

Risk factors for post-9/11 chronic rhinosinusitis in Fire Department of the City of New York workers

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ABSTRACT

Objectives Chronic rhinosinusitis (CRS) has high socioeconomic burden but underexplored risk factors. The collapse of the World Trade Center (WTC) towers on 11 September 2001 (9/11) caused dust and smoke exposure, leading to paranasal sinus inflammation and CRS. We aim to determine which job tasks are risk factors for CRS in WTC-exposed Fire Department of the City of New York (FDNY) firefighters and emergency medical services (EMS) workers.

Methods This cohort study included a 16-year follow-up of 11 926 WTC-exposed FDNY rescue/recovery workers with data on demographics, WTC exposure, job tasks and first post-9/11 complete blood counts. Using multivariable Cox regression, we assessed the associations of WTC exposure, work assignment (firefighter/EMS), digging and rescue tasks at the WTC site and blood eosinophil counts with subsequent CRS, adjusting for potential confounders.

Results The rate of CRS was higher in firefighters than EMS (1.80/100 person-years vs 0.70/100 person-years; $p < 0.001$). The combination of digging and rescue work was a risk factor for CRS (HR 1.54, 95% CI 1.23 to 1.94, $p < 0.001$) independent of work assignment and WTC exposure.

Conclusions Compared with EMS, firefighters were more likely to engage in a combination of digging and rescue work, which was a risk factor for CRS. Chronic irritant exposures associated with digging and rescue work may account for higher post-9/11 CRS rates among firefighters.

INTRODUCTION

The terrorist attack on 11 September 2001 (9/11) and the subsequent collapse of the World Trade Center (WTC) towers produced a dense dust cloud throughout lower Manhattan. The Fire Department of the City of New York (FDNY) rescue/recovery workers were exposed to the air pollutants within this dust. Upper airway filtration of larger particles protects the lower airway, but may result in inflammation of the nose and paranasal sinuses, leading to rhinosinusitis.

Chronic rhinosinusitis (CRS) is most commonly defined as an inflammation of the nose and the paranasal sinuses characterised by at least two of the following symptoms during 8–12 weeks: nasal congestion, nasal drip, facial pain and/or reduction or loss of smell, in addition to either endoscopic signs or CT scan changes.¹ It often requires topical

Key messages

What is already known about this subject?

- ▶ Previously, increased rates of chronic rhinosinusitis (CRS) were observed in firefighters who performed rescue/recovery work at the World Trade Center (WTC) site.
- ▶ Additionally, higher intensity WTC exposure and elevated post-9/11 blood eosinophil levels were shown to be risk factors for CRS treated with surgery in WTC-exposed firefighters.

What are the new findings?

- ▶ Among WTC-exposed rescue/recovery workers, firefighters had a higher rate of post-9/11 CRS than emergency medical services (EMS) workers.
- ▶ The job task combination of digging and rescue work at the WTC site is a risk factor for CRS, independent of work assignment (firefighter/EMS) and intensity of WTC exposure.

How might this impact on policy or clinical practice in the foreseeable future?

- ▶ This longitudinal study of a closed cohort contributes to the understanding of CRS pathogenesis in relation to job exposure.
- ▶ Rescue/recovery workers with risk factors for CRS may benefit from a more intensive follow-up and treatment.

and systemic therapy and in select refractory cases, surgery.^{2,3} CRS is a highly prevalent disease with a significant socioeconomic impact. According to survey-based studies, CRS prevalence varies from 5%–12% in the USA to 3%–6% in Canada and 11% in Europe, while the prevalence based on healthcare system analyses in these populations ranges from 1% to 2.5%.⁴ The economic burden of CRS in the USA estimated in 2016 includes an annual direct healthcare cost of more than \$12.5 billion, in addition to productivity costs of \$20 billion per year due to absenteeism and reduced productivity at work.⁴

In the first month after WTC exposure, respiratory disorders accounted for 16% of all rescue/recovery worker visits to medical disaster facilities established at the WTC site and to Manhattan emergency departments.⁵ FDNY rescue/recovery workers have been intensively screened as part of the FDNY WTC Health Program (FDNY-WTCHP).

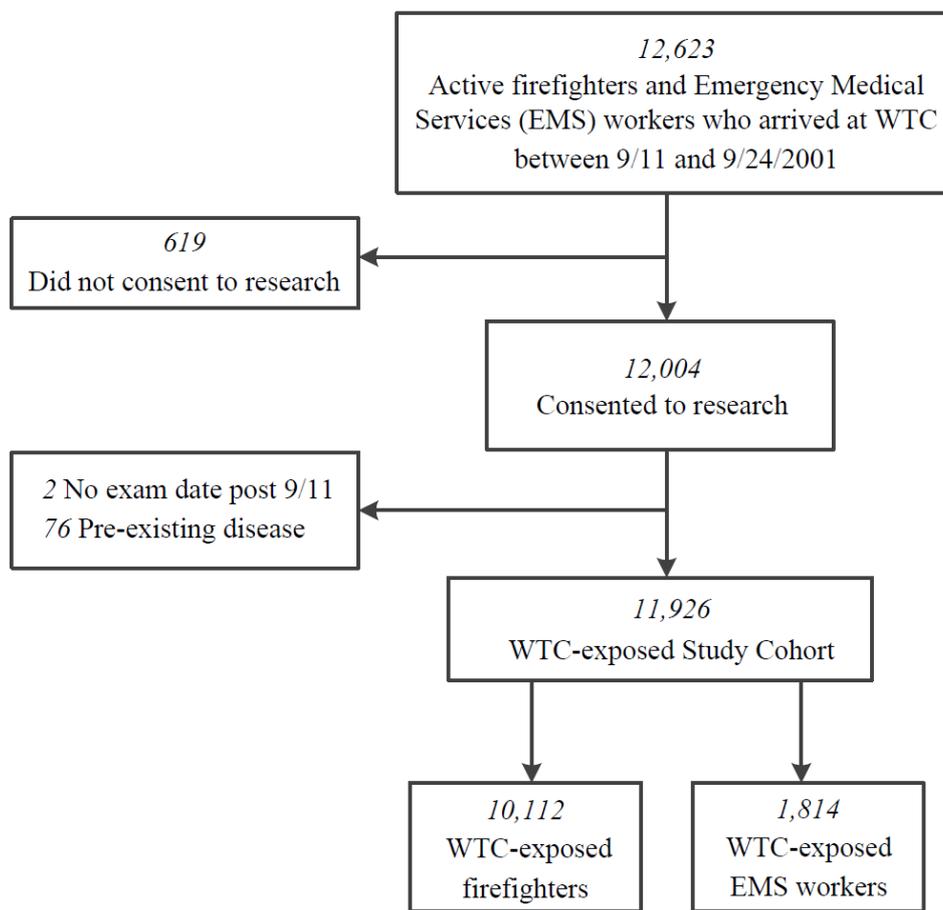


Figure 1 Study population of Fire Department of the City of New York (FDNY) World Trade Center (WTC)-exposed rescue/recovery workers. Shown are the number of firefighters and emergency medical services (EMS) workers employed by the FDNY on 11 September 2001, first arrived at the WTC site between 11 September and 24 September 2001 and consented to research.

Within the first weeks to months after 9/11, exposed firefighters experienced frequent upper airway symptoms, with 40%–54% reporting nasal congestion and 27%–41% reporting nasal drip.^{6,7} Additionally, Weakley *et al* observed high rates of chronic sinusitis.⁸ Over the subsequent 13.5 years, firefighters had high rates of CRS that was treated with surgery. We observed that both acute and prolonged WTC exposure and an elevated post-9/11 blood eosinophil count are risk factors for surgical intervention for CRS.⁹ The goal of this study is to determine if specific job tasks, in particular digging and rescue work at the WTC site, are risk factors for CRS among WTC-exposed firefighters and emergency medical services (EMS) workers. Additionally, the study assessed if work assignment (firefighter or EMS) is an independent risk factor for CRS and if WTC exposure and blood eosinophil count remain risk factors.

METHODS

Participants

Firefighters and EMS workers were included if they were employed by FDNY on 11 September, first arrived at the WTC site between 11 September and 24 September 2001 and consented to research.

Figure 1 shows the source population of 12 623 FDNY rescue and recovery workers who first arrived at the WTC site between 11 September and 24 September 2001. We excluded 619

individuals who did not consent to research, 76 with pre-9/11 CRS, defined as having at least two International Classification of Diseases (ICD)-10 diagnoses 8 weeks apart, and two who had lacked a post-9/11 medical monitoring examination, which resulted in a study population of 11 926.

WTC exposure and job tasks

We obtained demographic data from the FDNY employee database. Information on WTC site arrival time, work duration, job tasks and smoking status was derived from self-administered questionnaires taken during routine medical monitoring examinations at FDNY. Acute WTC exposure was defined as arrival on the morning of 11 September. Work duration was categorised by number of months worked for at least 1 day at the WTC site and chronic exposure was defined as working at the WTC site for at least 6 months. High-intensity exposure was defined as those with *both* acute and chronic exposure. Work assignment was firefighter or EMS. Job tasks included rescue work, digging, both digging and rescue work, neither rescue work nor digging.

Blood eosinophil counts were used from the first available complete blood count after 9/11 and were obtained from blood samples drawn at a WTCHP monitoring exam and sent to a single commercial vendor. A majority of the cohort (89%) had blood drawn within the first 2 years after 9/11. A binary eosinophil

variable with a cut-point of 240 cells/ μL , the top quartile of our study population, was used for further analyses.

Outcome

The definition of post-9/11 CRS for this study includes meeting at least one of the following criteria: (1) CRS which led to a surgical intervention, ‘CRS-surgery’; (2) two or more ICD-10 diagnoses of CRS (J 32.9) at least 8 weeks apart in the electronic medical record (EMR) with confirmatory CT scan of the paranasal sinuses; or (3) two or more self-reported sinus symptoms (sinus pain, congestion, drip, loss of smell) reported on at least two different annual medical questionnaires with confirmatory CT scan of the paranasal sinuses. Polyps were defined as sinus or nasal polyps on the first post-9/11 sinus CT scan of the paranasal sinuses.

The earliest of the CT date or the first symptom date (ICD-10 diagnosis or questionnaire) was used for analyses. If an individual’s CRS-surgery date was the earliest record of their CRS, we considered their date of CRS diagnosis to be 6 months before the surgery date. Sinus surgery dates were obtained from billing records, otolaryngologist records or FDNY-WTCHP EMR physician diagnosis. When the FDNY EMR physician diagnosis was the only record of CRS-surgery, a WTC treatment physician (MDW) reviewed the EMR notes to confirm the surgery date.

Because we cannot rule out that some cases were the exacerbation of pre-existing CRS, we do not refer to the outcome as incident CRS in the results.

Follow-up time

Follow-up time began on 11 September 2001 and ended on the date of the CRS diagnosis. For active FDNY members without CRS, follow-up time ended on 10 September 2017, and for retirees without CRS, follow-up ended at the earliest of the last FDNY medical visit or the end of the study.

Statistics

A Poisson model was used to compare the rates of CRS in firefighters versus EMS workers. Cox proportional hazards regression models were used to assess the associations of work assignment, job tasks (digging and rescue work) and post-9/11 blood eosinophil levels with CRS diagnoses. The unadjusted associations between these variables and CRS were first assessed, followed by multivariable models. In the full model we adjusted

for age, gender, race, body mass index (BMI) and smoking. Additional testing revealed that the proportional hazards assumptions were not met for work assignment.

Because we had previously observed that elevated eosinophil levels were associated with having CRS-surgery,⁹ we conducted a sensitivity analysis to see if the associations of work assignment, digging and rescue work, and blood eosinophil counts with CRS remained the same among those who did not receive sinus surgery ($n=11\,114$).

A secondary analysis stratified by work assignment was used to examine if an interaction existed between work assignment and job tasks. In another secondary analysis, we assessed the risk of CRS with polyps and CRS without polyps as separate outcomes using a marginal Cox regression model for multiple events.

The Kaplan-Meier estimator was used to estimate cumulative incidence. Cumulative incidence curves were created using Python V3.5.

A difference was considered statistically significant if the two-tailed p value was less than 0.05. SAS V9.4 was used to perform the statistical analyses.

RESULTS

This cohort study included a 16-year follow-up of WTC-exposed FDNY rescue/recovery workers (11 September 2001 to 10 September 2017). Among those followed were 2353/10 112 (23%) firefighters and 164/1814 (9%) EMS who were diagnosed with CRS (figure 1). CRS rates were 1.80 per 100 person-years (95% CI 1.72 to 1.87) in firefighters vs 0.70 per 100 person-years (95% CI 0.62 to 0.78) in EMS ($p<0.001$). Firefighters were 2.5 times more likely to be diagnosed with CRS than EMS (unadjusted HR 2.57; 95% CI 2.19 to 3.01, $p<0.001$) (figure 2A). The proportion of CRS-surgery among persons with a diagnosis of CRS was 651/2353 (28%) firefighters and 39/164 (24%) EMS ($p=0.28$). The proportion of persons with a diagnosis of CRS who had polyps (sinus or nasal) on the first post-9/11 sinus CT scan was 1036/2353 (44%) firefighters and 52/164 (32%) EMS ($p=0.002$).

Table 1 shows the demographics of the full study cohort and separately for firefighters and EMS. The firefighter and EMS populations are significantly different in gender, age, race, BMI and smoking status. Compared with firefighters, the EMS population had a higher proportion of individuals with acute exposure (22.9% vs 16.5%). However, a similar proportion

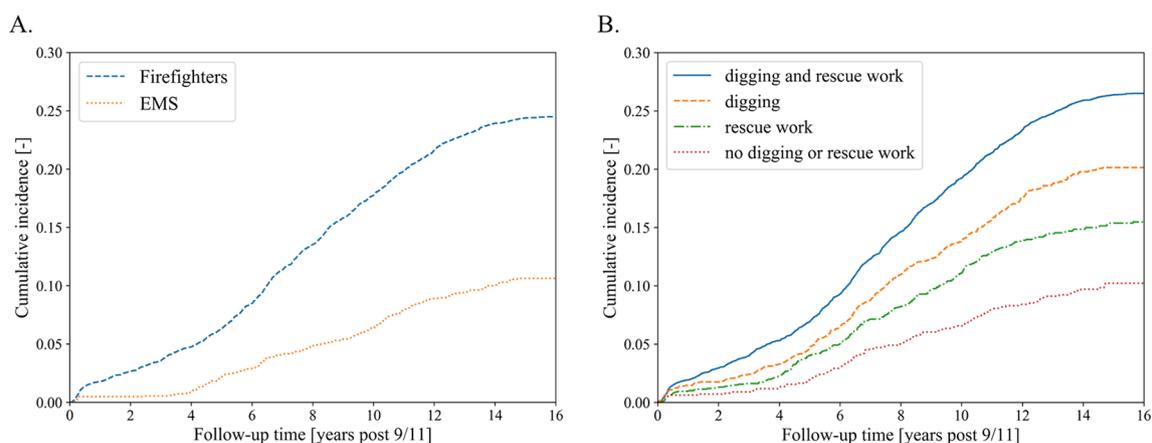


Figure 2 Cumulative incidence of chronic rhinosinusitis (CRS) from 11 September 2001 to 10 September 2017. Panel (A) shows the incidence of CRS stratified by work assignment: firefighters versus emergency medical services (EMS) workers. Panel (B) shows the incidence over time stratified by job task, comparing digging and rescue work, digging, rescue work to no digging or rescue work.

Table 1 Characteristics of the study population

	Study cohort, n 11 926	Firefighters, n (%) 10 112 (84.8)	EMS, n (%) 1814 (15.2)
Male			
n (%)	11 569 (97.0)	10 089 (99.8)	1480 (81.6)
Age on 11 September			
Mean (\pm SD), years	39.7 (\pm 7.8)	40.4 (\pm 7.4)	35.9 (\pm 8.7)
Race, n (%)			
Caucasian	10 458 (87.7)	9499 (93.9)	959 (52.9)
African-American	634 (5.3)	258 (2.6)	376 (20.7)
Hispanic	762 (6.4)	326 (3.2)	436 (24.0)
Other	72 (0.6)	29 (0.3)	43 (2.4)
BMI			
Mean (\pm SD), kg/m ²	29.1 (\pm 4.0)	28.8 (\pm 3.5)	30.4 (\pm 6.2)
Smoking status, n (%)			
Never smoker	7102 (59.6)	6235 (61.7)	867 (47.8)
Ever smoker	4821 (40.4)	3874 (38.3)	947 (52.2)
Arrival time to the WTC site, n (%)			
Morning of 11 September	2082 (17.5)	1666 (16.5)	416 (22.9)
Afternoon of 11 September or 12 September	8048 (67.5)	7188 (71.1)	860 (47.4)
On 13–24 September	1796 (15.1)	1258 (12.4)	538 (29.7)
Work duration (number of months at the WTC site), n (%)			
1 month	3501 (29.4)	2901 (28.7)	600 (33.1)
2–5 months	5575 (46.8)	4773 (47.2)	802 (44.2)
\geq 6 months	2850 (23.9)	2438 (24.1)	412 (22.7)
Job task at the WTC site, n (%)			
Rescue work only	1684 (14.1)	913 (9.0)	771 (42.5)
Digging only	1648 (13.8)	1592 (15.7)	56 (3.1)
Digging and rescue work	7394 (62.0)	7185 (71.1)	209 (11.5)
First post-9/11 blood eosinophil count			
Mean (\pm SD), cells/ μ L	191.0 (\pm 135.4)	187.7 (\pm 133.5)	209.1 (\pm 144.0)
\geq 240 cells/ μ L, n (%)	3070 (25.7)	2506 (24.8)	564 (31.1)

BMI, body mass index; EMS, emergency medical services; WTC, World Trade Center.

of individuals reported prolonged chronic exposure (24.1% vs 22.7%). Compared with EMS, firefighters had a higher proportion of individuals who engaged in digging alone (16% vs 3%) and the combination of digging and rescue work (71% vs 12%). The proportion of individuals who only did rescue work was lower in firefighters compared with EMS (9% vs 43%). The mean first post-9/11 eosinophil count for the study cohort was 191.0 cells/ μ L and ranged from 161 to 223 cells/ μ L, depending on the month in which the sample was drawn.

Primary analyses

Compared with those who reported neither digging nor rescue work, individuals who participated in either rescue work or digging alone had higher CRS risk (unadjusted HR 1.58; 95% CI 1.25 to 2.00, $p < 0.001$ and unadjusted HR 2.11; 95% CI 1.68 to 2.65, $p < 0.001$, respectively). The combination of both digging and rescue work produced the highest risk (unadjusted HR 2.90; 95% CI 2.37 to 3.55, $p < 0.001$) (figure 2B).

In a multivariable Cox model adjusted for gender, age, race, BMI and smoking status, firefighters had a twofold increase in CRS risk compared with EMS (HR 2.01; 95% CI 1.63 to 2.49, $p < 0.001$) (table 2). The combined activity digging and rescue work was associated with a 50% increase in CRS risk (HR 1.54; 95% CI 1.23 to 1.94, $p < 0.001$). Unlike the univariate analysis, individuals who performed only one of these job tasks did not have significantly elevated CRS risk. Top quartile blood eosinophil count was also a significant risk factor for CRS (HR 1.24;

95% CI 1.14 to 1.35, $p < 0.001$). High-intensity WTC exposures were significant risk factors for CRS as well (HR 1.62; 95% CI 1.38 to 1.90, $p < 0.001$ and HR 1.47; 95% CI 1.31 to 1.65, $p < 0.001$, respectively).

Sensitivity analysis

When the multivariable analyses were repeated excluding those who had sinus surgery, the results were similar; there was an increased risk of medically treated CRS in those with top quartile blood eosinophils (HR 1.12; 95% CI 1.01 to 1.24, $p = 0.03$).

Secondary analyses

The results for the secondary analyses stratified by work assignment (firefighter vs EMS) were similar (results not shown). In another secondary analysis, a multivariable marginal Cox regression that included CRS without polyps and CRS with polyps as the outcomes of interest showed that work assignment was a predictor for both (table 3). However, the association was stronger between work assignment and CRS with polyps compared with CRS without polyps ($p = 0.01$). We also observed that the association between top quartile blood eosinophil count and CRS with polyps was greater than that found in those without polyps ($p = 0.02$). The job task combination of digging and rescue work was a risk factor for CRS without polyps.

Table 2 Cox regression model predicting chronic rhinosinusitis (CRS) among World Trade Center-exposed Fire Department of the City of New York rescue/recovery workers

Covariate†	Study cohort (n=11 801)*		
	HR	95% CI	P values
Arrival time			
Morning of 11 September	1.62	1.38 to 1.90	<0.0001
Afternoon of 11 September or 12 September	1.34	1.16 to 1.54	<0.0001
On 13–24 September	Reference		
Work duration (month)			
1	Reference		
2–5	1.21	1.08 to 1.34	0.0006
≥6	1.47	1.31 to 1.65	<0.0001
Work assignment (firefighter vs EMS)	2.01	1.63 to 2.49	<0.0001
Job task			
No digging or rescue work	Reference		
Rescue work	1.20	0.95 to 1.53	0.13
Digging	1.25	0.97 to 1.59	0.08
Digging and rescue work	1.54	1.23 to 1.94	0.0002
First post-9/11 blood eosinophil count (≥240 vs <240 cells/μL)	1.24	1.14 to 1.35	<0.0001

*125 were excluded from the analysis due to missing data.
 †Adjusting for age, gender, race, body mass index (BMI) and smoking status (results not shown).
 EMS, emergency medical services.

DISCUSSION

We present 16 years of post-9/11 longitudinal follow-up for CRS diagnoses in FDNY rescue/recovery workers who suffered both acute and chronic irritant exposure at the WTC site. The rate of CRS was greater in firefighters (1.80/100 person-years) compared with EMS (0.70/100 person-years). The lower rate of CRS in EMS is consistent with our prior observations.¹⁰ FDNY

WTC-exposed firefighters were observed to have a higher rate of CRS than the general US population (1.1/100 person-years),¹¹ while the rate in EMS workers was lower.

The intensity and chronicity of WTC exposure, defined by arrival time and duration of work at the WTC site, respectively, were associated with an increased CRS risk. Job task was also associated with CRS diagnosis; specifically, the combination of digging and rescue work was an independent risk factor for CRS. The activities of digging and rescue work involved disturbing settled dust, as well as exposure to products of combustion from the fires that burned for months after 9/11. Individuals who did a combination of digging and rescue work therefore had the greatest exposure to irritants from the dust and smoke. Since EMS engaged in significantly less digging and rescue work than firefighters,¹⁰ it is not surprising that the rate of CRS in EMS was less than in firefighters. However, this did not account for all of the differences observed in the analyses. We believe that the repeated irritant exposure exacerbated inflammation of the nose and paranasal sinuses, which eventually resulted in CRS. Similar mechanisms have been observed in other cohorts with occupational exposures.¹² Mechanisms such as this likely explain why prolonged irritant exposure (work at the WTC site of 6 months or more) was also a risk factor for developing sinus disease years after 9/11, as the rate of CRS increased 5 years post-9/11.⁸

Exposure to components found in WTC dust,¹³ such as metals, could potentially result in CRS.¹⁴ Previously, chronic dust exposure has been associated with increased risk of CRS in coal miners.¹⁵ Additionally, Bhattacharyya found that improvement in air quality was associated with a decrease in the prevalence of sinusitis.¹⁶ Cigarette smoking has also been linked to an increased risk of CRS,¹⁷ although ever smoking was not associated with CRS in our study population.

We previously found that elevated post-9/11 blood eosinophils were an early risk factor for CRS-surgery.⁹ The sensitivity analysis in our current study that excluded individuals with CRS-surgery showed that the association between eosinophils and CRS

Table 3 Cox regression model predicting chronic rhinosinusitis (CRS) without polyps versus CRS with polyps among World Trade Center-exposed Fire Department of the City of New York rescue/recovery workers

Covariate†	Study cohort (n=11 801)*					
	CRS without polyps (n=1423) versus no CRS			CRS with polyps (n=1084) versus no CRS		
	HR	95% CI	P values	HR	95% CI	P values
Arrival time						
Morning of 11 September	1.49	1.21 to 1.83	0.0002	1.85	1.44 to 2.38	<0.0001
Afternoon of 11 September or 12 September	1.24	1.04 to 1.48	0.0197	1.51	1.21 to 1.89	0.0003
On 13–24 September	Reference			Reference		
Work duration (month)						
1	Reference			Reference		
2–5	1.17	1.02 to 1.35	0.0293	1.26	1.06 to 1.49	0.0077
≥6	1.43	1.23 to 1.67	<0.0001	1.54	1.29 to 1.85	<0.0001
Work assignment (firefighter vs EMS)	1.67	1.27 to 2.19	0.0002	2.94	2.04 to 4.23	<0.0001
Job task						
No digging or rescue work	Reference			Reference		
Digging	1.29	0.95 to 1.74	0.0980	1.11	0.74 to 1.65	0.6215
Rescue work	1.26	0.91 to 1.73	0.1599	1.26	0.84 to 1.89	0.2584
Digging and rescue work	1.65	1.24 to 2.21	0.0007	1.45	0.99 to 2.13	0.0555
First post-9/11 blood eosinophil count (≥240 vs <240 cells/μL)	1.13	1.01 to 1.27	0.0395	1.39	1.22 to 1.58	<0.0001

*125 were excluded from the analysis due to missing data.
 †Adjusting for age, gender, race, body mass index (BMI) and smoking status (results not shown).
 EMS, emergency medical services.

was slightly attenuated compared with the primary analyses, although it remained significant. This suggests that higher levels of inflammatory biomarkers, measured soon after exposure, indicated a higher risk of sinus inflammation years later, and is consistent with other studies reporting that eosinophilia was related to CRS.^{18,19} In our secondary analyses, top quartile eosinophil count of ≥ 240 cells/ μ L was a stronger risk factor for CRS with polyps than for CRS without polyps. Similar results were found by Brescia *et al*: blood eosinophil count of $\geq 240/\mu$ L was associated with recurrence of CRS with nasal polyps.²⁰

The main limitation of this study is the potential under-reporting of upper airway problems in the initial years after 9/11.⁸ At that time other more severe morbidities, such as the lower airway diseases, were more prominent. Second, because all the active FDNY rescue/recovery workers at the time were called in to assist in the 9/11 rescue/recovery effort, a non-exposed comparison group is unavailable. Another limitation is that the proportional hazards assumptions were not met. After testing for hazard assumptions and running Cox models censoring at different time points, we conclude that the average association for work assignment is representative for the whole 16-year time interval. We also lost 1% of the cases in the Cox regression analyses due to missing data. Since this is a small fraction, it is unlikely that it changed the results. One more limitation is the possibility of misclassification bias due to under-reporting of CRS cases pre-9/11. The FDNY medical record is not a global health record, but an occupational health record. If an FDNY rescue/recovery worker was diagnosed with CRS by their private physician but did not present to the FDNY clinic with the diagnosis of CRS, a review of the FDNY record will not capture this diagnosis. Elevated post-9/11 CRS rates could be due to incident cases or exacerbation of unrecorded pre-existing disease. Lastly, there may be unmeasured confounding, which is a limitation of all observational studies.

The strengths of this paper include an extensive longitudinal analysis comparing WTC-exposed firefighters and EMS and examining specific job tasks performed at the WTC site as risk factors for CRS. The study involved a cohort of nearly 12 000 FDNY rescue/recovery workers and a follow-up period of 16 years, so there is a wealth of data available for research. Another strength of the study is the CRS definition, which combines symptom/clinical data with objective criteria such as evidence of sinusitis on a CT scan or a surgical intervention.

CONCLUSIONS

The post-9/11 rate of CRS is higher in WTC-exposed firefighters than in EMS. Greater acute and chronic WTC exposures to irritants via specific job tasks such as digging and rescue work on the pile, and increased inflammation demonstrated by elevated post-9/11 blood eosinophil levels may be independent risk factors for CRS. Non-WTC occupational firefighting may also account for the higher rates in firefighters.

Contributors MDW had full access to all of the data in the study and agrees 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. MDW conceived the study, and designed it in conjunction with BP, RZO, CBH and DJP. MDW, BP, AS, RZO and TS analysed and interpreted the data. MDW, BP, AS and RZO drafted the first manuscript with critical revisions from CBH, DJP, MPW, TS, HWC and CB. All authors approved the final manuscript.

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Ethics approval Montefiore Medical Center/Albert Einstein College of Medicine Institutional Review Board.

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