Military deployment-related respiratory problems: an update

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Purpose of review
Military personnel deployed to Southwest Asia and Afghanistan were potentially exposed to high levels of fine particulate matter and other pollutants from multiple sources, including dust storms, burn pit emissions from open-air waste burning, local ambient air pollution, and a range of military service-related activities that can generate airborne exposures. These exposures, individually or in combination, can have adverse respiratory health effects. We review exposures and potential health impacts, providing a framework for evaluation.

Recent findings
Particulate matter exposures during deployment exceeded U.S. National Ambient Air Quality Standards. Epidemiologic studies and case series suggest that in postdeployment Veterans with respiratory symptoms, asthma is the most commonly diagnosed illness. Small airway abnormalities, most notably particularly constrictive bronchiolitis, have been reported in a small number of deployers, but many are left without an established diagnosis for their respiratory symptoms. The Promise to Address Comprehensive Toxics Act was enacted to provide care for conditions presumed to be related to deployment exposures. Rigorous study of long-term postdeployment health has been limited.

Summary
Veterans postdeployment to Southwest Asia and Afghanistan with respiratory symptoms should undergo an exposure assessment and comprehensive medical evaluation. If required, more advanced diagnostic considerations should be utilized in a setting that can provide multidisciplinary expertise and long-term follow-up.

Keywords
burn pit, constrictive bronchiolitis, deployment, particulate matter

INTRODUCTION

During land-based deployments, military personnel in Afghanistan (2001–2021) and Southwest Asia (Iraq 2003–2011) were potentially exposed to high levels of fine particulate matter (PM) and other pollutants from multiple sources. These include dust storms, emissions from open-air waste burning (burn pits), local ambient air pollution sources, and a range of military service-related activities. These exposures, individually or in combination, can have potential adverse respiratory health effects [1,2]. We overview exposures, associated adverse respiratory health effects, and a suggested framework for evaluation of symptomatic deployers, whether receiving care through Veterans Health Administration (VHA) or non-VHA providers.

EXPOSURE OVERVIEW

Open-air waste burning (in burn pits) including plastics, metals, and medical waste was a primary means of waste management at military bases [1]. Desert dust exposures from military operations and dust storms that also included airborne fungal spores, bacteria, and pollen were common [3–6]. Additional exposures to PM, combustion byproducts, and other fumes occurred during combat, other military operations, military job-related tasks, and through ambient pollution from near-by civilian industrial sources. The Department of Defense

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KEY POINTS

- During deployment to Southwest Asia and Afghanistan sources of exposure to high levels of fine particulate matter and other pollutants included dust storms, burn pit emissions, ambient air pollution, and a range of military service-related activities.
- Postdeployment respiratory conditions have included asthma, and less commonly, small airway abnormalities, including constrictive bronchiolitis.
- Assessment of symptomatic Veterans should include a comprehensive assessment of pulmonary function, and the investigation of small airway abnormalities should be considered.
- There is limited information available regarding the long-term respiratory health status postdeployment, including the development of future pulmonary disease, including, but not limited to chronic airflow obstruction.

(DoD) conducted the Enhanced Particulate Matter Surveillance Project at 15 locations from 2006 to 2007 [7,8]. Annual mean 24-h $PM_{2.5}$ ($PM \leq 2.5$ μm in diameter; Fig. 1) concentrations were elevated (~40–120 μg/m^3) compared to the U.S. National Ambient Air Quality annual and 24-h $PM_{2.5}$ standards (12 μg/m^3 and 35 μg/m^3, respectively), and the 1-year Military Exposure Guideline (MEG). Concentrations estimated based on visual range measurements at military airports were similarly elevated [9].

Measurements also were collected at Joint Base Balad, site of the largest burn pit in Iraq [10]. Concentrations of $PM_{2.5}$ upwind and downwind were similar, consistent with off-base sources (representing ambient $PM_{2.5}$) contributing to on-base exposures. The 2011 Institute of Medicine report, *Long-Term Health Consequences of Exposure to Burn Pits in Iraq and Afghanistan*, concluded that 'a broader consideration of air pollution than exposure only to burn pit emissions–might be associated with long-term health effects, particularly in highly exposed populations ... or susceptible populations mainly because of the high ambient concentrations of PM' [1]. Most of the PM in question appears to be geologic in origin (e.g., dust), but also included lead, zinc, and other metals, presumably from nearby industrial sources or leaded gas, as well as carbon from mobile and stationary combustion sources, the latter including burn pits [1,7].

In epidemiologic studies conducted in the general population assessing chronic exposure to ambient air pollution [11–13] and occupational exposure to vapors, dusts, gases, or fumes [14▪,15–17], adverse effects on pulmonary function have been noted as well as emphysema on CT scan. Small airway remodeling has also been observed in association with ambient pollution and mineral dusts [18,19]. Although there is a well established association between ambient air pollution and asthma in children, the evidence is weaker in adults; nonetheless mechanistic studies support links between air pollution components and allergic sensitization, oxidative stress, and airway remodeling that may be relevant [20]. As opposed to long-term exposure air pollution effects, Veterans experienced high PM exposures over a relatively short duration of deployment, typically <1 year [2]. Previous epidemiologic studies have not assessed such shorter-term exposures.

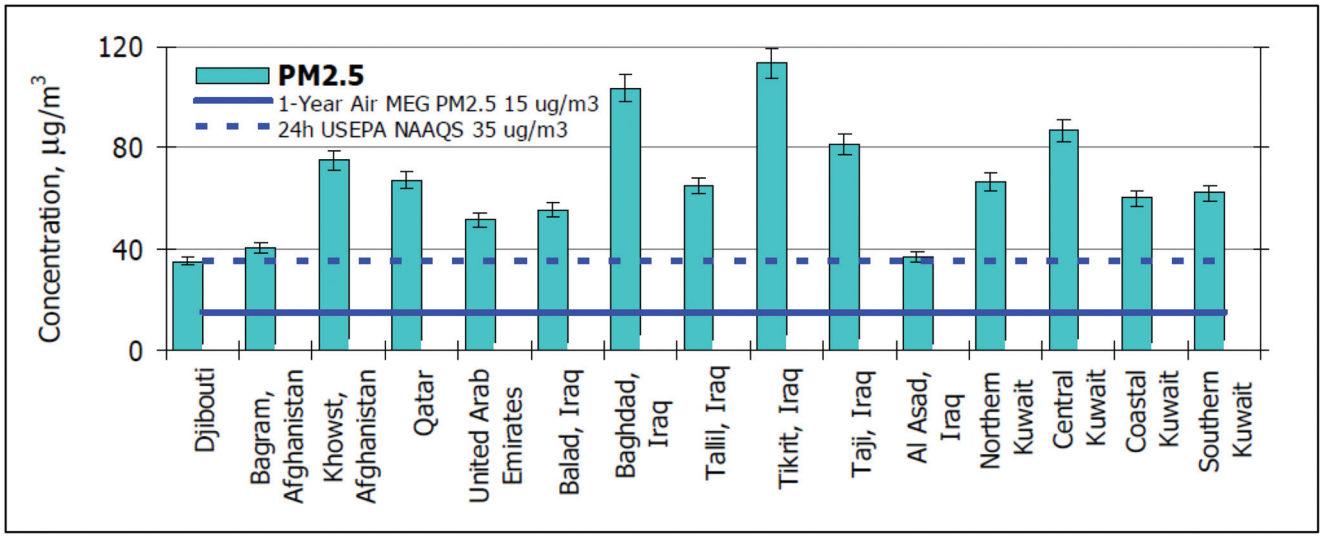

FIGURE 1. Mean $PM_{2.5}$ concentrations 2006–2007 obtained by the Enhanced Particulate Matter Surveillance Project at 15 sites in Iraq, Afghanistan, Kuwait, and other military locations [8].

RESPIRATORY HEALTH EFFECTS DURING DEPLOYMENT

In nonmilitary populations, dust storms and desert dust exposures are associated with hospital admissions and emergency visits for asthma [21–23], asthma symptoms [24], healthcare visits for allergic rhinitis [25,26], associations with pulmonary infections [27–29], and chronic obstructive pulmonary disease (COPD) exacerbations [30,31]. Postdeployment assessments, including in non-US troops [32], strongly suggest that deployed military personnel have experienced respiratory symptoms and illnesses similar to conditions noted in desert-dust exposed nonmilitary populations, particularly in persons with a history of asthma predeployment [33,34].

RESPIRATORY HEALTH EFFECTS FOLLOWING DEPLOYMENT

Department of Defense and Veterans Health Administration (VHA) healthcare utilization

Initial reports noted that returning personnel sought VHA care for asthma more frequently than nondeployed veterans [35,36]. Analysis of International Classification of Disease (ICD) encounter codes in DoD facilities identified increased postdeployment healthcare encounters for respiratory symptoms and obstructive lung diseases, mainly asthma [37–39]. For example, in one study, encounter rates for asthma/COPD and allied conditions were more frequent compared to predeployment [rate ratio = 1.25; 95% confidence interval [CI]: 1.13, 1.39] [37]. In another study, personnel deployed at any of four bases, two with burn pits and two without burn pits, and personnel eligible for deployment but not deployed were compared [38]. Among the deployed, the risk of encounters for respiratory symptoms (relative risk [RR] = 1.25; 95% CI: 1.20, 1.30) and for asthma (RR = 1.54;95% CI: 1.33, 1.78) were elevated. This did not vary among bases with and without a burn pit. A separate analysis found that deployment to Kabul, Afghanistan was associated with increased risk of respiratory symptom (RR = 1.54; 95% CI: 1.43, 1.62) and asthma encounters (RR = 1.61; 95% CI: 1.22, 2.12) [39].

Postdeployment VHA data are consistent with these DoD findings. One study reported that encounters for chronic lung disease, mainly asthma, were greater in former deployers [40]. Another approach has used military occupational job codes to assess exposure among veterans using a job exposure matrix that categorized military job duties as likely, somewhat likely, or not likely to involve inorganic dust exposure [41,42▪▪]. Encounters for COPD were defined based on ICD code and pulmonary medication use (noted in 0.4%) [42▪▪]. There was a 23% increased odds of COPD (odds ratio [OR] = 1.23; 95% CI: 1.15–1.31) associated with moderate/high dust exposure. Taken as a group, these DoD and VHA studies are consistent with an increased risk of respiratory symptoms and chronic airway disease postdeployment.

Millennium cohort, new generation, Service and Health Among Deployed Veterans, and Swedish Veterans Studies

These epidemiologic studies provide additional support for associations between deployment-related environmental and occupational exposures and respiratory health. Among 46 077 participants in the Millennium Cohort Study who completed questionnaires 2001–2003 and surveyed again 2004–2006, deployers reported persistent or recurring cough or shortness of breath more frequently (14%) than nondeployers (10%) [43]. The highest odds were associated with army (OR = 1.73; 95% CI: 1.57, 1.91) or Marine Corps deployment (OR = 1.49; 95% CI: 1.06, 2.08), which may reflect land-based service. Among 77 770 participants followed through 2013, there was an increase in risk of health professional diagnosed asthma for those with combat experience as compared to nondeployers for both men (RR = 1.30; 95% CI: 1.14, 1.47), and women (RR = 1.24; 95% CI: 1.05, 1.46) [44].

The New Generation of U.S. Veterans study assessed 20 563 veterans surveyed in 2009–2011 [45]. The odds of physician-diagnosed sinusitis diagnosed after 2001 were increased among deployed compared to nondeployed veterans (OR = 1.30; 95% CI: 1.13, 1.49), but not for asthma and bronchitis. Among 1,080 Swedish military personnel surveyed 36 months to 5 years after deployment, to mainly Afghanistan, there was increased wheeze, nocturnal coughing, and chronic bronchitis; nocturnal cough and chronic bronchitis were associated with dust storms [46].

VA Cooperative Studies Program #595, 'Service and Health Among Deployed Veterans' (SHADE) began recruitment in June 2018 at six VA Medical Centers, and recruited 1960 participants with land-based deployments randomly selected from deployment rosters before pausing due to the coronavirus disease 2019 (COVID-19) pandemic. An interviewer-administered questionnaire in the ongoing SHADE study elicits responses regarding 32 exposures grouped into five broader categories including: burn pit smoke; combustion engine exhaust and ground dusts; other military open combustion sources (i.e., burning vehicles); insecticides and other toxicants; and military occupation-related vapors, dusts, gases,

or fumes [47]. In a preliminary analysis, burn pit smoke exposure was statistically associated with chronic bronchitis (chronic cough and phlegm); combustion engine exhaust and ground dust exposures were associated with elevated odds ratios for chronic bronchitis and wheeze with confidence intervals close to but not excluding 1.0 [48▪].

Case series

Four centers have published case series of veterans postdeployment. These include the War Related Illness and Injury Study Center (WRIISC; a national VHA case referral program) [49–51]; National Jewish Health (NJH) [52]; Brooke Army Medical Center and other military facilities [53–55]; and Vanderbilt University Medical Center [56,57▪▪,58▪▪]. Asthma, and the upper respiratory tract, have been particular subjects of study in these case series. Of 124 Veterans with dyspnea assessed at the WRIISC, 26% had a positive bronchodilator response [49], and of 138 Veterans, 19.6% had an obstructive deficit [50]. At NJH, among 127 symptomatic deployers, asthma was diagnosed in 31.5%, rhinitis/rhinosinusitis in 15%, and inducible laryngeal obstruction in 14.2%. The most common symptoms were exertional dyspnea in 82%, chest tightness in 75%, wheezing in 68%, and cough in 64% [52].

Brooke Army Medical Center investigators reviewed Army personnel undergoing medical discharge with asthma. Of 194 deployers, 52% were newly diagnosed after deployment [53]. In a standardized assessment of 50 active duty personnel with new onset dyspnea during deployment, asthma or nonspecific bronchial hyper-reactivity was noted in 40%, while 42% had a nondiagnostic evaluation. [54]. In an additional description of 380 army personnel who also underwent a standardized assessment for respiratory symptoms, primarily exertional dyspnea, the most common diagnoses included asthma (23%; based on evidence of airflow obstruction and airway hyperreactivity); airway hyperreactivity with normal spirometry (15%); and inducible laryngeal obstruction upper airway disorders in 4%. Thirty-two percentage remained undiagnosed although many had nonspecific pulmonary function abnormalities [55].

In addition to upper airways abnormalities, small airway disease has emerged as another adverse effect of concern. In 2011, a series of 49 military personnel primarily with unexplained shortness of breath and exercise limitation underwent lung biopsy at Vanderbilt [56]. Thirty-eight had pathology interpreted as consistent with constrictive bronchiolitis. As noted in a 2019 ATS Workshop [2], there is heterogeneity of views regarding the definition of constrictive bronchiolitis used and biopsy interpretation in that study. The characteristic histopathological finding of constrictive bronchiolitis is subepithelial fibrotic scarring with concurrent bronchiolar narrowing or obliteration [59,60], whereas in the Vanderbilt study, the predominant bronchiolar tissue changes were variable and included smooth muscle changes. The same group subsequently analyzed archived tissue blocks from a subset of their original series [56] and from additional Veterans with similar biopsy findings [57▪▪,58▪▪]. Findings included smooth muscle hypertrophy and adventitial thickening in pulmonary arteries adjacent to small airways, increased alveolar elastin and collagen, pleural inflammation and fibrosis, infiltration of $CD4^+$ and $CD8^+$ T lymphocytes in airway walls, T-cell activation, and upregulation of inflammatory pathways [59]. Based on these findings, the authors proposed that postdeployment findings included both abnormalities of the small airway and other nearby anatomic locations that made postdeployment pathologic changes different from classic constrictive bronchiolitis.

The clinical syndrome observed that provided the rationale for these biopsies (dyspnea with normal or mild, nonspecific pulmonary function abnormalities) also differed substantially from that associated with classic constrictive bronchiolitis, ie. As seen post lung or bone marrow transplant, or related to autoimmune connective tissue diseases [59–61], or secondary to inhalation injuries such as from mustard gas or diacetyl [62,63], with subsquent severe progressive airway disease. Only limited follow-up information is available for deployers who underwent lung biopsy in the original Vanderbilt case-series. Follow-up over a median of 5 years (range 1–15 years),suggests there is a persistence of symptoms with a mild decrease in mean forced vital capacity and total lung capacity that generally remained within a normal range [57▪▪]. In a case-report of constrictive bronchiolitis dagnosed by lung biopsy reported by the WRIISC, the patient's symptoms abated 2 years later [51].

Other published biopsy results relevant to constrictive bronchiolitis was reported by NJH. In their series of 127 postdeployment personnel, 52 participants had lung biopsies with overlapping abnormalities including bronchiolitis (some with constrictive bronchiolitis), emphysema with hyperinflation, and granulomatous pneumonitis [52]. The general prevalence of postdeployment constrictive bronchiolitis and other abnormalities reported among postdeployment Veterans remains to be established. In a review of pulmonary diagnoses using DoD Joint Pathology Center records 2002–2015, there were 404 lung biopsies among deployers, representing $<0.02\%$ of

all deployers [64]. Constrictive bronchiolitis was observed in 10/194 (5%) of the surgical lung biopsies analyzed.

CLINICAL ASSESSMENT

Recognizing that a number of sources contributed to PM exposures among deployers, the clinical exposure history should assess multiple potential exposures, including job duties, combat-related, and burn pit related. Table 1 includes questions useful for assessing burn pit related exposures and trash incineration exposures developed for the SHADE study [47]. Clinicians assessing deployers referred for respiratory symptoms should be guided by the history and examination, including consideration of nonpulmonary contributors.

For symptomatic deployers, pulmonary function studies should include assessment of spirometry, bronchodilator response, lung volumes, and diffusion capacity. In addition, methacholine challenge, assessment of dynamic upper airway collapse, and cardiopulmonary exercise testing may be warranted. Beyond these modalities, forced oscillation testing for assessment of bronchodilator response [55] and small airway abnormalities [51,65] can be considered. Inspiratory and expiratory chest CT imaging may reveal mosaic perfusion or air trapping, respectively, findings suggestive of small airway disease [51]. Computerized analysis of chest CT scans may offer additional diagnostic information, supplementing visual interpretation [66▪▪]. As emphasized by a recent consensus statement, lung biopsy considerations (e.g., to diagnose constrictive bronchiolitis) should be informed by multidisciplinary review as well as by specific expertise in pulmonary pathology [67▪▪]. As there is no specific treatment for constrictive bronchiolitis postdeployment, performing a biopsy after a nondiagnostic evaluation may not alter clinical decision making. Perhaps most importantly, providers should provide longitudinal follow-up for symptomatic deployers, for example, to detect accelerated lung function decline. Surveillance protocols for asymptomatic deployers have not been developed but may emerge as experience accumulates.

Table 1. Suggested burn pit exposure history questions [47,48▪]

1. Did you experience heavy exposure to smoke or fumes from personally operating or working with trash incineration or at a burn pit? This includes regularly burning trash and burn pit security.
2. Did you experience heavy sustained exposure outdoors to smoke or fumes from burn pits or planned incineration, for example, when the wind changed or there was other heavy exposure?
3. Did you experience heavy sustained exposure to smoke or fumes from burn pits or planned incineration coming into your work site or housing?
4. Were you engaged in doing regular exercise or other physical exertion alongside of the perimeter or right beside a burn pit site?

PACT ACT AND AIRBORNE HAZARDS AND OPEN BURN PIT REGISTRY

Public Law 112–260, enacted in 2013, required the VHA to implement the 'Airborne Hazards and Open Burn Pit Registry' for individuals who may have been exposed to burn pit emissions (69). There is an internet-based portal that allows Veterans to self-enroll, complete an exposure and health questionnaire, and request a clinical assessment. The more recent Sergeant First Class Heath Robinson Honoring our Promise to Address Comprehensive Toxics (PACT) Act was passed by Congress in August 2022. This legislation states that service during certain time periods, including on or after September 11, 2001 in Afghanistan, Southwest Asia, and other countries, deployment related environmental hazards exposure is presumed. The nonneoplastic illnesses defined as presumptive service-connected conditions include asthma diagnosed after service, chronic bronchitis, COPD and emphysema, chronic rhinitis, chronic sinusitis, constrictive or obliterative bronchiolitis, granulomatous lung disease, interstitial lung disease, pleuritis, and sarcoidosis [68]. Prior to the PACT act, asthma, sinusitis, and rhinitis were the only presumptive conditions considered in September 2021. The PACT act allows post 9–11 Veterans to receive medical care for conditions based on the accumulated evidence regarding postdeployment respiratory conditions.

SUMMARY CONCLUSIONS

Important clinical research questions remain regarding the recognition, diagnosis, and long-term clinical course of postdeployment respiratory diseases, particularly small airway abnormalities. Although asthma has been the most common specific condition diagnosed, other important conditions have been noted. Assessment of symptomatic Veterans should include a comprehensive assessment of pulmonary function, and consider measurement of nonspecific airway responsiveness, assessment of dynamic upper airway collapse, cardiopulmonary exercise testing, oscillometry, and inspiratory/expiratory CT scanning. Although lung biopsy and histological examination of samples from symptomatic deployers have provided insight into small airway and other abnormalities, the

decision to perform a lung biopsy and its impact on clinical care is best informed through multidisciplinary assessment. The relationships between specific exposures, job duties, and duration of exposure remain to be more fully defined. Better understanding of the relationship between exposure and diseases could promote prevention of disease in other deployed military personnel by instituting mitigation efforts. Symptomatic Veterans, particularly those without a clear diagnosis, may require long-term follow-up that includes but may not be limited to serial pulmonary function testing over time. The contribution of deployment-related exposures and potential small airway disease to future pulmonary disease, including, but not limited to chronic airflow obstruction, remain important questions.

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Conflicts of interest

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