Original research

Impact of World Trade Center dust exposure on upper-aero digestive tract disorders and sinonasal surgery: findings from patients seen in the Department of Otolaryngology – Head and Neck Surgery at Mount Sinai Hospital

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ABSTRACT

Objective We assessed upper-aero digestive tract disorders in World Trade Center (WTC) patients seen in the Otolaryngology – Head and Neck Surgery Department of a large New York City hospital system and the association between WTC exposure and sinonasal surgery for chronic rhinosinusitis (CRS).

Methods Retrospective review of medical records of all WTC patients seen between July 2002 and December 2023. Primary exposure was measured by arrival date and exposure length to the disaster site. Primary outcomes were upper-aero digestive tract disorders and sinonasal surgery.

Results 3118 WTC patients were reviewed. Of these, 1162 (37.3%) had CRS. CRS patients were more likely female (p=0.03) and had higher proportion of comorbid obstructive sleep apnoea (OSA) (p<0.0001), allergic rhinitis (p<0.0001) and gastro-oesophageal reflux disease (p<0.0001). 355 (31.0%) CRS patients underwent sinonasal surgery. Relative to the medically managed patients, surgical CRS patients were younger at time of 9/11 (p=0.006), had a higher proportion of comorbid OSA (p=0.02) and earlier exposure (arrival date 11 September–13 September prior to rainfall) (p=0.001). CRS patients with early exposure demonstrated significantly greater odds of undergoing sinonasal surgery compared with those with late exposure (adjusted OR 1.61; 95% CI 1.2 to 2.3).

Conclusions Earlier arrival at WTC site increased the risk of needing surgery for responders with CRS. Higher levels of irritant exposure prior to rainfall on 14 September 2001 may have caused significant epithelial injury to the sinonasal mucosa of WTC patients, leading to an elevated prevalence of CRS requiring surgical intervention.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ World Trade Center (WTC) rescue and recovery workers were exposed to airborne pollutants and particulate matter potentially damaging to mucous membranes of the upper airway. A high prevalence of upper-aero digestive tract disorders, including chronic rhinosinusitis (CRS), has been widely reported among WTC patients.

WHAT THIS STUDY ADDS

⇒ WTC patients with CRS who experienced early exposure to the 9/11 disaster site have 61% higher odds of undergoing sinonasal surgery to treat their CRS compared with those with later exposure.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Physicians treating patients with WTC exposure should account for arrival date when considering severity of sinonasal disease and level of intervention. Additional research linking WTC exposure to the development of CRS is important for helping us understand the mechanisms behind the disease progression to best intervene.

INTRODUCTION

The 11 September 2001 attacks on the World Trade Center (WTC) exposed recovery and clean-up workers to substantial amounts of smoke, pollution and combustion products.[1] It is estimated that over 90 000 workers and volunteers, including firefighters, law enforcement officers, medical staff, construction and sanitation workers, were involved in rescue operations, clean-up and restoration of services.[1–3] These workers were exposed to a dust cloud containing multiple pollutants, chemicals and carcinogens, including volatile compounds and particulate matter.[3 4]

At the time of the WTC disaster, the US Environmental Protection Agency reported airborne dust in the area ranging from 1000 to >100 000 μg/m^3.[5] Elevated levels of air contaminants and spikes in levels of toxic compounds only noticeably decreased in January 2002. Additional studies described the pollutants released as alkaline (pH>10), inhalable in size (>10 μm) and containing hazardous compounds such as silica dust, cement dust, glass fibres, asbestos, lead, polycyclic aromatic hydrocarbons and polychlorinated biphenyl.[3–8] The

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abundance of cement dust in this complex mix made it alkaline and potentially damaging to mucous membranes.[6 9]

Since the upper-aero digestive tract filters large particles from reaching the lower airway, exposure to caustic alkaline irritants caught in the nose and throat has the potential to induce inflammatory mucosal changes with significant impact on the upper-aero digestive tract.[6] Chen and Thurston reported that more than 95% of the WTC dust particles were greater than 10 µm in diameter, small enough to breathe but too large to reach the lungs.[6] Shortly after exposure, workers and volunteers reported new or worsening cough, hoarseness, dyspnoea, nasal congestion, nasal drip and sore throat.[10–12] Multiple studies reported that these symptoms persisted long-term. A longitudinal survey-based study of New York City firefighters reported that sore throat and rhinosinusitis symptoms (eg, runny nose, facial pain, nasal obstruction and hyposmia) were still present 4 years after the WTC disaster, at rates 10-fold higher than their pre-exposure rates.[13] A clinical study of 554 WTC-exposed patients, of all occupations treated and observed for 3 years, reported a 78.5% prevalence of chronic rhinitis, sinusitis and pharyngitis.[14] Years later, a longitudinal cohort study of 449 WTC participants reported 9-year cumulative risks of sinusitis (42.3%), asthma (27.6%) and gastro-oesophageal reflux disease (GERD) (39.3%).[15] More recently, a 2019 study of 601 WTC subjects found the prevalence of chronic rhinosinusitis (CRS) to be 43.5%.[16]

Standards of care for persistent, unimproved or alarming symptoms of sinusitis require an otolaryngology evaluation that includes a comprehensive head and neck physical exam with nasal endoscopy, laryngoscopy and sinus CT imaging.[17] Medical management of sinusitis is the primary treatment modality and effective in the majority of patients. Endoscopic sinus surgery is indicated for patients who are unresponsive to medical treatment.[18] Endoscopic sinus surgery can improve sinus drainage, remove nasal polyps, reduce mucosal disease and has been shown to significantly improve quality of life for patients.[19] A study by Kwon *et al* found that exposed Fire Department of New York firefighters had a 23.2% prevalence of CRS and those who arrived prior to 13 September 2001 had a 45% increased risk of undergoing surgery to treat their CRS.[20] However, firefighters make up only a fraction of WTC-exposed patients and due to the nature of their work may have a history of prior increased environmental exposure. Therefore, they may not be representative of the WTC-exposed patient cohort. Additionally, given that rainfall did not occur until 3 days later, likely decreasing the concentration of airborne contaminants suspended in the air, a cut-off of 14 September 2001 may be more appropriate for an exposure analysis.[20] This study assessed upper-aero digestive tract disorders in WTC responders of all occupations seen in the Otolaryngology – Head and Neck Surgery Department of a large New York City hospital system, which is part of the World Trade Center Health Program (WTCHP) and explored the association between patient WTC-exposure timing and sinonasal surgery.

METHODS

Study population

A retrospective review of medical records of all patients seen from July 2002 to December 2023 within the Department of Otolaryngology – Head and Neck Surgery at Mount Sinai Hospital who had the WTCHP listed as the payer for their medical service was performed. All otolaryngology visits, including those prior to the establishment of the WTCHP, were reviewed. In 2010, the James Zadroga 9/11 Health and Compensation Act funded the establishment of the WTCHP. The WTCHP is designed as a monitoring programme that includes annual physical examinations with an occupational and environmental medicine physician. WTC patients presenting with alarming or chronic upper airway symptoms that have failed adequate medical treatment are referred to otolaryngologists for evaluation and treatment.[21]

Characterisation of patients and medical history

Electronic medical records of patients' primary and subsequent visits were reviewed. Demographic information, chief complaints, medical history, surgical history and current visit diagnoses were stored using Research Electronic Data Capture Software (REDCap) hosted at the Icahn School of Medicine at Mount Sinai.[22 23] Demographic variables included sex, body mass index (BMI), age at exposure, race, ethnicity and occupation. BMI was calculated using the first recorded height and weight at an otolaryngologist visit at Mount Sinai Hospital. Age at time of disaster was calculated using the patient's date of birth and 11 September 2001. Race and ethnicity variables are based on self-selected responses in patients' electronic medical records. Categories of race included white, black/African American and Asian. Categories for ethnicity included Hispanic and non-Hispanic. For both race and ethnicity, unknown and unreported variables were combined into one category. Occupation at time of exposure is based on categories reported in the electronic medical record notes for annual visits to the WTCHP clinic at Mount Sinai. The categories for occupation include construction, law enforcement, sanitation worker, other and not reported. The 'law-enforcement' category combined police officers and firefighters. The 'other' category included WTCHP patients who reported working in media, finance, food and material delivery, and miscellaneous professions. Upper airway diagnoses were collected from visit diagnoses and included allergic rhinitis, chronic rhinitis, CRS, gastro-oesophageal reflux (GERD), laryngopharyngeal reflux (LPR) and obstructive sleep apnoea (OSA). CRS status was determined based on diagnosis made by otolaryngologist at time of visit to the Department of Otolaryngology – Head and Neck Surgery. Surgery and smoking history were collected from notes in the patient's electronic medical record associated with Otolaryngology department or WTCHP clinic.

WTC exposure data

Arrival date and length of exposure as measured by effort months to the WTC site were obtained through linkage to the WTCHP Data Center registry and added to the REDCap entries for each responder. Responders with available exposure data were divided into two groups: (1) Early-exposure: those that arrived between 11 September 2001 and 13 September 2001 and (2) Late-exposure: those that arrived on or after 14 September 2001.

Statistical analysis

Descriptive statistics were performed using analysis of variance and Tukey's post hoc analysis for continuous variables, χ^2 tests and adjusted residuals for categorical variables where appropriate. Multivariable logistic regression analysis was used to calculate the odds of sinonasal surgery between exposure level groups, adjusting for covariates of interest, including age, BMI, sex, effort time in months, OSA, LPR and chronic rhinitis status. All statistical analyses were conducted using SAS software, V.9.4 (SAS Institute).

RESULTS

Patient demographics and characteristics

The study cohort consisted of 3118 WTC patients seen within the Department of Otolaryngology – Head and Neck Surgery at

Mount Sinai Hospital between 1 July 2002 and 31 December 2023. Of these patients, 1162 (37.3%) had a diagnosis of CRS, of whom 355 (30.6%) underwent sinonasal surgery for treatment, and 807 (69.4%) were medically managed. Patients were predominantly male (83.7%), white (58.6%) and non-Hispanic (55.8%). Mean age at exposure was 51.5±8.3 years and mean BMI at first otolaryngology visit was 30.6±5.4 kg/m^2. Law enforcement was the most common occupation at time of exposure (54.2%). The prevalence of upper aero-digestive diagnoses among WTC patients includes chronic rhinitis (74.7%), GERD (57.7%), OSA (39.1%), CRS (37.3%), LPR (27.0%) and allergic rhinitis (9.8%) (table 1).

Relative to patients without CRS, patients with CRS were more frequently female (p=0.03) and had more comorbid conditions, including OSA (p<0.0001), allergic rhinitis (p<0.001) and GERD (p<0.001). Compared with medically managed CRS patients, patients who underwent sinonasal surgery for CRS were younger at time of 9/11 (p=0.006), had comorbid OSA (p=0.02) and had an earlier exposure to the WTC disaster site (p=0.001). Surgical patients had a lower proportion of LPR (p=0.0004) and chronic rhinitis (p=0.0002) (table 1).

Sinonasal surgery in CRS patients by WTC exposure level

Length of exposure as measured by effort months did not have an association with CRS diagnosis or sinonasal surgery as a treatment for CRS (table 2). Early exposure CRS patients demonstrated significantly greater odds of undergoing sinonasal surgery compared with late exposure patients (OR 1.70; 95% CI 1.2 to 2.4). After adjustment for age, BMI, sex, effort months and comorbid OSA, LPR and chronic rhinitis, this association remained significant (adjusted OR 1.61; 95% CI 1.2 to 2.3) (table 3).

DISCUSSION

Our findings show that WTC patients referred to the Department of Otolaryngology – Head and Neck Surgery have a 37.3% prevalence of CRS (37.3%), which is comparable to other WTC patient cohorts.[16 21 24] Early exposure (arrival date before 14 September 2001 to the WTC disaster site) increased odds of undergoing surgical treatment for CRS by 61% compared with late exposure. Due to rainfall early in the day on 14 September 2001, levels of suspended dust particles were highest between 11 September 2001

Table 1 Demographics of WTC-exposed patients

	WTC-exposed patients (n=3118)	CRS− (n=1956)	CRS+ (n=1162)	P value*	CRS-nonsurgical (n=807)	CRS-surgery (n=355)	P value†
Sex, n (%)							
Female	509 (16.3)	297 (15.2)	212 (18.2)	0.03	157 (19.5)	55 (15.5)	0.1
Male	2609 (83.7)	1659 (84.8)	950 (81.8)		650 (81.0)	300 (84.5)	
BMI (kg/m^2), mean (SD)	30.6 (5.4)	30.7 (5.5)	30.4 (5.2)	0.3	30.6 (5.3)	30.1 (4.8)	0.4
Age at 9/11, (years), mean (SD)	51.5 (8.3)	51.5 (8.3)	51.4 (8.3)	0.07	51.9 (8.5)	50.3 (7.5)	0.006
Race, n (%)							
White	1828 (58.6)	1134 (58.0)	694 (59.7)	0.6	467 (57.8)	227 (63.9)	0.2
Black or AA	233 (7.5)	152 (7.8)	81 (7.0)		64 (7.9)	17 (4.8)	
Asian	30 (1.0)	17 (0.9)	13 (1.1)		<10	<10	
Unknown/NR	1011 (32.4)	641 (32.8)	370 (31.8)		263 (32.6)	107 (30.1)	
Ethnicity, n (%)							
Hispanic	484 (15.5)	289 (14.8)	195 (16.8)	0.09	126 (15.6)	69 (19.4)	0.2
Not Hispanic	1740 (55.8)	1082 (55.4)	658 (56.6)		457 (56.6)	201 (56.6)	
Unknown/NR	893 (28.7)	584 (29.9)	309 (26.6)		224 (27.8)	85 (23.9)	
Ever smokers, n (%)	957 (30.7)	712 (36.4)	378 (32.8)	0.09	265 (33.0)	113 (32.2)	0.7
Occupation, n (%)							
Construction	517 (16.6)	305 (15.6)	212 (18.2)	0.1	152 (18.8)	60 (16.9)	0.1
Law enforcement	1691 (54.2)	1067 (54.6)	624 (53.7)		423 (52.4)	201 (56.6)	
Sanitation worker	234 (8.0)	144 (7.4)	90 (7.8)		65 (8.1)	25 (7.0)	
Other	590 (18.9)	378 (19.3)	212 (18.2)		155 (19.2)	57 (16.1)	
Not reported	86 (2.8)	62 (3.2)	24 (2.1)		12 (1.5)	12 (3.4)	
Upper aerodigestive disorder, n (%)							
OSA+	1218 (39.1)	673 (34.4)	545 (46.9)	<0.001	360 (44.6)	185 (52.1)	0.02
Allergic rhinitis	306 (9.8)	160 (8.2)	146 (12.6)	<0.001	95 (65.1)	51 (34.9)	0.2
LPR	871 (27.0)	554 (28.4)	317 (27.3)	0.5	245 (77.3)	72 (22.7)	0.0004
GERD	1799 (57.7)	1023 (52.3)	776 (66.8)	<0.001	546 (70.4)	230 (29.6)	0.3
Chronic rhinitis	2330 (74.7)	1461 (74.7)	869 (74.8)	0.95	623 (72.4)	240 (27.6)	0.0002
CRS	1162 (37.3)	0 (0)	1162 (100.0)	–	807 (69.4)	355 (30.6)	–

*Comparing CRS+ and CRS−.
†Comparing CRS surgical and CRS non-surgical.
AA, African American; BMI, body mass index; CRS, chronic rhinosinusitis; GERD, gastro-oesophageal reflux disorder; LPR, laryngopharyngeal reflux; NR, not reported; OSA, obstructive sleep apnoea; WTC, World Trade Center.

Table 2 Associations between WTC exposure level, prevalence of chronic rhinosinusitis and surgical treatment

	WTC-exposed patients (n=2637)	CRS− (n=1632)	CRS+ (n=1005)	P value*	CRS non-surgical (n=700)	CRS surgery (n=305)	P value†
WTC exposure level							
Early (11 September–13 September)	2020 (76.6)	1273 (78.0)	747 (74.3)	0.03	500 (71.4)	247 (81.0)	0.001
Late (14 September or later)	617 (23.4)	359 (22.0)	258 (25.7)		200 (28.6)	58 (19.0)	
Effort months, mean (SD)	4.5 (3.4)	3.8 (3.6)	4.4 (3.4)	0.4	4.5 (3.4)	4.1 (3.5)	0.08

*Comparing CRS+ and CRS−.
†Comparing CRS surgical and CRS non-surgical.
CRS, chronic rhinosinusitis; WTC, World Trade Center.

and 14 September 2001.[4 20 25] Therefore, it is likely that responders who arrived before 14 September were more highly exposed to pulverised particles that irritated their upper aerodigestive mucosal surfaces, compared with those that arrived later.[11] Early exposure to a high concentration of caustic toxins suspended in the air in the 3 days following the disaster may have exposed responders to mucosal injury and non-resolving inflammation of the nasal airway that required surgical intervention.

Prior work on occupational airborne exposures supports this hypothesis. Environmental exposures including tobacco smoke and ambient air pollutants have been associated with the presentation and symptom severity in patients with CRS.[26–28] Bhattacharyya found an association between improving air quality and a decrease in sinusitis prevalence.[26] A study by Mady *et al* concluded that air pollutants correlate with CRS symptom severity and that these symptoms are influenced by exposure levels.[28] Velasquez *et al* showed that exposure to vapours, gases, dusts, fumes, fibres and mists at varying intensities correlated with increased prevalence of endoscopic sinus surgery and use of corticosteroids in patients with CRS.[29] Additionally, a recent study by Worden *et al* suggested that inhalational exposure is associated with changes in CRS patients' inflammatory transcriptome and that inhalational exposure should be an important consideration when managing CRS.[30] There is also growing literature on how disrupting the sinonasal epithelium activates innate and adaptive immunologic responses associated with CRS.[31]

A disruption of the nasal mucosa can produce a reduction in the structural competence of the sinonasal epithelium, leading to dysfunctional cellular tight junctions and increased ion permeability.[31] This phenomenon may be further exacerbated by activation of eosinophils, granzymes, natural killer cells and an imbalance of protease and protease inhibitor activity associated with CRS.[31] Based on studies showing acquired mucociliary clearance impairment after exposure to microbial toxins, it is possible that WTC toxin exposure led to an impairment of mucociliary clearance.[32] The combined increase in tissue permeability, decreased mucociliary function and immunological response may facilitate the chronic inflammation, fibrosis and tissue remodelling seen in CRS patients requiring surgical intervention.

Table 3 Logistic regression for sinonasal surgery and WTC-exposure level groups in patients with chronic rhinosinusitis

Exposure level	OR	95% CI	$OR_{adjusted}$*	95% CI
Early	1.7	(1.23 to 2.4)	1.61	(1.15 to 2.3)
Late	1.00 (REF)		1.00 (REF)	

*Adjusted for age, BMI, sex, effort months, OSA, LPR and CR.
BMI, body mass index; CR, chronic rhinitis; LPR, laryngopharyngeal reflux; OSA, obstructive sleep apnoea; WTC, World Trade Center.

It is becoming increasingly clear that CRS has an impact that reaches far beyond the sinuses. CRS symptoms, including nasal congestion, nasal drainage, facial pain and pressure, have been widely associated with decreased quality of life and productivity in patients.[33–35] Additionally, studies have shown that CRS is an independent risk factor for OSA and significantly associated with decreased sleep quality, sleep duration and increased insomnia.[16 36] CRS has also been linked to the progression of cognitive impairment in dementia.[37] In a separate study, patients with CRS had significantly more cognitive dysfunction and fatigue and had decreased reaction times on computerised testing.[38 39] Therefore, adequate treatment of CRS is highly important to prevent the progression of comorbidities and improve the quality of life of patients.

Strengths and limitations

Our study is limited by various factors. The retrospective study design of WTC patients seen in the Otolaryngology – Head and Neck Surgery department at the Icahn School of Medicine at Mount Sinai may not be reflective of all WTC patients in the WTCHP. Nevertheless, Mount Sinai's WTC health clinic is the largest and accounts for most patients in the programme. It is also inclusive of patients of all occupational groups, including police officers, firefighters and construction workers. Our database categorised occupation at time of exposure into construction, law enforcement, sanitation, other and not reported. Additional information on the type of work performed within these categories would have allowed us to further understand patient exposure. It is also important to acknowledge that patients who are sicker may be more likely to seek care and be part of the WTCHP. Additionally, while patients referred to the Otolaryngology department from the WTC clinic may overrepresent patients with more severe CRS, the high prevalence rate of CRS we found matched that of several other studies involving WTC patients. Due to our reliance on WTCHP claims as the source of patient identification, there is a possibility of under-ascertainment of WTC patients who received otolaryngology care prior to 2011, before the WTCHP became a payer, but did not have subsequent WTCHP-paid claims (eg, individuals who died before 2011 or did not return for care). While the extent of this underascertainment is uncertain, it should be considered when interpreting the findings. Additionally, our study was designed to assess the risk of undergoing surgical treatment for CRS based on early exposure to the WTC disaster site, but we were not able to directly account for pre-existent or repeated occupational or environmental exposures since 9/11. Our exposure assessment is based on arrival date to the WTC disaster site either before or after rainfall on 14 September 2001. While other studies, such as those by Kwon *et al* and Niles *et al*, have used arrival date as a surrogate for WTC exposure, it may be considered a coarse analysis of airborne contaminant exposure.[20 25] While our arrival date analysis found an association between early arrival and higher odds of undergoing sinonasal surgery, Kwon *et al* also found that increased surgery risk was associated with increasing blood eosinophil counts.[20] Due to the retrospective nature of our study and the resources available for our analysis, we were unable to collect the blood eosinophil data for our analysis.

Conclusions

Our findings suggest that WTC patients who arrived before 14 September 2001 experienced a significantly greater burden of sinonasal surgery to treat their CRS compared with those who arrived later. While our findings are unable to confirm the mechanism behind this association, it is possible that WTC patients with high levels of irritant exposure experienced significant injury to the epithelial layers of the upper airway mucosa, exacerbating inflammation of the nose, paranasal sinuses and upper-aerodigestive tract, leading to chronic inflammatory conditions like CRS requiring surgery. The long-term effects of CRS and upper airway diseases are extensive. In addition to negatively impacting quality of life, untreated CRS has been identified as a risk factor for OSA and associated with mild cognitive impairment. Physicians treating patients with WTC exposure should account for their arrival date when considering the severity of disease and the level of intervention. Additionally, continuous monitoring and treatment of WTC patients is of high importance for increasing our understanding of occupational exposures and their management.

Contributors All authors contributed substantially to the conception, design and execution of the study, as well as the interpretation of the data. HMRC, AY, KL, MvG and MM led the data collection process. HMRC, MvG and MS led the data analysis. HMRC, MvG and MS drafted the manuscript, and all authors critically revised it for important intellectual content. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work. MvG is the guarantor of this work and accepts full responsibility for the conduct of the study, the integrity of the data, and the accuracy of the data analysis.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This retrospective study protocol was approved by the Icahn School of Medicine at Mount Sinai's Institutional Review Board (STUDY# 22-01653). Participants were not required to provide consent prior to participating. Participant data were collected and stored confidentially, with all identifying information removed before analysis.

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REFERENCES

1 Herbert R, Moline J, Skloot G, *et al*. The World Trade Center disaster and the health of workers: five-year assessment of a unique medical screening program. *Environ Health Perspect* 2006;114:1853–8.
2 Levin SM, Herbert R, Moline JM. Physical Health Status of World Trade Center Rescue and Recovery Workers and Volunteers—New York City, July 2002–August 2004. *JAMA* 2004;292:1811–3.
3 Landrigan PJ, Lioy PJ, Thurston G, *et al*. Health and environmental consequences of the world trade center disaster. *Environ Health Perspect* 2004;112:731–9.
4 Lioy PJ, Weisel CP, Millette JR, *et al*. Characterization of the dust/smoke aerosol that settled east of the World Trade Center (WTC) in lower Manhattan after the collapse of the WTC 11 September 2001. *Environ Health Perspect* 2002;110:703–14.
5 U.S. Environmental Protection Agency. EPA's response to the world trade center collapse: challenges, successes, and areas for improvement. report no. 2003-p-00012. U.S. Environmental Protection Agency; 2003.
6 Chen LC, Thurston G. World Trade Center cough. *Lancet* 2002;360:s37–8.
7 Clark R. Environmental studies of the world trade center area after the september 11, 2001 attack. 2001. Available: https://pubs.usgs.gov/of/2001/ofr-01-0429/ [Accessed 15 May 2024].
8 McGee JK, Chen LC, Cohen MD, *et al*. Chemical analysis of World Trade Center fine particulate matter for use in toxicologic assessment. *Environ Health Perspect* 2003;111:972–80.
9 Soffritti M, Falcioni L, Bua L, *et al*. Potential carcinogenic effects of world trade center dust after intratracheal instillation to Sprague-Dawley rats: first observation. *Am J Ind Med* 2013;56:155–62.
10 Salzman SH, Moosavy FM, Miskoff JA, *et al*. Early respiratory abnormalities in emergency services police officers at the World Trade Center site. *J Occup Environ Med* 2004;46:113–22.
11 Prezant DJ, Weiden M, Banauch GI, *et al*. Cough and bronchial responsiveness in firefighters at the World Trade Center site. *N Engl J Med* 2002;347:806–15.
12 Centers for Disease Control and Prevention (CDC). Physical health status of World Trade Center rescue and recovery workers and volunteers - New York City, July 2002-August 2004. *MMWR Morb Mortal Wkly Rep* 2002;53:807–12.
13 Webber MP, Gustave J, Lee R, *et al*. Trends in respiratory symptoms of firefighters exposed to the world trade center disaster: 2001-2005. *Environ Health Perspect* 2009;117:975–80.
14 de la Hoz RE, Shohet MR, Chasan R, *et al*. Occupational toxicant inhalation injury: the World Trade Center (WTC) experience. *Int Arch Occup Environ Health* 2008;81:479–85.
15 Wisnivesky JP, Teitelbaum SL, Todd AC, *et al*. Persistence of multiple illnesses in World Trade Center rescue and recovery workers: a cohort study. *Lancet* 2011;378:888–97.
16 Sunderram J, Weintraub M, Black K, *et al*. Chronic Rhinosinusitis Is an Independent Risk Factor for OSA in World Trade Center Responders. *Chest* 2019;155:375–83.
17 Rosenfeld RM, Andes D, Bhattacharyya N, *et al*. Clinical practice guideline: adult sinusitis. *Otolaryngol Head Neck Surg* 2007;137:S1–31.
18 Lourijsen ES, Reitsma S, Vleming M, *et al*. Endoscopic sinus surgery with medical therapy versus medical therapy for chronic rhinosinusitis with nasal polyps: a multicentre, randomised, controlled trial. *Lancet Respir Med* 2022;10:337–46.
19 Soler ZM, Smith TL. Quality-of-life outcomes after endoscopic sinus surgery: how long is long enough? *Otolaryngol Head Neck Surg* 2010;143:621–5.
20 Kwon S, Putman B, Weakley J, *et al*. Blood Eosinophils and World Trade Center Exposure Predict Surgery in Chronic Rhinosinusitis. A 13.5-Year Longitudinal Study. *Ann Am Thorac Soc* 2016;13:1253–61.
21 de la Hoz RE, Shohet MR, Cohen JM. Occupational rhinosinusitis and upper airway disease: the world trade center experience. *Curr Allergy Asthma Rep* 2010;10:77–83.
22 Harris PA, Taylor R, Minor BL, *et al*. The REDCap consortium: Building an international community of software platform partners. *J Biomed Inform* 2019;95:103208.
23 Harris PA, Taylor R, Thielke R, *et al*. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42:377–81.
24 Orlandi RR, Kingdom TT, Smith TL, *et al*. International consensus statement on allergy and rhinology: rhinosinusitis 2021. *Int Forum Allergy Rhinol* 2021;11:213–739.
25 Niles JK, Webber MP, Liu X, *et al*. The upper respiratory pyramid: early factors and later treatment utilization in World Trade Center exposed firefighters. *Am J Ind Med* 2014;57:857–65.
26 Bhattacharyya N. Air quality influences the prevalence of hay fever and sinusitis. *Laryngoscope* 2009;119:429–33.
27 Nachman KE, Parker JD. Exposures to fine particulate air pollution and respiratory outcomes in adults using two national datasets: a cross-sectional study. *Environ Health* 2012;11:25.
28 Mady LJ, Schwarzbach HL, Moore JA, *et al*. Air pollutants may be environmental risk factors in chronic rhinosinusitis disease progression. *Int Forum Allergy Rhinol* 2018;8:377–84.
29 Velasquez N, Moore JA, Boudreau RM, *et al*. Association of air pollutants, airborne occupational exposures, and chronic rhinosinusitis disease severity. *Int Forum Allergy Rhinol* 2020;10:175–82.

30 Worden CP, Thorp BD, Ebert CS Jr, *et al*. Inhalational exposure history is associated with differential sinonasal gene expression profiles and clinical outcomes in chronic rhinosinusitis patients: A pilot study. *Int Forum Allergy Rhinol* 2024;14:1652–5.
31 Kato A, Schleimer RP, Bleier BS. Mechanisms and pathogenesis of chronic rhinosinusitis. *J Allergy Clin Immunol* 2022;149:1491–503.
32 Chegini Z, Noei M, Hemmati J, *et al*. The destruction of mucosal barriers, epithelial remodeling, and impaired mucociliary clearance: possible pathogenic mechanisms of Pseudomonas aeruginosa and Staphylococcus aureus in chronic rhinosinusitis. *Cell Commun Signal* 2023;21:306.
33 Rudmik L, Smith TL, Schlosser RJ, *et al*. Productivity costs in patients with refractory chronic rhinosinusitis: Productivity Costs in Patients with Refractory CRS. *Laryngoscope* 2014;124:2007–12.
34 Campbell AP, Hoehle LP, Phillips KM, *et al*. Symptom control in chronic rhinosinusitis is an independent predictor of productivity loss. *Eur Ann Otorhinolaryngol Head Neck Dis* 2018;135:237–41.
35 Saratziotis A, Emanuelli E, Zanotti C, *et al*. Endoscopic sinus surgery outcomes in CRS: quality of life and correlations with NOSE scale in a prospective cohort study. *Eur Arch Otorhinolaryngol* 2021;278:1059–66.
36 Ayappa I, Chen Y, Bagchi N, *et al*. The Association between Health Conditions in World Trade Center Responders and Sleep-Related Quality of Life and Sleep Complaints. *Int J Environ Res Public Health* 2019;16:1229.
37 Jung HJ, Lee JY, Choi YS, *et al*. Chronic rhinosinusitis and progression of cognitive impairment in dementia. *Eur Ann Otorhinolaryngol Head Neck Dis* 2021;138:147–51.
38 Soler ZM, Eckert MA, Storck K, *et al*. Cognitive function in chronic rhinosinusitis: a controlled clinical study. *Int Forum Allergy Rhinol* 2015;5:1010–7.
39 Cvancara DJ, Wood HA, Aboueisha M, *et al*. Cognition and saccadic eye movement performance are impaired in chronic rhinosinusitis. *Int Forum Allergy Rhinol* 2024;14:1206–17.