Mortality among survivors of the Sept 11, 2001, World Trade Center disaster: results from the World Trade Center Health Registry cohort

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Summary

Background The Sept 11, 2001 (9/11) World Trade Center (WTC) disaster has been associated with several subacute and chronic health effects, but whether excess mortality after 9/11 has occurred is unknown. We tested whether excess mortality has occurred in people exposed to the WTC disaster.

Methods In this observational cohort study, deaths occurring in 2003–09 in WTC Health Registry participants residing in New York City were identified through linkage to New York City vital records and the National Death Index. Eligible participants were rescue and recovery workers and volunteers; lower Manhattan area residents, workers, school staff and students; and commuters and passers-by on 9/11. Study participants were categorised as rescue and recovery workers (including volunteers), or non-rescue and non-recovery participants. Standardised mortality ratios (SMR) were calculated with New York City rates from 2000–09 as the reference. Within the cohort, proportional hazards were used to examine the relation between a three-tiered WTC-related exposure level (high, intermediate, or low) and total mortality.

Findings We identified 156 deaths in 13 337 rescue and recovery workers and 634 deaths in 28 593 non-rescue and non-recovery participants. All-cause SMRs were significantly lower than that expected for rescue and recovery participants (SMR 0·45, 95% CI 0·38–0·53) and non-rescue and non-recovery participants (0·61, 0·56–0·66). No significantly increased SMRs for diseases of the respiratory system or heart, or for haematological malignancies were found. In non-rescue and non-recovery participants, both intermediate and high levels of WTC-related exposure were significantly associated with mortality when compared with low exposure (adjusted hazard ratio 1·22, 95% CI 1·01–1·48, for intermediate exposure and 1·56, 1·15–2·12, for high exposure). High levels of exposure in non-rescue and non-recovery individuals, when compared with low exposed non-rescue and non-recovery individuals, were associated with heart-disease-related mortality (adjusted hazard ratio 2·06, 1·10–3·86). In rescue and recovery participants, level of WTC-related exposure was not significantly associated with all-cause mortality (adjusted hazard ratio 1·25, 95% CI 0·56–2·78, for high exposure and 1·03, 0·52–2·06, for intermediate exposure when compared with low exposure).

Interpretation This exploratory study of mortality in a well defined cohort of 9/11 survivors provides a baseline for continued surveillance. Additional follow-up is needed to establish whether these associations persist and whether a similar association over time will occur in rescue and recovery participants.

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Introduction

In the years since Sept 11, 2001 (9/11), exposure to the World Trade Center (WTC) disaster and its aftermath has been associated with several chronic physical and psychological health effects. An increased risk of asthma and other respiratory illnesses has been reported in people exposed to smoke, fumes, and dust released during the disaster and subsequent rescue, recovery, and clean-up activities.[1–4] Psychological trauma resulting from the disaster was associated with a heightened risk of post-traumatic stress disorder (PTSD) and serious psychological distress.[1,5,6] Directly exposed individuals might also be at risk for premature death due to new-onset respiratory diseases, exacerbation of pre-existing respiratory disorders, or complications of mental health disorders, including substance abuse.

Although respiratory illnesses and PTSD are the main sequelae of 9/11 described so far,[1–6] the detection of several carcinogens in WTC dust has raised concern that exposure could have increased the risk of cancer.[7–9] Insufficient time has passed to establish whether exposure conferred an increased risk for most cancers. However, an increase in the incidence of haematological malignancies, which have fairly short latency periods, could be detected within several years after 9/11; a case series of multiple myeloma in WTC rescue and recovery workers has been reported.[10] Cardiovascular disease has been associated with exposure to both psychological stress[11] and inhaled particulate matter,[12] therefore a

reasonable biological mechanism could also be postulated for a relation between WTC exposure and cardiovascular disease. Ecological studies have suggested such an association,[13,14] but definitive studies are not yet available.

We sought to determine whether excess mortality has occurred in people exposed to the 9/11 disaster. We also examined relations between WTC-related exposures and specific causes of death that could be related to those exposures, including respiratory diseases, complications of mental illness, haematological malignancies, and cardiovascular disease.

Methods

Study population

The methods used to gather data for the WTC Health Registry are described elsewhere.[1,15] Between Sept 12, 2003, and Nov 24, 2004, 71437 people completed a computer-assisted (95%) or in-person (5%) enrolment interview on demographics, exposures incurred during and after the WTC disaster, and health information. All participants provided verbal informed consent for their responses to be used in data linkages and analyses. Eligible participants were rescue and recovery workers and volunteers (ie, those involved in rescue, recovery, cleanup work at the WTC site, Fresh Kills Landfill [Staten Island], or transporting debris via barges), lower Manhattan area residents, workers, school staff and attendees, and commuters and passers-by on 9/11. Lists of eligible participants were obtained from lower Manhattan area employers and government agencies (list-identified participants), and broad-based, multilingual media campaigns encouraged WTC-exposed people to contact the Registry via a website or toll-free telephone number for eligibility screening, which consisted of several questions related to exposure to the WTC disaster. We refer to those recruited through the media campaigns as self-identified participants. The US Centers for Disease Control and Prevention (CDC) and New York City Department of Health and Mental Hygiene institutional review boards approved the Registry protocol.

Panel 1: **Three-tiered definitions of the overall levels of exposure to the World Trade Center incurred for rescue and recovery and non-rescue and non-recovery participants**

Definitions of WTC-related rescue and recovery exposure*

- High exposure: participants who were in Manhattan, south of Chambers Street, between the time of the first plane impact and 1200 h on 9/11 (encompassing the collapse of WTC towers) and who worked on the WTC dust and debris pile on 9/11 or worked at the WTC site for more than 90 days, starting before Sept 18, 2001.
- Low exposure: participants who began work at the WTC site after Sept 17, 2001, did not work on the WTC debris pile, worked fewer than 30 days at the WTC site, and were not present south of Chambers Street between the first plane impact and 1200 h on 9/11.
- Intermediate: participants whose level of exposure fell between high and low.

Definitions of WTC-related residential, office, school, or transit exposure

- High exposure: participants who reported two or more injuries on 9/11, and for residents in zip codes including Canal Street and south, in lower Manhattan, who did not evacuate their home on 9/11, and for school students and school staff south of Canal Street, who were present at school on 9/11.
- Low exposure: participants who reported no injuries on 9/11, residents in zip codes including Canal Street and south, in lower Manhattan, who also evacuated their home on 9/11 (for any amount of time), and school students and school staff south of Canal Street, who were not present at school on 9/11.
- Intermediate exposure: participants whose exposure level fell between high and low.

*Rescue and recovery workers who worked exclusively on Staten Island, barges, or transfer stations were excluded.
9/11=Sept 11, 2001. WTC=World Trade Center.

Procedures

We used New York City vital records as the primary source of mortality data because it provided the most up-to-date information, and because 60% of Registry participants resided in New York City on Registry enrolment. This analysis was therefore limited to participants residing in the city at enrolment. We excluded those for whom both age and date of birth were missing (158) and rescue and recovery workers who worked only on the Staten Island recovery operation landfill or barge because of scarcity of information about their specific tasks and exposures (378).

Data that identified study participants were linked to death certificates in New York City vital records from Jan 1, 2003, to Dec 31, 2009. Potential matches were records that matched parts of key identifiers such as name, address, date of birth, and social security number. Key identifiers from the Registry and datasets from the vital records were electronically compared and a score was assigned for each potential match on the basis of degree of similarity. These scores aided identification of deaths of Registry enrolled participants during manual review by two independent reviewers. In the case of disagreement, a third reviewer determined whether the case was a match. Deaths among New York City residents occurring outside the city, which were not recorded in vital records, were identified by linkage to the National Death Index up to Dec 31, 2007—the most recent year in which these data were available at the time of analysis. Participants who were not linked to a death certificate were judged to be alive as of Dec 31, 2009. We did not have National Death Index mortality data for 2008–09, and therefore could not identify deaths occurring during those years among participants who had moved out of New York City after study enrolment (about 24 additional deaths).

Study participants were categorised as rescue and recovery workers (including volunteers), or non-rescue and non-recovery participants (including lower Manhattan area residents, workers, school staff or students, and commuters and passers-by on 9/11). Participants who did rescue and recovery work but also belonged to one of the other groups were classed as rescue and recovery workers.

International Classification of Disease codes, 10th revision (ICD-10), for underlying cause of death[16] were obtained from New York City vital records or the National Death Index and categorised according to the 119-cause

rate file from the National Institute for Occupational Safety and Health's (NIOSH) life table analysis software (LTAS.NET).[17]

WTC exposures were defined on the basis of responses to the 2003–04 enrolment questionnaires. All participants were asked whether they were caught in the dust or debris cloud on 9/11, and whether they had any of the following acute injuries on the day due to the disaster: cut, abrasion, or puncture wound; eye injury or irritation; sprain or strain; burn; broken or dislocated bone; or concussion or head injury. Participants classed as rescue and recovery workers were asked about the date of arrival for work, number of days worked, whether work was done on the WTC dust and debris pile, and type of tasks they undertook. To enable comparisons within the cohort, we explored ways to classify the overall level of WTC-related exposure into distinct high and low categories. We developed summary definitions on the basis of consistently reported associations between the individual component variables and adverse WTC-related health outcomes.[1,15,18] Dust cloud exposure was analysed separately. We created separate three-tiered definitions of the overall levels of exposure incurred for each of the two categories of study participants (rescue and recovery and non-rescue and non-recovery participants; panel 1). The combinations of variables that best predicted the risk of asthma after 9/11 were retained, because asthma is the most commonly reported respiratory disorder in WTC-exposed people, and a dose-response relation between WTC-related exposures and asthma has consistently been identified in both rescue and recovery participants and non-rescue and non-recovery participants in several WTC-survivor study cohorts.[1,4,19,20]

We defined pre-9/11 heart disease as self-reported, physician-diagnosed coronary artery disease, angina, heart attack, or any other heart disorder before 9/11, and pre-9/11 cancer as self-reported, physician-diagnosed cancer, except for non-melanoma skin cancer, before 9/11. Participants reporting physician-diagnosed heart disease, stroke, emphysema, diabetes, or cancer before 9/11 were judged to have pre-9/11 chronic disease. For participants missing income data (6918 [16·5%]), income was assigned from the median income for their home zip code obtained from 2000 US census data.

Statistical analysis

Person-time began on the date of participant enrolment into the WTC Health Registry and ended on the date of death or Dec 31, 2009, whichever came earlier. We analysed data for rescue and recovery participants and non-rescue and non-recovery participants separately because of striking differences between sociodemographic and WTC-exposure characteristics. Standardised mortality ratios (SMRs) adjusted for age, sex, race, and calendar year were calculated with LTAS.NET[17] to compare the observed number of deaths with the expected number on the basis of the New York City reference population; 95% CIs were calculated on the basis of Poisson distribution. SMR calculations included person-time and deaths of individuals aged 15 years or older during the study. For people who attained age 15 years during the study, the 15th birthday was judged to be the risk begin date, and person-time and any deaths subsequent to that date were included in SMR calculations.

	Rescue and recovery participants (N=13 337)	Non-rescue and non-recovery participants* (N=28 593)
Person-years of observation	74 967	161 519
Age on 9/11 (years)		
<25	820 (6%)	4759 (17%)
25–44	8277 (62%)	12 119 (42%)
45–64	4101 (31%)	9957 (35%)
≥65	139 (1%)	1758 (6%)
Sex		
Male	10 149 (76%)	11 860 (41%)
Female	3188 (24%)	16 733 (59%)
Race and ethnic origin		
Non-Hispanic white	7580 (57%)	14 380 (50%)
Non-Hispanic black	1957 (15%)	4764 (17%)
Hispanic	2781 (21%)	4335 (15%)
Other	1019 (8%)	5114 (18%)
Study recruitment source		
Self-identified	8781 (66%)	21 837 (76%)
List-identified	4556 (34%)	6756 (24%)
Total household income ($US) in 2002		
<25 000	1342 (10%)	4973 (18%)
25 000–49 999	3559 (27%)	8932 (32%)
50 000–74 999	3550 (27%)	4855 (17%)
≥75 000	4847 (36%)	9025 (33%)
Smoking status at study enrolment		
Never	7078 (54%)	17 321 (61%)
Former	3433 (26%)	6698 (23%)
Current	2681 (20%)	4210 (15%)
History of chronic illness before 9/11		
Yes	1128 (9%)	3382 (12%)
No	11 927 (91%)	24 620 (86%)
WTC-related rescue and recovery exposure level†		
Low	913 (7%)	..
Intermediate	10 599 (81%)	..
High	1639 (12%)	..
WTC-related residential, office, school or transit exposure level†		
None	10 130 (76%)	..
Low	1131 (8%)	13 132 (46%)
Intermediate	1496 (11%)	12 965 (45%)
High	545 (4%)	2091 (7%)

Data are number (%). The study cohort was composed of World Trade Center Health Registry participants who resided in New York City at the time of registry enrolment. Frequencies might not sum to total because of missing values. Percentages might not sum to 100% due to rounding or missing values. 9/11=Sept 11, 2001. WTC=World Trade Center. *Non-rescue and non-recovery worker category includes residents, workers, and school students and school staff, and passers-by of the lower Manhattan area, on 9/11. †Please see panel 1 for definitions of exposure levels.

Table 1: **Characteristics of the study participants**

	All participants		Rescue and recovery participants		Non-rescue and non-recovery participants*	
	n	SMR (95% CI)	n	SMR (95% CI)	n	SMR (95% CI)
All	790	0·57 (0·53–0·61)†	156	0·45 (0·38–0·53)†	634	0·61 (0·56–0·66)†
Tuberculosis and HIV-related disease (01)	20	0·30 (0·18–0·46)†	4	0·14 (0·04–0·36)†	16	0·41 (0·23–0·66)†
MN of buccal cavity and pharynx (02)	6	0·87 (0·32–1·90)	3	1·30 (0·27–3·80)	3	0·66 (0·14–1·92)
MN of digestive organs and peritoneum (03)	75	0·71 (0·55–0·88)†	20	0·72 (0·44–1·11)	55	0·70 (0·53–0·91)†
MN of respiratory system (04)	70	0·81 (0·63–1·02)	12	0·54 (0·28–0·94)‡	58	0·90 (0·69–1·17)
MN of breast (05)	26	0·77 (0·51–1·13)	1	0·22 (0·01–1·21)	25	0·86 (0·56–1·27)
MN of female genital organs (06)	19	0·82 (0·49–1·28)	2	0·67 (0·08–2·43)	17	0·84 (0·49–1·35)
MN of male genital organs (07)	10	0·58 (0·28–1·07)	1	0·28 (0·01–1·54)	9	0·66 (0·30–1·25)
MN of urinary organs (08)	15	1·18 (0·66–1·95)	2	0·63 (0·08–2·27)	13	1·37 (0·73–2·34)
MN of other and unspecified sites (09)	36	0·93 (0·65–1·29)	11	1·04 (0·52–1·87)	25	0·89 (0·57–1·31)
Neoplasms of lymphatic and haematopoietic tissue (10)	27	0·81 (0·53–1·18)	5	0·56 (0·18–1·30)	22	0·90 (0·57–1·37)
Benign and unspecified neoplasms (11)	8	1·79 (0·77–3·53)	3	2·77 (0·57–8·10)	5	1·48 (0·48–3·45)
Diseases of the blood and blood forming organs (12)	1	0·20 (0·00–1·09)	0	0·00 (0·00–2·78)	1	0·26 (0·01–1·47)
Diabetes mellitus (13)	24	0·50 (0·32–0·75)†	1	0·09 (0·00–0·50)†	23	0·63 (0·40–0·95)‡
Mental psychoneurotic and personality disorders (14)	22	0·85 (0·53–1·29)	9	0·97 (0·44–1·85)	13	0·79 (0·42–1·35)
Diseases of the nervous system and sense organs (15)	14	0·93 (0·51–1·55)	1	0·31 (0·01–1·75)	13	1·09 (0·58–1·86)
Diseases of the heart (16)	187	0·42 (0·36–0·48)†	34	0·39 (0·27–0·54)†	153	0·42 (0·36–0·50)†
Other diseases of the circulatory system (17)	44	0·54 (0·39–0·72)†	6	0·33 (0·12–0·72)†	38	0·60 (0·42–0·82)†
Diseases of the respiratory system (18)	57	0·64 (0·48–0·83)†	3	0·18 (0·04–0·54)†	54	0·74 (0·55–0·96)‡
Diseases of the digestive system (19)	26	0·60 (0·39–0·87)†	7	0·52 (0·21–1·06)	19	0·63 (0·38–0·99)‡
Diseases of the skin and subcutaneous tissue (20)	3	1·50 (0·31–4·40)	0	0·00 (0·00–9·54)	3	1·87 (0·38–5·45)
Disease of the musculoskeletal and connective systems (21)	5	0·86 (0·28–2·00)	0	0·00 (0·00–2·71)	5	1·12 (0·36–2·61)
Diseases of the genitourinary system (22)	8	0·36 (0·15–0·70)†	0	0·00 (0·00–0·93)‡	8	0·43 (0·19–0·85)‡
Symptoms and ill-defined conditions (23)	2	0·19 (0·02–0·68)†	0	0·00 (0·00–0·92)‡	2	0·30 (0·04–1·09)
Transportation injuries (24)	6	0·41 (0·15–0·90)‡	3	0·56 (0·11–1·63)	3	0·33 (0·07–0·96)‡
Falls (25)	8	0·82 (0·36–1·62)	1	0·36 (0·01–2·01)	7	1·01 (0·40–2·07)
Other injury (26)	22	0·46 (0·29–0·70)†	12	0·58 (0·30–1·02)	10	0·37 (0·18–0·68)†
Violence (27)	17	0·48 (0·28–0·77)†	9	0·61 (0·28–1·15)	8	0·39 (0·17–0·76)†
Other causes (residual and blank codes; 28)	32	0·64 (0·44–0·90)†	6	0·41 (0·15–0·90)‡	26	0·73 (0·48–1·07)

Data are number or standardised mortality ratios (95% CI). Causes of death are from the National Institute for Occupational Safety and Health (NIOSH) major cause of death categories and are listed with the associated NIOSH number in parentheses. The New York City population was used as the reference population. International Classification of Diseases, 10th revision, codes for NIOSH categories have been published elsewhere.[21] SMR=standardised mortality ratio. MN=malignant neoplasm. *Non-rescue and non-recovery worker category includes residents, workers, school students and staff, and passers-by of the lower Manhattan area on Sept 11, 2001. †p<0·01. ‡p<0·05.

Table 2: **Observed deaths and standardised mortality ratios for major causes of death in participants of the World Trade Center Health Registry residing in New York City, 2003–09**

Cox proportional hazards regression models were used to estimate hazard ratios and 95% CIs for mortality in people of all ages. Separate models were constructed for rescue and recovery participants and non-rescue and non-recovery participants. To assess whether self-referral to the Registry biased the relation between the level of WTC-related exposure and overall mortality, we further stratified our analysis of the association between exposure and mortality in non-rescue and non-recovery participants by study recruitment source. Individuals with missing exposure data were excluded from multivariable models. Multivariable hazard ratios were adjusted for covariates associated with mortality which had a p value less than 0·20 in bivariable analyses: age, sex, race and ethnic origin, income, smoking, and, for non-rescue and non-recovery participants, Registry recruitment source (self-identified *vs* list-identified). We also included history of chronic disease before 9/11 in models of all-cause mortality, and history of heart disease or diabetes in models of heart-disease-related mortality. Rescue and recovery workers who worked exclusively on Staten Island, barges, or transfer stations were excluded because the exposure information obtained in the wave-one survey was insufficiently detailed to allow categorisation.

We assessed the trends in the hazard ratios for exposures by including each exposure as a continuous variable in a multivariable model and testing whether its coefficient was significantly different from zero. There was no evidence that the data violated the proportional hazards assumption. Analyses of proportional hazards were done with SAS version 9.2.

	All participants		Rescue and recovery participants		Non-rescue and non-recovery participants*	
	n	SMR (95% CI)	n	SMR (95% CI)	n	SMR (95% CI)
Haematological malignancies						
Hodgkin's disease (037)	1	0·94 (0·02–5·24)	1	2·62 (0·07–14·59)	0	0·00 (0·00–5·42)
Non-Hodgkin's lymphoma (038)	13	0·96 (0·51–1·65)	1	0·26 (0·01–1·46)	12	1·24 (0·64–2·17)
Multiple myeloma (039)	4	0·58 (0·16–1·48)	1	0·59 (0·01–3·29)	3	0·57 (0·12–1·68)
Leukaemia (040)	9	0·76 (0·35–1·44)	2	0·65 (0·08–2·34)	7	0·80 (0·32–1·64)
Mental psychoneurotic and personality disorders						
Alcoholism (049)	6	0·47 (0·17–1·03)	1	0·18 (0·00–1·00)†	5	0·70 (0·23–1·63)
Other mental disorders (050)‡	16	1·23 (0·70–1·99)	8	2·18 (0·94–4·29)	8	0·85 (0·37–1·68)
Violence						
Intentional self-harm (116)	10	0·57 (0·27–1·04)	6	0·81 (0·30–1·77)	4	0·39 (0·11–1·00)
Assault and homicide (117)	7	0·42† (0·17–0·87)	3	0·43 (0·09–1·26)	4	0·41 (0·11–1·06)

Data are number or standardised mortality ratios (95% CI). Causes of death are from the 119 National Institute for Occupational Safety and Health (NIOSH) minor cause of death categories and are listed with the associated NIOSH number in parentheses. The New York City population was used as the reference population. International Classification of Diseases, 10th revision, codes for NIOSH categories have been published elsewhere.[21] SMR=standardised mortality ratio. *The category of non-rescue and non-recovery participants includes residents, workers, school students and staff, and passersby of the lower Manhattan area on 9/11. †p<0·05. ‡Specific causes of death categorised as other mental disorders in rescue and recovery participants: use of opioids (n=2); use of cocaine (n=2); use of multiple drugs and other psychoactive substances (n=3), and abuse of non-dependence-producing substances (n=1). Specific causes of death categorised as other mental disorders in non-rescue and non-recovery participants: dementia (n=3); use of opioids (n=1); use of cocaine (n=1); and abuse of non-dependence-producing substances (n=3).

***Table 3*: Observed deaths and standardised mortality ratios for selected causes of death of a priori interest in participants of the World Trade Center Health Registry residing in New York City, 2003–09**

Role of the funding source

The CDC's Agency for Toxic Substances and Disease Registry (ATSDR) supported the collection of survey data used in our analysis and participated in the overall design of the Registry, including the initial mortality study design. The sponsors of the study had no role in mortality study data linkage activities, data analysis, data interpretation, or writing of the report. New York City Department of Health and Mental Hygiene supported mortality matching infrastructure development and had a role in the design, data collection, development, and review of the manuscript. The corresponding author had full access to all data and had final responsibility to submit for publication.

Results

Table 1 shows the characteristics of the study group. Median age at 9/11 was 39 (range 12–94) years for rescue and recovery participants and 41 (0–97) years for non-rescue and non-recovery participants. Most rescue and recovery participants were men, whereas over half non-rescue and non-recovery participants were women (table 1). A history of smoking was more common in rescue and recovery participants. About a quarter of those who did rescue and recovery work also had WTC-related exposures at their residences, offices, or schools.

Linkage to mortality data from New York City vital records identified 745 deaths occurring between study enrolment and Dec 31, 2009, and linkage to the National Death Index identified 45 additional deaths up to Dec 31, 2007, for a total of 790 deaths. ICD-10 codes for underlying cause of death were unavailable for two of the deceased. 156 deaths occured in rescue and recovery participants and 634 in non-rescue and non-recovery participants. Of the two decedents aged less than 15 years at death, one died at age 5 years of a brain neoplasm (ICD-10 C71.9), the other at age 14 of a congenital brain malformation (ICD-10 Q04.9). These deaths were not included in SMR calculations, but were included in proportional hazards models.

SMRs for all causes of death were significantly lower than expected for both rescue and recovery participants and non-rescue and non-recovery participants (table 2). No significant increases in SMRs occurred for the major cause of death categories, including respiratory-system diseases, heart diseases, and haematological malignancies; many causes occurred significantly less than expected. One death was due to thyroid cancer (SMR 0·72, 95% CI 0·02–3·99). Other leading causes of cancer deaths in the USA were cancer of the breast (SMR 0·77, 95% CI 0·51–1·13), colon (0·70, 0·44–1·06), rectum (0·68, 0·19–1·74), trachea, bronchus, and lung (0·77, 0·59–0·99), prostate (0·59, 0·28–1·08), and pancreas (1·03, 0·66–1·55).

Table 3 shows SMRs for selected causes of death of a priori interest, grouped according to the NIOSH cause of death categories. None of the SMRs were significantly increased, including those for multiple myeloma and other haematological malignancies, alcoholism, mental disorders, and suicide.

In the 119 NIOSH cause-of-death categories, the only significantly increased SMR was for benign neoplasms of the eye, brain, or other nervous system among all participants (SMR 6·48, 95% CI 1·34–18·94, n=3).

These deaths were due to meningioma, and occurred in 2005 (in non-rescue and non-recovery participants aged 47 and 67 years) and 2008 (a rescue and recovery worker aged 64 years).

We examined relations between mortality and WTC-related exposure levels within the cohort, with low levels of exposures used as the reference categories. Table 4 shows adjusted hazard ratios for all-cause mortality. The level of WTC-related exposure was not significantly associated with all-cause mortality in rescue and recovery participants (p for trend 0·49). In non-rescue and non-recovery participants, both intermediate and high levels of exposure were associated with mortality compared with low exposure (p for trend 0·003; table 4). In a subanalysis of non-rescue and non-recovery participants stratified by study recruitment source, the magnitude of the association between WTC exposure and mortality was similar in self-identified and list-identified participants (table 5).

In non-rescue and non-recovery participants, a high level of exposure was significantly associated with heart-disease-related death (table 6). Small participant numbers

	Rescue and recovery participants*			Non-rescue and non-recovery participants†		
	Person-years of observation	Number of deaths‡	Adjusted hazard ratio (95% CI)	Person-years of observation	Number of deaths‡	Adjusted hazard ratio (95% CI)
Age on 9/11 (years)	..	..	1·07 (1·05–1·09)	..	..	1·09 (1·08–1·10)
Sex						
Male	56 365	131	2·25 (1·38–3·68)	65 742	287	1·40 (1·19–1·65)
Female	17 562	19	Reference	93 531	331	Reference
Race and ethnic origin						
White	42 308	76	Reference	81 022	307	Reference
Black	10 782	35	1·72 (1·14–2·61)	26 597	101	1·27 (1·01–1·61)
Hispanic	15 252	28	1·11 (0·70–1·74)	24 055	69	0·93 (0·71–1·23)
Other or missing	5585	11	1·10 (0·57–2·15)	27 598	141	0·91 (0·72–1·13)
Study recruitment source						
Self-identified	..	..	..	122 394	426	Reference
List-identified	..	..	..	36 879	192	0·99 (0·82–1·17)
Total household income ($US) in 2002						
<25 000	7260	20	1·67 (0·96–2·89)	26 884	236	1·52 (1·16–1·99)
25 000–49 999	19 498	44	1·34 (0·87–2·07)	49 430	197	1·37 (1·06–1·76)
50 000–74 999	19 805	41	1·29 (0·84–1·97)	27 346	74	1·23 (0·91–1·66)
≥75 000	27 170	45	Reference	51 085	104	Reference
Smoking status at study enrolment						
Never	39 171	56	Reference	96 673	284	Reference
Former	19 115	47	1·24 (0·83–1·85)	37 383	207	1·15 (0·96–1·39)
Current	14 912	45	2·07 (1·40–3·08)	23 398	113	2·16 (1·72–2·70)
History of chronic illness before 9/11§						
Yes	6250	29	1·65 (1·08–2·51)	18 370	255	1·90 (1·60–2·26)
No	66 182	116	Reference	137 946	341	Reference
WTC-related rescue and recovery exposure level¶						
Low	5147	9	Reference	..	..	..
Intermediate	59 636	121	1·03 (0·52–2·06)	..	..	..
High	9144	20	1·25 (0·56–2·78)	..	..	..
WTC-related residential, office, school, or transit exposure level¶						
Low	..	..	..	74 497	173	Reference
Intermediate	..	..	..	72 923	390	1·22 (1·01–1·48)
High	..	..	..	11 853	55	1·56 (1·15–2·12)

Separate models were constructed for rescue and recovery participants (n=13 337) and non-rescue and non-recovery participants (n=28 593). 9/11=Sept 11, 2001. WTC=World Trade Center *Model for rescue and recovery participants did not adjust for study recruitment source because this variable was not associated with mortality (with p<0·20 in bivariable analysis). †The category of non-rescue and non-recovery participants includes residents, workers, school students and staff, and passers-by of the lower Manhattan area on 9/11. ‡Six deceased rescue and recovery participants and 16 deceased non-rescue and non-recovery participants were excluded from this analysis because of missing exposure data. Number of deaths may not sum to total due to missing values. §Chronic illness was defined as a self-reported physician diagnosis of one or more of the following disorders before 9/11: coronary artery disease, angina, heart attack, any other heart disorder, stroke, emphysema, diabetes, or cancer (except non-melanoma skin cancer). ¶Please see panel 1 for definitions of exposure levels.

Table 4: **Adjusted hazard ratios for all-cause mortality in rescue and recovery participants and non-rescue and non-recovery participants**

	Self-identified participants			List-identified participants		
	Person-years of observation	Number of deaths†	Adjusted hazard ratio (95% CI)	Person-years of observation	Number of deaths†	Adjusted hazard ratio (95% CI)
Low	55 177	116	Reference	19 320	57	Reference
Intermediate	57 554	270	1·30 (1·04–1·64)	15 369	120	1·07 (0·76–1·51)
High	9663	40	1·63 (1·13–2·34)	2190	15	1·46 (0·82–2·61)

Lists of potentially eligible people were obtained from lower Manhattan area employers and government agencies (list-identified participants), and broad-based, multilingual media campaigns encouraged World Trade Center (WTC) exposed people to contact the WTC Health Registry via a website or toll-free telephone number for eligibility screening (self-identified participants). Model for non-rescue and non-recovery participants (n=28 593) adjusted for sex, age, race and ethnic origin, income, smoking status, and history of chronic illness before Sept 11, 2001. *Please see panel 1 for definitions of exposure levels. †16 deceased non-rescue and non-recovery participants were excluded from this analysis because of missing exposure data.

Table 5: **Adjusted hazard ratios for all-cause mortality in non-rescue and non-recovery participants, by WTC-related residential, office, school, or transit exposure level*, stratified by study recruitment source**

	Person-years of observation	Number of heart-disease deaths‡	Adjusted hazard ratio (95% CI)
Low	74 497	34	Reference
Intermediate	72 923	99	1·21 (0·80–1·83)
High	11 853	14	2·06 (1·10–3·86)

Model for non-rescue and non-recovery participants (n=28 593) adjusted for sex, age, income, smoking status, pre-9/11 diabetes, pre-9/11 heart disease, and study recruitment source (self-identified *vs* list-identified). Non-rescue and non-recovery participant category includes residents, workers, and school students and staff, and passers-by of lower Manhattan area on 9/ 11. †See panel 1 for definitions of exposure levels. ‡Six rescue and recovery participants who died due to heart disease were excluded from this analysis because of missing exposure data.

Table 6: **Adjusted hazard ratios for heart-disease-related mortality among non-rescue and non-recovery participants, by WTC-related residential, office, school, or transit exposure level*†**

prevented further exploration of other specific causes of death, including deaths related to heart disease in rescue and recovery participants.

In models including both rescue and recovery and non-rescue and non-recovery participants and adjusted for the covariates shown in table 4 and table 5, dust cloud exposure on 9/11 was not associated with all-cause mortality (adjusted hazard ratio 0·97, 95% CI 0·84–1·12) or with mortality related to heart disease (1·04, 0·77–1·42).

Discussion

We did not identify excess overall mortality in the WTC Health Registry cohort between 2003 and 2009 relative to New York City rates. Within the cohort, however, high levels of WTC-related exposure were associated with an increased risk of all-cause mortality and heart-disease-related mortality in non-rescue and non-recovery participants, with hazard ratios that suggested a dose-response relation (panel 2).

Because most illnesses that are established or possible sequelae of WTC-related exposures have long latency or long median survival periods, the absence of a relation between reported dust-cloud exposure by itself and mortality risk in our study is not surprising. For non-rescue and non-recovery participants, a high level of exposure meant having two or more injuries on 9/11, not evacuating their home on 9/11 (for area residents), and being present at school on 9/11 (for area students and school staff). This combination of WTC exposures identifies a subgroup whose overall exposure level was more intense than that of other non-rescue and non-recovery participants. Our data are not sufficiently precise to identify specific exposures responsible for increased mortality risk. Therefore, our findings do not single out this highly exposed subgroup alone for clinical surveillance. They do, however, support long-term monitoring of the health of all 9/11 survivors, with emphasis on modification of risk factors for heart disease.

Although a long observation period might be necessary to detect excess deaths due to most chronic illnesses, our findings suggest that, by the end of 2009, the number of deaths in this study population was lower than what would be expected in the New York City general population. A deficit in mortality has been reported during the early years of observation in many other (non-WTC) cohort studies of volunteers, and of young people.[22–25] This deficit might be due in part to the healthy worker effect—an occurrence of lower-than-expected mortality in worker cohorts that is generally attributed to the high baseline level of health required to enter and remain in the workforce.[26] An analogous effect has been seen in people who volunteer for health studies, and also might have contributed to the low relative mortality in both rescue and recovery and non-rescue and non-recovery participants.[24]

The only significantly raised SMR was for meningioma-related deaths. Meningiomas related to radiation exposure, the single known aetiological risk factor for this form of cancer, usually have a latency period of 20 years or more,[27] so our finding was most probably due to chance. We also identified a two-times increase in substance-related deaths for rescue and recovery participants (table 3).

Because objective measures of WTC-related exposure are not available, our study relied on self-reported exposure data. We developed summary categories of WTC-related exposure that were sufficiently distinct from

Panel 2: Research in context

Systematic review

This is the first comprehensive report on mortality in survivors of the Sept 11, 2001 World Trade Center Disaster. We searched PubMed for reports published from Sept 11, 2001, to Feb 28, 2011, using the search terms "September 11 Terrorist Attacks", "World Trade Center", "WTC", and "September 11, 2001" without language restrictions. To ensure comprehensiveness, we compared the results of our search with relevant literature reviews. No population-based studies on mortality had been published at the time of the search.

Interpretation

Among World Trade Center Health Registry participants residing in New York City, overall death rates in 2003–09 were not higher than expected when compared to the general New York City population. However, within the cohort, non-rescue and non-recovery participants with high levels of WTC-related exposure had an increased risk of all-cause mortality and heart-disease-related mortality compared with those with low exposure. Continued monitoring of all-cause mortality and disease-specific mortality will be needed.

one another to enable comparisons within each of the two subcohorts. These categories were based on individual exposure variables, which have consistently been associated with asthma, PTSD, and other health outcomes in previous analyses.[1,28]

In keeping with a previous finding that injury during the disaster was associated with post-9/11 PTSD,[29] injuries sustained by Registry participants on 9/11 were a key component of the WTC-exposure definition for non-rescue and non-recovery participants. The type of injury most frequently reported by participants was eye injury or irritation, which might have been less severe than other injuries queried (such as a broken or dislocated bone), and thus a less powerful indicator of high overall exposure. Therefore, to ensure that our definition captured the most exposed group, two or more injuries were required for the highest exposure level in non-rescue and non-recovery workers. Additional exploration of the relation between acute injuries sustained by individuals on 9/11 and overall mortality is needed.

To assess whether self-selection bias could have influenced our findings, we assessed whether study recruitment source (list-identification *vs* self-identification) was an important confounding variable for the relation between WTC exposure and mortality. In bivariable analysis, study recruitment source was significantly associated with mortality in non-rescue and non-recovery participants, whereas it was not significant in rescue and recovery participants. We therefore included this variable in the multivariable model for non-rescue and non-recovery participants. We also stratified our analysis of the relation between WTC-related exposures and overall mortality in non-rescue and non-recovery participants by study recruitment source. The association between WTC exposure and mortality was not significant in list-identified participants, probably because of the small size of this subgroup. However, the magnitude of the association was similar in the two groups, suggesting that the exposure-outcome relation did not differ substantially according to study recruitment source.

During the months of disruption and concerted rescue and recovery efforts after the 9/11 disaster, most people directly exposed to the events of 9/11 in New York City were not enumerated. Since systematic sampling of the exposed population was not possible, we recruited potentially eligible people into the Registry from several groups who were known to be directly affected, including rescue and recovery workers and lower Manhattan area residents and workers. A previous Registry study using raking ratio estimation and census demographics suggested that WTC-exposure-outcome relations in residents of the lower Manhattan area were probably representative of such relations in the larger affected population.[28] Characteristics of Registry rescue and recovery participants were similar to those of rescue and recovery workers assessed in the WTC worker and volunteer medical screening programme.[20] An exception, a difference in the proportion of workers arriving on 9/11 (40·5% of rescue and recovery workers in the medical screening programme compared with 25·5% of those in the Registry), probably exists because the screening programme's goal was to identify WTC-related physical or mental health problems, whereas the Registry aimed to recruit all WTC-exposed people.

We also compared Registry participants who reported being firefighters employed by the Fire Department of New York City (FDNY) with a published description of 10 870 FDNY firefighters who were present at the WTC disaster.[2] We identified similarity between demographic and exposure characteristics of the two samples (data not shown). Beyond these comparisons, however, full definition of the representativeness of our sample is not possible, which might limit the generalisability of our study results.

We did not have sufficient statistical power for detailed analyses of the relations between WTC-related exposures and most specific causes of death, because of the short observation period. Our SMR calculations did not include the two participants aged 14 years or younger, one of whom died of a brain neoplasm and the other of a congenital brain malformation. Although our results mirror certain well-established risk factors for premature mortality in New York and the USA overall, including smoking status and black versus white race,[30,31] we did not have data for other known risk factors of mortality, including body-mass index and alcohol use. We plan to gather such data in future questionnaires.

Despite these limitations, this exploratory study comprehensively depicts mortality in a well-defined

cohort of 9/11 survivors, providing a baseline for continued surveillance. Results suggest that screening for and management of modifiable risk factors associated with heart disease, including smoking, might be of particular importance in this population. It will be crucial to determine whether these associations are sustained with extended observation, and whether such associations become apparent in rescue and recovery participants.

Contributors

RMB, MRF, and JEC initiated the study. JEC, JK, and HTJ undertook and supervised the collection of mortality data. HTJ, JEC, JL, and ID prepared data for analysis. HTJ drafted the report and did the main statistical analysis with input from SDS, JEC, LS, JL, CMG, JLH, RMB, and ID. All authors participated in interpretation of the final results and editing of the report. All authors saw and approved the final version of the report.

Conflicts of interest

We declare that we have no conflicts of interest.

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