

September 11

WTC

World Trade Center History

Twin Towers

- Built 1966 – 1973
- 110 floors (x2!)
- ~415m high
- 45 elevators (x2!)
- 50,000 routine workers
- 200,000 visitors/tourists per day

- Tallest building in the world 1970-74
- Tallest building in USA 1970-74
- Tallest building in NYC 1970-2001

עזריאלי עגול
49 קומות
187 מטר

September 11th, 2001

Event Timeline

היום בדיוק
לפני 18 שנים

- 8⁴⁶ am AA011 hits WTC North Tower
- 9⁰³ am UA175 hits WTC South Tower
- 9⁵⁹ am South Tower collapses
- 10²⁸ am North Tower collapses

September 11th, 2001

Casualties

- 2,996 people died
- >6,000 people injured
- ~80,000 people developed short/long-term morbidity

- ~14,000 rescue workers
 - **NYPD** (Police Dept.)
 - **FDNY** (Fire Dept.)
 - **EMS** (Emergency Medical Services)

September 11th, 2001

Airborne Dust

- **1,200,000 tons of dust**
- **Bricks/stones** (cement)
- **Gypsum** (CaHCO_3 , silicate)
- **Windows/glass** (SiO_2)
- **Metals** (Cr, Ni, Fe, Hg)
- **Asbestos**
- **VOC** (Volatile Organic Compounds)
- **90,000 Lit jet fuel** (C_xH_y , benzene, dioxins)

90% > 10 μm

11,000 tons PM_{2.5}

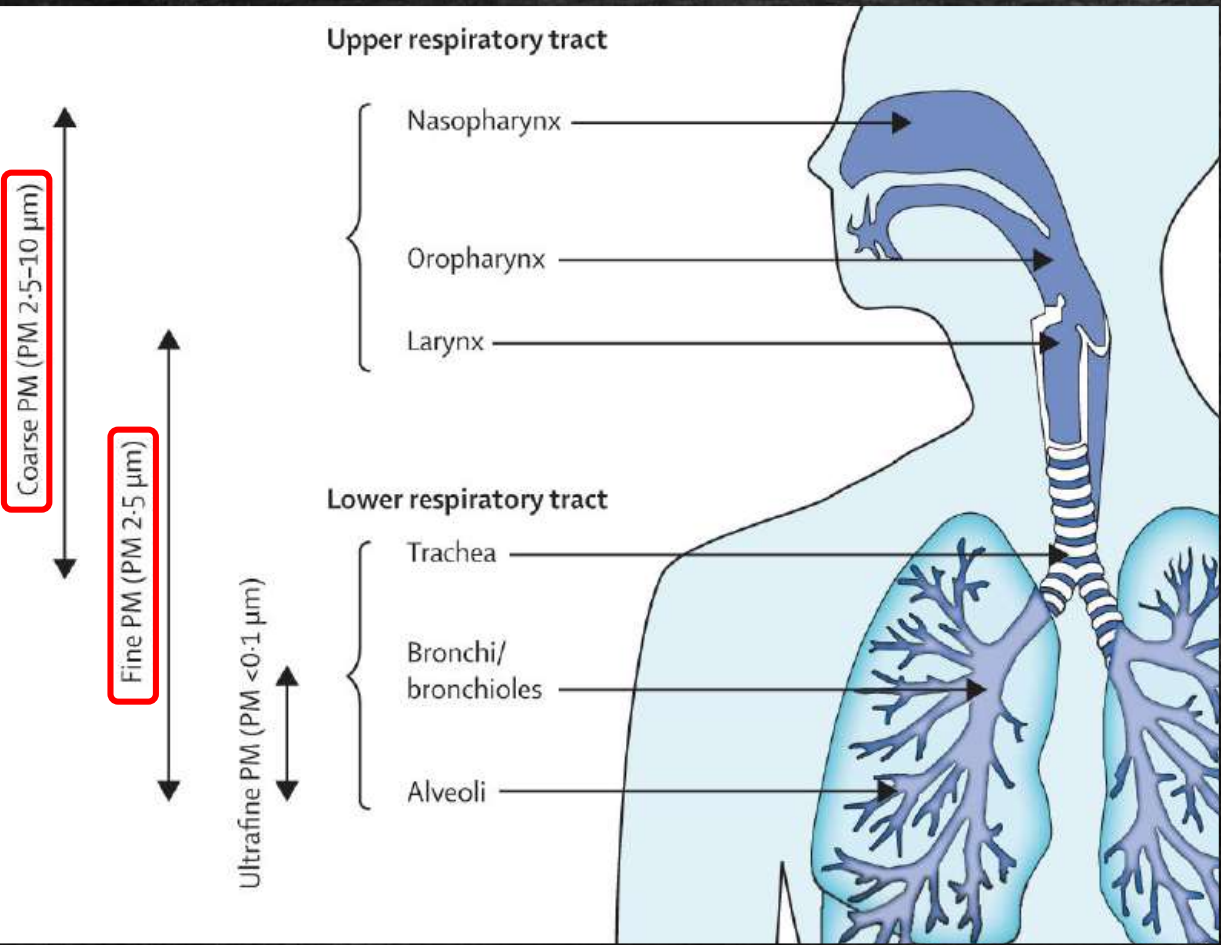
Airborne Dust

Particulate Matter 2.5

- **Particulate Matter (PM_{2.5}):**
 - airborne particles
 - <2.5μm
 - “respirable”
 - can penetrate distal airways

Airborne Dust

Airway "Generations" Sizes



Generation		Diameter, cm
Trachea	0	1.80
Bronchi	1	1.22
	2	0.83
	3	0.56
Bronchioles	4	0.45
	5	0.35
Terminal bronchioles	16	0.06
	17	↓
Respiratory bronchioles	18	↓
	19	0.05
	20	↓
Alveolar ducts	T ₃	↓
	T ₂	↓
	T ₁	↓
Alveolar sacs	T	0.04

$2.5\mu\text{m} = 0.00025\text{ cm}$

Air Pollution

Air Quality Index (AQI)

- Air Quality Index (AQI) =

- SO₂

- NO₂

- CO

- O₃

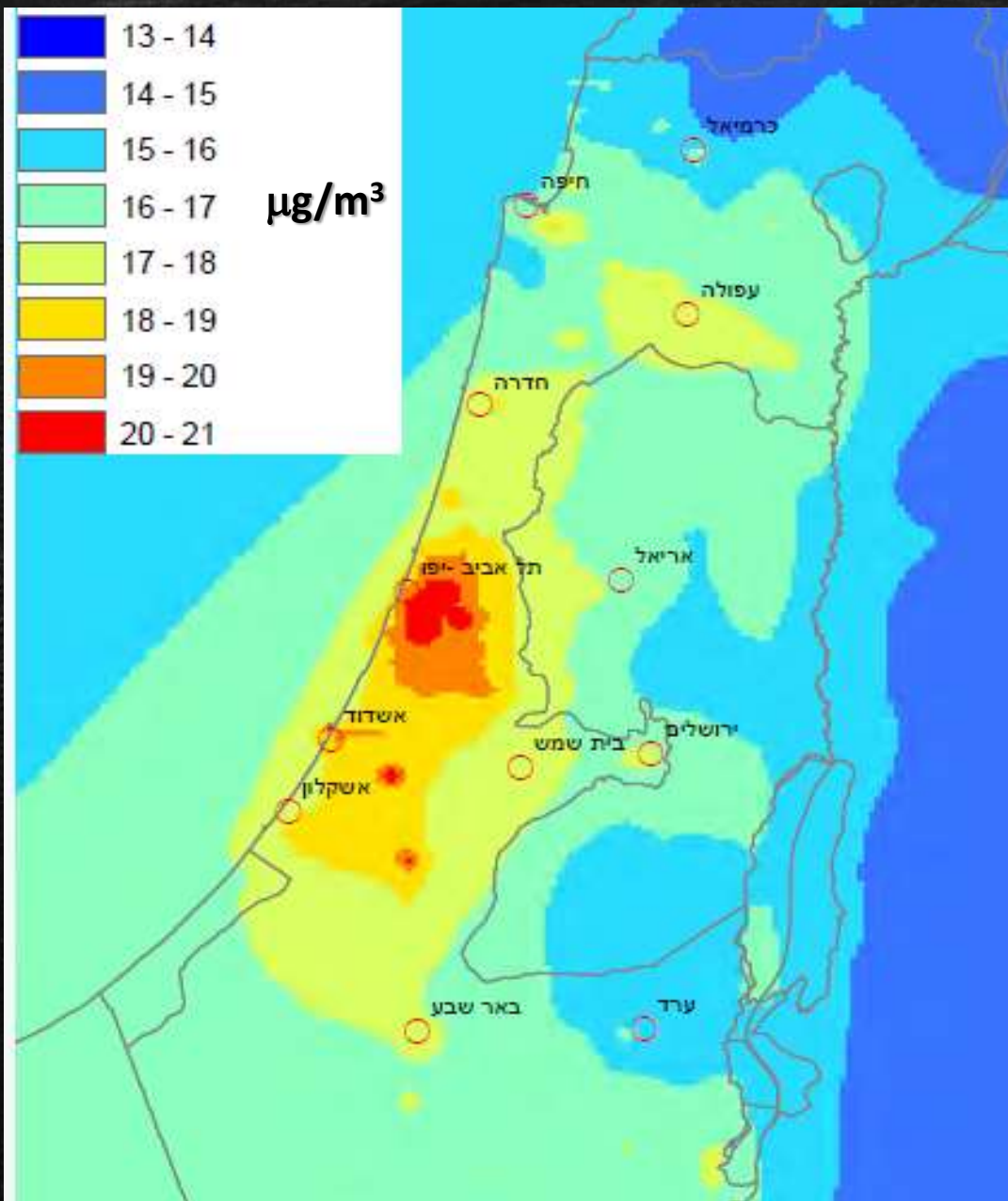
- PM₁₀

- PM_{2.5}

carbon / hydro-carbons (organic/elemental)

combustion (coal/oil/gas/wood)

ions (metals...)



ריכוזים שנתיים ממוצעים חלקיקים נשימים עדינים (PM_{2.5})

Air Quality Index (AQI)



AQI	Air Pollution Level	Health Implications	Cautionary Statement (for PM2.5)
0 - 50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk	None
51 -100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
101-150	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
151-200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects	Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion
201-300	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.	Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.
300+	Hazardous	Health alert: everyone may experience more serious health effects	Everyone should avoid all outdoor exertion

NYC~20 $\mu\text{g}/\text{m}^3$

Beijing~100 $\mu\text{g}/\text{m}^3$

Initial WTC collapse dust cloud: $\text{PM}_{2.5} \sim \underline{\text{mg}}/\text{m}^3$



COUGH AND BRONCHIAL RESPONSIVENESS IN FIREFIGHTERS AT THE WORLD TRADE CENTER SITE

DAVID J. PREZANT, M.D., MICHAEL WEIDEN, M.D., GISELA I. BANAUCH, M.D., GEORGEANN MCGUINNESS, M.D.,
WILLIAM N. ROM, M.D., M.P.H., THOMAS K. ALDRICH, M.D., AND KERRY J. KELLY, M.D.

ABSTRACT

Background Workers from the Fire Department of New York City were exposed to a variety of inhaled materials during and after the collapse of the World Trade Center. We evaluated clinical features in a series of 332 firefighters in whom severe cough developed after exposure and the prevalence and severity of bronchial hyperreactivity in firefighters without severe cough classified according to the level of exposure.

Methods "World Trade Center cough" was defined as a persistent cough that developed after exposure to the site and was accompanied by respiratory symptoms severe enough to require medical leave for at least four weeks. Evaluation of exposed firefighters included completion of a standard questionnaire, spirometry, airway-responsiveness testing, and chest imaging.

Results In the first six months after September 11, 2001, World Trade Center cough occurred in 128 of 1636 firefighters with a high level of exposure (8 per-

THE September 11, 2001, terrorist attack that resulted in the collapse of New York City's World Trade Center led to an intense, short-term exposure to inorganic dust, products of pyrolysis, and other respirable materials. The Fire Department of New York City (FDNY) operated a continuous rescue and recovery effort at the site involving approximately 11,000 firefighters, who were exposed to such respiratory irritants,¹ which have been implicated in the development of airflow obstruction.^{2,3} We identified conditions associated with airway obstruction — namely, severe, persistent cough ("World Trade Center cough") and airway reactivity — in exposed firefighters by assessing a case series of 332 firefighters with World Trade Center cough who required extensive medical leave as well as other firefighters who had been exposed but who did not require medical leave.

Persistent Hyperreactivity and Reactive Airway Dysfunction in Firefighters at the World Trade Center

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New York City Fire Department rescue workers experienced massive exposure to airborne particulates at the World Trade Center site. Aims of this longitudinal study were to (1) determine if bronchial hyperreactivity was present, persistent, and independently associated with exposure intensity, (2) identify objective measures shortly after the collapse that would predict persistent hyperreactivity and a diagnosis of reactive airways dysfunction 6 months post-collapse.

A representative sample of 179 rescue workers stratified by exposure intensity (high, moderate, and control) without current smoking or prior respiratory disease was enrolled. Highly exposed workers arrived within 2 hours of collapse, moderately exposed workers arrived later on Days 1–2; control subjects were not exposed. Hyperreactivity at 1, 3, and 6 months post-collapse was associated with exposure intensity, independent of ex-smoking and airflow obstruction. Six months post-collapse, highly exposed workers were 6.8 times more likely than moderately exposed workers and control subjects to be hyperreactive (95% confidence interval, 1.8–25.2; $p = 0.004$), and hyperreactivity persisted in 55% of those hyperreactive at 1 and/or 3 months. In highly exposed subjects, hyperreactivity 1 or 3 months post-collapse was the sole predictor for reactive airways dysfunction ($p = 0.021$). In conclusion, development and persistence of hyperreactivity and reactive airways dysfunction were strongly and independently associated with exposure intensity. Hyperreactivity shortly post-collapse predicted reactive airways dysfunction at 6 months in highly exposed workers; this has important implications for disaster management.

**Reactive
Airways
Dysfunction
Syndrome**

RADS

**Reactive Airways
Dysfunction Syndrome**

~~**ARDS**~~

דר' אופיר בר-און
חיפ"פ שניידר

11.9.2019

July 1985

Reactive airways dysfunction syndrome. Case reports of persistent airways hyperreactivity following high-level irritant exposures.

(PMID:4032082)

[Brooks SM](#), [Weiss MA](#), [Bernstein IL](#)

[Journal of Occupational Medicine. : Official Publication of the Industrial Medical Association](#) [01 Jul 1985, 27(7):473-476]

Type: Research Support, U.S. Gov't, P.H.S., Journal Article, Case Reports

Abstract

Two individuals developed an asthma-like illness after a single exposure to high levels of an irritating aerosol, vapor, fume, or smoke. Symptoms developed within a few hours. A consistent physiologic accompaniment was airways hyperreactivity, with the two subjects showing positive methacholine challenge tests. No documented preexisting respiratory illness was identified, nor did subjects relate past respiratory complaints. Respiratory symptoms and airways hyperreactivity persisted for at least four years after the incident. The incriminated etiologic agents all shared a common characteristic of being irritant in nature. Bronchial biopsy specimens showed an airways inflammatory response. This report suggests that acute high-level irritant exposures may produce an asthma-like syndrome in some individuals, with long-term sequelae and chronic airways disease. Nonimmunologic mechanisms seems to be operative in the pathogenesis of this syndrome.

Sept 1985



Chest

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Clinical Investigations

Reactive Airways Dysfunction Syndrome (RADS): Persistent Asthma Syndrome after High Level Irritant Exposures

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Ten individuals developed an asthma-like illness after a single exposure to high levels of an irritating vapor, fume, or smoke. In most instances, the high level exposure was the result of an accident occurring in the workplace or a situation where there was poor ventilation and limited air exchange in the area. In all cases, symptoms developed within a few hours and often minutes after exposure. We have designated the illness as reactive airway dysfunction syndrome (RADS) because a consistent physiologic accompaniment was airways hyperreactivity. When tested, all subjects showed positive methacholine challenge tests. No documented preexisting respiratory illness was identified nor did subjects relate past respiratory complaints. In two subjects, atopy was documented, but in all others, no evidence of allergy was identified. In the majority of the cases, there was persistence of respiratory symptoms and continuation of airways hyperreactivity for more than one year and often several years after the incident. The incriminated etiologic agent varied, but all shared a common characteristic of being irritant in nature. In two cases, bronchial biopsy specimens were available, and an airways inflammatory response was noted. This investigation suggests acute high level, uncontrolled irritant exposures may cause an asthma-like syndrome in some individuals which is different from typical occupational asthma. It can lead to long-term sequelae and chronic airways disease. Nonimmunologic mechanisms seem operative in the pathogenesis of this syndrome.

Reactive Airways Dysfunction Syndrome

Definition

- “Asthma-like” symptoms appearing minutes-hours after single inhalation of high concentration airborne irritant
- Previously health individuals
- Spirometry
 - airway hyper-responsiveness (Methacholine)
 - persist for months-years

Reactive Airways Dysfunction Syndrome

Diagnostic Criteria

Criteria for diagnosis of reactive airways dysfunction syndrome

A documented absence of previous respiratory complaints.

The onset of symptoms should occur after a single specific exposure.

The exposure should be to a gas, smoke, fume, or vapor with irritant qualities that was present in very high concentrations.

The onset of symptoms should occur within 24 hours of exposure and should persist for at least three months.

The symptoms should simulate asthma with cough, wheezing, and dyspnea.

Pulmonary function tests may or may not show airflow obstruction.

Methacholine challenge should be positive.

Other types of pulmonary diseases should be ruled out.

RADS Historic Case

- 1988
- Hospital lab
- 100% Acetic Acid
- Rapid odor spread
- 56 Exposed subjects
- Methacholine+

- Opportunity to establish existence of RADS

- RADS – valid clinical entity!

American Review of Respiratory Disease

Vol. 144, No. 5 | Nov 01, 1991

Outbreak of the Reactive Airways Dysfunction Syndrome after a Spill of Glacial Acetic Acid

David G. Kern

<https://doi.org/10.1164/ajrccm/144.5.1058>

PubMed: [1952431](https://pubmed.ncbi.nlm.nih.gov/1952431/)

Received: October 22, 1990

The reactive airways dysfunction syndrome (RADS) defines a chronic asthmalike illness with airway hyperresponsiveness that develops within 24 h of a single, brief, highly irritating inhalation exposure. Support for the syndrome has been limited to case reports. A chemical spill, exposing hospital employees to 100% acetic acid, offered an opportunity to more convincingly establish the existence of RADS. All 56 exposed subjects were asked both to complete a questionnaire focusing on their preexposure health status, potential for exposure, and symptom development after the accident, 8 months after the spill, and to undergo methacholine challenge testing to detect airway hyperresponsiveness. An industrial hygienist, blinded to clinical data, estimated each subject's exposure. Preemployment health history forms were reviewed to assess recall bias. The study questionnaire was returned by 51 (91%) subjects; 24 (47%) consented to methacholine challenge, including 7 of the 8 with RADS-consistent symptoms. Diagnostic criteria for RADS were satisfied by none of 7 (0%) subjects with low exposure, 1 of 30 (3.3%) with medium exposure, and 3 of 14 (21.4%) with high exposure (test of trend p value = 0.021). The odds ratio estimate of the relative risk of RADS in subjects with high exposure was 9.8 (95%CI, 0.902 to 264.6). Neither stratified analysis nor review of the preemployment health history forms revealed evidence of confounding or recall bias, respectively. The reactive airways dysfunction syndrome appears to be a valid clinical entity. Further study of RADS is especially appropriate given increasing evidence that airway inflammation may be etiologically important in all asthma.

RADS Historic Case

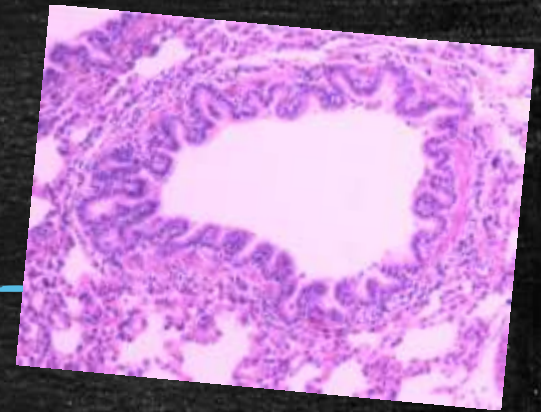
Pulmonary disease in rescue workers at the World Trade Center site

G. I. Banauch^a, A. Dhala^{b,c} and D. J. Prezant^{d,e}

Current Opinion in Pulmonary Medicine 2005, 11:160-168

World Trade Center cough, reactive airways dysfunction syndrome (RADS), reactive upper airways dysfunction syndrome (RUDS), and gastroesophageal reflux disease (GERD) are the major aerodigestive inflammatory consequences of WTC exposure. RADS and RUDS have previously been described after inadvertent high-level irritant exposures (with some publications referring to RUDS as chronic rhinitis). GERD has not yet been linked to environmental exposures, and WTC cough is a new clinical syndrome.

RADS Histology



- Mucosa denudation / desquamation
- Cilia destroyed
- Sub-mucosal hemorrhagic exudate

60 hours

- Sub-epithelial edema
- Basement membrane thickening

15-45 days

- Epithelial layer regeneration
- Re-innervation of mucosa

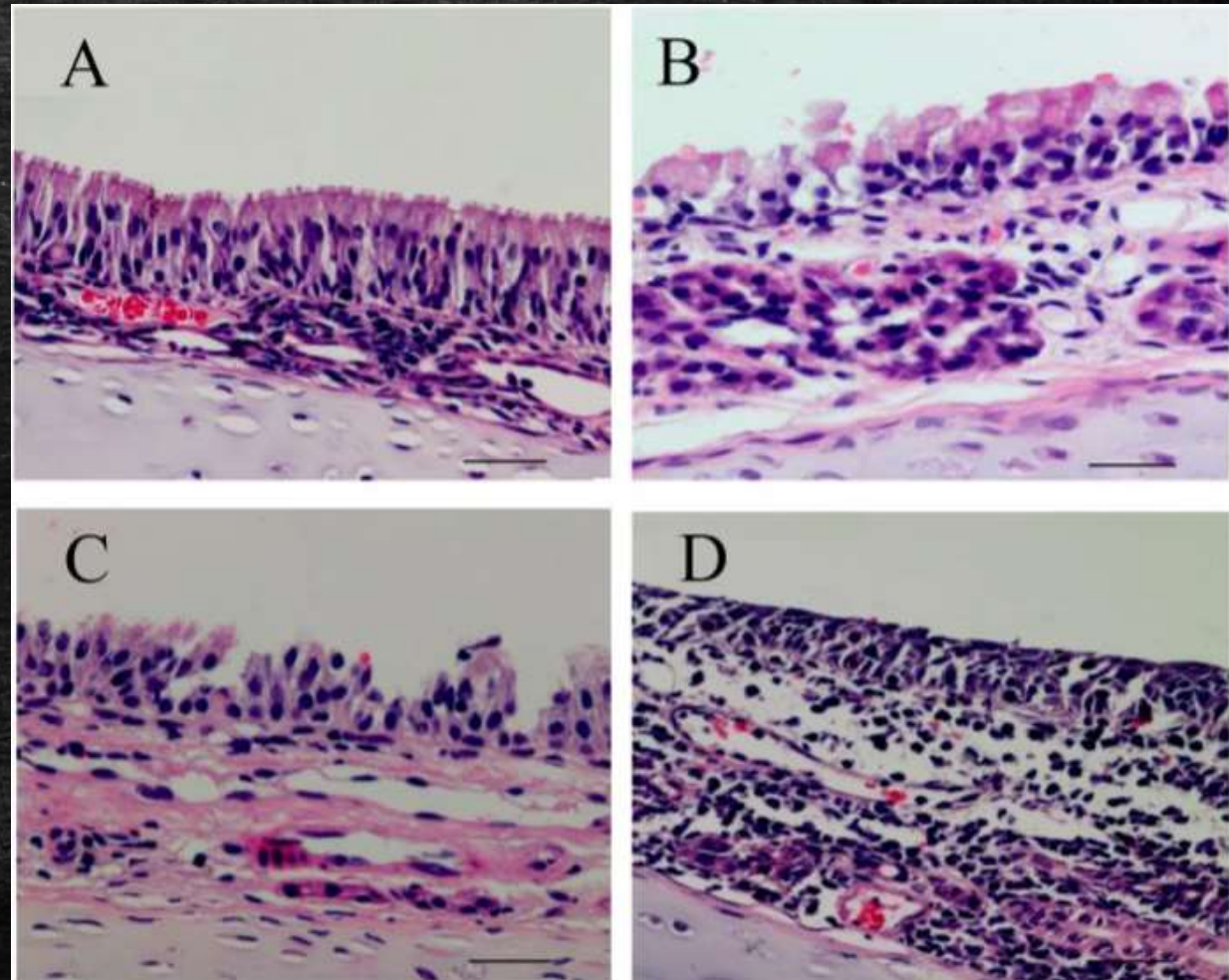
60-150 days

RADS

Histology

- A: Control
- B: $200\mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$
- C: $1000\mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$
- D: $3000\mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$

(3hr/day, 30 days)



RADS

Clinical Manifestation

- **Respiratory**
 - Cough, dyspnea, tachypnea, wheeze
- **Non-respiratory**
 - conjunctivitis / tearing
 - pharyngeal erythema
 - burning sensation throat/nose
- **CXR: Normal**
- **HRCT: Mosaic pattern (air-trapping)**

RADS

Risk Factors

- Incompletely characterized
- Risk factors:
 - insulting agent (Chloride)
 - concentration↑
 - wet aerosols > dry particulates
 - smoking
- Not risk factors:
 - atopy

RADS

Management

- **No formal trials** (animal experiments)
- **Same as acute asthma exacerbation**
- **Bronchodilators**
- **Systemic glucocorticoids** (~2wks)
- **Long-term LABA+ICS**

RADS – Then & Now...

Then and Now Reactive Airways Dysfunction Syndrome

Answered by *Stuart M. Brooks, MD,
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cine & Public Health, University of South
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Acute Irritant-Induced Asthma (IIA)

THEN

In 1969, when I first began my academic career at the University of Cincinnati following my internal medicine residency and pulmonary specialty training in Boston, my research interests were mainly focused on allergic-type occupational asthma, at the time, the preeminent category of work-related asthma. Between 1972 and 1985, approximately 2000 patients were evaluated, by me, at the University of Cincinnati Occupational Health Service. Nearly 25% of the examinees were believed to have occupational asthma. However, for about 30 of the asthmatic patients, I observed that their exposure-connected asthma differed from typical allergic-type occupational asthma. There was an absence of a preceding period for sensitization. The onset of asthma began within 24 hours of the exposure, and the exposure was charac-

NOW

Now, roughly 30 years later, RADS (ie, acute irritant-induced asthma) remains an implicit new-onset asthma without immunological sensitization, developing within 24 hours following a single, massive irritant aerosol, gas, vapor, or fume exposure.^{1,2} Characteristically, it is not possible to accurately gauge the precise concentration of the irritant exposure, as almost all cases are accidental and occur without warning such as with an

WTC Collapse & “Regular” Asthma

Crit Rev Toxicol. 2015 July ; 45(6): 492–530. doi:10.3109/10408444.2015.1044601.

Health effects of World Trade Center (WTC) Dust: An unprecedented disaster with inadequate risk management

Morton Lippmann, Mitchell D. Cohen, and Lung-Chi Chen

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ELSEVIER

Chest

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Clinical Investigations
WORLD TRADE CENTER

Symptoms, Respirator Use, and Pulmonary Function Changes Among New York City Firefighters Responding to the World Trade Center Disaster

Debra M. Feldman MD ^a, Sherry L. Baron MD ^a, Bruce P. Bernard MD ^a, Boris D. Lushniak MD ^a, Gisela Banauch MD ^c, Nicole Arcentales BA ^b, Kerry J. Kelly MD ^b, David J. Prezant MD, FCCP ^c 

WTC Collapse & “Regular” Asthma

Asthma Diagnosed after 11 September 2001 among Rescue and Recovery Workers: Findings from the World Trade Center Health Registry

Katherine Wheeler,¹ Wendy McKelvey,¹ Lorna Thorpe,¹ Megan Perrin,¹ James Cone,¹ Daniel Kass,¹ Mark Farfel,¹ Pauline Thomas,² and Robert Brackbill³

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VOLUME 115 | NUMBER 11 | November 2007 • Environmental Health Perspectives

Ann Allergy Asthma Immunol. 2016 November ; 117(5): 568–570. doi:10.1016/j.anai.2016.08.033.

Determinants of Asthma Morbidity in World Trade Center Rescue and Recovery Workers

Kevin Y Xu, BA^{1,2}, Emily Goodman, MS³, Ruchir Goswami, MD², Michael Crane, MD⁴, Laura Crowley, MD⁴, Paula Busse, MD⁵, Craig L Katz, MD^{1,6}, Steven Markowitz, MD⁷, Rafael E de la Hoz, MD, MPH^{3,4}, Hannah T Jordan, MD, MPH⁸, Gwen Skloot, MD⁹, and Juan P Wisnivesky, MD, DrPH^{3,9}

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812

APRIL 8, 2010

VOL. 362 NO. 14

Lung Function in Rescue Workers at the World Trade Center after 7 Years

Thomas K. Aldrich, M.D., Jackson Gustave, M.P.H., Charles B. Hall, Ph.D., Hillel W. Cohen, Dr.P.H.,
Mayris P. Webber, Dr.P.H., Rachel Zeig-Owens, M.P.H., Kaitlyn Cosenza, B.A., Vasilios Christodoulou, B.A.,
Lara Glass, M.P.H., Fairouz Al-Othman, M.D., Michael D. Weiden, M.D., Kerry J. Kelly, M.D.,
and David J. Prezant, M.D.

- 13954 FDNY+EMS
- 12781 participated
- 61746 Lung Fx Tests
- ~6 year follow-up
- FEV₁ ↓ first year
- Minimal recovery

Trade Center on September 11, 2001, exposed thou-
sand New York City (FDNY) rescue workers to dust, leading
to a decline in lung function in the first year. We sought to determine the

long-term effects. We analyzed the forced expiratory volume in 1 second
(FEV₁) of FDNY rescue workers on the basis of spirometry
performed at 12 to 18 months from March 12, 2000, to Septem-

RESULTS

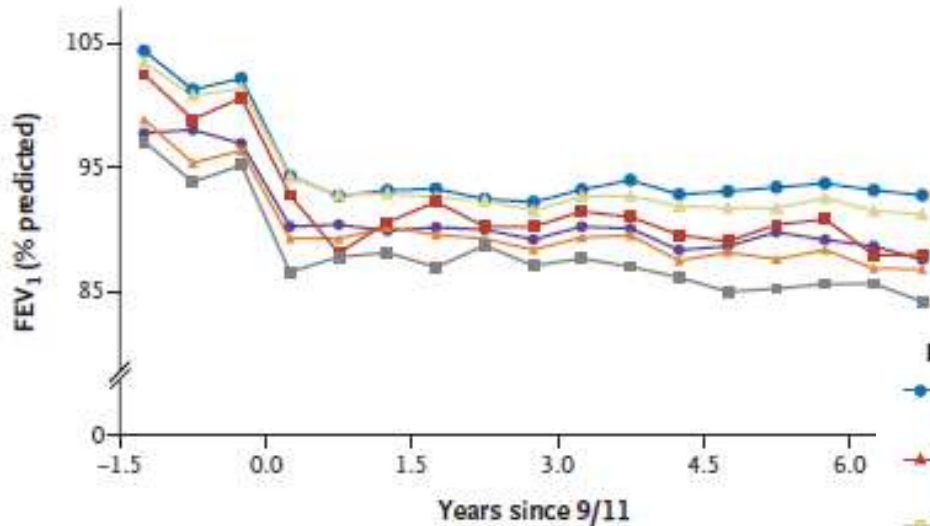
Of the 13,954 FDNY workers who were present at the World Trade Center between September 11, 2001, and September 24, 2001, a total of 12,781 (91.6%) participated in this study, contributing 61,746 quality-screened spirometric measurements. The median follow-up was 6.1 years for firefighters and 6.4 years for emergency-medical-services (EMS) workers. In the first year, the mean FEV₁ decreased significantly for all workers, more for firefighters who had never smoked (a reduction of 439 ml; 95% confidence interval [CI], 408 to 471) than for EMS workers who had never smoked (a reduction of 267 ml; 95% CI, 263 to 271) (P<0.001 for both comparisons). There was little or no recovery in FEV₁ during the subsequent 6 years, with a mean annualized reduction in FEV₁ of 25 ml per year for firefighters and 40 ml per year for EMS workers. The proportion of workers who had never smoked and who had an FEV₁ below the lower limit of the normal range increased during the first year, from 3% to 18% for firefighters and from 12% to 22% for EMS workers, stabilizing at about 13% for firefighters and 22% for EMS workers during the subsequent 6 years.

CONCLUSIONS

Exposure to World Trade Center dust led to large declines in FEV₁ for FDNY rescue workers during the first year. Overall, these declines were persistent, without recovery over the next 6 years, leaving a substantial proportion of workers with abnormal lung function.

Percent of Predicted FEV₁

- Firefighters, never smoked (n=7098)
- Firefighters, smoked before 9/11 (n=2790)
- Firefighters, smoked after 9/11 (n=590)
- EMS workers, never smoked (n=698)
- EMS workers, smoked before 9/11 (n=448)
- EMS workers, smoked after 9/11 (n=253)

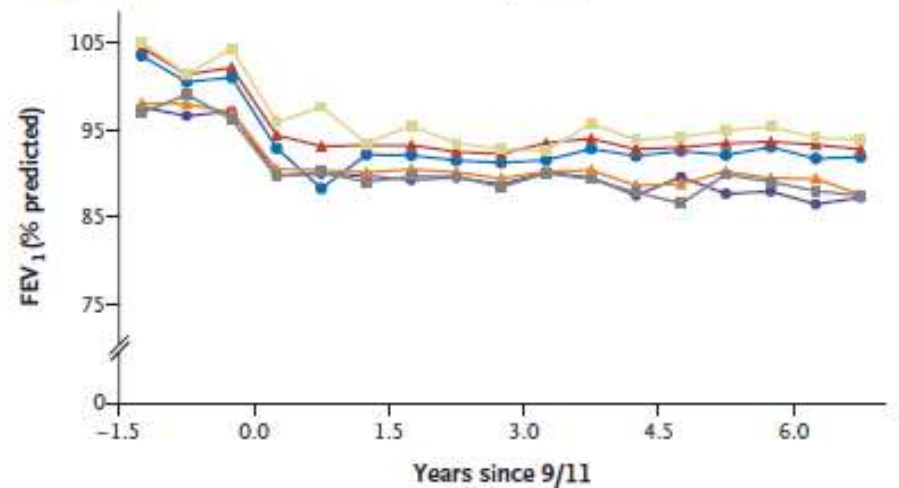


Lung Function (FEV₁%)
 NYFD vs EMS
 (Never Smoked)
 Arrival Time

Lung Function (FEV₁%)
 NYFD vs EMS
 Smoking Status

Percent of Predicted FEV₁

- Firefighters, arrived 9/11 a.m. (n=1125)
- Firefighters, arrived 9/11 p.m. or 9/12 (n=5397)
- Firefighters, arrived 9/13 to 9/24 (n=576)
- EMS workers, arrived 9/11 a.m. (n=144)
- EMS workers, arrived 9/11 p.m. or 9/12 (n=418)
- EMS workers, arrived 9/13 to 9/24 (n=136)



RADS

Summary

Reactive Airways Dysfunction Syndrome

- Acute new-onset non-immunological asthma
- Post single massive irritant exposure
- Airway epithelium damage
- Initial drop in FEV_1 (minimal recovery)
- Bronchial hyper-responsiveness (Methacholine)
- Persists for months/years
- Treatment \approx asthma
- Frequency? Not rare...!

One World Trade Center



Completed Nov 2014

**Tallest building in
Western Hemisphere
(541m)**

Memorial Plaza