WTC-related illnesses.

Between 9/11 and 3/31/2016, not including monitoring, 13,397 (86%) individuals visited an FDNY-WTCHP physician for diagnosis and treatment of a physical health problem, and 5,374 individuals (34%) went to FDNY-CSU for diagnosis and treatment of a mental health problem. Many of these conditions, initially acute, have evolved to become chronic illnesses requiring ongoing treatment. Over the last 12 months, 7,472 (48%) enrolled members with at least one certified WTC-related illness have presented for treatment of a physical or mental health problem at the FDNY-WTCHP.

Beginning in 2006, the FDNY-WTCHP provided free medications for WTC-related physical and mental health conditions, at first utilizing funding from the American Red Cross and the Federal Emergency Management Agency, and then from the National Institute of Occupational Safety and Health (NIOSH) under the Zadroga Act [Pub. L. No. 111-347]. To date, 10,181 persons have been certified by NIOSH as having at least one WTC-related health condition and 9,323 (60% of enrolled members) have filled at least one medication under this program (Table I). The most common medications for physical health conditions were: proton pump inhibitors for those certified with GERD; saline wash and nasal anti-inflammatory steroids for those certified with upper airway diseases, predominantly chronic rhinosinusitis; and, beta-adrenergic agents and inhaled corticosteroids for those certified with obstructive airways diseases including asthma, reactive airways dysfunction syndrome (RADS), chronic bronchitis, and emphysema. The three most common medications for those certified with mental health conditions, predominantly PTSD, depression, and anxiety were selective serotonin reuptake inhibitors, anti-anxiety drugs, and norepinephrine and dopamine reuptake inhibitors.

Importantly, FDNY-WTC rescue/recovery workers gave high ratings to the quality of care they received at the FDNY-WTCHP. In 2014, a convenience sample of 1,293 WTC-exposed firefighters and EMS workers completed an anonymous survey that inquired about overall satisfaction in key areas of FDNY medical care: communication with the medical staff, satisfaction with interpersonal behavior, technical quality of the office, accessibility and convenience, general satisfaction with care, and satisfaction with the amount of time spent with each patient. Based on a 5 point scale with 5 being the most satisfied, mean satisfaction ratings were 4 or higher in all six areas (unpublished data).

WTC-Exposed Retirees in FDNY-WTCHP

The participation of WTC-exposed retired responders in FDNY-WTCHP highlights an important achievement of FDNY advocacy efforts. Before 9/11, FDNY provided diagnostic and treatment care for active firefighters and EMS workers who sustained work-related injuries and illnesses, which were typically orthopedic injuries, burns, and in some cases, respiratory injuries. After retirement, access to medical care for service connected injuries and illness was limited, and was only available through private health insurance (firefighters) or workers' compensation (EMS workers). Recognizing that WTC-related illnesses could be extensive, complicated, and delayed in onset (e.g., respiratory diseases, cancer), FDNY BHS physicians successfully advocated for the inclusion of WTC-exposed retirees into the WTCHP. In 2006, FDNY-WTCHP increased program eligibility to include WTC-exposed retirees, granting them full access to the program's benefits, including free prescription medication. The provision of free treatment to retirees enabled the monitoring exams to be more effective and also reduced longitudinal dropout, thereby allowing health surveillance epidemiologic studies to be more representative of the entire FDNY rescue/recovery cohort.

WTC-exposed responders are also eligible for retirement with disability pensions or monetary awards under the 9/11 Victim Compensation Fund (VCF). In the 7 years before 9/11, disability retirements accounted for 48% of all retirements; this percentage increased to 66% in the 7 years

TABLE I. Selected Characteristics of WTC-Exposed Firefighters and EMS Workers Enrolled in the FDNY World Trade Center Health Program[a]

	Firefighters		EMS workers		Total	
Characteristics	**N**	**%**	**N**	**%**	**N**	**%**
Total	13,206	100	2,440	100	15,646	100
WTC arrival group						
Arrival on the morning of 9/11	1,814	13.7	459	18.8	2,273	14.5
Arrival during the afternoon of 9/11	6,100	46.2	721	29.6	6,821	43.6
Arrival on 9/12/2001	2,441	18.5	293	12.0	2,734	17.5
Arrival any day between 9/13/2001 and 9/24/2001	2,045	15.5	604	24.8	2,649	16.9
Arrival after 9/24/2001	266	2.0	215	8.8	481	3.1
Undefined Exposure	535	4.1	148	6.1	683	4.4
Duration—months at the WTC						
Median [IQR range]	3 [1–5]		2 [1–5]		2 [1–5]	
Age on 9/11—years						
Median [IQR range]	40.6 [34.0–46.7]		34.9 [28.3–41.0]		39.6 [33.0–46.0]	
Gender						
Male	13,175	99.8	1,958	80.3	15,133	96.7
Female	31	0.2	482	19.8	513	3.3
Race						
White	12,306	93.2	1,265	51.8	13,571	86.7
Nonwhite	900	6.8	1175	48.2	2075	13.3
Current smoking status[a]						
Current	663	5.0	329	13.5	992	6.3
Former	4,537	34.4	880	36.1	5,417	34.6
Never	7,713	58.4	1,196	49.0	8,909	56.9
Current retirement status[a]						
Retired	8,534	64.6	1,250	51.2	9,784	62.5
Not retired	4,672	35.4	1,190	48.8	5,862	37.5
Post-9/11 prevalence of respiratory health diagnoses[b]						
Chronic rhinosinusitis	4,316	32.7	318	13.0	4,634	29.6
Gastroesophageal reflux disease	3,973	30.1	339	13.9	4,312	27.6
Obstructive airways disease	3,494	26.5	299	12.3	3,793	24.2
Asthma	2,769	21.0	251	10.3	3,020	19.3
Chronic bronchitis	1,202	9.1	75	3.1	1,277	8.2
Chronic obstructive pulmonary disease	236	1.8	15	0.6	251	1.6
At least one of the above respiratory diagnoses[b]	6,793	51.4	590	24.2	7,383	47.2
Prevalence of probable mental health conditions in 2015[c]						
PTSD	699	8.0	99	6.9	798	7.9
Depression	1,404	16.1	214	15.0	1,618	15.9
At least one medication fill[d]	8,480	64.2	843	34.5	9,323	59.6

[a]As of April 2016.
[b]Between 2001 and 2015.
[c]Percentages of N = 10,164 who completed a mental health questionnaire in 2015.
[d]Under FDNY-WTCHP.

post-9/11 [Niles et al., 2011b]. Thereafter, from 2008 to 2014, over 1,500 disability retirements occurred, of which 47% were associated with WTC-related injuries or illnesses (Fig. 1). We note that although FDNY WTCHP-BHS physicians provide an initial impairment evaluation on retirees for FDNY's pension board and for the VCF, they do not participate in the final disability decisions by either entities.

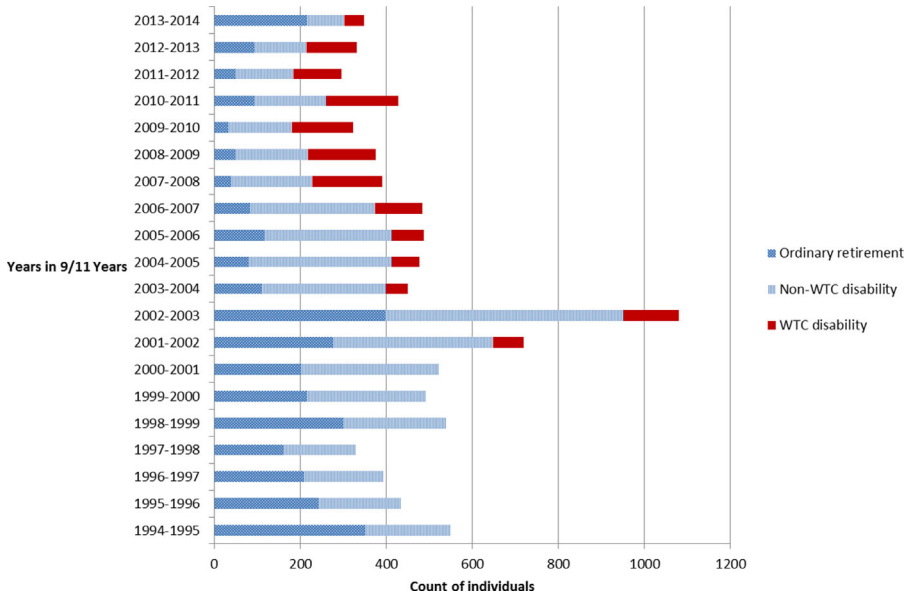

FIGURE 1. Retirements in FDNY responders (1994–2014).

RESEARCH

WTC-Exposure and Demographic Characteristics of the FDNY-WTC Cohort

We use two measures to characterize WTC-exposure in research studies: initial arrival time and duration of work at the WTC-site. Initial arrival time was obtained from the earliest post-9/11 questionnaire, which was completed a median of 4 months after 9/11. Duration of work was added to later questionnaires, and was obtained a median of 4 years post-9/11. Initial arrival time is categorized from highly exposed to least exposed as follows: arriving on the morning of 9/11 (highest exposure level); arriving during the afternoon of 9/11; arriving on 9/12/2001; arriving any day between 9/13/2001 and 9/24/2001; and arriving after 9/24/2001 (lowest exposure level). Duration of work is a summation of each calendar month that an individual worked for at least 1 day at the WTC-site (range 1–10 months). For most analyses we did not have a non-WTC-exposed group, as virtually all active FDNY members worked at the WTC-site.

Table I shows that close to 14% of firefighters and 19% of EMS workers arrived at the WTC site during the morning of 9/11, although most firefighters (46%) and EMS workers (30%) arrived during that afternoon. The median duration of time worked at the site was 3 months for firefighters and 2 months for EMS workers. The FDNY-WTC rescue/recovery cohort was mostly white (87%), male (97%) and had a median age of 40 years (IQR range: 33–46 years) on 9/11.

Symptoms and FDNY Physician Diagnoses

To describe various health conditions, we use both self-reported symptoms from monitoring questionnaires and physician diagnoses from FDNY medical records. Pulmonary function was analyzed using forced vital capacity (FVC) and the forced expiratory volume in the first second (FEV_1) results from routine spirometry. Bronchial reactivity information was obtained from methacholine challenge tests.

Respiratory health

Lower respiratory. Figure 2 shows that immediately after 9/11, cough was the most common respiratory symptom reported by 53% of the FDNY-WTC rescue/recovery cohort, followed by shortness of breath (38%) and wheezing (33%). In the first published post-9/11 study on respiratory health, Prezant et al. [2002] described "World Trade Center Cough Syndrome" in an initial sample of 332 WTC-exposed firefighters who were evaluated 6 months after 9/11. WTC Cough Syndrome was characterized by a constellation of symptoms including persistent cough and upper respiratory and lower respiratory symptoms (e.g., nasal congestion, nasal drip, sore throat, bronchial hyperreactivity, and/or gastroesophageal reflux disease [GERD symptoms]). In this sample of 332, the prevalence of this syndrome was greatest in those arriving earliest at the WTC-site, on the morning of 9/11 [Prezant et al., 2002].

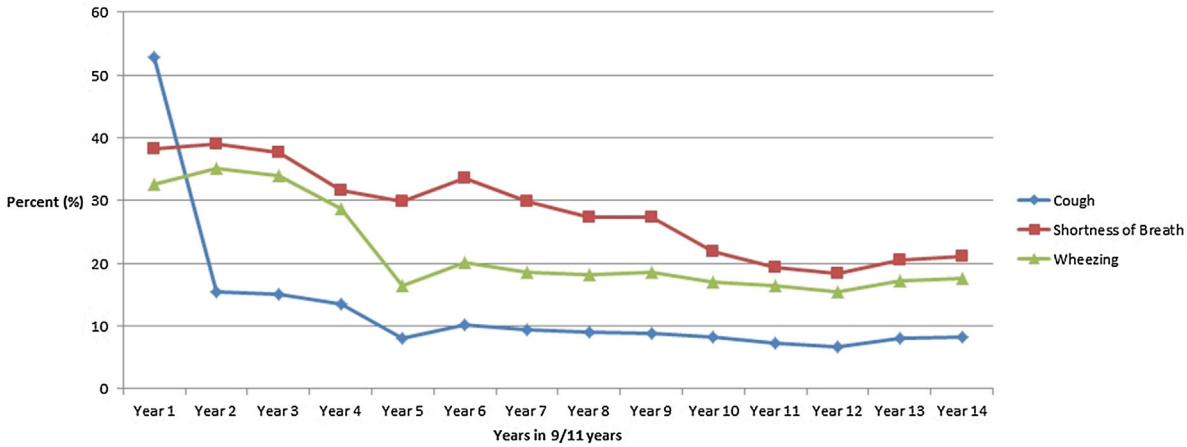

FIGURE 2. Self-reported lower respiratory symptoms by FDNY-WTC rescue/recovery workers.

Subsequent studies confirmed the association between WTC-exposure intensity (as measured by arrival time) and lower respiratory conditions, such as obstructive airways disease (OAD). OAD includes the following physician diagnoses from FDNY medical records: asthma/RADS, chronic obstructive pulmonary disease/emphysema, and chronic bronchitis. In a sample of 8,930 firefighters, those who arrived during the morning of 9/11 had four times the OAD diagnosis rate (relative rate: 3.96; 95%CI: 2.51–6.26) of later arriving firefighters during the first 15 months after 9/11 [Glaser et al., 2014a]. Similarly, EMS workers with the earliest arrival time have more than twice the risk (relative risk: 2.4; 95%CI: 1.7–3.6) of being diagnosed with OAD compared with their unexposed counterparts [Yip et al., 2016]. By 2015, the prevalence of FDNY physician-diagnosed OAD was 24%, with asthma at 19% as the most common diagnosis (Table I).

While not as immediately obvious as cough and other lower respiratory symptoms, chronic rhinosinusitis (CRS) symptoms were also commonly reported by FDNY firefighters and EMS workers. From the first post-9/11 year to 14 years post-9/11, CRS symptoms consistently affected about 40% of the FDNY-WTC rescue/recovery cohort (Fig. 3), in contrast to pre-9/11 reports of frequent rhinosinusitis by 4.4% of FDNY firefighters [Webber et al., 2009]. Rhinosinusitis symptoms 4 years post-9/11 were associated with WTC-exposure as measured by both arrival time and duration of work [Webber et al., 2009].

Examining FDNY medical records, the post-9/11 prevalence of physician-diagnosed CRS increased from 11% in 2005 [Niles et al., 2014] to 30% in 2015 (Table I), and was highest in FDNY-WTC rescue/recovery workers who arrived either during the morning (34%; Fig. 4) or afternoon of 9/11 (33%). Recent studies confirmed the risk of CRS among early arriving FDNY-WTC rescue/recovery workers: firefighters with the earliest arrival time had almost twice the rate of physician-diagnosed CRS when compared with later arriving firefighters (relative rate: 1.99; 95%CI: 1.64–2.41) [Weakley et al., 2016], and EMS workers with the earliest arrival time had nearly four times the risk of being diagnosed with CRS compared with their unexposed counterparts (relative risk: 3.7; 95%CI: 2.2–6.0) [Yip et al., 2016].

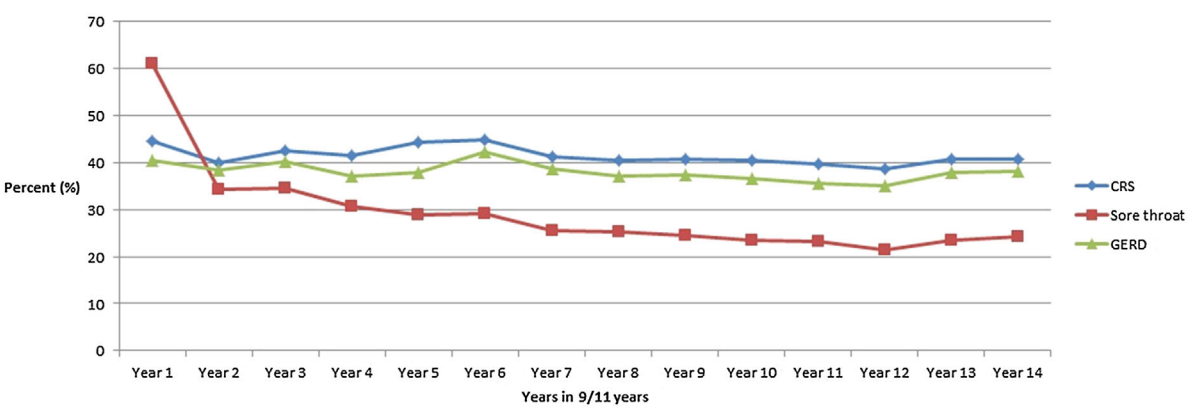

FIGURE 3. Self-reported upper respiratory symptoms by FDNY-WTC rescue/recovery workers.

GERD. Before 9/11, symptoms consistent with GERD (acid-reflux, sore throat, chest burning/tightness, and difficulty swallowing) were reported by 5.2% of FDNY firefighters [Webber et al., 2009]. However, in the first year post-9/11, 41% reported GERD symptoms, of which sore throat symptoms were the most prevalent (61%; Fig. 3). GERD symptoms, previously shown to be significantly associated with WTC arrival time and duration of work [Webber et al., 2009], consistently affected about 40% of the FDNY-WTC rescue/recovery cohort (Fig. 3).

The prevalence of FDNY physician-diagnosed GERD was 28% in 2015 (Table I), and was highest among FDNY-WTC rescue/recovery workers with the earliest arrival time (32%; Fig. 4). Firefighters with the earliest arrival time had 1.5 times the rate of having a GERD diagnosis than later arriving firefighters (relative rate: 1.48; 95%CI: 1.27–1.73) [Liu et al., 2016], and, EMS workers who arrived during the morning of 9/11 had nearly four times the risk of being diagnosed with GERD compared with unexposed EMS (relative risk: 3.8; 95%CI: 2.4–6.1) [Yip et al., 2016].

Interstitial lung diseases. Interstitial lung diseases (ILD) such as sarcoidosis, pulmonary fibrosis, and bronchiolitis obliterans remain far less common than OAD in our cohort, and, with the exception of sarcoidosis, are extremely rare. In the first 14 years post-9/11, we identified 75 FDNY-WTC rescue/recovery workers with new incident sarcoidosis. Pre-9/11, all had normal chest x-rays, normal spirometry and were asymptomatic [Izbicki et al., 2007]. This post-9/11 sarcoidosis rate of ~22/100,000 was considerably higher than the average pre-9/11 incidence rate of ~15/100,000. Further, in contrast to pre-9/11 sarcoidosis cases, many FDNY sarcoidosis cases diagnosed post-9/11 were symptomatic with OAD (69%) [Izbicki et al., 2007] and with rheumatologic issues (15%) [Loupasakis et al., 2015], the latter often requiring biologicals for disease control. Despite the increased incidence post-9/11, we did not find an association between sarcoidosis and WTC-exposure intensity (arrival time or duration), which may be due to limited statistical power.

Pulmonary function. Among 12,781 WTC-exposed firefighters and EMS workers who had 61,746 spirometry measurements, Aldrich et al. [2010] reported accelerated lung function decline from serial FEV_1 measurements, which averaged 372 ml over the first year after 9/11, the equivalent of 10–12 years of normal, age-related loss. During the subsequent 6 years post-disaster, there was little to no recovery. In updated studies extending follow-up time up to 14 years after 9/11, most firefighters continued to show a lack of lung function recovery [Aldrich et al., 2016a]. The dose-response association of WTC-exposure in relation to lung function remained: firefighters who arrived during the morning of 9/11 averaged lower lung function than did lesser-exposed firefighters, a difference that remained statistically significant during most of the follow-up [Aldrich et al., 2016b].

Methacholine challenge tests identify individuals with bronchial hyperreactivity (BHR), a hallmark of asthma/RADS. At 6 months post-9/11, firefighters who arrived during the morning of 9/11 were 6.8 times more likely to experience BHR than those who arrived later (odds ratio [OR]: 6.8; 95%CI: 1.8–25.2) [Banauch et al., 2005]. Further, in a recent follow-up study, we found that for many, BHR did not resolve with removal from the noxious exposure, even more than one decade post-9/11, and that persistent BHR predicted an accelerated decline in lung function [Aldrich et al., 2016a].

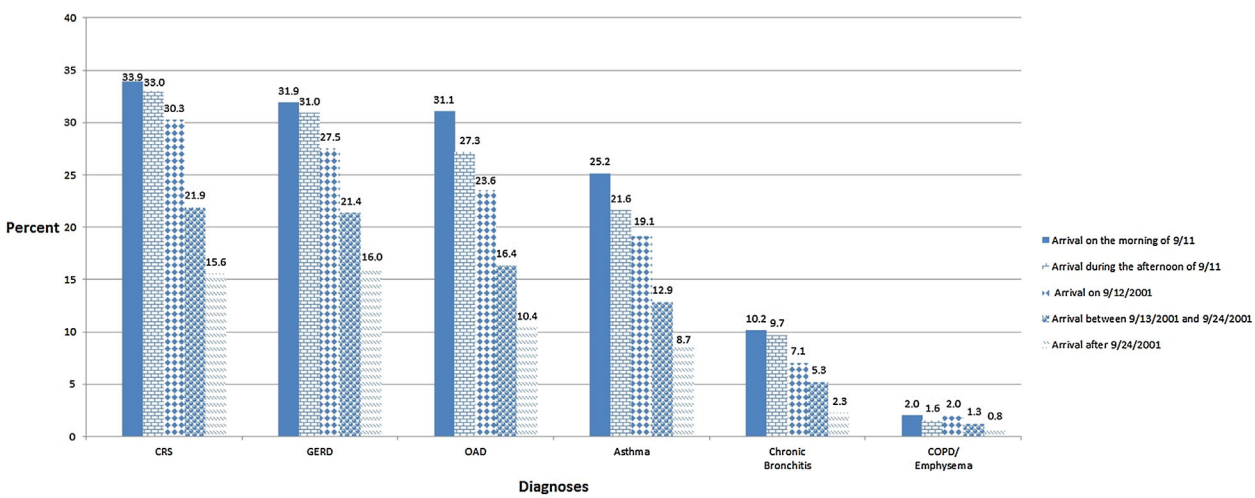

FIGURE 4. Post-9/11 prevalence of respiratory health and GERD diagnoses between 2002 and 2015.

Other physical health

Cancer. Seven years post-9/11, we [Zeig-Owens et al., 2011] showed that FDNY-WTC-exposed firefighters had a 10% higher overall cancer incidence rate (standardized incidence ratio [SIR]: 1.10; 95%CI: 0.98–1.25) than the general U.S. male population and a 32% higher rate than in unexposed FDNY firefighters (SIR: 1.32, 95%CI: 1.07–1.62), the latter reaching statistical significance. WTC-exposed firefighters had significantly higher rates for some specific cancers when compared with the general U.S. male population (e.g., prostate, SIR: 1.49; 95%CI: 1.20–1.85; thyroid, SIR: 3.07; 95%CI: 1.86–5.08) [Zeig-Owens et al., 2011]. In contrast, lung cancer incidence in WTC-exposed firefighters was significantly lower than expected (SIR: 0.42; 95%CI: 0.20–0.86) in the general U.S. male population, likely due to lower smoking rates and possibly the short follow-up period of 7 years post-9/11. Two other WTC-exposed cohorts, the WTC Health Consortium and the WTC Health Registry, showed results generally consistent with our findings. Specifically, both cohorts also found a modest excess of overall cancer cases and significantly elevated rates for thyroid cancer [Li et al., 2012; Solan et al., 2013; Boffetta et al., 2016].

In our recent study, we compared cancer incidence in FDNY-WTC-exposed firefighters to incidence in a combined cohort of career firefighters from Chicago, Philadelphia, and San Francisco [Moir et al., 2016]. Comparison to firefighters, rather than to the US general population, demonstrated similar, rather than increased, rates of all cancers combined, although rates for thyroid cancer and late-onset prostate cancer remained significantly elevated, similar to our previous results [Zeig-Owens et al., 2011].

Autoimmune disease. Between 2001 and 2013, we identified 59 FDNY-WTC rescue/recovery workers with rheumatologist-confirmed systematic autoimmune disease (SAIDs), of whom 37% had rheumatoid arthritis [Webber et al., 2015]. In a case-control study, prolonged work at the WTC-site was significantly associated with SAIDs: the odds for incident SAIDs increased by 13% (conditional OR: 1.13; 95%CI: 1.02–1.26) for each additional month worked at the site [Webber et al., 2015].

In a later study, we identified 63 rheumatologist-confirmed cases of SAIDs, but also included 34 additional "probable" cases, that, according to two rheumatologists, likely had SAIDs, but lacked adequate documentation [Webber et al., 2016]. Although we found that overall SAIDs rates were not significantly different from expected rates (SIR: 0.97; 95%CI: 0.77–1.21), based on comparison with incident cases from Rochester Epidemiology Project (REP) participants, highly WTC-exposed FDNY rescue/recovery workers had an excess of 7.7 cases of SAIDs, while lesser-exposed workers had 9.9 fewer cases than expected.

Obstructive sleep apnea. In 2011, we showed that early arrival time at the WTC-site was significantly associated with scoring at high risk for obstructive sleep apnea (OSA) using an adapted Berlin screening survey [Webber et al., 2011]. In a later study, we confirmed that 89% of 636 participants who scored high risk for OSA had polysomnogram-confirmed OSA [Glaser et al., 2014b]. We also found that FDNY rescue/recovery workers who arrived at the WTC during the morning of 9/11 had almost twice the odds (OR: 1.91; 95%CI: 1.15–3.17) of polysomnogram-confirmed OSA than those with lower levels of WTC-exposure.

Mental health

Immediately after 9/11, FDNY-WTC monitoring questionnaires included screening questions for PTSD. In 2005, mental health screening questionnaires were improved and expanded to include validated instruments to assess symptoms consistent with common mental health conditions. The PTSD Checklist (PCL-17) [Weathers et al., 1993] and Center for Epidemiological Studies-Depression scale (CES-D) [Radloff 1977] were used to assess probable PTSD and probable depression, respectively. Before 2005, FDNY assessed probable PTSD using a modified version of the PCL [Soo et al., 2011]. Alcohol Use Disorder Identification Test (AUDIT) [Babor et al., 2001] was used to assess harmful alcohol use. Details and scoring of the screening instruments have been previously described [Chiu et al., 2011; Yip et al., 2016]. Information from these instruments identified at-risk individuals who were referred to FDNY-CSU. Analyses of these screeners also helped describe the prevalence of probable PTSD, probable depression, and harmful alcohol use and its association with WTC-exposure.

Between 2002 and 2005 (years 1 through 4 on Fig. 5), the prevalence of probable PTSD was consistently above 7% and similar to the prevalence between years 6 and 14 (Fig. 5). The highest prevalence was found immediately post-9/11 (10%; Fig. 5) and was especially high among workers with the earliest arrival (25%; data not shown). In fact, this rate of 25% is similar to that reported in survivors of the WTC collapse [Brackbill et al., 2014]. In year 14, probable PTSD prevalence was 8% and continued to be higher among workers with the earliest arrival (13%; data not shown). Previous analyses have consistently found an association between PTSD and earliest arrival at the WTC-site [Berninger et al., 2010; Soo et al., 2011; Yip et al., 2016]. Notably, firefighters who arrived during the morning of 9/11 had six times the odds (OR: 6.0; 95%CI: 4.4–8.3) of screening positive for PTSD [Berninger et al., 2010] and EMS workers who arrived during the morning had seven times the risk (OR: 7.0; 95%CI: 3.6–13.5) of screening positive for PTSD [Yip et al., 2016].

High prevalence of probable depression is also documented among FDNY-WTC rescue/recovery workers,

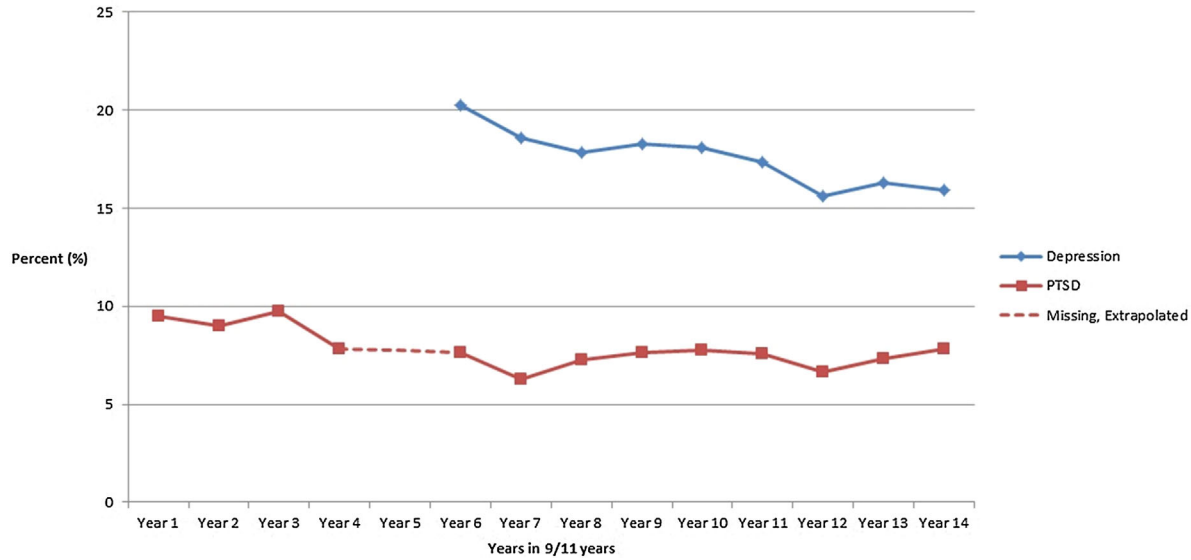

FIGURE 5. Probable depression and post-traumatic stress disorder (PTSD) in FDNY-WTC rescue/recovery workers.

ranging from 20% in year 6 to 16% in 14 (Fig. 5), and is highest among those with the earliest arrival (21% in year 14; data not shown).

Health comorbidities

Very substantial comorbidities exist between mental health conditions. Figure 6A shows that in 2015, 7% (N = 738) of the population screened positive for both probable PTSD and probable depression. Further, among FDNY-WTC rescue/recovery workers with probable PTSD (N = 798), 92% also screened positive for probable depression and among those with probable depression (N = 1,618), 46% also screened positive for probable PTSD. FDNY-WTC rescue/recovery workers with harmful alcohol use were twice as likely to screen positive for either PTSD (OR: 2.4; 95%CI: 1.9–4.3) or depression (OR: 1.9; 95%CI: 1.5–2.4) [Chiu et al., 2011].

Physical health conditions also commonly co-occur, such as between WTC cough syndrome and GERD [Prezant et al., 2002] and between CRS, OAD, and GERD [Liu et al., 2016; Yip et al., 2016] (Fig. 6B). By 2015, 1,419 (9%) of FDNY-WTC rescue/recovery workers had been diagnosed with all three health conditions: CRS, OAD, and GERD (Fig. 6B). Further, 1,086 (7%) had both CRS and GERD; 821 (5%) had CRS and OAD; and 611 (4%) had GERD and OAD (Fig. 6B).

Importantly, we found that receipt of an OAD diagnosis increased the risk of additional diagnoses: firefighters with an OAD diagnosis were more than four times more likely to have a CRS diagnosis (relative rate: 4.15; 95%CI: 3.70–4.66) and more than three times more likely to have a GERD diagnosis (relative rate: 3.18; 95%CI: 2.90–3.48) [Liu et al., 2016]. Finally, physical and mental health conditions also frequently occur in the same individuals: 13% of the population had both a diagnosis of OAD and reported symptoms consistent with depression (Fig. 7). Nearly 36% of FDNY-WTC rescue/recovery workers who ever screened positive for probable depression also had an OAD diagnosis (N = 2,001/N = 3,793) and 53% of those with OAD at any time also had probable depression (N = 2,001/N = 5,505). In another study, we found that firefighters who had probable PTSD shortly after 9/11 had increased odds of WTC cough syndrome up to 4 years post-9/11 (OR: 1.56; 95%CI: 1.23–1.99) [Niles et al., 2011a]. And among EMS workers who screened positive for PTSD, depression or harmful alcohol use, 35% had at least one respiratory condition: CRS, GERD, or OAD [Yip et al., 2016].

Summary of results

FDNY firefighters and EMS workers who arrived during the morning of 9/11had the highest health burden across most physical and mental health outcomes. Lower and upper respiratory health symptoms and diagnoses that were common immediately post-9/11 continue to affect the health of FDNY-WTC rescue/recovery workers. To date, 47% of the FDNY-WTC cohort has acquired at least one respiratory diagnosis of OAD, CRS, or GERD (Table I), while a smaller proportion (25%) has two or more. Autoimmune diseases were associated with the highest level of WTC-exposure, although in one study the association was significant only for prolonged work at the WTC-site. FDNY rescue/recovery workers with the earliest arrival time were at increased risks for probable PTSD and probable depression, which, in 2015, affected 8% and 16% of the FDNY-WTC cohort,

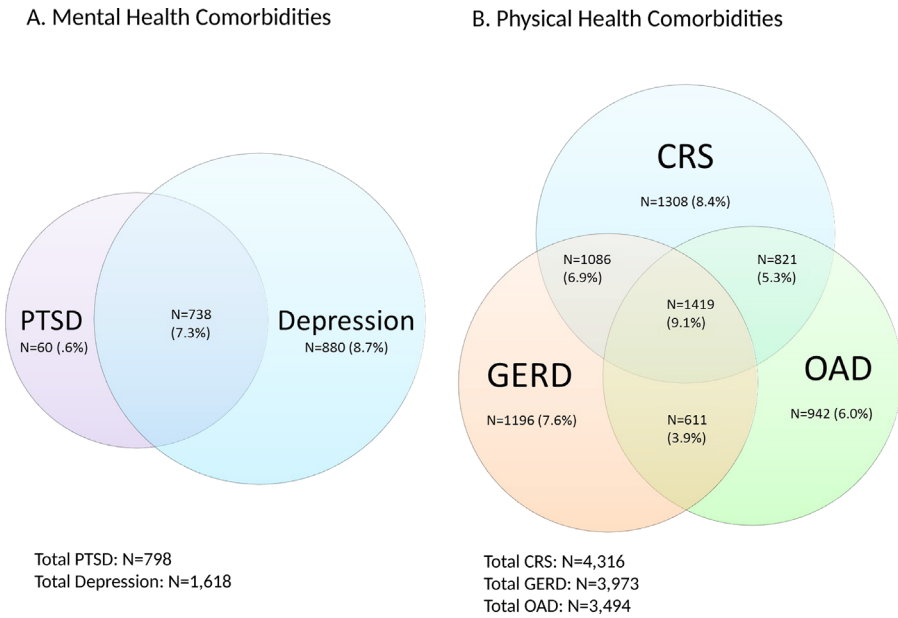

FIGURE 6. Physical and mental health comorbidities in FDNY-WTC rescue/recovery workers in 2015. Percentages of probable PTSD and probable depression were among N = 10,164 who completed a mental health questionnaire in 2015. Percentages of CRS, GERD, and OAD were among N = 15,646.

respectively. High comorbidities were documented between physical and mental health conditions, particularly between probable depression and probable PTSD. Cancer studies, with only 7 years of available follow-up data, demonstrate modest increased rates when compared to the general U.S. population, but similar rates when compared to firefighters without WTC-exposure, although thyroid cancer and late-onset prostate cancer rates remained elevated. Continued follow-up of late emerging diseases such as cancers, autoimmune, and cardiovascular diseases remain a priority area for future study.

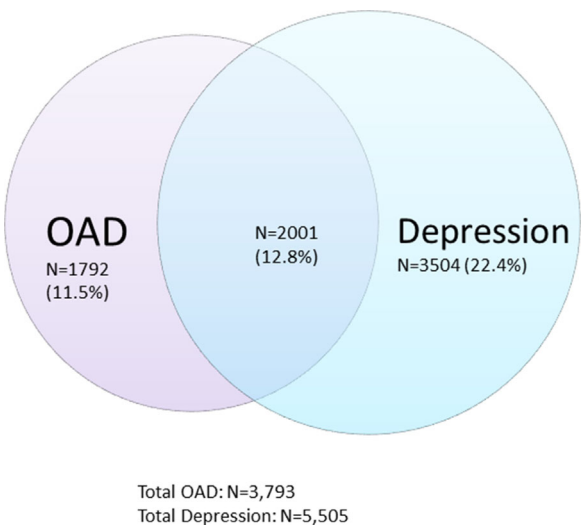

FIGURE 7. Obstructive airways disease and probable depression comorbidity ever since 9/11. Percentages were among N = 15,646.

DISCUSSION

This report showed that FDNY firefighters and EMS workers with the highest levels of WTC-exposure had the greatest risk for adverse health conditions ranging from OAD to PTSD and that, over time, this disproportionate health burden remained. The added burden of comorbidity in this group is not surprising, given the likelihood of concurrent environmental and psychologically disturbing exposures, compounded by stressors including long work shifts and fears for personal safety [Herbert et al., 2006]. To date, the most highly exposed continue to have the highest prevalence of physician-diagnosed respiratory health conditions such as OAD (31% vs. overall 24%), CRS (34% vs. overall 30%), and GERD (32% vs. overall 28%); in 2015, they have the highest prevalence of mental health conditions such as probable PTSD (13% vs. overall 8%) and probable depression (21% vs. overall 16%).

A substantial number of FDNY-WTC rescue/recovery workers exhibited impaired pulmonary function. Most of those who experienced an unprecedented decline in lung function shortly after 9/11 continue to show either lack of recovery or only a partial recovery up to 14 years later. Symptoms or diagnoses of respiratory health conditions were rare before 9/11; by 2015, almost half (47.2%) of the FDNY-WTC rescue/

recovery cohort had at least one of the following physician diagnoses: OAD, CRS, or GERD.

The pathophysiological causes of these respiratory conditions, which frequently co-occur in the same individuals, are a topic of intense investigation. Inhalation injures of toxic, highly alkaline dust at the WTC-site, and the lack of personal protective respirators, likely triggered upper and lower respiratory tract injury, inflammation, and symptoms [Prezant et al., 2008]. For the majority of those affected, this has resulted in airways obstruction, as indicated by pulmonary function and methacholine challenge tests and chest CT scans [Weiden et al., 2010]. As for the high incidence of GERD symptoms, ingestion of WTC dust and other hazardous substances, along with risk factors such as stress in general and PTSD specifically, poor diet, side-effects from medications prescribed for WTC-related conditions, and weight gain, likely irritated the gastroesophageal tract [Prezant et al., 2002, 2008]. Given the observed high comorbidity between GERD, CRS, and OAD, it is unknown whether GERD causes respiratory symptoms or contributes to the persistence of airway inflammation [Prezant et al., 2002, 2008]. Nonetheless, treatment guidelines suggest that successful management of respiratory conditions is linked to successful treatment of GERD symptoms [Prezant et al., 2008]. It is also important to consider evaluation of possible mental health problems such as PTSD in the treatment of persistent respiratory and GERD conditions.

Persistence of disease is likely the result of chronic inflammation initiated by exposure to the dust and potentiated by host characteristics as demonstrated by induced sputum studies showing significantly increased percentages of inflammatory biomarkers, neutrophils, and eosinophils in those with high WTC-exposure [Fireman et al., 2004] and by serum studies from blood drawn within 6 months of 9/11 showing elevated levels of known inflammatory biomarkers, such as macrophage derived chemokines, that were associated with increased risk of subsequent abnormal pulmonary function [Nolan et al., 2012]. The protease/anti-protease imbalance defined by mild to moderate genetic deficiency of alpha-1 antitrypsin deficiency [Banauch et al., 2010] and the elevated set-points of eosinophils and IgE levels observed in those with non-resolving upper and lower airways inflammation [Kazeros et al., 2013; Kwon et al., 2016] are intrinsic characteristics of patients that can be assessed repeatedly using inexpensive, commercially available techniques. As the association between WTC-exposure and disease diminishes over time, these and other innate biomarkers of risk for immune injury will become important for stratification of WTC-exposed rescue/recovery workers. The ultimate goal of this line of investigation is to develop risk stratification models that allow for more intensive monitoring and treatment of those individuals at the highest risk for WTC-related health effects based not only on WTC-exposure intensity but also on host sensitivity. In so doing, it may also identify targets for more effective therapeutic agents in those with poorly controlled symptoms.

Strengths and Limitations

As described elsewhere [Zeig-Owens et al., 2011; Yip et al., 2016], our studies may have limitations. First, some of our results may be affected by surveillance bias because the WTCHP schedules periodic monitoring evaluations and provides free treatment for FDNY-WTC rescue/recovery workers. As such, FDNY-WTC rescue/recovery workers have increased access to care than the general population. However, we consistently make efforts to address this potential bias. For example, in our first cancer study, we delayed the recorded cancer diagnosis date by 2 years or more in some analyses, and found results similar to those uncorrected for surveillance bias [Zeig-Owens et al., 2011].

Another limitation is the lack of a suitable comparison group to WTC-exposed FDNY firefighters. Nearly 99% of the active firefighter workforce participated in the WTC rescue/recovery efforts either on the day of the collapse or in subsequent months. The small minority of firefighters who never worked at the WTC-site were older on 9/11 and had worse pre-9/11 health status compared with those who worked at the site, rendering the two groups dissimilar. For that reason, many of our analyses have used external comparison groups including the general U.S. population, REP participants [Webber et al., 2015], and more recently, NIOSH 3-cities firefighter cohort [Moir et al., 2016]. Because FDNY-WTC rescue/recovery workers had stringent pre-hire health requirements, and were routinely screened post-hire, previous comparisons with the general U.S. male population and REP participants may be limited by dissimilar health status at baseline [Zeig-Owens et al., 2011; Webber et al., 2016]. The NIOSH 3-cities firefighter cohort, a group more similar to FDNY WTC firefighters, is limited by data that ends in 2009 [Daniels et al., 2014; Moir et al., 2016] and an absence of data on smoking status and other potential confounders.

In addition, for mental health conditions, our research studies used validated screening tools rather than physician diagnoses. The use of screeners taken as part of routine monitoring exams, however, may have yielded more complete information about the size of the at-risk population. Finally, we acknowledge limited generalizability of our findings to women and minorities and to individuals with lower levels of WTC-exposure. The FDNY WTC-exposed cohort is highly exposed and comprised predominantly of white males.

Despite these limitations, FDNY-WTCHP has strengths that enabled us to identify new health conditions and to make

causal inferences about the role of WTC-exposure in their development. These strengths result from the fact that this cohort existed prior to 9/11, minimizing selection bias, and was served by a pre-existing health infrastructure that had the confidence of both FDNY rescue/recovery workers and their leaders to continue serving in this capacity after 9/11. First, because the cohort existed prior to 9/11, we avoided self-selection bias into the FDNY-WTC cohort. Second, because FDNY members had routine health assessments by BHS starting years before 9/11, we have pre-9/11 health information on nearly all of the enrollees, which has allowed us to document the temporal order of disease development in relation to WTC-exposure. Third, for physical health conditions, we have direct access to FDNY medical records, which contain FDNY physician diagnoses and clinical data from pulmonary and radiographic tests. Finally, due to the full support of labor and management, the FDNY-WTCHP has had limited longitudinal dropout.

Lessons Learned

To minimize misclassification of exposure, we stress the importance of acquiring immediate, in-depth exposure information, preferably from multiple sources. These sources should include personal and environmental monitoring including electronic card readers with GPS capacity to identify specific work times and locations, supplemented by questionnaire data, which may be particularly useful in describing job tasks. We also recommend the implementation of measures such as mandatory respiratory protection for professional and volunteer workers. While this may be difficult to achieve during the immediate rescue operation, it certainly should be required during prolonged rescue and recovery operations. In the early WTC recovery period, respiratory masks were limited in availability, and, when available, were only used intermittently. For rescue/recovery workers likely to have respiratory exposures, we recommend pre-exposure pulmonary function testing and early post-exposure screening exams. Because rescue/recovery workers carry the largest burden in disaster management, additional efforts such as imposing limits on work hours and instituting mandatory task rotations may minimize the long-term health risks of exposure to a disaster site. To assess and mitigate adverse health effects after exposure to a disaster, monitoring programs should be designed and instituted with integrated physical and mental health components that include, whenever possible, treatment, health surveillance, and research.

FDNY's Next Steps

The FDNY WTCHP and its data center continue to study the effects of 9/11 on well-characterized health conditions such as respiratory illnesses as well as on later-emerging conditions such as cancer, autoimmune, and cardiovascular diseases. We continue to collect mortality information for future studies that will investigate cause-of-death and calculate mortality rates. Analyses on mortality rates and later-emerging conditions with longer follow-up time may yield increased case accrual and account for latency periods.

We recognize two primary challenges in assessing the role of WTC-exposure in the development of health conditions as the time since 9/11 elapses. First, the likelihood of conditions such as cardiovascular disease and cancer increases with age, underscoring the importance of a comparable WTC-unexposed population to assess the contribution of WTC-exposure to disease development. Second, possible attrition in the FDNY-WTC cohort creates a challenge as more FDNY-WTC rescue/recovery workers retire and move outside of the New York area. To date this has not occurred, but efforts to address this potential problem are already in progress. These measures include the implementation of out-of-state clinical partnerships and initiation of a comprehensive phone or web-based questionnaire to reach out-of-state retirees and other FDNY WTCHP members who do not attend monitoring visits because of poor health or for other reasons.

CONCLUSION

The collective experience of FDNY-WTCHP physicians and researchers has contributed greatly to the identification and treatment of WTC-related health conditions. FDNY and the FDNY-WTCHP remain committed to providing effective medical care and documenting existing and emergent health conditions for the FDNY-WTC rescue/recovery cohort and, by extension, for all affected individuals in the NYC community and beyond.

We and our enrollees are proud of the fact that this has been the most successful labor-management health initiative in the history of FDNY, NYC, and quite possibly, the nation. This success is the result of many factors including a pre-existing health infrastructure that had developed credibility with the workforce prior to, during and after the WTC attack; the availability of funding to expand critical health services; and, strong leadership that rose to the immense challenges presented by the disaster and emerged with an expanded appreciation of the benefits of a comprehensive health program.

AUTHORS' CONTRIBUTIONS

JY, MW, RZO drafted the first manuscript with critical revisions from KK and DP. MV and AS contributed to data analysis and editing of the manuscript. JY, MW, RZO, and DP agree to be accountable for all aspects of the work so that

questions related to the accuracy and integrity of the research are appropriately investigated and resolved.

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ETHICS APPROVAL AND INFORMED CONSENT

The Institutional Review Board for Albert Einstein College of Medicine and Montefiore Medical Center, Bronx, NY approved the protocols for the studies reported in the manuscript.

DISCLOSURE (AUTHORS)

The authors declare no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Steven Markowitz declares that he has no competing or conflicts of interest in the review and publication decision regarding this article.

DISCLAIMER

None.

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