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Exposure to the World Trade Center Disaster, Health, and Health-Related Quality of Life Nearly 20 Years After 9/11

Julia S. Sisti | Ananya Dhanya | Howard E. Alper | Nicholas Millet | Ayda Ahmadi | Robert M. Brackbill

New York City Department of Health and Mental Hygiene, World Trade Center Health Registry, Long Island City, New York, USA

Correspondence: Julia S. Sisti (jsisti@health.nyc.gov)

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ABSTRACT

Background: Exposure to the terrorist attacks on the World Trade Center (WTC) on September 11, 2001, has been associated with several chronic physical and mental health conditions. We assessed the burden, nearly 20 years after the attacks, of several 9/11-related health conditions and indicators of poor health-related quality of life (HRQOL) among individuals exposed to the WTC disaster.

Methods: Among individuals enrolled in the longitudinal WTC Health Registry in 2020–2021 ($N = 26{,}964$), we estimated post-9/11 prevalence of: self-reported diagnosed physical health conditions known to be associated with WTC exposure; probable posttraumatic stress disorder (PTSD) and depression; and poor HRQOL indicators. We also compared lifetime prevalence of selected conditions and poor-HRQOL indicators among WTC-exposed rescue and recovery workers and community members, separately, to New York State general population estimates, using multivariable-adjusted logistic regression.

Results: Prevalence of post-9/11 physical health conditions ranged from 10.5% (chronic obstructive pulmonary disease, COPD) to 26.3% (gastroesophageal reflux disease). Prevalence of probable post-9/11 PTSD and depression were 9.6% and 12.7%, respectively. Lifetime prevalence of physician-diagnosed asthma, COPD, and depression were higher among WTC-exposed individuals compared to the general population. Indicators of poor HRQOL were higher among WTC Registry enrollees relative to the general population, and among enrollees with any physical or probable mental health conditions compared to enrollees without any conditions.

Conclusions: Nearly 20 years after 9/11, WTC-exposed populations experience a high burden of health conditions that affect their wellbeing, highlighting the need for continued monitoring of this population.

1 | Introduction

The September 11, 2001 terrorist attack on the World Trade Center (WTC) resulted in nearly 3000 immediate deaths, and ongoing health consequences for those exposed to the disaster. The attack exposed thousands of individuals to psychological trauma and high concentrations of environmental pollutants from the cloud of smoke, dust, and debris created by the initial impact and subsequent collapse of the WTC towers. Highly exposed populations included rescue and recovery workers (RRWs) involved in the initial emergency response and months-long cleanup effort at the WTC site, as well as persons who lived, worked, and attended school in the vicinity of the disaster (community members). In the more than twenty years since the disaster, a broad range of health outcomes have been linked to WTC

exposure, with continued impacts on the mental and physical well-being of exposed persons.

Previous research has found that WTC exposure is associated with prevalence of mental health conditions, notably posttraumatic stress disorder (PTSD), which is often comorbid with depression [1, 2]. PTSD symptoms among persons exposed to the disaster were noted shortly after 9/11 and have persisted over time [3–5]. In 2015–2016, the prevalence of probable PTSD was 13% among enrollees in the World Trade Center Health Registry ("Registry"), a longitudinal cohort study of WTC-exposed individuals [6]. Physical health consequences of WTC exposure are also well-documented, including increased prevalence of aerodigestive disorders, which include upper respiratory diseases such as chronic sinusitis; obstructive airway diseases including asthma and chronic obstructive pulmonary disease (COPD); and gastroesophageal reflux disorder (GERD) [7–10]. Incidence and symptom severity of some physical conditions, including asthma, are higher among those with PTSD [11–13], leading to a high burden of comorbidity among those exposed to the WTC disaster.

Health conditions linked to WTC exposure, including asthma and PTSD, are associated with lower health-related quality of life (HRQOL) in the general population [14–16], and a higher burden of WTC-related conditions predicts poorer HRQOL among those exposed to the disaster [17, 18]. However, it is not currently clear whether a higher burden of these health conditions among WTC-exposed individuals is associated with worse HRQOL relative to the general population. While estimates of disease prevalence can help quantify increased risks of health conditions, HRQOL has additional value as a measure of how individuals perceive these conditions to affect their overall health and functioning [19]; therefore, assessing HRQOL is important to achieve a comprehensive understanding of how exposure to the disaster continues to affect the wellbeing of the WTC-exposed population.

This study estimates the prevalence of physical and mental health conditions diagnosed after 9/11 among Registry enrollees nearly 20 years after the disaster, and approximately 5 years since prevalence estimates from the Registry were last reported [6]. Updated estimates of WTC-related conditions among exposed populations are necessary for understanding how the prevalence of these conditions has changed in the 20 years following the disaster. We focused on conditions known to be associated with WTC exposure, specifically those that are monitored and treated through the World Trade Center Health Program (WTCHP), a federal program established in 2010 to provide care at no out-of-pocket cost to WTC-exposed RRWs and populations with certified covered conditions. To assess whether disease burden is higher among Registry enrollees compared to the general population, we compared prevalence of asthma, depression and COPD among Registry enrollees residing in New York State (NYS) to estimates from the 2020 NYS Behavioral Risk Factor Surveillance Survey (BRFSS). Lastly, we compared the prevalence of indicators of poor HRQOL among the Registry enrollees versus NYS BRFSS to investigate whether HRQOL is worse among those exposed to the WTC disaster.

2 | Materials and Methods

2.1 | Study Sample

The Registry is a closed, longitudinal cohort study established to monitor the physical and mental health effects of exposure to the September 11, 2001 terrorist attacks. The cohort comprises the following WTC-exposed groups: RRWs who performed rescue, recovery and/or cleanup work at the WTC site, on barges, or at the Staten Island landfill between 9/11/01 and 6/30/02; and community members who lived, worked, attended school, or were passersby in the vicinity of the attack (Lower Manhattan, defined as south of Chambers Street) on 9/11. Registry recruitment and methods have been described in detail elsewhere [20]; briefly, enrollment began in 2003 and was completed in 2004 with approximately 71,000 enrollees responding to a baseline survey. To date, there have been four follow-up Registry surveys: Wave 2 (2006–2007), Wave 3 (2011–2012), Wave 4 (2015–2016), and Wave 5 (2020–2021). The Wave 5 sample population included 39,647 enrollees who completed at least three prior waves, including Wave 1 and 2 (i.e., completed Waves 1–4, Waves 1–3, or Waves 1, 2, & 4) who had not died or withdrawn consent, and new adult enrollees who were <18 years old at the time of Registry enrollment. Wave 5 surveys were self-administered and completed by either web survey or mailed paper form, with Spanish and Chinese translations available for paper surveys only. Overall, 28,356 enrollees returned the Wave 5 survey between April 2020 and February 2021. This study excludes enrollees <18 years old on 9/11 ($N=1001$) or with unknown age ($N=2$) and whose Wave 5 survey was completed by a proxy ($N=389$). The Registry protocol was approved by the US Centers for Disease Control and Prevention (CDC) and the New York City Department of Health and Mental Hygiene (DOHMH) institutional review boards (#02-058). Informed consent was obtained verbally from participants at the Wave 1 interview.

2.2 | Measures

2.2.1 | Physical and Mental Health Conditions

Physical health conditions were based on self-reported physician diagnosis and included asthma, GERD, COPD, chronic sinusitis, and sleep apnea. COPD was defined as self-reported diagnosis of either (a) chronic bronchitis, or (b) emphysema/COPD. Self-reported diagnosed mental health conditions examined were PTSD and depression.

Past 30-day symptoms of 9/11-related PTSD were measured on the Wave 5 survey with the self-administered PTSD Checklist-5 (PCL-5) [21], which assessed 20 self-reported symptoms of PTSD specific to enrollees' 9/11 experiences. The 8-item Patient Health Questionnaire (PHQ-8) was also included on the Wave 5 survey to assess self-reported, past 30-day symptoms of depression. Consistent with recommended cut-offs, enrollees

with PCL-5 scores of ≥ 33 (maximum score: 80) were considered to have probable 9/11-related PTSD, and those with PHQ-8 scores of ≥ 10 (maximum score: 24) were considered to have probable depression [22, 23].

2.2.2 | HRQOL

We assessed HRQOL using the CDC's four core Healthy Days Measures (CDC HRQOL-4): self-rated health status, physically unhealthy days in past 30 days, mentally unhealthy days in past 30 days, and activity limitation in past 30 days [19]. Poor general health was defined as fair or poor self-rated health status, and number of days with activity limitation in past 30 days were dichotomized as < 14 or ≥ 14 days. Unhealthy days in past 30 days were calculated as the sum of physically and mentally unhealthy days and dichotomized as < 14 or ≥ 14 days.

2.2.3 | Sociodemographic Characteristics and 9/11-Related Exposures

Wave 1 survey data were used to categorize enrollees' age at 9/11, gender, race/ethnicity, Registry eligibility group, self-reported 9/11 exposures (e.g., witnessing traumatic events, sustaining a 9/11-related injury) and among RRWs, the first date of work at disaster site and duration of work. Self-reported intensity of exposure to the dust cloud based on data collected at Waves 1 and 2. Sociodemographic characteristics queried at Wave 1 and in subsequent wave surveys were household income, educational attainment, employment status, routine checkup in past 12 months, and current cigarette smoking status.

2.3 | Statistical Analyses

To assess differences between our study population and the original Registry cohort, we examined baseline sociodemographic characteristics and 9/11 exposures among all Wave 1 respondents aged ≥ 18 years at 9/11 and among Wave 5 respondents included in our study population. We calculated Wave 5 prevalence of self-reported diagnosed physical health conditions and probable mental health conditions among enrollees who did not report a pre-9/11 diagnosis of each condition. To reduce potential misclassification, we used the diagnosis year reported from the earliest survey to categorize conditions as pre- or post-9/11. Post-9/11 prevalence was estimated among those without a pre-9/11 diagnosis, excluding enrollees who reported a diagnosis year of 2001 or earlier, or who never reported a year of diagnosis. We additionally calculated lifetime prevalence at Wave 5. We calculated estimates overall and stratified by sociodemographic characteristics at Wave 1 and 9/11 exposures. We also calculated overall estimates age-adjusted to the 2000 US Standard Population age 35 and older, as the minimum age of enrollees in our study was 36 years. We calculated the prevalence of each HRQOL indicator separately among enrollees with: no physical or mental health conditions, physical health condition(s) only, mental health condition(s) only, or both physical and mental health conditions. For HRQOL calculations, we did not restrict to those without pre-9/11 diagnoses of each condition.

To assess whether health conditions are more prevalent among WTC-exposed individuals compared to the general population, we used data from the 2020 NYS BRFSS, a cross-sectional, phone-based survey of health risk factors and outcomes among a representative sample of approximately 15,000 NYS adults [24]. NYS BRFSS collected data on self-reported physician-diagnosed health conditions, including asthma, depression, and COPD, and HRQOL using the CDC HRQOL-4 measures.

We first calculated age-adjusted prevalence of self-reported health conditions and poor HRQOL indicators in both the Registry and BRFSS, separately. To improve comparability, we restricted analyses to Registry enrollees who lived in NYS in 2020 ($N = 16,395$); to align with the age range of our enrollees at Wave 5, we excluded NYS BRFSS respondents under 35 years old. As BRFSS did not collect data on date of first diagnosis of health conditions, we did not restrict analyses to post-9/11 diagnoses among Registry enrollees; we also assessed self-reported diagnosed depression at Wave 5 instead of probable depression based on PHQ-8 score. Days with activity limitations were only assessed among respondents who reported any physically or mentally unhealthy days in the past 30 days, to align with BRFSS questionnaire skip patterns.

We estimated multivariable-adjusted prevalence ratios (PR) and 95% confidence intervals (95% CI) for each health condition and HRQOL indicator among Registry enrollees versus the general population from logistic regression models using SUDAAN's RLOGIST procedure with PREDMARG statements. The dependent variable of interest was a three-level indicator variable for respondent type (WTCHR RRW, WTCHR community member, and NYS BRFSS). Models were adjusted for age group, gender, race/ethnicity, and employment status, household income, routine check-up in past 12 months, smoking status, educational attainment, and region (NYC vs. rest of state); time-varying covariates (employment, income, past 12-month check-up, smoking, education, and region) were assessed at Wave 5 for Registry enrollees to align with the cross-sectional design of BRFSS. Due to lack of detailed data on smoking history, analyses of COPD were restricted to never-smokers. Analyses were stratified and weighted to account for BRFSS sampling methods; Registry enrollees were assigned a unique primary sampling unit and a weight and strata of one. Analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC) and SAS-callable SUDDAN version 11.0.

3 | Results

Baseline characteristics of all 68,041 Wave 1 respondents aged ≥ 18 years at 9/11 and the 26,964 Wave 5 respondents included in main analyses are shown in Table 1. Compared to all Wave 1 respondents, higher proportions of Wave 5 respondents were 45–64 years old at 9/11 (41% vs. 35%) and were more likely to be Non-Hispanic White (73% vs. 64%). Compared to all Wave 1 respondents, those who responded to Wave 5 were also more likely to report household incomes of ≥ $75,000 at the

TABLE 1 | Demographic characteristics and 9/11 experiences of World Trade Center (WTC) Health Registry Wave 1 (2003–2004) respondents and Wave 5 (2020–2021) respondents included in study population.

	All enrollees at Wave 1 aged ≥ 18 year at 9/11		Wave 5 study population	
	N	%	*N*	%
Total	68,041		26,964	
Age group at 9/11				
18–24 years	4397	6%	1175	4%
25–44 years	37,072	54%	14,315	53%
45–64 years	23,934	35%	11,096	41%
65+ years	2638	4%	378	1%
Gender				
Male	41,158	60%	16,649	62%
Female	26,883	40%	10,315	38%
Race/ethnicity				
Non-Hispanic White	43,383	64%	19,770	73%
Non-Hispanic Black	8185	12%	2393	9%
Hispanic	8916	13%	2774	10%
Non-Hispanic Asian	4735	7%	1231	5%
Non-Hispanic Other	2822	4%	796	3%
Wave 1 household income				
< $25,000	6705	11%	1606	7%
$25,000– < $50,000	13,047	22%	4313	18%
$50,000– < $75,000	12,768	21%	5417	22%
$75,000– < $150,000	20,594	34%	9954	41%
≥ $150,000	7089	12%	3273	13%
Wave 1 educational attainment				
Less than high school	3498	5%	637	2%
High school graduate	12,889	19%	4592	17%
Some college	16,407	25%	6606	25%
College graduate	34,108	51%	15,005	56%
Wave 1 smoking history				
Never	38,323	57%	15,495	58%
Former	17,990	27%	7,778	29%
Current	10,779	16%	3,570	13%
WTCHR eligibility group[a]				
Rescue/recovery worker	30,497	45%	12,893	48%
Area resident	11,034	16%	3277	12%
Area worker	23,213	34%	9572	36%
Passerby	3297	5%	1222	5%
Dust cloud intensity[b]				
None	22,155	48%	12,835	48%
Some	10,082	22%	5891	22%
Intense	13,780	30%	8238	31%
Witnessed traumatic events on 9/11[c]				
No	20,288	30%	8010	30%
Yes	46,348	70%	18,516	70%

(Continues)

TABLE 1 | (Continued)

	All enrollees at Wave 1 aged ≥ 18 year at 9/11		Wave 5 study population	
	N	%	*N*	%
Sustained any 9/11-related injury[d]				
No	58,420	87%	23,273	87%
Yes	8923	13%	3546	13%
Date first worked, rescue/recovery workers only				
9/11/2001	8201	28%	3855	31%
9/12/2001	5907	20%	2539	20%
9/13/2001 to 9/17/2001	6234	21%	2656	21%
9/18/2001 or later	8985	31%	3382	27%
Number of days worked, rescue/recovery workers only				
1–7 days	10,082	36%	4158	34%
8–30 days	8482	30%	3908	32%
31–90 days	4727	17%	2133	18%
> 90 days	5012	18%	1890	16%

Note: Due to missing data, category-specific numbers may not sum to total.
[a]Area workers includes enrollees who reported being students or staff in schools south of Chambers Street.
[b]Additionally restricted to respondents at Wave 2 (2006–2007), when dust cloud exposure was assessed.
[c]Includes witnessing any of the following: airplane(s) hitting WTC, buildings collapsing, people running from dust cloud, people being injured or killed, people jumping or falling from WTC.
[d]Includes broken bones, cuts, concussions, burns and sprains.

baseline survey (54% vs. 46%) and were more likely to have graduated from college (56% vs. 51%). Wave 5 respondents were less likely to report currently smoking at the baseline survey compared to all Wave 1 respondents (13% v. 16%). Among all Wave 1 respondents, 45% performed 9/11-related rescue and recovery work, compared to 48% of the Wave 5 study population, and the proportion of RRWs who began work between 9/11/2001-9/17/2001 was higher among the Wave 5 study population compared to all Wave 1 respondents (73% vs. 69%). Other self-reported exposures were similar among the Wave 5 study population compared to all Wave 1 respondents. For example, the proportion of enrollees who reported witnessing traumatic events was 70% among all Wave 1 respondents and among the Wave 5 study population. Characteristics and 9/11 exposures of the study population, stratified by rescue and recovery worker status, can be found in Supporting Information: Table 1.

The post-9/11 prevalence of self-reported diagnosed physical health conditions at Wave 5 is shown in Table 2. Among conditions examined, GERD was the most prevalent (26.3%), followed by sleep apnea (20.9%), chronic sinusitis (15.6%), asthma (15.4%), and COPD (10.5%). Gender differences in prevalence were most notable for sleep apnea (27% in males vs. 11% in females), and prevalence of several conditions, including asthma, was higher among Hispanic enrollees (23% in Hispanic vs. 14% in non-Hispanic White enrollees). Post-9/11 conditions were more prevalent in RRWs than community members, with COPD prevalence at 13%, compared to 8% in area workers, passersby, and 7% among residents. Among RRWs, a prevalence gradient was observed by date first worked, with highest prevalence among those who first worked on 9/11/2001 (e.g., 25% prevalence of asthma vs. 11% among those who arrived on 9/18/2001 or later). RRWs who worked for longer periods had higher prevalence of all physical conditions compared to those who worked for shorter periods, (e.g., > 90 vs. ≤ 7 days: GERD: 38% vs. 27%; asthma: 24% vs. 14%; COPD: 16% vs. 10%). Prevalence of physical conditions was generally not higher among those who witnessed traumatic events; however, those who reported intense dust cloud exposure or sustained any 9/11-related injury had higher prevalence of all conditions relative to those without dust cloud exposure and injuries, respectively. For example, chronic sinusitis prevalence was 19% among those who reported intense dust cloud exposure, and 14% among those who reported no or some exposure. Supporting Information: Table 2 shows the lifetime prevalence of self-reported diagnosed health conditions and diagnosed depression overall, regardless of timing of diagnosis relative to 9/11.

Table 3 shows the Wave 5 prevalence of probable 9/11-related PTSD and probable depression. Overall, 9.6% of enrollees had probable PTSD and 12.7% had probable depression. Similar to patterns observed for physical conditions, prevalence of probable PTSD and probable depression were higher among Hispanic relative to non-Hispanic White enrollees (e.g., 17% vs. 8% for probable PTSD). Among enrollees reporting the lowest incomes and educational attainment, prevalence of both probable mental health conditions was also higher compared to those reporting higher incomes and educational attainment, respectively. For example, the prevalence of depression was 22% among enrollees with household incomes of < $25,000 and 8% among those was household incomes ≥ $150,000. In contrast to physical conditions, prevalence of probable mental health conditions was not higher among RRWs; prevalence of probable PTSD and probable depression were similar among RRWs as among area workers (10% and 13%, respectively). However, among RRWs, those with higher WTC exposure had higher prevalence of both conditions (e.g., PTSD prevalence was 14% among those who worked > 90 days vs. 9% among those who worked ≤ 7 days).

TABLE 2 | Post-9/11 prevalence of self-reported diagnosed physical health conditions among World Trade Center (WTC) enrollees at Wave 5, 2020–2021.

	Asthma			Chronic obstructive pulmonary disorder (COPD)			Gastroesophageal reflux disorder (GERD)			Chronic sinusitis			Sleep apnea		
	***n*, Without pre-9/11 asthma**	***n*, Post-9/11 asthma**	**%, Asthma (age-adj.*)**	***n*, Without pre-9/11 COPD**	***n*, Post-9/11 COPD**	**%, COPD (age-adj.*)**	***n*, Without pre-9/11 GERD**	***n*, Post-9/11 GERD**	**%, GERD (age-adj.*)**	***n*, Without pre-9/11 sinusitis**	***n*, Post-9/11 sinusitis**	**%, Sinusitis (age-adj.*)**	***n*, Without pre-9/11 sleep apnea**	***n*, Post-9/11 sleep apnea**	**%, Sleep apnea (age-adj.*)**
	23,756	3,653	**15.4% (14.5)**	24,710	2593	**10.5% (8.4)**	24,461	6444	**26.3% (23.0)**	24,261	3789	**15.6% (14.4)**	25,209	5273	**20.9% (17.3)**
Age at 9/11, years															
18–24	990	125	13%	1123	50	4%	1110	174	16%	1112	128	12%	1131	95	8%
25–44	12,609	2150	17%	13,321	1332	10%	13,217	3734	28%	13,068	2339	18%	13,546	3160	23%
45–64	9827	1346	14%	9955	1174	12%	9837	2488	25%	9784	1299	13%	10,218	1982	19%
65+	330	32	10%	311	37	12%	297	48	16%	297	23	8%	314	36	11%
Gender															
Male	14,987	2230	15%	15,347	1755	11%	15,173	4245	28%	15,103	2558	17%	15,497	4173	27%
Female	8769	1423	16%	9363	838	9%	9288	2199	24%	9,158	1231	13%	9712	1100	11%
Race/ethnicity															
NH White	17,698	2498	14%	18,362	1943	11%	18,055	4839	27%	17,973	2896	16%	18,686	3959	21%
NH Black	2045	346	17%	2116	221	10%	2139	452	21%	2101	268	13%	2174	409	19%
Hispanic	2298	520	23%	2459	266	11%	2478	748	30%	2423	412	17%	2533	606	24%
NH Asian	1047	163	16%	1066	70	7%	1085	223	21%	1076	107	10%	1084	144	13%
NH Other	668	126	19%	707	93	13%	704	182	26%	688	106	15%	732	155	21%
Wave 1 income															
< $25,000	1317	278	21%	1349	155	11%	1367	306	22%	1347	192	14%	1402	211	15%
$25,000–< $50,000	3693	625	17%	3849	437	11%	3856	922	24%	3799	553	15%	3980	728	18%
$50,000– < $75,000	4805	765	16%	4976	589	12%	4899	1387	28%	4881	809	17%	5067	1160	23%
$75,000– < $150,000	8933	1401	16%	9275	1041	11%	9184	2667	29%	9101	1634	18%	9421	2264	24%
≥ $150,000	2898	309	11%	3094	210	7%	3032	645	21%	3014	342	11%	3123	525	17%
Wave 1 educational attainment															
Less than HS	520	126	24%	500	71	14%	492	154	31%	487	74	15%	497	86	17%
HS graduate	4067	717	18%	4107	577	14%	4097	1247	30%	4040	714	18%	4220	1070	25%
Some college	5821	1079	19%	6019	853	14%	5979	1914	32%	5898	1228	21%	6154	1604	26%
College graduate	13,238	1714	13%	13,975	1084	8%	13,785	3103	23%	13,733	1765	13%	14,229	2492	18%
Wave 1 smoking status															
Never	13,645	2073	15%	14,315	1067	7%	14,145	3634	26%	13,991	2149	15%	14,516	2925	20%
Former	6885	1067	15%	7082	841	12%	6970	1932	28%	6960	1088	16%	7251	1588	22%

(Continues)

TABLE 2 | (Continued)

	Asthma			Chronic obstructive pulmonary disorder (COPD)			Gastroesophageal reflux disorder (GERD)			Chronic sinusitis			Sleep apnea		
	n, Without pre-9/11 asthma	*n*, Post-9/11 asthma	%, Asthma (age-adj.*)	*n*, Without pre-9/11 COPD	*n*, Post-9/11 COPD	%, COPD (age-adj.*)	*n*, Without pre-9/11 GERD	*n*, Post-9/11 GERD	%, GERD (age-adj.*)	*n*, Without pre-9/11 sinusitis	*n*, Post-9/11 sinusitis	%, Sinusitis (age-adj.*)	*n*, Without pre-9/11 sleep apnea	*n*, Post-9/11 sleep apnea	%, Sleep apnea (age-adj.*)
Current	3131	492	16%	3203	670	21%	3239	848	26%	3205	538	17%	3332	735	22%
Eligibility group															
Rescue/recovery worker	11,574	2103	18%	11,871	1,592	13%	11,759	3929	33%	11,602	2484	21%	12,041	3426	28%
Area resident	2830	360	13%	2961	198	7%	2961	565	19%	2930	278	9%	3039	300	10%
Area worker[a]	8317	1030	12%	8776	719	8%	8658	1710	20%	8656	888	10%	8989	1342	15%
Passerby	1035	160	15%	1102	84	8%	1083	240	22%	1073	139	13%	1140	205	18%
Witnessed traumatic events on 9/11[b]															
No	7149	937	13%	7428	733	10%	7300	1871	26%	7255	1091	15%	7492	1651	22%
Yes	16,237	2655	16%	16,891	1825	11%	16,763	4482	27%	16,624	2655	16%	17,312	3556	21%
Dust cloud intensity															
None	11,405	1449	13%	11,883	1095	9%	11,730	2839	24%	11,653	1617	14%	12,019	2434	20%
Some	5156	740	14%	5406	524	10%	5343	1350	25%	5316	758	14%	5528	1070	19%
Intense	7195	1464	20%	7421	974	13%	7388	2255	31%	7292	1414	19%	7662	1769	23%
Sustained any 9/11-related injury[c]															
No	20,511	2864	14%	21,410	2029	9%	21,138	5160	24%	21,036	3012	14%	21,784	4295	20%
Yes	3117	761	24%	3183	546	17%	3206	1250	39%	3110	758	24%	3304	948	29%
Date first worked, rescue and recovery workers only															
9/11/2001	3497	888	25%	3535	633	18%	3531	1576	45%	3439	1026	30%	3620	1281	35%
9/12/2001	2320	458	20%	2341	364	16%	2332	879	38%	2306	581	25%	2378	746	31%
9/13/2001 to 9/17/2001	2359	368	16%	2440	288	12%	2422	732	30%	2394	453	19%	2474	663	27%
9/18/2001 or later	2986	337	11%	3135	257	8%	3059	643	21%	3057	369	12%	3146	641	20%
Number of days worked, rescue and recovery workers only															
1–7 days	3653	508	14%	3852	381	10%	3779	1010	27%	3783	585	15%	3897	906	23%
8–30 days	3553	632	18%	3612	476	13%	3579	1229	34%	3539	806	23%	3679	1094	30%
31–90 days	1937	445	23%	1970	363	18%	1950	824	42%	1902	546	29%	1981	665	34%
> 90 days	1702	401	24%	1709	278	16%	1727	661	38%	1666	415	25%	1,748	571	33%

Note: Due to missing data, category-specific numbers may not sum to total.
*Age-adjusted to 2000 US Standard population, 10 year increments from 35 to 65+.
[a]Includes 32 enrollees who reported being students or staff in schools south of Chambers Street.
[b]Includes witnessing any of the following: airplane(s) hitting WTC, buildings collapsing, people running from dust cloud, people being injured or killed, people jumping or falling from WTC.
[c]Includes broken bones, cuts, concussions, burns and sprains.

TABLE 3 | Prevalence of probable mental health conditions among World Trade Center (WTC) Health Registry enrollees at Wave 5, 2020–2021.

	Posttraumatic stress disorder (PTSD)			Depression		
	***n*, Without pre-9/11 PTSD**	***n*, Wave 5 PTSD symptoms**	**%, PTSD symptoms (age-adj.*)**	***n*, Without pre-9/11 depression**	***n*, Wave 5 depression symptoms**	**%, Depression symptoms (age-adj.*)**
	24,263	2328	**9.6% (9.4)**	23,275	2959	**12.7% (13.6)**
Age at 9/11, years						
18–24	1067	95	9%	1033	155	15%
25–44	12,986	1427	11%	12,562	1829	15%
45–64	9897	792	8%	9376	952	10%
65+	313	14	4%	304	23	8%
Gender						
Male	15,178	1453	10%	14,887	1782	12%
Female	9085	875	10%	8388	1177	14%
Race/ethnicity						
NH White	18,034	1480	8%	17,105	1962	11%
NH Black	2053	223	11%	2056	273	13%
Hispanic	2412	418	17%	2496	444	19%
NH Asian	1074	119	11%	1064	160	15%
NH Other	690	88	13%	654	120	18%
Wave 1 income						
< $25,000	1301	228	18%	1230	266	22%
$25,000– < $50,000	3749	503	13%	3599	637	18%
$50,000– < $75,000	4863	506	10%	4676	647	14%
$75,000– < $150,000	9174	748	8%	8878	955	11%
≥ $150,000	3041	163	5%	2866	243	8%
Wave 1 educational attainment						
Less than HS	479	103	22%	504	109	22%
HS graduate	4031	519	13%	4010	634	16%
Some college	5896	664	11%	5779	813	14%
College graduate	13,753	1032	8%	12,877	1387	11%
Wave 1 smoking status						
Never	14,098	1216	9%	13,562	1530	11%
Former	6927	629	9%	6569	824	13%
Current	3139	469	15%	3043	590	19%
Eligibility group						
Rescue/recovery worker	11,673	1127	10%	11,407	1443	13%
Area resident	2885	227	8%	2623	304	12%
Area worker[a]	8626	840	10%	8253	1054	13%
Passerby	1079	134	12%	992	158	16%
Witnessed traumatic events on 9/11[b]						
No	7298	469	6%	6983	698	10%
Yes	16,585	1822	11%	15,937	2218	14%

(Continues)

TABLE 3 | (Continued)

	Posttraumatic stress disorder (PTSD)			Depression		
	***n*, Without pre-9/11 PTSD**	***n*, Wave 5 PTSD symptoms**	**%, PTSD symptoms (age-adj.*)**	***n*, Without pre-9/11 depression**	***n*, Wave 5 depression symptoms**	**%, Depression symptoms (age-adj.*)**
Dust cloud intensity						
None	11,674	811	7%	11,156	1149	10%
Some	5259	469	9%	5063	651	13%
Intense	7330	1048	14%	7056	1159	16%
Sustained any 9/11-related injury[c]						
No	21,076	1726	8%	20,113	2296	11%
Yes	3077	577	19%	3048	632	21%
Date first worked, rescue and recovery workers only						
9/11/2001	3484	402	12%	3492	452	13%
9/12/2001	2307	292	13%	2287	336	15%
9/13/2001 to 9/17/2001	2378	229	10%	2340	316	14%
9/18/2001 or later	3080	183	6%	2870	298	10%
Number of days worked, rescue and recovery workers only						
1–7 days	3771	340	9%	3590	474	13%
8–30 days	3581	318	9%	2477	385	11%
31–90 days	1925	186	10%	1936	229	12%
> 90 days	1659	227	14%	1677	272	16%

Note: Due to missing data, category-specific numbers may not sum to total.
*Age-adjusted to 2000 US Standard population, 10-year increments from 35 to 65+.
[a]Includes 32 enrollees who reported being students or staff in schools south of Chambers Street.
[b]Includes witnessing any of the following: airplane(s) hitting WTC, buildings collapsing, people running from dust cloud, people being injured or killed, people jumping or falling from WTC.
[c]Includes broken bones, cuts, concussions, burns and sprains.

Other indicators of 9/11 exposure were also associated with higher prevalence of probable PTSD and depression. For example, 21% of enrollees who sustained a 9/11-related injury had probable depression, compared to 11% of enrollees who did not sustain an injury.

Among enrollees in our population with complete data on probable mental health conditions and lifetime diagnoses of physical health conditions of interest, 2847 (12%) had both physical and probable mental health conditions, 10,368 (44%) had physical health condition(s) only, 974 (4%) had probable mental health condition(s) only, and 9475 (40%) had neither physical nor probable mental health conditions (see Supporting Information: Figure 1 for overlap in conditions). The prevalence of poor HRQOL indicators by physical and probable mental health conditions (any vs. none) among Registry enrollees is shown in Figure 1. The prevalence of all three indicators was lowest among enrollees without any conditions, and highest among enrollees with both physical and probable mental health conditions. For example, 8% of enrollees without physical or probable mental health conditions rated their health as fair or poor, compared to 59% of those with both types of conditions. Enrollees who had probable mental health conditions but did not report physical health conditions also had higher prevalence of poor HRQOL indicators compared to enrollees who reported physical health conditions only. The prevalence of ≥ 14 unhealthy days in past 30 days was 27% among those with only physical health conditions and 72% among those with probable PTSD or depression; the prevalence of ≥ 14 days with activity limitations was 12% and 43%, respectively.

Prevalence estimates and multivariable-adjusted PRs and 95% CI for poor HRQOL indicators and selected self-reported conditions among Registry enrollees compared to the NYS general population are shown in Table 4 Compared to the general population, the prevalence of asthma was 2.4 times higher among Registry RRWs (95% CI: 2.1–2.7), and two-fold higher among Registry community members (PR = 2.0, 95% CI: 1.8–2.3). Compared to the general population, the prevalence of COPD among non-smokers was nearly six times higher among Registry RRWs (PR = 5.9, 95% CI: 4.3–8.1) and more than three times higher among Registry community members (PR = 3.6, 95% CI: 2.7–5.0). Depression was also more prevalent among Registry enrollees compared to the general population (RRWs: PR = 1.5, 95% CI: 1.3–1.7; community members: PR = 1.7, 95% CI: 1.5–1.8). Registry enrollees were more likely than the general population to report poor HRQOL across all

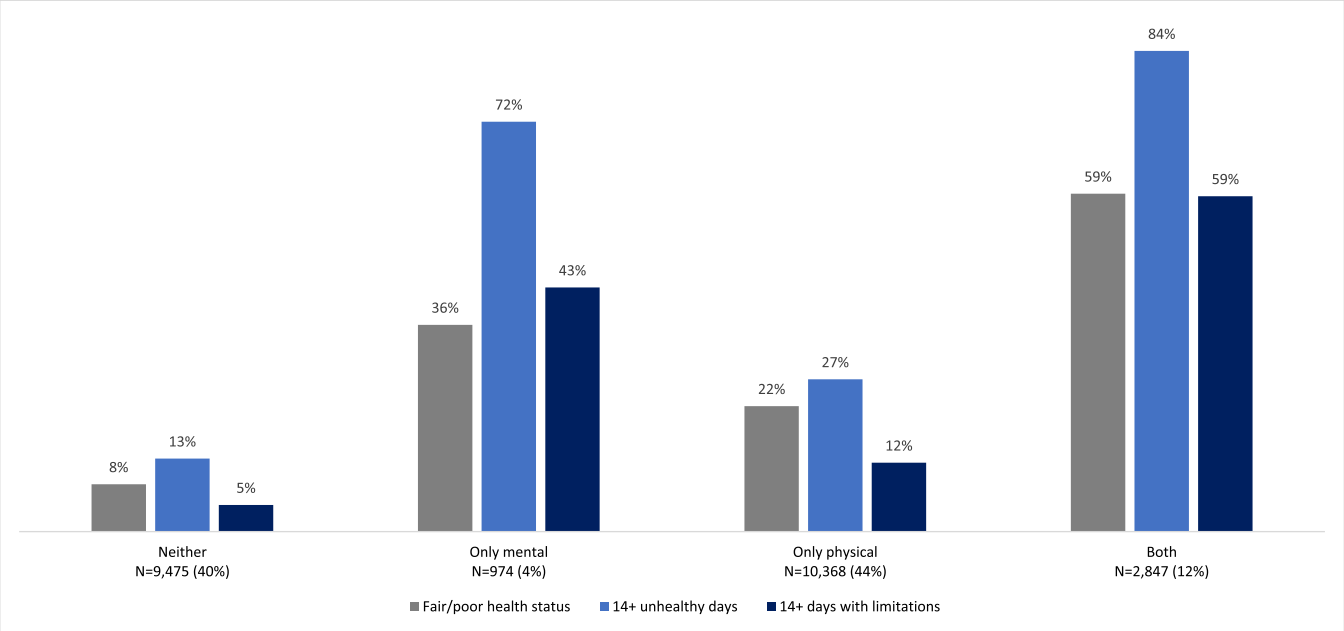

FIGURE 1 | Prevalence of poor health-related quality of life (HRQOL) indicators by self-reported physical and probable mental health conditions (any vs. none) among World Trade Center Health Registry enrollees at Wave 5, 2020–2021. Enrollees were considered to have physical health conditions based on self-reported lifetime diagnosis at Wave 5 of at least one of the following: asthma, GERD, COPD, chronic sinusitis, or sleep apnea. Enrollees were considered to have probable mental health conditions based on Wave 5 symptoms of either depression or PTSD. Bar colors represent each poor HRQOL indicator and bar height represents the proportion of enrollees reporting each poor HRQOL indicator. [Color figure can be viewed at wileyonlinelibrary.com]

three indicators, including ≥ 14 unhealthy days in past 30 days (RRWs: PR = 2.1, 95% CI: 2.0–2.3; community members: PR = 1.9, 95% CI: 1.8–2.1). Among those reporting any unhealthy days, the prevalence of ≥ 14 days with activity limitations was also elevated among Registry enrollees compared to the general population (RRWs: PR = 1.8, 95% CI: 1.5–2.0; community members: PR = 1.7, 95% CI: 1.5–1.9). Lastly, the prevalence of fair or poor self-rated health status was more than two times higher among Registry RRWs (PR = 2.5, 95% CI: 2.3–2.7) and community members (PR = 2.2, 95% CI: 2.0–2.4) compared to the general population.

4 | Discussion

We estimated the prevalence of WTC-related health conditions among a population exposed to the disaster, approximately 20 years after 9/11. We found self-reported prevalence of physical health conditions commonly certified by the WTCHP ranging from 10.5% to 26.3% (COPD and GERD, respectively), and nearly one in 10 enrollees had probable 9/11-related PTSD. Among conditions for which general population estimates were available—asthma, depression, and COPD—self-reported lifetime prevalence was higher among WTC-exposed individuals than among the general population. Having WTC-related health conditions was associated with poorer health-related quality of life measures, and the high prevalence of these conditions among those exposed to the WTC disaster may account for our finding that HRQOL was poorer among WTC-exposed community members and RRWs compared to the general population.

Acute and long-term physical and mental health effects of WTC exposure have been well documented [6, 25]; however, because Registry enrollment was limited to those directly exposed to the disaster, most analyses of this cohort have not included an unexposed referent population. Studies that have compared WTC-exposed populations to external populations have generally examined mortality as an outcome and have found lower all-cause mortality rates among both WTC-exposed RRWs and community members compared to national, NYS, and NYC general populations. [26, 27]. Findings of lower mortality among WTC-exposed populations may be partially explained by the availability of no-cost medical monitoring and treatment for covered health conditions via the WTCHP. The healthy worker effect may also contribute to these findings among RRWs if mortality is lower among employed individuals due to better health status, though some evidence contradicts this hypothesis [28]. As our analysis focused primarily on chronic conditions that may be managed effectively with treatment and lifestyle modifications, our finding of higher prevalence of these conditions among WTC-exposed individuals does not necessarily contradict these prior findings.

Our findings that lower respiratory tract diseases are associated with WTC exposure are in line with previous studies. WTC-exposed firefighters have been found to have higher prevalence of asthma and COPD compared to firefighters without WTC exposure [29] as well as compared to the general population [30]. Notably, our RRW population includes primarily non-firefighter responders (> 85%), including emergency medical service workers, construction workers, police, and volunteers, who may be exposed to fewer occupational risk factors for respiratory conditions

TABLE 4 | Multivariable-adjusted[a] prevalence ratios (PRs) and 95% confidence intervals (95% CI) of self-reported health conditions and poor HRQOL indicators by World Trade Center exposure compared to NYS general population aged ≥ 35 years (2020 NYS BRFSS), among World Trade Center Health Registry enrollees residing in New York State, 2020–2021.

	Prevalence,[b] % (95% CI)	PR	95% CI
Ever diagnosed with asthma			
NYS BRFSS	12.8 (11.9–13.7)	1.0	Ref.
Registry rescue and recovery workers	26.9 (25.0–28.9)	**2.4**	**2.1–2.7**
Registry community members	23.8 (22.4–25.2)	**2.0**	**1.8–2.3**
Ever diagnosed with depression			
NYS BRFSS	15.6 (14.6–16.6)	1.0	Ref.
Registry rescue and recovery workers	20.2 (18.4–22.1)	**1.5**	**1.3–1.7**
Registry community members	24.6 (23.2–26.1)	**1.7**	**1.5–1.8**
Ever diagnosed with COPD, non-smokers only			
NYS BRFSS	2.7 (2.2–3.3)	1.0	Ref.
Registry rescue and recovery workers	12.2 (10.9–13.6)	**5.9**	**4.3–8.1**
Registry community members	7.4 (6.5–8.4)	**3.6**	**2.7–5.0**
≥ 14 unhealthy days, past 30 days			
NYS BRFSS	19.2 (18.1–20.4)	1.0	Ref.
Registry rescue and recovery workers	31.6 (29.6–33.6)	**2.1**	**2.0–2.3**
Registry community members	31.0 (29.6–32.6)	**1.9**	**1.8–2.1**
Fair or poor self-rated health status			
NYS BRFSS	14.1 (13.2–15.1)	1.0	Ref.
Registry rescue and recovery workers	23.2 (21.6–24.7)	**2.5**	**2.3–2.7**
Registry community members	19.1 (18.0–20.2)	**2.2**	**2.0–2.4**
≥ 14 days with activity limitations, past 30 days[c]			
NYS BRFSS	17.6 (16.1–19.2)	1.0	Ref.
Registry rescue and recovery workers	25.1 (23.0–27.3)	**1.8**	**1.5–2.0**
Registry community members	19.4 (18.1–20.8)	**1.7**	**1.5–1.9**

Note: Analyses are stratified and weighted to account for BRFSS complex sampling procedures.
Abbreviations: BRFSS, Behavioral Risk Factor Surveillance System; HRQOL, health-related quality of life; NYS, New York State.
[a]Adjusted for age group (5-year intervals from 35–40 to 80 +), gender (male, female), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, non-Hispanic Asian, non-Hispanic other), household income (< $25,000, $25,000– < $50,000, $50,000– < $75,000, and ≥ $75,000), educational attainment (less than high school, high school, some college, college degree or more), employment status (employed, not employed), smoking status (current, former, never), check-up within past 12 m (yes, no), NYS region (NYC, rest of state).
[b]Prevalence estimates are age-adjusted to US 2000 Standard Population.
[c]Among those who reported at least one day of poor mental or physical health in past 30 days.

than firefighters. However, a previous study of WTC general responders that included a majority of non-firefighters reported a 60% higher lifetime prevalence of asthma compared to the US population between 2002 and 2005 [31] We also found higher rates of respiratory conditions among WTC-exposed community members compared to the general population. Previous Registry studies found a higher risk of asthma and lower respiratory symptoms among community members who reported more intense dust exposure in their homes or workplaces [10, 32, 33]. Fewer studies have reported the prevalence of COPD among exposed community members; however, an analysis of WTC-exposed community members who were patients at a WTCHP clinic reported a spirometry-based prevalence estimate of 9.6% among non-smokers [34], supporting our findings of high prevalence of COPD among WTC-exposed community members compared to the general population.

Our estimates of probable 9/11-related PTSD and probable depression among Registry enrollees in 2020–2021 were lower than the corresponding 2015-2016 estimates (age-adjusted estimates: 9.4% vs. 13.1% and 13.6% vs. 14.5%, respectively) [6]. The finding that prevalence of probable depression was lower than in the previous survey wave was somewhat surprising, given that the Wave 5 survey launched in April 2020, shortly after COVID-19 restrictions were implemented in response to the global pandemic. National surveys fielded early in the pandemic, as well as later in 2020, showed higher prevalence of depression compared to the pre-pandemic period [35, 36]. Our findings may be at least partially explained by the age distribution of the Registry population (median age, 61 year; 38% ≥ 65 year), as national studies reported greatest increases in depression among younger age groups [37]. With regard to PTSD, a previous Registry analysis identified a slightly higher proportion of enrollees with a decreasing trajectory of PTSD

symptoms than of those with increasing symptoms (12.8% vs. 9.5%), suggesting that the proportion of enrollees with PTSD may decline over time [38]. Despite these decreases, however, PTSD prevalence in our population remains higher than that previously reported among US veterans (4.7%), though that analysis used a higher PCL-5 cutoff of 38 to define probable PTSD. Of note is that previous Registry questionnaires used 17-item PCL checklist (PCL-17) to assess PTSD symptoms based on DSM-IV criteria [39]. While national estimates of PTSD prevalence were slightly lower when assessed using DSM-V relative to DSM-IV criteria [40], other studies indicated similar estimates from each criteria when assessing PTSD prevalence among US veterans and earthquake survivors [39, 41].

The prevalence of diagnosed chronic sinusitis, which is characterized by long-term inflammation of the nasal and sinus cavities, has not previously been reported among Registry enrollees. Though corresponding prevalence estimates were not available from NYS BRFSS, the age-adjusted post-9/11 prevalence among enrollees in our study was higher than the lifetime prevalence of diagnosed sinusitis among the US adult population in 2018 (14% vs. 11%, respectively) [42]. Prevalence was higher among RRWs in our study (21%), and was within the range of previous estimates from study of WTC-exposed responders that reported post-9/11 prevalence of 23% among firefighters and 9% among emergency medical service workers in 2017 [43]. Our overall estimates were also similar to self-reported lifetime diagnosis of sinusitis (13%) among US veterans deployed to Iraq and Afghanistan who reported any deployment-related respiratory exposures (e.g., dust and sand, chemical fumes, and smoke); prevalence of sinusitis among veterans who reported high levels of exposure (23%) was similar to that among RRWs in our study [44].

The age-adjusted prevalence of sleep apnea in our study was lower than national estimates of 26% among US adults aged 30–70 years (17% vs. 26%, respectively) [45]. Other studies of WTC-exposed responders, including those enrolled in the WTCHP and New York City firefighters, have reported sleep apnea prevalence of 75% or higher, though prevalence may be higher among those receiving treatment for 9/11-related conditions though the WTCHP [46, 47]. Additionally, our study may underestimate the prevalence of sleep apnea, as previous estimates relied on sleep apnea diagnosis by polysomnography, while our analysis only included self-reported diagnosed cases. Associations between intensity of WTC exposure and sleep apnea severity have been reported among responders and community members [47, 48], though other studies have not found associations between WTC exposure and prevalence of sleep apnea among responders [49, 50].

Our finding that HRQOL was poorer among Registry enrollees compared to the general population suggests that the high prevalence of several chronic conditions contributes to poorer quality of life among WTC-exposed individuals. Previous studies have reported associations between burden of WTC-related conditions and poor indicators of HRQOL [17] particularly for those experiencing symptoms of PTSD [18]. Among firefighters who responded to the WTC disaster, the burden of health conditions has been shown to mediate the association between WTC-exposure and diminished HRQOL [51]. Similarly, we found that HRQOL was worse among Registry enrollees with health conditions that are associated with WTC exposure. In our analysis, probable mental health conditions appeared to be more strongly associated with poor HRQOL than physical health conditions. However, the relative contribution of physical and mental health conditions cannot be directly compared, as physical disease estimates were based on self-reported diagnosis at any prior time and may not reflect the current symptom burden of these disorders, whereas probable mental health conditions were assessed based on current symptoms. However, given that physical and mental conditions frequently co-occur among WTC-exposed responders and community members [13, 52, 53], our findings of poorest HRQOL among those with comorbid conditions highlights the need for ongoing, coordinated physical and mental health screening and treatment of individuals exposed to the WTC disaster.

Limitations of our analysis must be acknowledged. First, the baseline Registry population included < 20% of approximately 400,000 individuals estimated to have been exposed to the WTC disaster [54] and those who enrolled in the study may not be representative of all exposed individuals (e.g., if those experiencing health effects were more likely to enroll). There has been significant attrition in the Registry cohort over nearly 20 years of follow-up, and differences in sociodemographic characteristics between our study population and all adult Wave 1 enrollees were observed, potentially leading to biased estimates of disease prevalence. Earlier analyses showed that Registry enrollees who responded to the first three survey waves reported better health outcomes relative to those who did not complete all three surveys [55]; these analyses should be replicated with additional survey waves. Additionally, as we used self-reported data on physical health conditions, some misclassification of these outcomes is likely. Our reliance on physician-diagnosed conditions also has implications for our comparison to the general population. Access to health monitoring and screening through the WTCHP may increase the likelihood of Registry enrollees receiving a medical diagnosis, which may lead to overestimates of the association between WTC exposure and the conditions examined; this may be of particular concern for RRWs, as some (e.g., firefighters, police) receive regular occupational health screening. As the Registry RRW population comprises primarily nontraditional responders, we did not specifically examine disease prevalence among firefighters and police; however, other cohorts (e.g., WTC General Responder Cohort and WTC-exposed NYC firefighters) have focused on health outcomes among these subgroups [56, 57]. Our comparisons to the general population were also limited to enrollees living in New York State at the time of their Wave 5 survey, potentially limiting the generalizability of these findings. While we adjusted for several demographic and socioeconomic characteristics, it is possible that differences between WTC-exposed NYS residents and the general population may bias associations between WTCHR exposure and health outcomes and HRQOL indicators. Efforts to identify appropriate comparison groups, particularly for rescue and recovery workers, who may have different occupational exposures and health status than the general population, should remain a focus of future research.

Our findings underscore the long-term impacts of the WTC disaster on the health and quality of life of exposed populations.

More than 20 years after 9/11, the role of monitoring and treatment for conditions related to WTC exposure is still critical. Findings also highlight the importance of the Registry's ongoing outreach efforts to encourage and help potentially eligible enrollees to apply to the WTC Health Program (WTCHP). In particular, higher prevalence of some conditions among enrollees with low incomes and lower educational attainment may reflect systemic inequities leading to disparities in exposure to disease risk factors and access to healthcare. Future WTCHP referral efforts should address these disparities by prioritizing outreach to populations who have been historically underserved. Future work in the Registry should continue to focus on tracking the prevalence of conditions known to be related to WTC exposure and identifying populations at highest risk of poor health outcomes to inform future policy and interventions.

Author Contributions

All authors contributed to conception of the research questions, and Ayda Ahmadi and Ananya Dhanya conducted initial analyses. Julia S. Sisti developed the analytic approach, conducted the statistical analyses, and wrote the original manuscript, with revision and input from Howard E. Alper, Robert M. Brackbill, Ananya Dhanya, Ayda Ahmadi, and Nicholas Millet. Nicholas Millet wrote the Results section and Ananya Dhanya created data visualizations. All authors read and approved the final draft, and agree to be accountable for all aspects of the work.

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Disclosure by AJIM Editor of Record

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

Ethics Statement

The Registry protocol was approved by the US Centers for Disease Control and Prevention (CDC) and the New York City Department of Health and Mental Hygiene (DOHMH) institutional review boards (#02-058).

Consent

Informed consent was obtained verbally from enrollees at the time of their enrollment.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. Registry survey documents and deidentified survey data limited to specific variables are available at: https://www.nyc.gov/site/911health/about/wtc-health-registry.page. Complete data are not publicly available due to privacy or ethical restrictions; however, additional data may be made available to researchers following review of applications to the Registry.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.