HHS Public Access

Author manuscript

Curr Opin Allergy Clin Immunol. Author manuscript; available in PMC 2023 March 23.

Published in final edited form as:

Curr Opin Allergy Clin Immunol. 2011 April ; 11(2): 97–102. doi:10.1097/ACI.0b013e3283449063.

Occupational lower airway disease in relation to World Trade Center inhalation exposure

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Abstract

Purpose of review—To summarize the knowledge about the occupational lower airway diseases that seem related to exposures at the World Trade Center disaster site.

Recent findings—Those diseases have been characterized as irritant-induced asthma, chronic nonspecific bronchitis, chronic bronchiolitis/small airway disease, and aggravated preexistent chronic obstructive lung disease (most frequently chronic obstructive pulmonary disease, but also asthma), with the expected overlapping features among them. One remarkable characteristic of the irritant-induced asthma observed among these workers was the slow onset of symptoms and long delay in clinical diagnoses.

Summary—Longitudinal studies suggest that both the incidence and the associated functional decline of these predominantly obstructive lung diseases stabilized several years ago, but longer follow-up is clearly necessary.

Keywords

airway diseases; asthma; bronchial hyperreactivity; bronchiolitis; chronic obstructive pulmonary disease; inhalation injury; irritants; lung diseases; occupational diseases; toxic inhalation

Introduction

The terrorist attack to the World Trade Center (WTC), the subsequent tower collapse, and the 9.5-month recovery of the site exposed hundreds of thousands of people to a poorly characterized mix of debris, dust, smoke, fumes, and volatile and particulate combustion products. In relation to occupational exposures at the WTC disaster site, several symptom surveys and detailed clinical studies (reviewed in [1,2]) have described a spectrum of presumably related chronic inflammatory conditions of the upper and lower airway, as well as other diseases. In this review, we summarize those findings (with a focus on lower airway diseases, LADs), and what WTC-related clinical studies and follow-up epidemiologic surveys have begun to contribute to the understanding of inhalation injuries.

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Occupational inhaled toxicant exposures at the World Trade Center

Monitoring of the occupational exposures during the rescue and recovery work at the WTC disaster site was suboptimal. The characterization of the released toxicants at the WTC site was deficient, particularly so for its volatile components. It is estimated that the burning and collapse of the WTC towers, the subsequent 3-month smoldering fires, and the recovery work released a complex mixture of irritant dust, smoke, and gaseous combustion materials, with widely variable composition and concentrations over time. The majority of the dust samples analyzed were collected after the first 48 h of the attack, that is, after the exposure time period that has been most consistently associated with lower respiratory symptoms and disease. A study of outdoor settled WTC dust samples (collected 4 days after the collapse of the towers) described a mixture of pulverized cement, glass fibers, asbestos, silica, lead, polycyclic aromatic hydrocarbons (PAHs), metals, and polychlorinated biphenyls (PCBs) [3,4]. In that study [4], more than 98% of the particles had an aerodynamic diameter exceeding 10 μm, and had a very alkaline pH. Settled dust inside buildings surrounding the WTC site showed similar characteristics [5,6]. In contrast, a study of suspended particles reported a higher but highly variable proportion of fine ($PM_{2.5}$) particles, a steep gradient of total and fine particle concentrations from the center of the WTC disaster site, towards its periphery just three to four city blocks away, and a particle concentration decrement between those two time points [7]. In exposed laboratory animals, although capable of inducing bronchial hyperreactivity and pulmonary inflammatory mediator release, WTC fine particles appeared of comparatively low respiratory toxicity [8].

Although subject to several possibly substantial selection biases, workers' self-reports of their occupational exposures at the WTC site provide some valuable information [9-12]. Early arrival at the WTC site and long exposure duration were highly common among these workers. In one clinical study [12], for instance, about half of the workers arrived at the WTC site within the first 48 h of the terrorist attack, and their occupational exposure duration averaged 18 weeks. The specific duties of the different workers also usually determined their arrival time, location within the recovery area, and exposure duration. For instance, laborers primarily participated in cleaning of buildings surrounding the fallen towers arrived on or after the fifth day after the terrorist attack, and their exposure duration averaged about 20 weeks [13]. Firefighters, police officers, and ambulance workers, on the other hand, arrived very soon after the attack, worked at or very close to the site of the fallen towers, but their exposure duration was less prolonged. As may be expected, during the first few hours and days after the attack, rescue, and search duties were fairly similar across occupational groups, but differentiated according to their respective expertise as time passed. Most workers stayed within certain specific locations, and the working population declined exponentially after the first few days and weeks of the towers' collapse.

Despite the limited knowledge about the inhaled particles at the WTC disaster site, and the almost total absence of information about volatile compounds, the hydrosolubility and size characteristics of the particles make them plausible irritants, capable of causing inflammatory mucosal changes throughout the respiratory tract. Practically all studies have identified early arrival at the WTC disaster site (within the first 48 h of the attack) as the main risk factor for the presumed WTC-related lower airway diseases that have been so

far observed [9,11-13]. Exposure duration appears to have been a weaker predictor of LAD [11,12,14••].

Other factors in all likelihood contributed to determine individual susceptibility to inhaled toxicants, including worksite location (e.g. near the site of the collapsed towers [11]), occupational activities [13], cleanup methods, and use of appropriate protective equipment and strategies. The well reported limited availability, adequacy, and/or use of protective respiratory equipment in all likelihood made the respiratory toxicant exposures more hazardous [7,10,15,16]. Besides these exposure-related factors, underlying or preexistent medical conditions (particularly lung diseases [12,17]) influenced, if not the causation, at least the clinical expression of WTC-related LAD. A history of present or former tobacco use was identified as a risk factor for WTC-related LAD in the single clinical study of WTC workers [12], where, it needs to be noted, aggravated chronic obstructive pulmonary disease (COPD) was also one of the outcome diagnoses. On the other hand, atopy did not seem to be a risk factor for LAD (as it seemed to be for presumed WTC-related rhinitis and upper airway disease [17]).

Occupational irritant-induced asthma and lower airway diseases

The high prevalence of seemingly WTC-related respiratory symptoms reported by the exposed workers, mandated a detailed, objective, and multidisciplinary diagnostic investigation to arrive at their diagnostic characterization [12].

Clinical presentation

Following a variety of symptom-based survey reports, a clinical characterization of the presumed WTC-related occupational respiratory diseases categorized the chronic airway diseases as irritant-induced asthma, chronic nonspecific bronchitis, chronic bronchiolitis/small airway disease, and aggravated preexistent chronic obstructive lung disease (most frequently chronic obstructive pulmonary disease, but also asthma) [2,12,18]. Notably, very few cases presented as acute or short-latency irritant-induced asthma (or reactive airway disease syndrome, RADS). Clinical follow-up has supported the validity of those disease categories, with the expected overlapping characteristics.

The most difficult category to diagnose is that of bronchiolitis/small airway disease, because of the well known limitations of available diagnostic resources. Although a few case reports clearly documented it histologically [12,19], mostly indirect functional and imaging findings suggest its presence in this patient population. Those findings have included: the high prevalence of a reduced spirometric forced vital capacity (FVC) pattern [20]; low frequency of methacholine reactivity generally, and in individuals with asthma-like clinical presentation [12,21]; FVC reduction response pattern in broncho-provocation testing [12,22]; air trapping by paired inspiratory/expiratory chest computed tomography (CT) scans [18,23]; in at least some cases, the presence of restriction in the absence of interstitial, chest wall or neuromuscular causes, presumably due to loss of lung units in parallel distally to obstructed bronchioles [12,18,20]; and evidence of long-term accelerated FVC decline in those lacking bronchodilator response at baseline (which might reflect small airway remodeling) [24•].

Spirometric studies among firefighters (the only occupational group at the WTC with a large amount of available preexposure spirometric records) documented that the functional deficits (most commonly, by far, a reduced FVC) were modest postexposure, but very large in comparison to the preexposure functional levels [9]. The deficits observed by lung volume and diffusion capacity measurements were also apparently modest [9,12], but, not surprisingly, preexposure data are unavailable for comparisons for all occupational groups.

Clinicians aware of the characterization of the bronchial disease syndromes as irritant-induced, noted that the onset of symptoms could be relatively slow, in many cases without a complete clinical expression until a few months after leaving the disaster worksite. This clinical observation may be related to the relatively low pro-inflammatory potential of the WTC dust, as evidenced in experimental animals [8].

Accordingly, prolonged occupational irritant exposure durations were almost the rule. This observation assisted in the attribution of occupational WTC-relatedness, so that experienced clinicians used a 6-month latency period from end of exposures to symptom onset [12]. A large, longitudinal, symptom-based survey seemed to validate thus far the presence of that time window for clinical onset of WTC and occupationally related asthma symptoms. The data suggested an increased incidence (above a referent expected population-based rate) of self-reported asthma for 18 months after 11 September 2001 (i.e. 9 months after the official end of the site recovery effort) [14••].

Although a study suggested air trapping (and thus, obstruction) as a relatively frequent finding among WTC firefighters [25], it failed to report whether that finding was correlated with that of reduced FVC by spirometry. On the other hand, that study underscored the notable infrequency (thus far) of restriction.

Other pulmonary diseases

A higher than expected incidence of histologically confirmed sarcoid-like granulomatous lung disease or sarcoidosis was reported among New York City Fire Department firefighters and ambulance workers in the first 5 years after the attack to the WTC [26], with half of the cases in the first of those years. All 26 reported cases presented intrathoracic adenopathy, and six (23%) had extrathoracic manifestations. On the other hand, only three of the 26 patients had total lung capacity or diffusion capacity below 80% of predicted. Sarcoidosis is often asymptomatic and found through screening chest radiographs, thus some cases diagnosed after 11 September 2001 may have been the result of increased detection from screening of a large number of individuals with respiratory symptoms, and increased reporting for disability purposes.

Although parenchymal or interstitial lung diseases could potentially result from WTC exposures [27], surveillance among firefighters has failed to reveal thus far an increased incidence of this type of disease [26], and clinical studies among other types of workers have failed to identify a substantial number of cases [12,25]. There have been isolated case reports of other lung diseases such as eosinophilic pneumonia [28], interstitial fibrosis with predominantly peribronchiolar changes [12], and granulomatous pneumonitis [29]. Overall, cases of interstitial lung disease of any type, including sarcoidosis, remain few and

heterogeneous when compared with the thousands of WTC-exposed individuals with upper and lower airway disease, but surveillance systems are (and need to stay) in place to try to identify additional incident cases.

Longitudinal trends

With regards to lower respiratory symptom trends, among WTC firefighters, the prevalence of 'shortness of breath' and wheezing remained relatively unchanged from 2001 to 2005. On the other hand, 'daily cough' (more prevalent at baseline than shortness of breath or wheezing) decreased markedly by the second year of the follow-up [9,30]. The decline in 'daily cough' prevalence was not associated with a similar decline in a few selected rhinosinusitis symptoms [30].

As mentioned before, longitudinal follow-up of self-reported incident asthma diagnoses among a cohort including WTC recovery workers, community reoccupants, and passersby demonstrated an increase over a reference general population rate for about 18 months after 11 September 2001 [14••].

With regards to functional changes after WTC occupational exposures, and among nonfirefighting WTC workers, average spirometric measurements remained quite stable, with a normal distribution of changes. The only significantly associated risk factors for accelerated spirometric decline in a minority of those workers (in comparison to the mean for all workers) were the absence of bronchodilator response at baseline, and further weight gain on follow-up [24•]. It was not surprising to observe the adverse functional effect of current smoking. A similar study [31•], restricted to firefighters and emergency medical technicians, with preexposure spirometric data, and longer follow-up corroborated the observation of lung function stability after the initial WTC-related decline. Both studies demonstrated that early arrival at the WTC site (a risk factor for development of occupationally related lower airway disease) did not predict accelerated FVC and FEV_1 decline on follow-up.

Other comorbidities

Several highly prevalent comorbidities deserve mention in this patient population, since they share symptoms with, and/or enhance clinical severity of lower airway disease. Additionally, some of them seem to have resulted from the occupational hazards at the WTC site.

Chronic rhinosinusitis and upper airway disease

Almost 80% of the workers of the largest published clinical case series [12] were diagnosed with mostly perennial rhinosinusitis (often associated with pharyngitis and laryngitis), with onset at or shortly after leaving the WTC disaster site. The condition was perennial. The irritant-induced inflammatory process led to nonallergic rhinosinusitis, or substantial worsening of preexisting allergic rhinosinusitis. A triad of WTC-related lower and upper airway, and gastroesophageal reflux diseases was the most common presentation (almost 30%) among workers treated for chronic persistent illness in or before 2003 [12].

Gastroesophageal reflux disease

The high prevalence of seemingly WTC-related gastroesophageal reflux disease (GERD) remains unexplained. GERD seemed temporally related with WTC LAD diagnoses, and shared the association with arrival at the WTC site within the first 48 h of the attack [12]. GERD also seemed associated with the presence of spirometric abnormalities and with being diagnosed with a WTC-related lower airway disease, and not with being diagnosed with a WTC-related psychiatric disease diagnosis [32]. In detailed, but small, clinical studies, however, the reflux syndromes have been somewhat heterogeneous [32], which supports the need for objective characterization of the diagnoses, and additional research to clarify this proposed association.

Other medical conditions

Overweight and obesity are prevalent in at least 80% of the WTC workers [12,24•,31•], clearly exceeding what has been reported for the United States population as a whole. Further weight gain on follow-up was one of the two risk factors for further reduction in expiratory flows on follow-up of a cohort [24•]. Obesity can cause early closure of the airways on expiration, and is suspected to be associated with small airway dysfunction. It can be a contributing or confounding factor to the observed spirometric abnormalities (particularly that of reduced FVC).

Additionally to the high prevalence of excess body weight, the frequent diagnosis of obstructive sleep apnea is not surprising in view of the strong male sex predominance of the WTC occupational cohorts [33,34]. As expected, occupational WTC exposure indicators have so far proven to be either insignificantly, or only weakly predictive of obstructive sleep apnea in this population. The effect of compensability and coverage of sleep apnea by different WTC-specific systems and health plans, respectively, will limit the ability to study that association in a meaningful way.

To date, no specific cancer types have been identified resulting from exposure to the WTC disaster, but the characteristic long latency periods between occupational exposures and causally related cancers mandate long-term surveillance and prospective studies.

Psychological diseases

Psychological illnesses affect respiratory symptom perception, adherence and response to treatment, and possibly the course of the disease. Clinical studies of former WTC workers and volunteers have documented formally diagnosed psychological illness in close to 42% of workers [12]. The most frequent diagnoses (often combined) have been chronic posttraumatic stress disorder (PTSD), major depressive disorder, and agoraphobia with panic disorder [12]. Symptom surveys have suggested that early arrival and exposure duration both seemed to be related to the risk of developing chronic PTSD symptoms [35].

Clinical model for management of disaster situations

Clinical expertise in the diagnosis and treatment of the WTC workers' symptoms was developed at the WTC Health Effects Treatment Program (WTC HETP), established at

Mount Sinai Hospital in January 2003, as the first dedicated multidisciplinary clinical center to provide individualized diagnostic and treatment services to these workers [12]. Besides establishing clinical diagnostic and treatment guidelines (reviewed in [1,2]), the program quickly developed an effective multidisciplinary approach to the complex (and inevitably interrelated) clinical, socioeconomic, and medicolegal challenges presented by the situation [13]. That approach was also supported by administrative changes that allowed sufficient time to evaluate, treat, and educate patients, and for communication among specialists, but it also illustrated the reason why neither established private nor public health insurance programs are likely to be suitable payors for it.

Conclusion

The WTC exposure incident underscored the need for careful attention to occupational hazards in disaster situations. Despite their relative low toxicity in experimental animal studies, which may explain the prolonged exposures and slow development of respiratory symptoms among workers, the inhaled toxicants demonstrated a potential to affect the entire airways. The bronchial inflammatory effects seemed largely independent of susceptibility factors like atopy, but affected to some degree by previous or current smoking habits, differential exposure to inhalants, and, in a good number of cases, confirmed or suspected preexisting respiratory disease. A major contribution of this experience to the understanding of work-related asthma, was the demonstration that irritant-induced asthma can exhibit a prolonged interval between exposure and recognition (by either patients, physicians, or both) of clinical symptoms and disease. That interval can result from relatively low level exposure or intrinsic toxicity, but further exposure modeling will be required to gain any better understanding of this very interesting situation. Moreover, the experience illustrated how the inflammatory effects of occupational inhalants add clinical manifestations that vary according to preexisting factors (known and unknown), and lead to different, but overlapping, clinically recognizable diagnoses. It also illustrated the importance of detailed objective clinical characterization to arrive at a diagnosis. So far these diagnoses have largely clustered within the broad category of chronic obstructive airway diseases. Long term and close follow-up of the cohorts is necessary, however, to establish whether other types of diseases (e.g. granulomatous, interstitial, or neoplastic), for which there is at least a potential, will result from the WTC exposures.

Acknowledgements

The publication of this work was made possible by the Centers for Disease Control and Prevention and the National Institute for Occupational Safety and Health (CDC/NIOSH), cooperative agreement no. U10 OH008225. The contents of this article are the sole responsibility of the author and do not necessarily represent the official views of the CDC/NIOSH.

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Papers of particular interest, published within the annual period of review, have

been highlighted as:

• of special interest

•• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 153).

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