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RESEARCH ARTICLE

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Stroke hospitalizations, posttraumatic stress disorder, and 9/11-related dust exposure: Results from the World Trade Center Health Registry

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Abstract

Background: Few studies have examined the association between disaster-related factors and stroke by subtype or number. We investigated the association between 9/11-related posttraumatic stress disorder (PTSD), dust exposure, and stroke subtype as well as recurrent strokes.

Methods: The study included 29,012 individuals enrolled in the World Trade Center Health Registry. Stroke cases were obtained by matching Registry enrollees to the New York State Department of Health's discharge records for inpatient visits between 2000 and 2016. Cox proportional hazards regression models were performed to examine the association between 9/11-related risk factors and stroke by subtype. Multinomial logistic regression models were conducted to assess the associations between the same risk factors and the number of stroke hospitalizations.

Results: Having PTSD significantly increased the risk of developing ischemic and hemorrhagic stroke, with adjusted hazards ratios (AHRs) of 1.64 (95% confidence interval [CI]: 1.28–2.10) and 1.73 (95% CI: 1.10–2.71), respectively. The point estimate for dust cloud exposure, although not significant statistically, suggested an increased risk of ischemic stroke (AHR = 1.20, 95% CI: 0.96–1.50). PTSD was significantly associated with recurrent strokes with an adjusted odds ratio of 1.79 (95% CI: 1.09–2.95).

Conclusions: PTSD is a risk factor for both ischemic and hemorrhagic stroke and is associated with recurrent strokes. Dust exposure on 9/11 is a possible risk factor for ischemic stroke but not for hemorrhagic stroke, and was not associated with recurrent strokes. Our findings warrant additional research on stroke-morbidity and mortality associated with 9/11-related PTSD and dust exposure.

KEYWORDS

9/11 disaster, dust exposure, hemorrhagic stroke, ischemic stroke, PTSD, recurrent stroke, World Trade Center

1 | INTRODUCTION

The long-term health effects of the World Trade Center (WTC) terrorist attacks on September 11, 2001 (9/11) have been acknowledged in recent literature. The frequently studied health outcomes linked to 9/11 include physical health conditions such as asthma, autoimmune diseases, cardiovascular diseases, and cancer,[1–6] mental health conditions such as posttraumatic stress disorder (PTSD) and depression,[7–10] and physical and mental health comorbidities.[11] Many studies have reported significant associations between these health outcomes and 9/11-related dust exposure,[1–6] with some studies also noting the temporal associations between mental health problems, particularly 9/11-related PTSD, and physical health outcomes.[12–17]

A number of studies have observed an association between heart disease and 9/11 exposures including PTSD and dust/debris cloud and injury.[3,4] Other circulatory conditions such as stroke have also been shown to be associated with PTSD and less significantly so with dust cloud exposure.[18,19] In general, traumatic stress is related with higher risk of cardiovascular diseases among civilians as well as military veterans.[20–24] In the WTC Health Registry (WTCHR, or the Registry) cohort, 9/11-related PTSD measured at study enrollment was first found to be associated with increased cerebrovascular disease hospitalizations (including various types of stroke) during 2003–2010 among male survivors.[18] Findings from a recent study reported baseline PTSD as a risk factor for stroke for both male and female 9/11 first responders involved in debris clean-up at the disaster site.[19] Using self-reported stroke from survivors and rescue and recovery workers (RRWs) over a longer period of observation, our previous study[13] reported results consistent with Remch and her colleagues[19] while also accounting for the course of PTSD measured across multiple survey waves.

The association between dust cloud exposure and stroke is not as consistent as that between PTSD and stroke. One early study suggested higher stroke prevalence among survivors exposed to the dust and debris cloud,[25] but more recent studies did not identify an association between dust cloud exposure and stroke hospitalizations.[18,19] Our previous study[13] on this topic found that individuals with intense dust exposure had an increased risk of developing stroke, but we recognized that stroke cases used in that study were self-reported which may have resulted in bias in the stroke–dust cloud association. Self-reported cases, as opposed to confirmed hospitalizations, might include relatively mild cases of stroke such as transient ischemic attacks (TIAs) which could affect the association with dust exposure when all strokes are combined and treated as one outcome. Several non-9/11-related studies have suggested that the association between particulate matter (PM) exposure and stroke might only exist for ischemic stroke but not for hemorrhagic stroke.[26,27]

Recognizing that risk factors for two major subtypes of stroke, ischemic, or hemorrhagic, could be similar and distinct, and the risk for recurrent strokes could differ by subtype,[28] the present study is a follow-up analysis using matched stroke hospitalization data for the same Registry cohort as our previous study. With hospitalization data that can distinguish stroke subtypes, we first aim to validate our previous findings on PTSD and stroke, and then provide more robust and in-depth findings on the association of dust exposure and stroke subtype. Recurrent strokes account for about 30% of strokes in population-based studies and are more likely to lead to disability or death than the first stroke.[29] This study also aims to assess, for the first time, the association between 9/11-related exposure and the number of strokes.

Using the Registry survey data and the New York State Department of Health's hospitalization data, this study investigates how PTSD and dust cloud exposure on 9/11 are related to the risk of ischemic and hemorrhagic stroke as well as recurrent strokes. We hypothesize that PTSD increases the risk of both stroke subtypes while dust exposure increases the risk of ischemic stroke. We also hypothesize that PTSD, as a persistent condition with lasting impact, is associated with recurrent strokes while the effect of 9/11-related dust exposure tends to be instant and transitory and thus would not be associated with recurrent stroke.

2 | METHODS

2.1 | Data sources

The WTC Health Registry monitors the long-term physical and mental health effects of the September 11, 2001 terrorist attacks in New York City. The initial survey, conducted in 2003-2004 (Wave 1), enrolled over 71,000 individuals into the Registry who were also invited to complete three follow-up surveys in 2006–2007 (Wave 2), 2011–2012 (Wave 3), and 2015–2016 (Wave 4). The development of the Registry cohort and recruitment methods have been described elsewhere.[30,31] The US Centers for Disease Control and Prevention and the New York City Department of Health and Mental Hygiene institutional review boards approved the Registry protocol, including use of the data.

The New York State Department of Health's Statewide Planning and Research Cooperative System (SPARCS) contains administrative data including patient demographics and diagnoses for all inpatient and outpatient (ambulatory surgery, emergency department, and outpatient service) visits reported by a New York State healthcare facility to the New York State Department of Health.[32] All 71,426 individuals enrolled in the Registry at the Wave 1 survey were matched to SPARCS discharge records of inpatient visits from January 1, 2000 to December 31, 2016 using a hierarchical deterministic matching algorithm based on letters from the patient's name, date of birth, last four digits of their social security number, and sex.

2.2 | Study sample

Enrollees who were residents of New York State on 9/11/2001 form the starting sample since SPARCS discharge records are limited to

visits in New York State facilities ($N = 43,757$). The study was further limited to Registry enrollees who completed at least Waves 1 and 2 as both waves contained questions used to derive the dust cloud exposure variable ($N = 29,497$). Enrollees hospitalized with a stroke before their study enrollment (i.e., before their interview date at Wave 1) were also excluded. Furthermore, because of the rarity of stroke at young age and differences in stroke risk, symptoms, and treatment between children and adults, enrollees less than 18 years of age on 9/11/2001 were also excluded from the study as were those whose age on 9/11 is unknown. The final analytical data set for this study included 29,012 enrollees.

2.3 | Study outcome

The outcome of interest, stroke, was defined by the enrollee having one or more inpatient records with a stroke diagnosis code in the hospitalization database between study enrollment (i.e., their interview date at Wave 1) and December 31, 2016. Using the 25 available diagnosis fields, we employed the matched WTCHR-SPARCS data set to identify enrollees hospitalized for stroke, and classified them by the subtypes TIA, ischemic stroke, and hemorrhagic stroke using the 9th and 10th revisions of the International Classification of Disease, Clinical Modification (ICD-9-CM and ICD-10-CM, respectively). Previously validated ICD-9-CM codes were used for this study, and their ICD-10-CM equivalent were identified with a general equivalence mappings tool and a review of codes published in 2013 with the updated stroke definition from the American Heart Association/American Stroke Association (Table 1).[33–35] ICD-9-CM codes captured discharges before October 1, 2015 while ICD-10-CM codes captured discharges on or after October 1, 2015.

In this study, ischemic strokes and TIAs were grouped and reported together as one subtype. Additionally, in the classification of stroke subtype for each visit, hemorrhagic strokes were prioritized over ischemic strokes or TIAs for enrollees with more than one subtype in a single hospital visit.[36,37] After classifying subtype for each visit, Registry data were left-joined to the stroke-based subset of the WTCHR-SPARCS matched data set to create an analytic sample. If an enrollee in the sample had no stroke hospitalizations, the enrollee was classified as not having stroke; for all others, two stroke-based outcomes were defined: (1) stroke, categorized by subtype (ischemic or TIA vs. hemorrhagic) with the earliest stroke hospitalization kept if an enrollee had multiple hospitalizations, and (2) total number of stroke hospitalizations grouped as 0, 1, or 2 or more strokes.

2.4 | PTSD, dust cloud exposure, and covariates

The two predictors in this study were probable PTSD and 9/11 dust cloud exposure. PTSD related to 9/11 was assessed using the PTSD Checklist-Specific (PCL-S), a 17-item self-reported symptom scale that referred specifically to the events of September 11, 2001.

TABLE 1 International Classification of Diseases codes for stroke by subtype

Stroke types	ICD-9-CM codes (discharges before October 1, 2015)	ICD-10-CM codes (discharges on or after October 1, 2015)
Hemorrhagic stroke	430	I60.x
	431	I61.x
	432.x	I62.x
Ischemic stroke	433.x1	I63.x
	434.x1	
	436	I67.89
Transient ischemic attack	435.x	I67.848, G45.0, G45.1, G45.2, G45.8, G45.9

Abbreviations: ICD-9-CM, International Classification of Diseases, 9th Revision, Clinical Modification; ICD-10-CM, International Classification of Diseases, 10th Revision, Clinical Modification.

This scale corresponded to the PTSD symptoms in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV 1994) and instructed enrollees to rate the degree to which they were bothered by symptoms in the last 30 days from 1 (*Not at all*) to 5 (*Extremely*). Responses to all 17 items in the checklist were then summed to generate a total score from 17 to 85 with probable PTSD (referred to as PTSD hereafter) being defined as a PCL score ≥44.[38] PTSD was assessed in all four waves of Registry surveys.

Dust cloud exposure on 9/11 was dichotomously classified as "intense" or "minimal or none" with intense exposure defined as having been in the dust cloud on 9/11 and reporting at least one of the following five experiences: unable to see more than a few feet in front of oneself, difficulty walking or finding one's way, trouble finding shelter, covered with dust from head to toe, and unable to hear anything. The "minimal or none" category consisted of those who reported being in the dust cloud but not experiencing intense exposure, or those who reported no dust cloud exposure at all.

Sociodemographic characteristics of interest in this study sample were age on 9/11/2001, sex, race/ethnicity, education, marital status, and Registry eligibility group. Marital status was defined as being partnered (married or living together) or nonpartnered (never married, widowed, or divorced or separated). Five hierarchical Registry eligibility groups were collapsed into two mutually exclusive groups based on likelihood of being exposed to dust cloud: RRWs and all others (lower Manhattan residents, area workers, or passers-by on the morning of 9/11, and school students/staff on 9/11). Risk factors for stroke such as smoking status, history of hypertension, and history of diabetes were also included in the models. Smoking status was classified as "Never smoker," "Former smoker," or "Current smoker." History of hypertension and diabetes were both established with an affirmative response to the self-report question "Have you ever been told by a doctor or other health professional that you had hypertension/diabetes?" at Waves 2, 3, or 4.

Since enrollees may not have completed all four wave surveys, we defined four "wave completion" subgroups to correctly characterize some of the study's risk factors and covariates: (a) Waves 1 through 4, (b) Waves 1 through 3 only, (c) Waves 1 and 2 only, and (d) Waves 1, 2, and 4 only. Values for PTSD, marital status, and smoking status were selected from the wave closest to, but preceding, the earliest-occurring stroke hospitalization by each wave completion subgroup because of our focus on the temporal relationship between these variables and the subsequent development of stroke. For enrollees who did not have a stroke, the values of PTSD, marital status, and smoking status reported in the most recent wave completed were used.

2.5 | Statistical analysis

Two types of analyses were performed controlling for smoking status, hypertension, diabetes, and potential confounders including age at 9/11/2001, sex, race/ethnicity, education, marital status, and eligibility group. Cox proportional hazards regression methods were employed to investigate the association between the two 9/11-related risk factors (PTSD and dust cloud exposure) and time from Registry enrollment to the occurrence of stroke. Separate models were developed by stroke subtypes: "ischemic stroke or TIA only" and "hemorrhagic stroke only." The survival time from Registry enrollment to the admission date of first hospitalization for stroke was treated as uncensored for enrollees who experienced stroke whereas the survival time from Registry enrollment to the date of their last completed survey was treated as censored for enrollees who did not experience stroke. The proportional hazards assumption was tested for PTSD and dust cloud exposure in separate Cox regressions from the main analyses by creating interaction terms between each variable and log (time to event for stroke/censoring) and testing the statistical significance of these interactions. Statistical tests were considered significant if the associated p-value was less than 0.05.

For the second analysis focusing on the number of stroke hospitalizations per enrollee characterized as 0, 1, or 2 or more strokes, multinomial logistic regressions were performed to determine the associations between the number of stroke hospitalizations and PTSD and dust cloud exposure. This analysis was done with all strokes irrespective of subtype and controlled for the covariates described above.

All analyses were performed using R version 3.5.2.

3 | RESULTS

Among the 29,012 enrollees in the study, 475 (1.64%) had at least one stroke hospitalization, 366 of which were categorized as having an ischemic stroke or TIA and 109 of which as having a hemorrhagic stroke (Table 2). Enrollees in this study sample were largely male, non-Hispanic White, college-educated, and partnered, and had no history of diabetes, no or minimal dust cloud exposure on 9/11, and

TABLE 2 Characteristics of study sample by stroke subtype (N = 29,012)

	Ischemic stroke or transient ischemic attack (n = 366)		Hemorrhagic stroke (n = 109)		No stroke (n = 28,537)	
	N	%	*N*	%	*N*	%
Sex						
Male	248	67.76	73	66.97	17,834	62.49
Female	118	32.24	36	33.03	10,703	37.51
Age at 9/11/2001, years						
18–44	106	28.96	33	30.28	18,074	63.34
45+	260	71.04	76	69.72	10,463	36.66
Race/ethnicity						
Non-Hispanic White	230	62.84	63	57.80	18,972	66.48
Non-Hispanic Black	70	19.13	21	19.27	3744	13.12
Hispanic	43	11.75	17	15.60	3788	13.27
Asian and multiracial	23	6.28	8	7.34	2033	7.12
Education						
High school or below	110	30.05	28	25.69	6655	23.32
College	189	51.64	57	52.29	16,582	58.11
Postgraduate	65	17.76	24	22.02	5219	18.29
Missing	2	0.55	0	–	81	0.28
Marital status						
Partnered	217	59.29	63	57.80	19,136	67.06
Nonpartnered	143	39.07	45	41.28	8961	31.40
Missing	6	1.64	1	0.92	440	1.54
Smoking status						
Current smoker	66	18.03	29	26.61	2948	10.33
Former smoker	128	34.97	36	33.03	8336	29.21
Never smoker	165	45.08	40	36.70	16,463	57.69
Missing	7	1.91	4	3.67	790	2.77
History of hypertension						
Yes	265	72.40	83	76.15	12,407	43.48
No	101	27.60	26	23.85	16,130	56.52
History of diabetes						
Yes	111	30.33	25	22.94	3751	13.14
No	255	69.67	84	77.06	24,786	86.86

TABLE 2 (Continued)

	Ischemic stroke or transient ischemic attack (*n* = 366)		Hemorrhagic stroke (*n* = 109)		No stroke (*n* = 28,537)	
	N	%	*N*	%	*N*	%
Posttraumatic stress disorder						
Yes	99	27.05	30	27.52	4973	17.43
No	260	71.04	77	70.64	22,949	80.42
Missing	7	1.91	2	1.83	*615*	2.16
Dust intensity						
Intense	158	43.17	38	34.86	9773	34.25
None/Minimal	208	56.83	71	65.14	18,763	65.75
Missing	0	–	0	–	1	<0.01
Eligibility group						
Rescue/recovery worker	176	48.09	47	43.12	14,016	49.12
Other	190	51.91	62	56.88	14,521	50.88

no PTSD. However, between stroke cases (for both subtypes) and non-stroke cases, the distribution by age, smoking status, history of hypertension and diabetes, and PTSD was noticeably different, with higher proportion of older enrollees (≥45 years old on 9/11), current smokers, enrollees with history of hypertension, diabetes, and PTSD among stroke cases. There were several differences in characteristics by stroke subtype as well. For example, 11.75% of enrollees who had an ischemic stroke or TIA were Hispanic compared with 15.60% who had a hemorrhagic stroke. Approximately 45.08% of enrollees who had an ischemic stroke or TIA never smoked compared with 36.70% who had a hemorrhagic stroke, while 18.03% who had an ischemic stroke or TIA were current smokers compared with 26.61% who had a hemorrhagic stroke. Enrollees who had an ischemic stroke or TIA had a smaller proportion with a history of hypertension compared with enrollees who had a hemorrhagic stroke (72.40% vs. 76.15%, respectively) but a higher proportion with a history of diabetes (30.33% and 22.94%, respectively). Finally, with regard to dust cloud exposure, 43.17% of those who had an ischemic stroke or TIA had intense dust cloud exposure compared with 34.86% of those who had a hemorrhagic stroke. These different characteristics between two stroke subtypes suggested that combining all strokes and treating them as one outcome may result in the loss of information or even misrepresentation of their actual associations with risk factors.

Table 3 summarizes the Cox proportional hazards regression results by stroke types. PTSD was significantly associated with the

TABLE 3 Risk factors for stroke hospitalizations by stroke subtype[a]

	N = 27,439 Ischemic stroke or transient ischemic attack (*n* = 348)		*N* = 27,194 Hemorrhagic stroke (*n* = 103)	
	AHR	95% CI	AHR	95% CI
Sex				
Male	**1.41**	**(1.08, 1.83)**	**1.67**	**(1.03, 2.71)**
Female		Ref		Ref
Age at 9/11/2001				
18–44		Ref		Ref
45+	**3.01**	**(2.35, 3.84)**	**2.76**	**(1.78, 4.29)**
Race/Ethnicity				
Non-Hispanic White		Ref		Ref
Non-Hispanic Black	**1.37**	**(1.02, 1.85)**	**1.73**	**(1.00, 3.01)**
Hispanic	0.97	(0.69, 1.36)	1.59	(0.90, 2.82)
Asian & multi-racial	1.01	(0.65, 1.58)	1.40	(0.66, 2.96)
Education				
High school or below		Ref		Ref
College	0.83	(0.65, 1.05)	1.09	(0.68, 1.76)
Postgraduate	0.97	(0.70, 1.36)	1.53	(0.84, 2.80)
Marital status				
Partnered	**0.79**	**(0.62, 0.99)**	0.78	(0.51, 1.19)
Nonpartnered		Ref		Ref
Smoking status				
Current smoker	**2.45**	**(1.82, 3.29)**	**4.38**	**(2.66, 7.23)**
Former smoker	**1.31**	**(1.03, 1.67)**	1.50	(0.94, 2.39)
Never smoker		Ref		Ref
History of Hypertension				
Yes	**1.85**	**(1.44, 2.38)**	**2.65**	**(1.64, 4.29)**
No		Ref		Ref
History of diabetes				
Yes	**1.63**	**(1.28, 2.06)**	1.00	(0.62, 1.62)
No		Ref		Ref
Posttraumatic stress disorder				
Yes	**1.64**	**(1.28, 2.10)**	**1.73**	**(1.10, 2.71)**
No		Ref		Ref

(Continues)

TABLE 3 (Continued)

	N = 27,439 Ischemic stroke or transient ischemic attack (n = 348)		N = 27,194 Hemorrhagic stroke (n = 103)	
	AHR	95% CI	AHR	95% CI
Dust intensity				
Intense	1.20	(0.96, 1.50)	0.87	(0.57, 1.32)
None/minimal		Ref		Ref
Eligibility group				
Rescue/recovery worker		Ref		Ref
Other	0.97	(0.76, 1.23)	1.18	(0.76, 1.82)

[a]Because of missing data in the outcome, predictors, or covariates, the sample and number of stroke cases used in the models are slightly different from what are shown in Table 2.

risk of ischemic stroke or TIA (adjusted hazards ratio [AHR]: 1.64, 95% confidence interval [CI]: 1.28–2.10) and the risk of hemorrhagic stroke (AHR: 1.73, 95% CI: 1.10–2.71). The point estimate for dust cloud exposure suggested that it had a positive but not statistically significant association with the risk of ischemic stroke or TIA (AHR: 1.20, 95% CI: 0.96–1.50), but not with hemorrhagic stroke (AHR: 0.87, 95% CI: 0.57–1.32). The risk of both stroke subtypes was greater for those who were male, 45 years of age or older, current smokers, and had a history of hypertension. non-Hispanic Black enrollees had a higher risk of ischemic stroke or TIA compared with non-Hispanic White enrollees (AHR: 1.37, 95% CI: 1.02–1.85) while the risk for hemorrhagic stroke was also significantly higher with a wider confidence interval (AHR: 1.73, 95% CI: 1.00–3.00). Being partnered was significantly associated with a lower risk of ischemic stroke or TIA (AHR: 0.79, 95% CI: 0.62–0.99) but was not associated with the risk of hemorrhagic stroke. Former smokers had a significantly higher risk of ischemic stroke or TIA (AHR: 1.31, 95% CI: 1.03–1.67) but not a higher risk of hemorrhagic stroke compared with never smokers. Similarly, those with a history of diabetes had a higher risk of ischemic stroke or TIA (AHR: 1.63, 95% CI: 1.28–2.06) but not a higher risk of hemorrhagic stroke. Education and Registry eligibility group were not associated with a risk for either stroke subtype.

The multinomial logistic regression results are shown in Table 4. PTSD was significantly associated with having one stroke (adjusted odds ratio [AOR]: 1.39, 95% CI: 1.09–1.77), and with two or more strokes (AOR: 1.79, 95% CI: 1.09–2.95) whereas dust cloud exposure was significantly associated with having one stroke (AOR: 1.33, 95% CI: 1.08–1.65) but not two or more strokes. Compared with those with no strokes, enrollees had higher odds of one stroke (AOR: 2.42, 95% CI: 1.81–3.22) and even higher odds of two or more strokes (AOR: 3.02, 95% CI: 1.69–5.42) if they were a current smoker, had a history of hypertension (one stroke—AOR: 2.26, 95% CI: 1.77–2.88; two or more strokes—AOR: 2.71, 95% CI: 1.54–4.79), or a history of diabetes (one stroke—AOR: 1.48, 95% CI: 1.16–1.89; two or more strokes—AOR: 2.04, 95% CI: 1.25–3.33). Older age was significantly associated with having one stroke (AOR: 3.32, 95% CI: 2.62–4.22) and, to a lesser magnitude albeit still significant, having two or more strokes (AOR: 2.65, 95% CI: 1.60–4.39). Being male was significantly associated with having two or more strokes (AOR: 2.08, 95% CI: 1.17– 3.67) as was being non-Hispanic Black (AOR: 2.60, 95% CI: 1.48–4.58). Education, marital status, and Registry eligibility group were not associated with having either one stroke or two or more strokes.

4 | DISCUSSION

Using New York State stroke hospitalization data up to December 31, 2016 for the WTC Health Registry cohort, this study investigated the association of stroke with two key 9/11-related measures, PTSD and dust cloud exposure, among 29,012 Registry enrollees. As a follow-up study to our first paper on the same topic,[13] this study validated our early findings on PTSD and stroke by examining ischemic and hemorrhagic stroke separately, and provided further insights on the association of dust cloud exposure and stroke subtypes.

We found that PTSD increased the risk of developing stroke among Registry enrollees in this study. While the stroke cases were identified from hospitalization data and the analyses were done separately for two subtypes, the association was almost identical to what we found in our earlier paper that used self-reported stroke information.[13] The AHR for developing ischemic stroke or TIA was 1.64 (95% CI: 1.28 –2.10), which was the exact value we reported in the previous study with all stroke types combined. The AHR for hemorrhagic stroke was slightly higher 1.73 (95% CI: 1.10–2.71). It is not surprising to see the results are closer in value with ischemic stroke or TIA when we combine all types and treat stroke as one outcome since ischemic strokes on average account for the majority of all strokes in general population; in this analysis, out of all enrollees with stroke, about 77% had ischemic stroke or TIA. The consistent findings on 9/11-related PTSD as a risk factor for stroke not only validated our earlier results but also added evidence to the growing body of literatures on this association. Furthermore, by separating strokes into subtypes, we demonstrated that PTSD was associated with increased risk of both ischemic and hemorrhagic stroke.

The point estimate for dust exposure on 9/11 showed an association, although not significant statistically, with increased risk of ischemic stroke or TIA, but not with risk of hemorrhagic stroke when we used stroke cases from hospitalization records. The finding on ischemic stroke was fairly consistent with what was found in our earlier study that used combined self-reported stroke cases (presumably consisted of significantly more ischemic than hemorrhagic strokes)[13]: the AHRs were the same at 1.20 and the wider confidence intervals of the present study (95% CI: 0.96–1.50 vs. 1.02–1.42) could be explained by the smaller sample size in this study compared with the previous study (*N* = 29,012 vs. *N* = 42,527). The lack of association between dust exposure and hemorrhagic stroke could be

TABLE 4 Stroke and recurrent strokes and their association with 9/11-related PTSD and dust exposure[a]

	0 strokes (n = 28,537)		1 stroke (n = 396)				≥2 strokes (n = 79)			
	N	%	*N*	%	AOR	95% CI	*N*	%	AOR	95% CI
Sex										
Male	17,834	98.23	264	1.45	1.27	(0.98, 1.63)	57	0.31	**2.08**	**(1.17, 3.67)**
Female	10,703	98.58	132	1.22	Ref		22	0.20	Ref	
Age at 9/11/2001										
18–44	18,074	99.24	114	0.63	Ref		25	0.14	Ref	
45+	10,463	96.89	282	2.61	**3.32**	**(2.62, 4.22)**	54	0.50	**2.65**	**(1.60, 4.39)**
Race/ethnicity										
Non-Hispanic White	18,972	98.48	252	1.31	Ref		41	0.21	Ref	
Non-Hispanic Black	3744	97.63	69	1.80	1.06	(0.78, 1.44)	22	0.57	**2.60**	**(1.48, 4.58)**
Hispanic	3788	98.44	47	1.22	0.91	(0.65, 1.27)	13	0.34	1.64	(0.85, 3.14)
Asian and multiracial	2033	98.50	28	1.36	1.05	(0.70, 1.58)	3	0.15	0.68	(0.21, 2.22)
Education										
High school or below	6655	97.97	115	1.69	Ref		23	0.34	Ref	
College	16,582	98.54	206	1.22	0.91	(0.72, 1.16)	40	0.24	1.04	(0.62, 1.76)
Postgraduate	5219	98.32	73	1.38	1.04	(0.75, 1.44)	16	0.30	1.60	(0.80, 3.22)
Marital status										
Partnered	19,136	98.56	237	1.22	0.82	(0.65, 1.02)	43	0.22	0.66	(0.41, 1.06)
Nonpartnered	8961	97.95	153	1.67	Ref		35	0.38	Ref	
Smoking status										
Current smoker	2948	96.88	76	2.50	**2.42**	**(1.81, 3.22)**	19	0.62	**3.02**	**(1.69, 5.42)**
Former smoker	8336	98.07	138	1.62	1.27	(1.00, 1.60)	26	0.31	1.27	(0.75, 2.15)
Never smoker	16,463	98.77	171	1.03	Ref		34	0.20	Ref	
History of hypertension										
Yes	12,407	97.27	286	2.24	**2.26**	**(1.77, 2.88)**	62	0.49	**2.71**	**(1.54, 4.79)**
No	16,130	99.22	110	0.68	Ref		17	0.10	Ref	
History of diabetes										
Yes	3751	96.50	108	2.78	**1.48**	**(1.16, 1.89)**	28	0.72	**2.04**	**(1.25, 3.33)**
No	24,786	98.65	288	1.15	Ref		51	0.20	Ref	
Posttraumatic stress disorder										
Yes	4973	97.47	103	2.02	**1.39**	**(1.09, 1.77)**	26	0.51	**1.79**	**(1.09, 2.95)**
No	22,949	98.55	284	1.22	Ref		53	0.23	Ref	
Dust intensity										
Intense	9773	98.03	170	1.71	**1.33**	**(1.08, 1.65)**	26	0.26	0.79	(0.48, 1.29)
None/minimal	18,763	98.53	226	1.19	Ref		53	0.28	Ref	
Eligibility group										
Rescue/recovery worker	14,016	98.43	185	1.30	Ref		38	0.27	Ref	
Other	14,521	98.29	211	1.43	0.97	(0.77, 1.23)	41	0.28	1.07	(0.65, 1.77)

Abbreviations: AOR, adjusted odds ratio; PTSD, posttraumatic stress disorder.

[a]Because of missing data in the outcome, predictors, or covariates, the sample and number of stroke cases used in the models are slightly different from what are shown in Table 2.

due to the biological mechanism in which dust works in the cerebrovascular system. As was reported in a study by Qiu et al., the likely association of PM exposure and stroke was only significant for ischemic stroke and not hemorrhagic stroke, but the underlying mechanism for the difference was not clear.[26] The fact that dust exposure was significantly associated with ischemic stroke, but not as strongly as the association between PTSD and stroke (in terms of AHR value and confidence interval), provides us with more insight on the relationship between dust exposure, PTSD, and stroke. One plausible explanation is that dust exposure on 9/11 is a one-time event happening within a short period of time, and its health impact may thus be acute and transitory. Alternatively, PTSD is a chronic mental health condition that can be present for a long period of time after the disaster. Impact of PTSD on physical health conditions such as stroke can appear to be stronger than dust exposure especially when we evaluate the long-term health impacts as we did in the present study. Furthermore, 9/11-related dust is a mixture of particles at different sizes, gases, and smoke clouds released by uncontainable combustion,[39,40] and so cannot simply be compared with the toxicity of PM pollution, which has been shown to trigger cardiovascular diseases.[41,42]

Another contribution of this article was that we assessed if and how PTSD and 9/11-related dust cloud exposure were related to the number of strokes experienced. We found that not only does having PTSD increase the likelihood of having a single stroke, there was an increased likelihood for having multiple/recurrent strokes. This finding further demonstrates that PTSD is not only a serious mental health condition with which people suffered after 9/11, but its impact on physical health conditions such as stroke can be significant and long-lasting. As survivors of stroke already tend to remain at a long-term increased risk of additional strokes,[28] having PTSD makes them even more vulnerable. On the contrary, intense dust cloud exposure on 9/11 did not seem to increase one's chance of having recurrent strokes, although it increased the likelihood of having a one-time stroke. This result is also consistent with our argument above on the long-lasting impact of PTSD versus the relatively transient effect of dust exposure on stroke.

Although the focus of this analysis was on 9/11-related PTSD and dust exposure, other key risk factors for stroke were also considered in both hazard ratio models and multinomial logistic regression models. Our results on these classic risk factors were consistent with both the existing literature and with our earlier study on this cohort: being male sex, older age, non-Hispanic Black, smoker, and history of hypertension were all associated with higher risk of developing stroke and recurrent stroke. The consistent findings on these risk factors further strengthened our conclusion on the impact of 9/11-related factors on stroke. When we compared the significance and magnitude of PTSD impact on stroke, it was clear that PTSD played an even larger role than sex (male) and race (non-Hispanic Black) in this population. It should be noted that the observed stroke disparities by race/ethnicity are likely to be attributed to racial-ethnic minority groups such as non-Hispanic Blacks' limited access to quality care and lower socioeconomic status, which resulted in their higher prevalence and worse control of traditional vascular risk factors.[43–45]

Using stroke cases from hospitalization data, this study took a step forward in identifying the association between 9/11-related PTSD, dust exposure, and stroke subtype as compared with our first study, which used self-reported stroke. However, the results should still be interpreted with caution as there are several limitations to note. In a longitudinal study, loss to follow-up is a common source of nonresponse bias. In addition to the usual reasons for losing participants over time, stroke-related disabilities, and deaths both contribute to nonresponse and underestimation of stroke cases. Another limitation of this study is that we restricted our sample to those who had completed at least Waves 1 and 2 because both surveys collected key information used for creating the dust exposure variable. Therefore, it is possible that stroke cases occurring between the Wave 1 and Wave 2 surveys (i.e., between year 2003/2004 and 2007) are slightly undercounted in this study if Wave 2 survey was not completed. Since these potentially missed strokes occurred not long after 9/11 disaster, the association between dust exposure and ischemic stroke found in this article could have been weakened somewhat due to the presumably more immediate effect of dust exposure relative to PTSD. To address concerns about the potential biased PTSD and stroke relationship due to our sample selection criteria, we conducted a sensitivity analysis of the relationship in which the 14,260 Wave 2 nonrespondents were not excluded from the Cox proportional hazards regression models. The results of the sensitivity analysis did not differ significantly from the results presented in this article in terms of crude hazard ratios. While we would expect our findings to hold considering potential undercount and underreporting of stroke, future studies should examine the association between PTSD, dust exposure, and stroke-related deaths by matching Registry data with mortality data to further clarify the impact of these disaster-related factors on stroke among 9/11 survivors.

5 | CONCLUSION

This study assessed the associations of two key 9/11-related measures, PTSD and dust cloud exposure, and the risk of developing stroke among survivors of the September 11 disaster, using stroke cases from hospitalization data. We found that PTSD was significantly associated with increased risk of both ischemic and hemorrhagic stroke. The likelihood of having recurrent strokes was also higher among those with PTSD versus those without PTSD. Dust exposure on 9/11 showed a nonsignificant association with increased risk of ischemic stroke, but no association with hemorrhagic stroke. Intense exposure to the dust cloud increased the odds of having stroke significantly, but not for recurrent strokes. Our results validated our earlier findings on 9/11-related PTSD and dust exposure as risk factors of stroke. Furthermore, this study emphasized the lasting impact of PTSD on stroke by demonstrating the increased likelihood of recurrent strokes among those with PTSD. Policy makers and

medical professionals should place greater emphasis on promoting and improving the treatment of PTSD among 9/11 survivors, which may change the course of PTSD over time and ultimately reduce the risk for stroke, especially recurrent strokes.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DISCLOSURE BY AJIM EDITOR OF RECORD

Steven Markowitz declares that he has no conflict of interest in the review and publication decision regarding this article.

AUTHOR CONTRIBUTIONS

All authors have read, contributed to, and approved this manuscript. Shengchao Yu conceived the study with contribution from Howard E. Alper, Angela-Maithy Nguyen, and Junaid Maqsood. Howard E. Alper performed the coding and statistical analysis of the data with input from Angela-Maithy Nguyen and Junaid Maqsood. Shengchao Yu wrote the manuscript with editing and interpretation input from Howard E. Alper, Junaid Maqsood, Angela-Maithy Nguyen, and Robert M. Brackbill. All authors discussed the results and implications and commented on the manuscript at all stages.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS APPROVAL AND INFORMED CONSENT

The US Centers for Disease Control and Prevention and the New York City Department of Health and Mental Hygiene institutional review boards approved the World Trade Center Health Registry protocol, including use of the data.

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