IDENTIFYING THE INTERDISCIPLINARY DETERMINANTS, BIOLOGIC MECHANISMS, AND BEST PRACTICES FOR THE PREVENTION AND ELIMINATION OF MINORITY HEALTH DISPARITIES

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IDENTIFYING THE INTERDISCIPLINARY DETERMINANTS, BIOLOGIC MECHANISMS, AND BEST PRACTICES FOR THE PREVENTION AND ELIMINATION OF MINORITY HEALTH DISPARITIES

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Editorial: Identifying the Interdisciplinary Determinants, Biologic Mechanisms, and Best Practices for the Prevention and Elimination of Minority Health Disparities

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Editorial on the Research Topic

Identifying the Interdisciplinary Determinants, Biologic Mechanisms, and Best Practices for the Prevention and Elimination of Minority Health Disparities

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From macro-level social processes, to environmental exposures, and molecular-level alterations, the causes of minority health disparities are varied and complex. To that end, the National Institute of Minority Health Disparities has developed a multilevel research framework that considers biologic, behavioral, environmental (physical, social, cultural), and health care system factors as jointly shaping health outcomes and health disparities (1). While comprehensive in its scope, minority health disparities research and practice often focus on singular components of the framework in part due to our discipline specific training. As the causes of minority health disparities cross disciplines, so too must investigator expertise and practice-based solutions. Moreover, in order to eliminate health disparities, research and practice should move beyond focus on proximal health care related determinants, and more broadly consider upstream contextual, social, and environmental causes. Also, the biologic mechanisms connecting the exogenous determinants to health disparities are not well-understood. Biologic factors that are sensitive to lived experience may be key in understanding how deleterious exposures become biologically embedded to drive health disparities. Thus, a critical interdisciplinary review of the many factors that contribute to minority health disparities is warranted. Doing so will help to identify gaps in the evidence base and highlight next steps for research and practice.

In this Research Topic, we present a collection of articles that focus on the causes of health disparities from both social and environmental perspectives, as well as innovative solutions. For example, in their review of energy insecurity (defined as the inability to meet household energy needs, such as heat and electricity), Jessel et al. discuss the adverse health consequences of unaffordable and inadequate household energy in the context of climate change for vulnerable populations. They note that energy insecurity co-occurs with, and is exacerbated by, other social determinants of health like socioeconomic status, race, and place. Such intersectional inequality is also discussed in Taylor et al. review of the multilevel determinants of HIV testing disparities among foreign born black men living in the United States. The authors discussed not only how individual, community and policy level factors can each thwart access to HIV testing, but also the

accumulated impact of these factors along with having multiple stigmatized identities (e.g., race, gender, sexual orientation, addiction) work to exacerbate risk among this population. In terms of solutions and strategies to prevent and eliminate health disparities, Gómez et al. describe the *Juntos por la Salud* (JPLS; Together for Health) initiative, which is a mobile health and wellness program for Mexican immigrant population living in 11 metropolitan areas in the United States. Mexican migrants experience a myriad of significant social and socioeconomic risks, including low educational attainment and low pay occupations, as well as high psychosocial stress related to immigration status (e.g., fear of deportation) and discrimination, which in turn results in low health care utilization and poor health outcomes. JPLS works to reduce barriers to health care for this population by providing culturally sensitive and linguistically matched health education and services for free. Taken together, these studies indicate that as the causes of health disparities are multifaceted and multilevel, so too must be the interventions.

The Research Topic also includes empirical papers that focused explicitly on biologic mechanisms—epigenetic alterations and telomere length—linking adversity to health outcomes. Epigenetic alterations, often measured by DNA methylation, can modulate gene expression and influence health outcomes. Epigenetic alterations are sensitive to adverse exposures commonly experienced by vulnerable populations, and can be altered during sensitive developmental periods like pregnancy, thereby possibly contributing to the biologic embedding and intergenerational transmission of health disparities (2, 3). In DeLano et al. study of pregnant women and their infants, higher levels of community socioeconomic deprivation during pregnancy was associated with significant epigenetic change to a gene involved in the infant's stress response system (*SLC6A4*), suggesting possible future developmental risk for the child. Similarly, telomere length (which refers to the structures at the end of chromosomes which shorten with age) is considered a biomarker of aging and research has shown telomere shortening and concomitant disease risk can be accelerated through experiences of stress and social adversity (4). In a nationally representative US sample of Hispanic adults, Ishino et al. found variation in telomere length according to different profiles of acculturation (e.g., low acculturation, assimilated, integrated), suggesting stress related to acculturation over the life course may impact biology.

Finally, our Research Topic includes timely papers related to disparities and the COVID-19 pandemic. For example, Strully et al. take up the critical point of COVID-19 vaccine hesitancy among racial and ethnic minorities, who have been disproportionately impacted by the pandemic. Using data collected from minority populations in New York State, Strully et al. discuss the legacy of historical health injustice and ongoing inequities that fuel continued medical distrust, as well as the need for vaccine campaigns to rely on trusted community voices and community assets to promote vaccination. The associated commentary paper by Teo, as well as the perspective paper by Ullah et al. discuss a COVID-19 future, both in terms of data needs for promoting vaccination uptake, and impacts of the pandemic on future birth rates due to changes in economic conditions, mental health, and mortality.

Taken together, the papers in this Research Topic represent the interdisciplinary and innovative thinking that is necessary to effectively address and eliminate health disparities. Moreover, in addition to the myriad of risks that jointly contribute to disparities, we must also consider community and individual level assets that can promote health and resilience. Wu et al. paper on sleep duration and ideal cardiovascular health (5) is one example of this positive approach. It is our hope that this collection of papers will lay stimulate collaborations across disciplines and lay the foundation for future minority health disparities research and practice.

AUTHOR CONTRIBUTIONS

AA conceptualized, drafted, edited, and finalized this editorial.

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BRIEF RESEARCH REPORT
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Together for Health: An Initiative to Access Health Services for the Hispanic/Mexican Population Living in the United States

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A disproportionately small percentage of the Hispanic/Mexican population in the United States has adequate access to health services, which decreases quality of life at both the individual and community levels. In addition, it increases risk for preventable diseases through insufficient screening and management. The Mexican Section of the U.S./Mexico Border Health Commission, in efforts to address barriers to accessing preventive health care services for vulnerable populations, launched the initiative *Juntos por la Salud* (JPLS) that offers health promotion and disease prevention services to Hispanics living in and around 11 U.S. metropolitan cities via mobile health units. This paper presents a descriptive analysis of the JPLS initiative and potential positive impact it has had in reducing barriers faced by the Hispanic population. JPLS screens and provides referrals to primary care services to establish a medical home and has the potential to reduce health care costs in a high-risk population through education and timely health screenings.

Keywords: access to health services, preventive programs, collaborative programs, migration and health, mobile health services, immigrant

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INTRODUCTION

The health system in the United States (U.S.) divides the population among those who receive public or private medical care and those who cannot access health services (1). This only serves to heighten health disparities and create structural barriers to accessing available and affordable health care services (2). Moreover, lack of access to health services for undocumented residents in the U.S. affects both physical and emotional health (3, 4).

Despite the implementation of the Patient Protection and Affordable Care Act (ACA), the number of vulnerable Mexican immigrants with deteriorating health situation continues to grow. The ACA was established through federal legislation in 2010 to address high uninsurance rates, lack of access to care, and variable quality of care received in the U.S. (5). Immigration status often plays a role in lack of access to health insurance and quality health services. However, in some states, special programs are available for vulnerable populations, specifically women and children.

California, for example, offers MEDI-CAL and New York offers Child Health Plus, a health insurance plan for children (6). Federally Qualified Community Health Centers (FQHCs) are also available and affordable for those with limited resources and lacking health insurance, regardless of immigration status.

According to studies carried out by the Mexican *Consejo Nacional de Población* (CONAPO-Nacional Council on the Population of Mexico), about 6.2 million Mexican immigrants (more than 50% of this population) did not have health insurance or access to health services between 2004 and 2013. Recent data indicate that 45% of undocumented immigrants are currently uninsured whereas only 8% of citizens are uninsured; in families with mixed citizenship statuses, children with one or more non-citizen parent are twice as likely to be uninsured than children of citizens (7). This proportion is higher compared to other groups of immigrants (8); however, this figure did decrease (3%) in the indicated period (6). This slight decrease could be attributed to the passage of the ACA, which increased coverage for all populations, but most notably for Hispanics. While the uninsured rate for all Hispanic adults was 40.5% prior to the main provisions of the ACA taking effect in 2013, this rate decreased slightly by 7.1 percentage points in 2014 (9).

CONAPO data also demonstrated that males of Mexican origin living in the U.S. were less likely to have health insurance coverage than their female counterparts in 2013, when 55% of the Mexican immigrant population with insurance coverage was female. Only one in three youth between 18 and 29 years of age were covered by health insurance. Further, four out of ten children under 18 years of age, six out of ten adults between 30 and 44 years of age and half of adults between 45 and 64 years of age were without health insurance (10).

Barriers to access to health services for Mexican migrants in the U.S. include socioeconomic factors such as low educational attainment, and working in low-paying occupations (11–14), which may be related to underemployment, undocumented employment, or low knowledge about worker's rights. Race and ethnicity are additionally associated with reduced access to offers of employment-based health insurance for minority groups including Hispanics compared to white workers in similar occupations (15). In addition, immigration status or immigration status of family members are associated with reduced utilization of health care services due to fears of discrimination or legal repercussions (16). Commonly cited as barriers to seeking basic health care include lack of understanding of the U.S. healthcare system, language barriers (4, 17–21), and work- related migration between the U.S. and Mexico as well as within the U.S. (22–25).

Given limited health care utilization by Mexican immigrants to the U.S., the government of Mexico launched an initiative called the *Ventanillas de Salud* (VDS; "Health Windows") in 2003. The mission was improving access to primary and preventive health services, increasing public insurance coverage, connecting individuals to medical homes, and promoting a culture of self-care in Mexicans living in the U.S. Currently, the Mexican Consulates in the U.S. operate 49 VDS and two mobile VDS. In addition to general health information, the VDS provide: counseling and guidance services about disease prevention and health promotion; preventive health screening; referral to primary healthcare services; and eligibility aids for ACA insurance plans.

From 2013 to 2017, the VDS provided 21 million services to 7.7 million people. In the same period, the number of preventive health screenings offered grew by 337% and the number of Mexican immigrants qualifying for health insurance in the U.S. increased by 106% (26). This increase demonstrates both direct and indirect contributions of the VDS to the health and well-being of the Mexican immigrant population and in keeping with the overarching mission of decreasing emergency room visits and uncompensated care.

Juntos por la salud Initiative

A diagnostic health mapping of the Mexican population living in the U.S. conducted by the Mexican Section of the US/Mexico Border Health Commission (CSFMEU) found that the state of health of a large proportion of the Hispanic population was gravely vulnerable, especially in geographic areas beyond the reach of the VDS. Identified risk factors for vulnerable health status included immigration status, limited English proficiency, low economic status, and few or no services in remote areas where people reside, all of which contribute to limited or no access to health services (4). Additionally, the political context of the U.S. regarding migrants is associated with increased uncertainty and stress (16) which are barriers to accessing both social and health services by the population most in need.

Thus, VDS expansion was deemed necessary to reduce health related risks for the most vulnerable subsets of Hispanics in the U.S. CSFMEU introduced the *Juntos por la Salud* Mobile Health and Wellness Initiative (JPLS). The aim of this initiative was to strengthen the VDS strategy and provide preventive health services to rural and hard-to-reach communities in the U.S. with difficult access to regular medical care. JPLS is an ongoing collaboration between the Mexican Ministry of Health (SSA), the Office of Foreign Relations (SRE), the Institute of Mexicans Abroad (IME), and the *Ventanillas de Salud* (VDS) Strategy. JPLS mobile units differ from mobile VDS services because they operate independently from the consulates and are organized at the community level.

The primary goal of JPLS is to reduce barriers to health care for the Mexican population residing in the U.S. by providing access to preventive programs in their preferred language and in a culturally sensitive and linguistically appropriate manner. However, the reach and potential for public health impact created by JPLS has not been previously described in the scientific literature. The objective of this paper is to present a qualitative descriptive analysis of the JPLS initiative and its potential to reduce barriers faced by the Mexican immigrant population living in the U.S. JPLS is hypothesized to increase access to health care services and encourage establishment of a medical home, thus reducing health care costs through education and timely health screenings.

In 2016, the initial phase was launched with five mobile health units in the following cities: Chicago (Illinois), Dallas

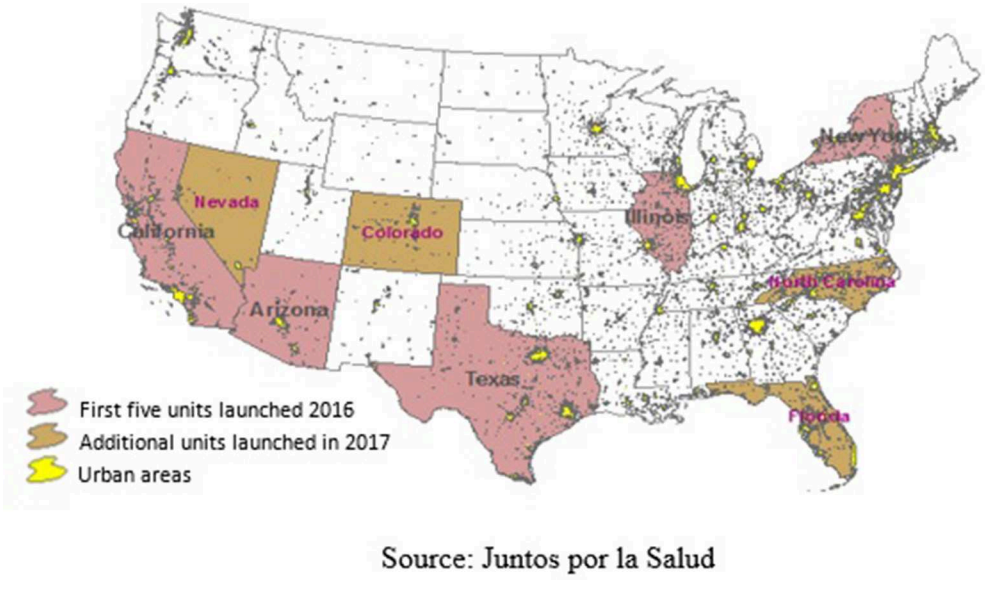

FIGURE 1 | Geographic locations of *Juntos por la Salud* Mobile Health Units.

(Texas), Los Angeles (California), Phoenix (Arizona), and New York (New York). Subsequently, in a second phase, an additional six mobile health units launched in the cities of Denver (Colorado), Las Vegas (Nevada), Tucson (Arizona), Miami (Florida), Orlando (Florida), and Raleigh (North Carolina) (**Figure 1**).

JPLS provides health education on priority health issues, such as nutrition, obesity, diabetes, women's health, children's health, mental health, substance use, exposure to violence, HIV/AIDS and other sexually transmitted infections, as well as legal and financial guidance. In addition, mobile health units provide preventive health screenings, referrals to clinics or community programs, follow-up on referrals and administration of immunizations. All participants are informed and verbally consent to share their personal information and risk factors. Each mobile health unit has built a network of local health agencies and community based organizations increasing access to a number and diversity of health care services, as well as referrals to local community clinics at low cost or free of charge. All of the services at JPLS are provided free of charge regardless of national origin.

Each mobile unit is managed and operated by a leading local agency in the U.S. and has a network of strategic allies integrated by specialized health institutions in the area including hospitals, laboratories, community clinics, and community programs that coordinate to handle referrals. All of the materials offered at the JPLS units are developed to be culturally appropriate and are offered by bilingual staff and volunteers. Staffing is highly dependent on the fiscal agent operating the mobile health unit and includes community health workers, health science students, nurse assistants, or public health trained professionals. Mobile unit locations are determined monthly based on neighborhood demography (i.e., concentration of vulnerable Hispanics/Mexicans) and invitations from strategic allies per their agency policies. Locations and hours of services vary and are primarily advertised via social networks, local radio stations and word-of-mouth.

Additional activities of the individual mobile health units included: participatory relationship-building with existing health and community stakeholders; monitoring of high-risk cases; implementation of capacity-building programs to train health workers among residents of targeted communities; registration and monitoring of the services offered; and maintenance of the mobile health units. Program goals included the following, though data related to their success are not reported: refer ∼50% of un- or under-insured users to appropriate public benefit health insurance programs; provide medical referrals to 100% of individuals with abnormal health screening results to a primary care provider; establish a medical home for ∼50% of clients referred to community clinics; provide general health consumer education sessions to individuals at the mobile health units during the term of this contract.

METHODS

Data Collection at JPLS Mobile Health Units

JPLS uses a database system which captures information on those served through JPLS and services provided, for the period between February 2016 and December 2018. The JPLS mobile health units were strategically placed in target cities based on the concentration of Hispanic population determined by the network of consular offices in the U.S. and the Mexico Section of the U.S. Mexico Border Health Commission. Additional health and needs assessment were subsequently conducted by each community based organization funded within the 11 mobile health unit sites selected.

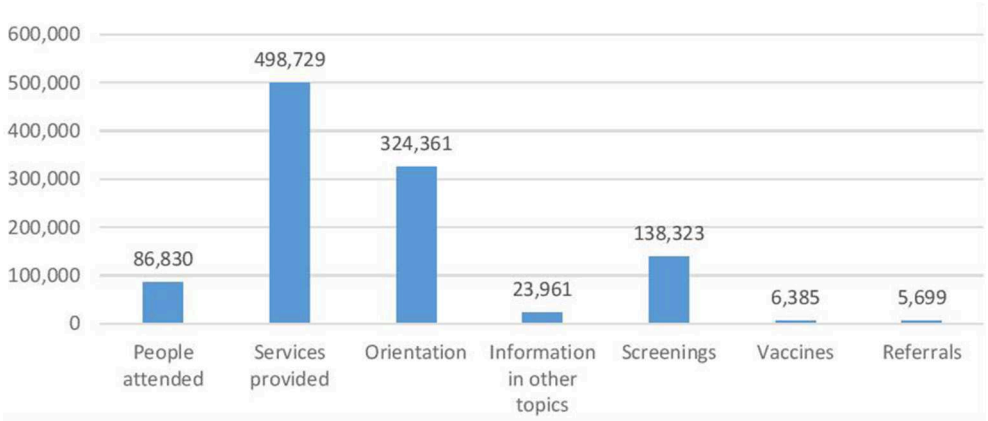

FIGURE 2 | *Juntos por la Salud* Program: services provided (February 2016–December 2018). *Juntos por la Salud*, CSFMEU.

TABLE 1 | Prevalence of the main causes of morbidity among Mexicans in the U.S. *Juntos por la Salud* initiative (February 2016–December 2018).

Type of detection	Number of tests performed	High/positive results	Prevalence
Overweight/obesity	21,110	15,721	74.5%
Total cholesterol	8,171	2,565	31.4%
Blood pressure	30,190	8,693	28.8%
Glucose	22,129	4,516	20.4%
HIV/AIDS	1,105	6	0.5%

Juntos por la Salud data base, CSFMEU, February 2016–December 2018.

Descriptive Analysis

Our descriptive analyses are derived from fully anonymized deidentified secondary data sources with no individual-level identifiers. Demographic and epidemiological characteristics of the target population were summarized from an ecological level (i.e., only population summary data are available). Prevalence estimates for commonly identified disease states and count data for health screening, health education and referral services provided through JPLS were estimated. As this analysis used secondary data and was not deemed human subjects research, ethical approval was not required.

RESULTS

Services Provided

Between February 2016 and December 2018, JPLS registered 86,830 participants and provided 498,729 services including health education, preventive health screenings, vaccination, and referrals, among others. On average, each participant received 5.7 services during each visit (**Figure 2**). Of over 86,000 service recipients in the mobile units, 86% reported not having medical insurance.

Of the total services provided, 65% involved health education on priority health issues, raising awareness about the importance of timely detection related to chronic diseases, oral health, eye care and occupational health; nutrition and physical activity, sexual and reproductive health, and mental health. Approximately, 30% of total services included the following preventive health screenings: blood pressure, glucose levels and hemoglobin A1c, anthropometric measurements, cholesterol, and HIV/AIDS.

Other services offered by these mobile health units include group health education sessions on topics such as prevention of chronic degenerative diseases, sexual and reproductive health, preventive programs (nutrition and physical activity, dental, occupational, mental or visual health), substance abuse or domestic violence, financial wellness, educational or access to secondary prevention services. Likewise, these group education sessions also hosted vaccination days to immunize against seasonal flu. During this same period, there were ∼1,025 group sessions with an average of 38 attendees per session. Fifty-four percent of the education imparted included information about preventing chronic-degenerative diseases such as hypertension, diabetes, obesity and cancer, among others. Twelve percent focused on other preventive programs; nine percent sexual and reproductive health information, seven percent substance abuse, seven percent mental health information.

Those who screened positive for health conditions of interest were referred to community clinics or specialized medical services. Referrals were most frequently made for hypertension, obesity and high glucose levels, indicating chronic health problems of the targeted population. Between February 2016 and December 2018, 6,385 vaccines were administered, of which 70% were influenza vaccines and almost 20% were for Hepatitis; the remaining proportion include vaccines for tetanus, pertussis, and routine childhood immunizations.

Demographic Profile of Participants Served

Between February 2016 and December 2018, 77% of service recipients were of Mexican origin; 7.4% were born in the U.S.

and 9.8% came from Central America, South America and the Caribbean. Sixty-two percent were women and a large percentage of these women (58%) were of reproductive age. Eighty-four percent had lived in the U.S. for more than 10 years. About 29% had between 1 and 6 years of education. The three most common occupations reported by service recipients were construction, house/office cleaning and factory work. Only 20% reported English language proficiency.

Epidemiologic Profile

The population served by JPLS from February 2016 to December 2018 indicated that 75% were overweight or obese, 31% had high cholesterol levels, and 29% had high blood pressure levels (**Table 1**). Moreover, prevalence of overweight and obesity in the population attended by the JPLS mobile health units was 50% higher than the population seen in the VDS, which reported a prevalence of 50%, during the period from 2013 to 2018 (26). In regards to mental health 2,389 individuals reported having a prior diagnosis of depression or anxiety, 38% reported not receiving treatment.

DISCUSSION

The JPLS program provides needed services for a very vulnerable population in the U.S. Barriers such as their immigration status, limited proficiency of English, low economic status, and living in remote areas, yield insufficient access to health care services (9, 13). Of the total number of people served by mobile health units, 86% reported not having health insurance. This highlights their vulnerability, especially when 80% report living in the U.S. for >10 years. As for the main causes of morbidity of this population, 75% are overweight and obese, which is 25% higher than the prevalence reported by the population served by the *Ventanillas de Salud* (50%) (26). This situation indicates that the mobile health units are likely reaching individuals who are otherwise unable to access medical care and emphasizes the potential impact of the JPLS program.

Mobile health units are designed to implement screening measures that can deter serious illnesses requiring urgent medical attention, thus reducing inappropriate or inefficient medical service utilization. The need for targeted services among those who do not have consistent access to primary or preventive care is demonstrated by the higher ecological prevalence of overweight and obesity among service recipients attending the mobile clinics compared to those accessing similar services via the VDS initiative (50 vs. 75%). However, additional differences in the characteristics of those seeking care at the mobile health units, such as untreated diabetes, hypertension, or other chronic conditions are not known due to limitations in the available data. Future research on JPLS service recipients is needed to determine motivating factors for seeking care at mobile health units.

Some illnesses may be attributed to lifestyle behaviors (diet, physical inactivity, etc.), which may have changed upon arriving to the U.S. The services provided by mobile health units play an important role, especially in orientation and counseling on priority health issues, and timely detection, before experiencing a need for emergency services.

The rate of referrals to outside services by JPLS is numerically low (5,699 referrals made to 86,830 people seen, 6.5%); however, qualitatively this rate is acceptable for the purposes of the mobile unit considering the scope of work and personalized attention each referral entails. Comprehensive preventative health services that led to referrals for follow up care include: guidance and personalized counseling, navigation in accessing health services, health screenings, follow-up to establish a medical home, and assurance that the participant accessed the medical attention needed. The vast majority (86%) of the JPLS program participants reported not having any health insurance due to sociodemographic barriers to accessing health services. A central goal of the JPLS program is to connect community members with a trusted and safe health promotion environment. The 5,699 referrals were provided to individuals who have rarely or never received comprehensive services and access to care due to financial or structural barriers. However, not everyone who is offered a referral will accept or follow the referral instructions, and the acceptance rate following a JPLS visit is not currently known. Each JPLS mobile health unit is continually working to increase the number of referrals using different mechanisms that include innovative strategies to disseminate vital health information, logistics related to the referrals and building a network of trusted health institutions to link participants with services.

Impact of the JPLS Initiative

The JPLS mobile health units purport to improve the health conditions of a Hispanic population experiencing a state of vulnerability and increased barriers to health services. However, the long-term impact of JPLS, if any, is unknown. However, we propose the following potential mechanisms for impact that warrant specific study:

- By means of health promotion and disease prevention services, JPLS is postulated to reduce emergency room visits for non-emergency health care.
- JPLS reaches the Mexican immigrant population living in the in a state of vulnerability and outside the range of the VDS (which is broadly utilized where it has been implemented).
- JPLS mobile units strengthen the efforts of VDS to reduce the prevalence of the main causes of mortality in hard-to-reach populations.
- The services provided are anticipated to be highly acceptable to the target population as they increase the network of interprofessional allies to facilitate access to health services, at low cost or free, in a linguistically and culturally appropriate manner.
- Though JPLS targets the Mexican immigrant population, the mobile health units provide service to anyone interested in them, regardless of the country of origin or insurance status.

Our initial qualitative descriptive analysis indicates a need for future exploration of the contribution of the JPLS initiative as well as a model to duplicate for greater impact and intervention studies in health care.

CONCLUSION

The Hispanic population in the U.S., particularly Mexican immigrants, lack access to health care services, affecting the quality of their physical and mental well-being (26). Fear of deportation and discrimination greatly affects the population and affects social and health service-seeking behaviors. Thus, it is imperative to develop and invest in effective strategies that allow provision of basic and preventive health services such as screenings, health promotion, and disease prevention, despite the current political context in the U.S. Innovative mobile healthcare strategies such as JPLS are one potential avenue for accessing hard to reach populations including Mexican immigrants in the U.S. who may otherwise go without basic access to preventive health screening, health education, and referral services.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on reasonable request to the corresponding author.

AUTHOR CONTRIBUTIONS

AL assisted with the initial proposal of the article and with the analysis of information. CR, JT, JL, EA, AS, and MR helped with the review of information, data interpretation, and discussion.

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REVIEW
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Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature

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Household energy is increasingly vital for maintaining good health. Unaffordable and inadequate household energy presents adverse consequences that are amplified by poverty and a changing climate. To date, the connections between energy, socioeconomic disadvantage, and well-being are generally underappreciated, and household energy connection with climate change is under-researched. Building on the energy insecurity framework, this review explores literature related to household energy, poverty, and health in order to highlight the disproportionate burdens borne by vulnerable populations in adequately meeting household energy needs. This paper is based on a comprehensive review of books, peer-reviewed articles, and reports published between 1990 and 2019, identified via databases including JSTOR and PubMed. A total of 406 publications were selected as having potential for full review, 203 received full review, and 162 were included in this paper on the basis of set inclusion criteria. From the literature review, we created an original heuristic model that describes energy insecurity as either acute or chronic, and we further explore the mediators and pathways that link energy insecurity to health. In the discussion, we posit that the extant literature does not sufficiently consider that vulnerable communities often experience energy insecurity bundled with other hardships. We also discuss energy, poverty, and health through the lens of climate change, making the criticism that most research on household energy does not consider climate change. This evidence is important for enhancing research in this field and developing programmatic and policy interventions as they pertain to energy access, affordability, and health, with special emphasis on vulnerable populations, climate change, and social inequality.

Keywords: energy insecurity, climate change, vulnerable populations, housing, health

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INTRODUCTION

Global energy demand and consumption have increased substantially and are expected to continue rising (1); this is particularly evident in countries with strong economic growth such as China and India (2). The U.S. Energy Information Administration (EIA) has predicted that world energy use will increase by 28% by 2040 (2). In 2017 alone, global energy demand rose 2.1%—twice as much as in 2016 (3). As climate change worsens, the demand for more energy services and the strain on existing services will increase. As of 2017, residential energy consumption accounted for 20% of

the total energy consumption across all sectors in the U.S. (4). Ensuring affordability, access, and adequate production of household energy is vital for maintaining individual and population-scale health and well-being. Household energy uses include cooking, lighting, heating, cooling, cleaning, and technological, medical, and other life-sustaining devices (5–7). Yet, millions of households around the world live without an adequate amount of energy (8).

Adequate access to energy is encumbered by limited and faulty infrastructure, affordability challenges, and service disruptions due to disasters and extreme weather events, often linked to climate change. This phenomenon, known as energy insecurity, is defined as the "inability to adequately meet household energy needs" (9). The energy insecurity framework includes physical, economic, and behavioral dimensions that lead to or exacerbate adverse health issues (9). The physical dimension includes poor housing quality, the structure of the home environment, and inefficient appliances (9). The economic dimension consists of affordability challenges (though it is not based merely on an economic ratio or threshold), while the behavioral dimension focuses on coping strategies, social vulnerabilities, and indicators of resilience (9). This conceptual framework helps us to understand the phenomenon of energy insecurity and its consequences. This framework parallels that of food insecurity—the "disruption of food intake or eating patterns because of lack of money and other resources" (10)—in that it reflects cost, quality, and health impacts.

In this article, we present the results of our review of the existing literature on energy insecurity and demonstrate the range of concerns and of approaches to resolving them. We propose the new terms- "acute" and "chronic" energy insecurity to further understand and break down household energy issues. Our findings suggest that the literature does not sufficiently consider the intersectionality of vulnerability types and multiple hardships. Furthermore, the use of numerous terms for household energy insecurity further compartmentalizes energy issues by geography and discipline, hampering the possibility for a comprehensive, or systematic literature base. This compartmentalization foregoes the opportunity to address energy insecurity as a complex, interdisciplinary, intersectional, and multidimensional issue, especially in the context of the pressing threat of climate change. For the sake of clarity, we provide below a brief overview of terms currently used to describe household energy issues as they relate to socioeconomic disadvantage, and in some cases, health.

HOUSEHOLD ENERGY TERMINOLOGY

Many different terms have been used to describe the demand side of energy-related hardship. Researchers, policymakers, and practitioners have popularized terms such as fuel poverty, energy burden, energy vulnerability, and energy poverty, among others. These terms differ in their geographic usage and somewhat in their methods of measurement, but all similarly reference issues related to energy consumption and affordability. Energy burden and fuel poverty are mirroring terms that are used separately in different geographic regions; the former in the U.S. and the latter mostly in the United Kingdom (U.K.), Ireland, and New Zealand. Both terms are generally defined by an economic ratio whereby households that allocate more than 10% of their gross income for indoor energy expenses are considered energy burdened or fuel poor (9, 11–13). Energy poverty is generally attributed to the Global South and refers to the lack of modern energy services and low energy consumption (5, 14–20). Outcomes and indicators of energy poverty center on socioeconomic development, well-being, and poverty (21). A newer term, energy vulnerability, was developed to bridge the geographical research gap between fuel poverty and energy poverty in order to shed light on energy hardship as a global problem (14, 21). Importantly, these terms and their definitions have not yet incorporated the uncertain realities of climate change and its impact on energy, even though climate impacts are fundamentally rooted in how energy is produced and consumed, and its availability is threatened by the aftermath of extreme weather events, often caused by climate change.

Despite evidence of a strong association between energy access, affordability, and health, none of the above terms inherently focus on health. Research and policy tend to focus on the economic factors of energy burden, fuel poverty, and energy vulnerability, leading to financially-motivated interventions. For example, household-level financial subsidies (e.g., bill assistance) are a popular intervention, as opposed to more structural measures such as energy efficiency upgrades or adoption of clean energy technologies. Moreover, such an economic focus does not address the full scope of the problem, as it leaves out psychosocial and behavioral factors, among others, that contribute to energy hardship. Even energy poverty's focus on well-being and socioeconomic development omits housing quality and affordability constraints as a focus. By comparison, energy insecurity more broadly encompasses a wider spectrum of energy-related hardships that may be internal or external to an individual's experience of the phenomenon and is attuned to an expansive range of socioeconomic, psychological, and environmental determinants that produce energy-related hardship. The energy insecurity framework offers the opportunity to evaluate health predictors and outcomes in the context of climate change (22).

The present review provides an encompassing account of the relationship between energy, health, poverty, and climate change and the pathways by which these factors are interlinked. We address the critical gap in the importance of energy for population health (15, 23) by focusing not only on medical issues but also on the cycles of social disadvantage implicated in the nexus of energy, health, and poverty. We outline the impacts of global climate change on household energy access and how it contributes to the severity of health effects and discuss the need to accommodate growing demand on energy systems. This review provides evidence that health is a necessary consideration amidst increases in global energy demand. This is particularly important when: (1) developing methods for energy efficiency and production; (2) deciphering how to distribute and provide energy to low-income, marginalized, and vulnerable households equitably; and (3) preparing for climate change and acute threats to energy access.

PAPER ORGANIZATION

We begin our analysis with a heuristic model linking the various factors that emerged during the review process, including the phenomena of chronic and acute energy insecurity (see **Figure 2**). This paper is organized into four thematic sections with subthemes. First, we propose new terminology to describe different manifestations of energy insecurity. Second, we review the evidence on energy insecurity and the social determinants of health by discussing the social patterning of energy insecurity by gender, age, health status, education, employment, socioeconomic status, and race. Next, we review evidence on the association between energy insecurity and place, noting the spatial inequalities in neighborhood resources and demographics that contribute to the increased likelihood that some community members will experience energy insecurity. Third, we outline findings regarding the connection between energy insecurity, housing quality, and home energy infrastructure by exploring the relationships between housing tenure, energy efficiency, and home age. Fourth, we highlight the salience of coping strategies and behaviors enacted by households experiencing energy insecurity and describe the health effects of temperature extremes, high-effort coping, and the depletion of resilience reserves. The *resilience reserve* is a framework that describes how resilience that should be preserved for use in a specific event, such as in response to a natural disaster, becomes depleted due to constant use in response to a greater prevalence of chronic daily struggles (24). To conclude, we summarize the findings of our review and describe the cumulative hardships of energy insecurity. In the discussion, we offer a critical analysis of the literature, highlighting that the research does not adequately consider the intersectionality of experiences of energy insecurity, infrequently employs an environmental justice framework, and lacks cohesive terminology. These critiques are discussed in relation to the growing wealth gap, increasing energy costs and demand, research into household energy in the Global South, and the inevitable impact of climate change.

METHODS

This review is based on a comprehensive search for relevant literature published between 1990 and 2018 and archived in JSTOR and PubMed. The literature review conceptually frames energy issues along the lines of climate change, health, and socioeconomic factors. The literature review search was conducted using a matrix of terms in varying combinations with one another. The search terms and their categories are outlined in **Table 1**. Terms from each category were searched along with terms from other categories. For example: (1) [(energy insecurity) AND (poverty) AND (climate change) AND (health)]; and then, (2) [(fuel poverty) AND (poverty) AND (climate change) AND (health)]. A term from the "Social," "Health," and "Energy" category was used in every search because one of our inclusion criteria is that articles discuss the relationship between household energy, health, and socioeconomic status. We did not include "climate change" as a required term for every search, as part of the review is analyzing the extent to which the existing literature on household energy considers climate change. We excluded sources about energy and climate change that did not have a health outcome or a socioeconomic focus. Any source that did not discuss energy at the household, neighborhood, or community level was also excluded. Beyond this, our criteria were purposefully broad in order to capture the breadth of topics related to household energy use, health, and climate.

The search was limited to articles in English. Books, peer-reviewed articles, and reports were included, and all other source types were excluded. Our initial database search plus additional articles added from reviewing the reference sections of various sources yielded 750 results. After discarding duplicate sources and literature that was not relevant based on title, we had 406 sources. These sources underwent title and abstract screening. At this point, we identified 203 sources for full review. Of these, 162 were analyzed and incorporated into the final manuscript (**Figure 1**). Some sources out of the 203 identified were not included in the final manuscript due to the subsequent irrelevance of their topic once the topics discussed in the manuscript had been refined during editing.

HEURISTIC MODEL

Energy insecurity can impact health in a multitude of ways. Studies on energy insecurity encompass not only direct but also indirect health impacts because they consider social determinants of health and the coping strategies people use in response to energy insecurity. Inadequate household energy has been linked to the following health outcomes for both adults and children: cardiovascular, pulmonary, and respiratory illnesses; cancer; arthritis; acute hospitalization; excess mortality in summer and winter; and anxiety, depression, and stress (9, 13, 22, 25). Indirect health impacts, such as food insecurity, are also associated with energy insecurity (6, 26–30). It is important to highlight how indirect health problems contribute to and compound direct health impacts related to household energy insecurity. With health as an endpoint, our innovative, original heuristic model (**Figure 2**) tracks the multifaceted pathways that directly and indirectly link energy insecurity to health by distinguishing between chronic and acute energy insecurity.

DEFINING CHRONIC AND ACUTE FORMS OF ENERGY INSECURITY

Energy insecurity is a complicated, multifaceted issue that may be best understood by parsing out its various forms—acute and chronic energy insecurity. For this reason, we propose the incorporation of these terms into the lexicon of energy insecurity work. *Chronic energy insecurity* is a long-term issue that can arise from a consistent inability to afford or access adequate energy to meet household needs. An example of chronic energy insecurity would be living in a home that is consistently cold because the cost of heating is unaffordable. The lack of adequate household energy is often predicated on a number of social and demographic factors including age, gender, socioeconomic

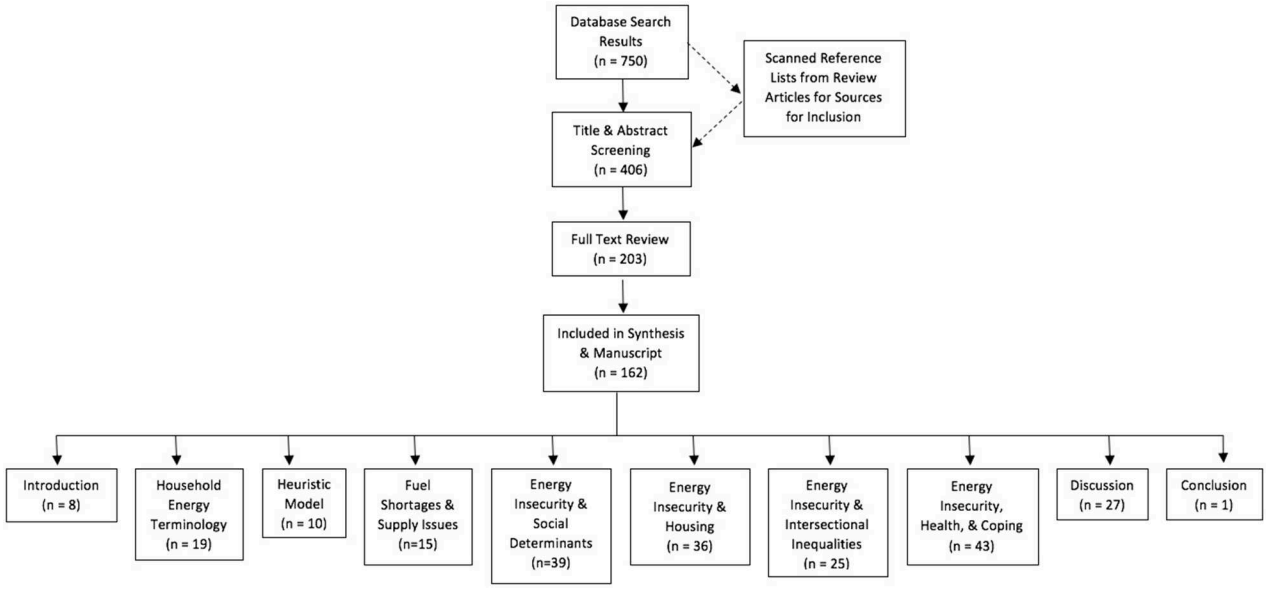

FIGURE 1 | Flow chart of literature selection and review process.

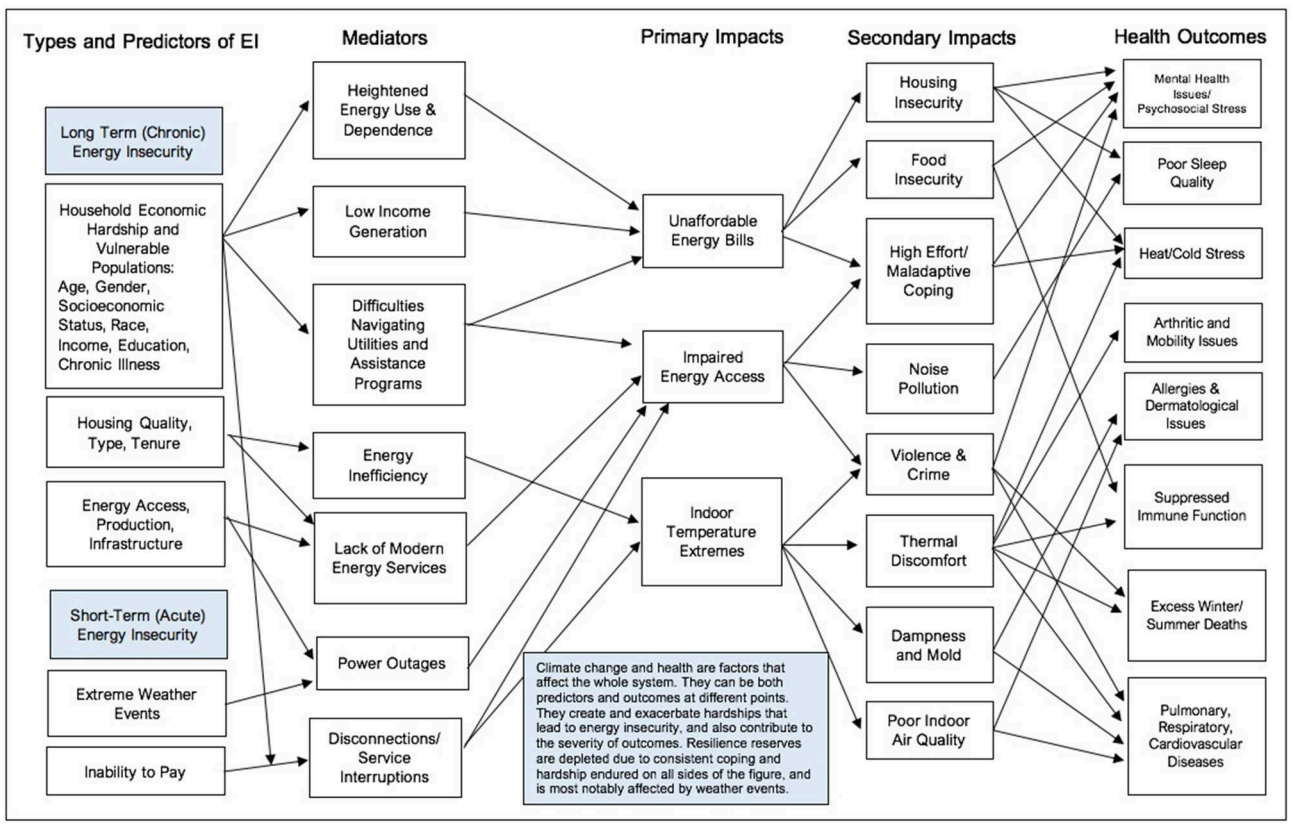

FIGURE 2 | Connection between household energy insecurity (EI) and health.

TABLE 1 | Search terms used in the literature review.

ENERGY TERMS
• *Fuel poverty*
• *Energy poverty*
• *Energy burden*
• *Energy vulnerability*
• *Energy insecurity*
• *Energy inefficiency*
HEALTH TERMS
• *Health*
• *Chronic illness or conditions*
• *Excess winter mortality, excess heat death*
HOUSEHOLD TERMS
• *Household, Housing, or Home*
• *Neighborhood or Community*
SOCIAL TERMS
• *Low-income*
• *Poverty*
• *Socioeconomic Status*
• *Vulnerable population*
• *Social vulnerability*
• *Resilience*
• *Coping*
• *Housing/Food insecurity*
CLIMATE TERMS
• *Natural disaster*
• *Extreme Weather event*
• *Climate change*
• *Global warming*
• *Heat wave*
• *Hurricane*
• *Power outage or shutoff*

status, education, income, race, and employment status. These characteristics may have implications for earnings potential, can determine a household's ability to navigate available resources, and affect access to efficient housing and energy use patterns.

Acute energy insecurity is a short-term issue that tends to arise from infrastructural, maintenance, environmental, or other external sources that disrupt access to energy sources. Some examples of acute energy insecurity include a power outage from a hurricane or a gas shutoff from a reported leak. Interestingly, chronic energy insecurity can lead to a significant crisis point of acute energy insecurity, such as shut-offs due to non-payment. Shutoffs are an acute form of energy insecurity because, for the most part, they are short-lived, and services are reinstated upon cost recovery by the energy service provider. Three primary forms of acute energy insecurity—fuel shortages and supply issues, power outages, and shut-offs—and the links between service interruptions and ill health are described next.

FUEL SHORTAGES AND SUPPLY ISSUES

Health impacts from energy access issues (when infrastructure is available) can arise when demand exceeds supply via two primary routes: (1) fuel shortages and (2) capacity of the energy infrastructure to handle excess demand during extreme weather. Fuel shortages across the world also indirectly impact health by increasing fuel cost and making sources unaffordable, leading to inaccessibility. Sometimes, other resources necessary for life are contingent on energy access. For example, during a fuel shortage, rural Iñupiaq Eskimo villages in Alaska's Northwest Arctic Borough were unable to access clean water because they did not have heat or electricity to prevent pipes from freezing (31). The shortage led to increased rates of infectious disease, hygiene-related diseases, and pneumonia (31). Fuel shortages may become worse as climate change worsens, increasing the prevalence of health issues related to energy insecurity (32).

In other instances, the energy infrastructure has proven incapable of tolerating higher than normal demands. A polar vortex, which occurred in January 2019 across the United States, brought extremely cold temperatures that strained energy systems. Some parts of the Midwest reached temperatures as low as minus 38 degrees Fahrenheit (33). An estimated 21 people died across the country from causes directly related to the polar vortex, such as death by hypothermia while indoors (34). One woman in Milwaukee died from the cold when her thermostat malfunctioned (34). In many cities, gas companies ordered households and industry to lower their heat in order to prevent citywide gas shortages (33). This compromised capacity is related to reliance on an aging infrastructure and increased demand, which is likely to be an issue over time and as weather patterns become more extreme as a result of climate change.

Power Outages

Infrastructural issues, extreme weather, and natural disasters may result in power outages and energy service interruptions. Short-term power outages often occur for the following reasons: (1) older and less reliable infrastructure; (2) overloading from high electricity demand; (3) household maintenance defects; and/or, (4) other systems fail (35). Long-term power outages are typically a result of disasters such as hurricanes. In 2017, Hurricane Maria left Puerto Rico's residents without power for an unprecedented average of 84 days. An estimated 83% of these households were in the most remote regions of Puerto Rico (36). These outages interrupted healthcare for people with chronic illnesses who required care and medication (36). Moreover, the death toll attributable to Hurricane Maria in Puerto Rico was estimated to be 4,645 people, and 9.5% of those deaths were due to an inability to access electricity needed for respiratory equipment (36). The adverse impacts of service interruptions—both short- and long-term—are ubiquitous. Elevator shutdowns impede movement, transit systems close, medical device access can be cut off, blackouts can increase crime and cause accidents, food can spoil in warming refrigerators, temperature control can be lost, and much more (35, 37–39).

Shutoffs

Affordability challenges may lead to a different type of service interruption—shutoffs or disconnections due to non-payment. It is challenging to measure a national prevalence rate of shutoffs, because utility companies seldom, if ever, report which and

how many households are shut off, and these data are generally not publicly available. Hernández and Laird (40) used the Residential Energy Consumption Survey (RECS), administered by the Energy Information Administration (EIA), to analyze the prevalence of disconnection notices and service disconnections based on a nationally representative sample of US households. Hernández and Laird (40), presenting their results at the annual conferences of the American Sociological Association (ASA) and the American Public Health Association (APHA), demonstrated that in 2015 an estimated 3% of US households were disconnected and another 15% received a disconnection notice, suggesting that there is indeed some hardship. Consistent with previously observed patterns of inequality, the authors also found that low-income households, African-American and Latino households, households with children, renters, and people living in older and poorly insulated homes were most likely to receive disconnection notices and service interruptions. Hernández and Laird's (40) research further explores the coping strategies that families resort to, such as forgoing food and medicine and keeping homes at an unhealthy temperature, that compromise health and may even lead to death. Hernández and Laird (40) found that households rely on these strategies to prevent and respond to the threat and occurrence of shutoffs (40).

Service Interruptions and Health

Shutoffs and power outages have a number of direct health impacts (30, 35, 37). Temperature-related issues such as hypothermia and heat stress increase when interruptions occur at times of extreme outdoor temperature. Chronic health conditions are strained by short- and long-term service interruptions in electricity and hot water services (30, 41). Additionally, people with chronic illnesses, particularly those with cardiovascular, respiratory, and renal diseases, are often forced to seek outside medical care during interruptions, increasing the rate of hospitalization (35, 42). Rates of all-cause and external-cause mortality are significantly higher during power-outage periods, especially when outages are due to weather events such as hurricanes, heatwaves, and snowstorms (30, 35). Households that have faced threats of shutoffs have reported more long-term mental health issues stemming from financial, physical, and environmental stress, as well as fears and anxiety over potential future service interruptions (13, 43).

ENERGY INSECURITY AND SOCIAL DETERMINANTS

Both acute and chronic energy insecurity are influenced by the social determinants of health, which are defined by the Centers for Disease Control and Prevention (CDC) as the political, economic, and social circumstances in which people live, work, and play (44). These determinants include factors such as gender, age, health status, education, employment, socioeconomic status, and race. Here, we review literature indicating that the social determinants of health play an important role in predicting the existence of household energy difficulties and outline the importance of making a connection between the impact of climate change on social determinants of health and energy insecurity. As climate change increases the frequency, duration, and magnitude of extreme weather events, it is important to consider the populations that are most vulnerable to the impacts of such events within the context of household energy use (45, 46).

Age and Life Course Vulnerability

Age-related vulnerabilities (i.e., being young or elderly) and exposure to environmental hazards are predictors of energy insecurity. The elderly, because they are at a higher risk of experiencing medical events during heatwaves than other populations due to a combination of social isolation, heightened physiological vulnerability, and the likelihood of not having air conditioning, are more likely to endure heat stress (46–48). Children are at risk of asthma, especially those living in urban, low-income communities, and are therefore in more need of adequate energy for ventilation and temperature control (49–51). Both the elderly and children spend more time in their home environments than other groups (1), increasing their exposure to the health risks of energy insecurity (52).

Education: Literacy and Impacts on Academic Achievement

Education, as it relates to energy insecurity, also has implications for health. Lacking sufficient knowledge and ability to navigate the bureaucracy of utility companies makes it difficult for less-educated households to address and prevent energy insecurity. Knowing how to access resources such as financial subsidies or medical certifications to prevent shutoffs requires knowledge of how such bureaucratic systems work. Understanding the risks associated with using alternative methods to address energy needs also requires education. On average, those with less educational attainment have more limited income potential, making it more difficult to afford and make energy payments (6, 15).

Energy insecurity also perpetuates a cycle of lower educational attainment, most notably for children. Environmental stress and financial insecurity can lead to mental health issues and result in worse educational outcomes (53). The stress of energy hardship is associated with behavioral problems in children, whereby they are more likely to have low academic motivation, difficulty concentrating, and often act out (54, 55). Children experiencing energy insecurity and food insecurity (discussed in detail in subsequent sections) are also more likely to experience intensified behavioral issues such as depression, rule-breaking behavior, and somatic complaints (54). Asthmatic children in energy-insecure households with poor air quality miss more days of school due to illness than do non-asthmatic children (55, 56). Homes that use unsuitable energy sources expose children to toxic gasses that impair cognitive development. Additionally, children living in energy-insecure households often have trouble focusing on their homework due to noise pollution from generators, other loud energy sources, and open windows, which can lead to lower academic success (57). As a coping strategy, some households confine energy use to specific rooms to keep energy bills low or because there are limitations in their heating and cooling systems;

this forces all residents to be in the same room, resulting in homework distractions and crowding, among other issues. Poor or restricted lighting to certain rooms also makes schoolwork and reading for pleasure more challenging.

Employment

Energy insecurity perpetuates the detrimental health effects associated with low-income employment. Many low-paying jobs require work in extreme temperature conditions (58), such as farming in excess heat or working in refrigerated warehouses. Those working in extreme temperature conditions are also more likely to be experiencing energy insecurity at home because they are low-income. Exposure to thermal discomfort at work and at home has a cumulative effect on temperature-sensitive health problems. Members of low-income households are also more likely to work multiple jobs to pay bills and support their families, meaning they are often physically absent from the home. This absence of caretakers can affect children's developmental needs and contribute to social deprivation and caretaker stress. Single mothers are more likely to be primary caretakers and often experience augmented impacts because they do not have a partner with whom they can share the burden and responsibility. Single mothers are also more at risk of experiencing energy insecurity compared to other groups (9, 23).

Socioeconomic Status and Household Income

Socioeconomic factors are a predictor of energy insecurity. In most households, utilities make up a substantial portion of living costs, and in low-income households, this proportion is much greater (9, 30, 59). Therefore, it can be difficult for low-income households to pay for enough energy to meet household needs and also afford other expenses (9, 30). Households at or near the Federal Poverty Level (FPL) are significantly more burdened by energy insecurity than other socioeconomic groups (9). A brief look at 2011 American Community Survey (ACS) data on the characteristics of people experiencing the gap between energy affordability and unaffordability found that 44% of low-income families (defined as below 200% of the FPL) experience economic energy insecurity compared to 2% of families who are not low-income (60). A 2016 report by the American Council for an Energy-Efficient Economy (ACEEE) found that lower-income households experience higher median energy burden (7.2%), defined as the percentage of household income spent on energy bills, whereas non-low-income households experienced a median energy burden of 1.5% (61). Furthermore, a recent study found that low-income households in the studied U.S. cities spend on average from 10 to 20% of their income on energy bills, while wealthier households spend on average between 1.5 to 3 percent on energy bills despite being the higher consumers (59). The 2015 RECS found that the lower the income, the higher the energy expenditure and energy consumption per square foot of the home due to a number of potential factors (62). For example, socioeconomic status has major implications for affordability, access, and levels of environmental hazards in the home. Additionally, low-income households are often unable to afford utility bills and therefore live without adequate energy due to heightened conservation and/or an inability to upgrade energy-related appliances and systems (59).

Race

Race is another social determinant of health that can predicate energy insecurity. Minorities tend to suffer from higher rates of energy cost burden than non-Hispanic whites in United States' cities (59). In the U.S., African Americans suffer more from energy insecurity than do any other racial groups (23, 60, 63). Of surveyed households with an African-American head of household (HOH) and children under the age of 18, 35% reported facing energy insecurity compared to 21% of Latino HOHs with children under 18 and 14% of Caucasian HOHs with children under 18 (60). Across all income levels, Black families still maintained the highest rates of energy insecurity (60). In the Washington Heights neighborhood in New York City, energy-insecure households were more likely to be black and Hispanic/Latino, low-income, and have less education (64). In Detroit, a study found that African-American households were twice as likely to be behind on utility payments and three times more likely to suffer from arrearage or shut-offs than white households (65).

When considering racial disparities, the association between environmental hazard exposure and geographical location is stronger for Black and Latino communities than for other racial groups (66). The health impacts of energy insecurity are compounded for racial-minority households that live in areas with high rates of exposure to environmental hazards energy inefficiencies (59, 66). The disparity in the impacts of acute energy insecurity is especially apparent for minority racial groups. For example, a study by O'Neill et al. (67) found that during heatwaves in four different cities across the U.S., the rate of air conditioning use was more than two times higher among the white population than the black population, suggesting that black residents did not have access to or could not afford to use air conditioning at the same rate as white residents. Additionally, the mortality rate of black residents was significantly higher than that of other racial groups across all four cities (67). This trend could be attributed to low income levels and unaffordable electricity, which disproportionately impact racial and ethnic minority households.

Gender

Gender is another social factor associated with energy insecurity that has direct and indirect health implications. In the Global South, women and girls, who are responsible for cooking, use biomass fuel, resulting in high rates of respiratory illness. Respiratory illness from solid-fuel cooking is one of the greatest causes of premature mortality globally (5, 7, 15, 68). In the Global North, women are more likely to be caretakers and spend more time at home, increasing their rate of exposure to other energy inefficiencies. Single mothers are especially vulnerable because they take on financial and psychosocial burdens alongside the responsibility of being the sole caretaker (23). It is important to note, however, that the literature in this review often fails to recognize that the separation of how gender relates to energy insecurity in the Global North vs. the Global South is reductive

and essentialized, as all of the mechanisms by which women and girls are impacted by energy issues crosscut both spheres of the world.

Health Status

Illness and chronic health problems often determine energy demand and have implications for energy consumption, thereby making poor health both a predictor and outcome of energy insecurity. Residents with health conditions such as cardiovascular, pulmonary, and respiratory diseases and arthritis are sensitive to temperature extremes, meaning that a home that is too cold or too hot can exacerbate and worsen symptoms (13, 69–71). People living with a chronic health condition may be especially reliant on energy-dependent devices for treatment or maintenance of their condition, lowering their ability to withstand inadequate or unavailable energy services. For example, patients with kidney disease, chronic obstructive pulmonary disease (COPD), and cardiovascular disease (CVD) rely on dialysis and oxygen machines that require electricity (72) and diabetics must refrigerate their insulin. Cancer patients in active treatment need more heat (73), and those suffering from hypertension are more susceptible to cold stress (74). Not only do people with chronic health conditions have an increased need for energy, but they also spend more time in their households, further increasing energy use (75).

ENERGY INSECURITY AND HOUSING

A number of household characteristics beyond location predict the existence of unmet household energy needs. The type of housing, whether owned or rented, its level of energy efficiency, and its age are all associated with energy insecurity. Low-income and minority residents face a higher proportion of difficulties related to these housing characteristics.

Housing Tenure and Type

Energy insecurity is affected by housing tenure because renting and owning can lead to unique challenges that perpetuate energy insecurity. Low-income renters often face difficulties affording household costs (76) and tend to spend the greatest portion of their income on energy bills when compared to other socioeconomic groups (77). They also tend to live in the most structurally deficient homes due to a lack of weatherization and efficiency upgrades (77). Energy insecurity can become a chronic issue, partly because low-income renters have limited ability to persuade landlords to maintain proper upkeep and implement effective modifications related to energy efficiency (43, 78). They also have limited social and economic capital to afford self-repairs or to hold landlords accountable through the court system (43). Low-income owners are also at risk for energy insecurity due to the high cost of upgrading homes to higher efficiency standards or because buying a home that is already efficient is expensive. Homeowners are often responsible for the entire burden of utility bills and other operational costs, including property taxes, home insurance, and water, garbage, and sewer costs. The stress of low-income housing on both renters and owners is associated with adverse mental health outcomes and poor self-rated health (43, 76).

Housing type also influences rates of energy insecurity. Similar to homeowners, renters of single-family units face difficulties because they are responsible for the entire cost burden. Multifamily housing can be more advantageous than single-family housing because there is a shared cost with property owners. However, residents in multifamily housing and low-income tenants often lack control over the conditions (e.g., heat) of their units and have restricted ability to combat energy insecurity, mostly due to financial constraints and lack of control over housing infrastructure (9). The New York City Housing Authority (NYCHA), the country's largest public housing authority, has faced notorious housing quality and energy infrastructure issues that have plagued residents by severely compromising their housing experience and, likely, their physical, and mental health. One challenge is that NYCHA is not subject to the same maintenance regulations as private housing or developers, resulting in structural deficiencies and energy inefficient housing, attributable in part to deferred maintenance (79). Public housing is not alone in this regard. Rental housing, including subsidized, or affordable housing, presents challenges for renters since the property owners determine the level of energy efficiency and other aspects of housing quality. In most cases, there are no guidelines that stipulate a minimum level of efficiency, particularly in older housing that was constructed when building codes were less focused on sustainability. This conundrum, known as the "split incentive," occurs when the incentive structure for an asset is not equally beneficial to both parties. In such cases, the deciding actor works in their own best interest, as is the case with owners who dictate the terms of housing without consideration of tenancy. Previous research demonstrates that subsidized housing recipients face an increased burden because they are more likely to rent from private landlords who neither weatherize nor optimize energy efficiency due to upfront costs and administrative encumbrances, which generally privileges the property owners and negatively impacts the tenants both economically and experientially (77, 80).

Beyond rental and multiunit housing, people living in manufactured housing, such as trailers or mobile homes, are disproportionately impacted by physical energy insecurity. These housing structures are often not well-insulated or weatherized, so residents tend to spend a high proportion of their income on energy and heating bills. For example, the ACEEE found that mobile home residents are more likely to be energy burdened (61). Residents living in these manufactured housing types also tend to be low-income and therefore the least able to sustain high utility bill costs or afford general maintenance (81).

Energy Inefficiency

Energy inefficiency is a common housing problem and aspect of energy insecurity that has serious health implications. Energy inefficiency is marked by poor insulation, drafts, leaks, and other points of intrusion of the outside elements that make it difficult to control indoor temperatures (82–84). Other structural deficiencies and poor housing quality conditions, such as a lack of central air conditioning and proper ventilation, can also lead to high utility bills and unsafe conditions (85). Energy inefficiency caused by poor housing quality and structural deficiencies

spurs costly utility bills that are unaffordable for low-income people (86) Poor energy efficiency has been associated with an increase in household dampness (85), which is associated with worsened arthritis symptoms, dizziness, headaches, and fevers (79), and increases the presence of mold, exacerbating medical conditions such as allergies, eczema, and asthma (69, 87–90). Energy inefficiency is also associated with an increase in a number of thermal-related illnesses (85), and homes with poor ventilation and outside air infiltration have more dust mites and cockroach feces, which are known to exacerbate or lead to acute respiratory illnesses (27, 91–93). Households that are unable to open windows (see also the section entitled Heat Stress and Forbearance) have the additional risk of dampness as a result of obstructed airflow (57).

A popular intervention for older and/or poorly constructed homes is retrofitting (87). However, energy efficiency without attention to ventilation can lead to excess tightness in the building envelope, thereby obstructing airflow and exacerbating the aforementioned health issues related to ventilation and air quality (94). Air-tightness due to energy efficiency improvements is also associated with increased levels of radon, which significantly increases the risk of lung cancer (95, 96).

Age of Housing

Older housing is a frequent contributor to energy insecurity because much of the aged housing stock around the world is neither weatherized nor energy-efficient, which results in an increased prevalence of thermally inadequate home environments (97). Low-income, older and minority householders are often relegated to substandard living conditions, in part due to residence in older housing that has not been renovated (98). The effect of older, less efficient housing on energy insecurity has been studied mostly in the fuel poverty literature from northern Europe and New Zealand, where the regularity of colder outdoor temperatures heightens the need for consistent indoor heating (82, 99). Excess winter deaths are a measure of mortality as a result of cold homes, a problem known to be caused by a lack of insulation (13, 47, 69, 84, 99–101). Heat stress is a common health effect of hotter outdoor temperatures, whereas newer technology such as centralized air conditioning may not exist in older homes. A lack of air conditioning contributes to heat stress, excess deaths, and hospitalizations during heatwaves (67, 102). Therefore, the use of newer technology is important for health and safety, particularly as it relates to the prevention of premature death.

Newer homes are subject to current housing codes, many of which include public health considerations, and tend to be more energy-efficient and have fewer maintenance issues (97). Many states have ventilation standards, for example, which can combat mold from dampness and therefore reduce asthma symptoms (98). Regulations on toxin levels in homes, such as through initiatives for lead-free homes, also exist. It is, of course, easier to control risks that are never introduced into the housing sphere. Therefore, living in new housing stands to benefit occupants. However, the most vulnerable groups are often the least likely to benefit from such advantages.

ENERGY INSECURITY AND INTERSECTIONAL INEQUALITIES

Research has demonstrated that socioeconomic status and race are predictors of neighborhood, place, and presence of other hardships that can lead to or exacerbate energy insecurity. For example, residents in low-income and minority neighborhoods tend to experience issues such as increased exposure to environmental hazards, a lack of investment in housing maintenance, and poorer quality housing, all of which contribute to energy insecurity. Moreover, poverty and material hardship are complex issues in and of themselves, whereby the inability to meet basic needs extends far beyond any one category. In this section, we explore the overlapping issues that intersect with energy insecurity.

Socioeconomic Status, Race, and Place

The coalescence of socioeconomic status, race and neighborhood factors can lead to or exacerbate energy insecurity and present other hardships as well. For example, racial residential segregation, a proxy for concentrated neighborhood disadvantage, is a demonstrated predictor of energy insecurity (103). Black and Latino/a-headed households are more likely to live in an energy-insecure household because of their home's lack of energy efficiency (103). For example, NYCHA housing, predominantly inhabited by minorities, is facing a backlash over its dilapidation and lack of maintenance, which has resulted in widespread power outages, lack of heating, and the presence of mold and lead problems (79). Of these issues, NYCHA has been criticized severely for the persistent lack of available heat in its properties due to faulty boilers (104). In the winter of 2017/2018, ∼80% of NYCHA residents faced a heat outage, which lasted 48 hours on average (105). Some advocates state that the difference in regulations for NYCHA housing compared to private housing is unjust and disproportionately disadvantages low-income communities of color (79, 106).

Low-income and minority neighborhoods collectively bear the brunt of more environmental hazards in and outside of their individual households (50, 107). For example, the siting of highly-polluting sources such as bus depots, landfills, highways, and plants or factories tend to be located in low-income communities. Low-income homes are also more likely to have maintenance defects, rodents, mold, and other poor housing conditions (66). Households in low-income and minority neighborhoods are also more likely to be overcrowded; this is especially true for immigrant populations in New York City and other urban areas. Overcrowded homes are associated with psychosocial stress, disease outbreaks, and higher asthma rates; they are also a predictor of the existence of other physical and social housing-related hardships that contribute to the burden of disease (93, 98, 108).

Furthermore, institutional and systemic racism and place-related social factors are drivers of higher rates of energy insecurity for minority populations. Ethnic minorities, immigrants, and indigenous groups are some examples of people who experience housing discrimination (57), a barrier to accessing more energy-efficient homes. Gentrification in many urban areas in the U.S is another social process that perpetuates

racial and ethnic disparities in energy insecurity prevalence. Gentrifying or newer residents are less likely to experience energy insecurity or have an energy inefficient home compared to longer-term residents who live in older households in the area (97). Long-term residents of Washington Heights in New York City, for example, are Dominican immigrants and African Americans, and they suffer far more energy insecurity than new neighborhood residents (64).

Neighborhoods and Spatial Inequality

Energy insecurity, as we have noted, is highly correlated with spatial inequality, where residents of different neighborhoods are more or less likely to experience energy insecurity due to their neighborhood's economic, environmental, and social makeup. The mean annual energy use intensity (EUI), which is a proxy for energy insecurity by way of high energy use from low housing efficiency, is much higher in urban areas that have lower socioeconomic status, less education, and more racial minority dwellers (65, 103). In cities that are more racially segregated, neighborhoods with low-income and minority populations are more likely to suffer from difficulties in affording or accessing energy (65, 109). As the gentrification of urban areas continues, racial residential segregation increases such that lower socioeconomic status populations are forced to live in areas that have substandard conditions both in housing quality and neighborhood characteristics.

Low-income and racial-minority neighborhoods in urban areas often suffer from the highest amount of environmental hazard exposure through air and noise pollution and substandard sanitation (110). This increased prevalence of environmental hazards can contribute to the health impacts of existing energy insecurities. For example, housing with poor ventilation in an area with high levels of air pollution can aggravate a child's asthma. There are well-established, clear disparities in neighborhood rates of asthma due to both indoor and outdoor environmental hazards (50), and there is an association between neighborhoods with energy insecurity and asthma prevalence (22). There is also spatial inequality and disparity in the prevalence of psychosocial stress. Low-income and minority neighborhoods suffer from higher rates of stress, which can compound the negative health effects that result from their already-increased exposure to environmental hazards (e.g., air pollution) (111). For example, family stress combined with exposure to neighborhood violence has been found to increase the incidence of traffic pollution-induced asthma in children, due to the strain on psychosocial pathways (112). The spatial disparities in energy insecurity and health also exist between urban and rural areas, where some low-income rural communities do not have access to natural gas or even electricity services, whereas lack of access to electricity services is rare in urban communities (113).

Bundled Hardships: Energy and Other Insecurities

As demonstrated by this robust review, energy insecurity is a complex problem, and it does not occur in a vacuum. The hardship of energy insecurity intersects with other hardships, such that each compounds the severity of the others and contributes to detrimental health consequences. Competing needs and hardships, such as food insecurity, water insecurity, and housing insecurity, result in tradeoffs where basic needs are prioritized and sometimes foregone (9, 114, 115). The stress from having to make trade-offs between basic needs for food, water, housing, and energy profoundly affects adult and child mental health (116, 117), which can exacerbate many kinds of physical health and social issues.

With food insecurity, the "heat or eat" dilemma occurs when households must decide whether to expend resources on proper nutrition or adequate energy services because they cannot access or afford both (28, 30, 118, 119). Often, this dilemma leads to undernutrition, especially during the winter and summer months when there are higher energy use needs when it has been found that low-income adults and children have decreased caloric intake compared to lower-energy use months in the spring or fall (28, 118). Other health impacts from food insecurity include acute hospital visits, poor diabetes control, developmental delays, fatigue, and behavioral issues in children (54, 120, 121). In response to high energy bills, people also opt out of medical and dental care, which can lead to worse health outcomes in the future (119).

Water insecurity is another co-occurring hardship. Water and electricity tend to be dependent on one another. On a large scale, hydroelectric dams need water and electricity to function, power plants need cooling water when there are high temperatures, and nuclear plants use large volumes of water (122–124). It is not only water that is needed for energy, but the other way around as well. At the community and household level, access to hot water can be encumbered by energy insecurity (30, 41). When concerned about the cost of energy, some residents may cut back on hot water use (30). Furthermore, water pipes can freeze if there is a fuel shortage or shut-off in time of freezing outdoor temperatures (31). Without water, people's ability to access energy reduces.

Lastly, housing insecurity is a frequently cited competing hardship to energy insecurity (22). The dimensions of housing insecurity include frequent moves, lack of housing options, homelessness, high housing costs, overcrowding, and unstable neighborhoods (125–127). Households that do not have enough money to afford high-quality housing also suffer from an inability to pay high utility bills, which can result in household debt owed to utility companies. Low-income families juggling financial hardships often prioritize other financial obligations such as paying for rent or groceries, seemingly more immediate needs, over paying off debt; this behavior can leave families in prolonged debt cycles (128). Debt owed to utility companies often prevents low-income households from moving because utility debts are not transferable (9), forcing residents to continue living in poor-quality housing. A home cannot be rented without a utility account in the renter's name, which is not possible if they have arrears at another address (9). Frequent moving is also a common form of housing insecurity. Low-income families are five times more likely than higher-income families to experience eviction, resulting in a move (50, 129). Evictions generally occur when rent prices increase beyond what a family is capable of affording. Utility shut-offs play an important role in housing insecurity,

as they are often the precursors to eviction. In both instances, households may encounter the double burden of housing *and* energy insecurity (23). As gentrification spreads across US cities, urban housing affordability is unachievable for most low-income families, forcing evictions, moves, overcrowding, and an increase in homelessness, and while newer buildings often enjoy energy-efficiency upgrades, older homes and buildings, which are often less efficient and more expensive to operate from an energy cost perspective, do not receive such upgrades (64, 130). In short, energy cost burdens can increase housing affordability strains whereas lower energy bills can protect against high housing costs and promote residential stability.

ENERGY INSECURITY, HEALTH, AND COPING

Health issues are linked to energy insecurity. In particular, such direct health outcomes are often a result of indoor temperature extremes and inadequate energy access. Thermal stress occurs when residents are unable to heat or cool their homes properly, frequently due to unaffordable utility bills or an inability to access adequate services. As a result of inadequate home energy, residents resort to coping strategies, which, with chronic use, can be taxing and overburden resilience reserves.

Improvising and Coping Without Energy

Residents implement coping strategies to manage and respond to unmet energy needs; we consider this to be the behavioral dimension of energy insecurity. Despite the ingenuity and agency many people demonstrate in the face of suboptimal energy circumstances, these coping strategies have negative health implications. One such coping strategy is the use of emergency energy technology (i.e., generators), which is generally reserved for disasters but is often employed by energy-insecure households. Generator use is strongly associated with carbon monoxide (CO) fatalities, especially when the generator is placed incorrectly in the household (e.g., in the garage or outside of a bedroom window) (35, 37, 131). Even when placed correctly, generators constantly release CO, which in small, consistent doses can lead to cognitive decline, headaches, nausea, and dizziness. Maintenance issues can aggravate the health impacts of some coping methods, such as poorly maintained households exposing people to higher levels of toxins (50). For instance, some residents living in low-quality housing use unvented gas heaters as their primary heat source and/or hot air units that do not have ducts because they are unable to afford or access improvements. Both practices are associated with increased levels of nitrogen dioxide (NO_2) and volatile organic compounds (VOCs), which exacerbate allergies and respiratory illness symptoms, create ear, nose, and throat irritation, and contribute to cognitive delays (51, 132). People also resort to avoiding energy sources in their homes or use extreme conservation strategies to reduce energy expenditure. For example, some avoid using a refrigerator, which is associated with undernutrition due to a lack of fresh food in the diet, and/or avoiding hot water use, which can lead to infections and hygiene-related illnesses. Other survival strategies include practices such as only heating one room of the house, going to bed early, and using low lighting (114).

Cold Stress and Coping

In the winter, cold homes due to a lack of proper heating lead to excess deaths and a number of health problems (13, 47, 69, 99, 100, 133, 134). Cardiovascular symptoms as a result of inadequately heated homes are a prevalent cause of medical issues (69, 135), and rates of hypertension increase in cold temperatures, which can lead to strokes and heart attacks (69, 74, 101, 135). The elderly and people that are already diagnosed with CVD are more at risk of heart attack and stroke due to cold stress (13, 47). Furthermore, research has found that arthritis symptoms worsen in cold homes (12). The rate of pneumonia and other infections, mostly among children, increases due to suppressed immune function from the cold (70), and upper and lower respiratory symptoms, such as coughing and wheezing, are worsened by the cold as well (69, 99, 100). Asthmatic residents and caretakers of asthmatic children living in inadequately heated homes report higher rates of poor well-being and more frequent hospital visits (27, 136). Alzheimer's patients have a higher rate of mortality from a combination of physiological and behavioral factors as a result of the cold (137). Poorer well-being and financial strain from an increased number of medical visits can exacerbate mental health issues, such as depression and anxiety, that may already be heightened due to the stress of energy insecurity (114).

In response to a cold home, many households cope by using alternative heating methods that have a direct impact on health (23). For example, using generators and stoves to provide heat also results in the release of toxic gasses such as NO_2 and CO that can impair cognitive function, exacerbate respiratory illnesses, and cause mortality (35, 49, 51, 138–140). The use of space heaters or ovens as alternative heat sources can also increase the risk of fire and injury, which could potentially lead to displacement or death (23, 104).

Heat Stress and Forbearance

Heat stress occurs when households are unable to afford or access energy to cool their homes. The health effects from this type of energy insecurity, such as increased morbidity and mortality rates, are most often seen during heatwaves when excess heat from outside conditions creates heat stress (135, 141, 142). Cardiovascular issues such as heat strokes, hypertension, and heart attack, dehydration, hyperthermia, and nervous system morbidities are examples of health impacts that occur under heat stress (69, 135, 143). Other health effects include a higher likelihood of acute renal failure (42) and increased sleep disturbances as a result of the extreme heat in inadequately cooled homes, which can exacerbate mental health conditions triggered by the stress of energy insecurity (53, 57). This increase in morbidity and mortality is motivated by other social determinants of health that predict energy insecurity (142).

Coping mechanisms for dealing with heat stress have their own related stressors and issues. For example, opening windows for ventilation and relief from heat may seem like an easy, free solution to cool down warm homes; however, in neighborhoods

that are perceived to be unsafe, many people cannot or do not travel to cooler locations nor do they leave windows open due to fear of crime and violence (141, 144). Furthermore, open windows expose households to noise pollution, particularly in urban areas where there is high traffic flow, which causes sleep disturbances and obstructed concentration on tasks (57). Open windows also increase the infiltration of outdoor air pollution, such as from motor vehicle exhaust, that is associated with respiratory and cardiovascular health risks (57).

High-Effort Coping and Resilience Reserves

Energy insecurity plays a role in depleting a person's resilience reserve (24). The *resilience reserve* framework offers a different lens than does past resilience research, which found that marginalized groups were less resilient because they had less social and material support and more life stressors (145). The resilience reserve framework argues instead that marginalized groups that contend with social, economic, medical, physical, and geographic vulnerabilities expend resilience resources to manage everyday hardships, leaving less opportunity to accumulate the psychological and material means with which to respond to and recover from large shocks such as extreme climate events (24). Therefore, after a disaster, marginalized groups have greater difficulties coping and rebounding, because they have already depleted their reserves. For example, years after Hurricane Sandy, which occurred in 2012, low-income NYCHA residents reported longstanding physical and psychosocial difficulties, citing the Hurricane's exacerbation of existing hardships and emotional trauma (24). Specifically, NYCHA residents cited the lack of electricity, heat, and functional elevators as a source of struggle, not just after the Hurricane, but before it as well. Housing, economic, and energy-related hardships had long been a source of chronic stress, constantly gnawing at their resilience reserve before the hurricane hit (24). One risk of an increased frequency of extreme weather events is the potential to exacerbate existing hardships and deeply impact the resilience capacity of vulnerable populations as they confront a growing number of social, economic, health, and energy challenges on a normal basis.

DISCUSSION

Energy insecurity is a multifaceted phenomenon with short- and long-term iterations influenced by social determinants and a changing climate, ultimately impacting health. This paper reviews existing literature in order to trace the pathways by which chronic and acute energy insecurity directly and indirectly result in various adverse health conditions. Our heuristic model is a unique contribution to the literature that intends to depict seemingly far-flung factors associated with energy, poverty, health, and climate change. We demonstrate the disproportionate effects on vulnerable populations and the mechanisms of household energy that lead to poor health and excess death. Contributors to acute energy insecurity include power outages, fuel shortages, supply issues, and shut-offs stemming from affordability challenges. For the most part, these acute issues are short-lived, though their impact can still be significant for short- and long-term health, well-being, and survival. Meanwhile, the fundamental causes of chronic energy insecurity are rooted in socioeconomic disadvantage as determined by race, income, educational level, position within the life course, and medical conditions that affect energy needs and dependency. It is also deeply affected by housing quality and the concentration of inefficient housing at the neighborhood level that is unfortunately closely patterned along the axes of social inequality and racial residential segregation. The literature suggests that the social determinants of health, housing characteristics, and neighborhood quality seem to predict and/or exacerbate household energy insecurity. As a result, residents turn to coping methods that can have a number of negative health consequences, such as toxic exposure from generators, fires from space heaters, noise pollution and crime from open windows, and many more. Energy production and infrastructure, both globally and locally, contribute to energy insecurity in terms of access and environmental degradation. High energy demand can strain systems, weather events can create power outages, and affordably issues can lead to shut-offs and arrearages. The result of such energy insecurity contributes to outcomes such as psychosocial stress and mental health issues, poor sleep, cardiovascular and respiratory issues, and heat stress, among others. These energy-related difficulties can also deplete people's resilience reserves, such that affected populations are less able to bounce back from acute and chronic hardships. In the context of climate change, more wear-and-tear on the energy systems, housing infrastructure, and population health seems inevitable.

The following discussion offers a critical analysis of the vast but disjointed literature on energy insecurity. One critique of the present literature is that much of it lacks an environmental justice framework, which should be integral to energy insecurity research, and we exemplify this issue by discussing the lack of intersectional consideration of the rising wealth gap, coupled with increasing urbanization, and energy transitions. Second, we explore connections to energy-related issues in the Global South. Although the Global South was not the focus of this review, energy-related issues are prevalent across countries in Africa, Asia, and Latin America and must be taken into consideration when designing interventions, because energy reform anywhere has global implications. Lastly, we discuss the current and future impact of climate change on energy insecurity and the need for greater consideration of climate change when conducting research on energy insecurity. We contend that the use of acute and chronic energy insecurity terminology can be helpful to researchers using a climate change framework because it separates the direct energy-related effects of climate events (acute) from more long-term effects (chronic).

Wealth Inequality, Urbanization. Energy Transitions, and Environmental Justice

As energy becomes more expensive and the wealth gap increases in the U.S., poorer households may have greater difficulty affording adequate household energy. The difference in the

proportion of income allocated to paying for energy bills could grow wider between the rich and the poor; low-income households may increasingly spend a higher proportion of their income on energy bills, because energy bills may increase at a rate faster than does their income (22). In contrast, wealthier households may experience an increase in their income at a rate that can sustain the increased price of energy. Take, for example, the yellow vest protests in France, which were incited by increased fuel costs. Wealth inequality should be addressed in energy insecurity literature, not only to ensure that lower-income households can afford and access energy through evidence-based policy but because socioeconomic status plays a direct role in determining a persons' health environment beyond energy needs.

The growing wealth gap is influenced by the exponential influx of people to urban areas, which do not have adequate infrastructure to provide for the growing population. As urbanization increases, more people are expected to benefit from urban advantage—the idea that there are health benefits to living in urban vs. rural areas (146). However, higher-income urban residents tend to benefit more from the urban advantage, and more often, low-income residents are left in unhealthy, poorly maintained neighborhood and residential environments (146). Thus, poorer residents are left without support and endure intergenerational socioeconomic hardships that prevent families from accumulating wealth. Constantly coping with hardships is financially costly, and high energy bills can be an obstacle to saving money among low-income households (9). Higher-income residents, on the other hand, pay less of their household income toward energy bills and benefit from more efficient and comfortable living environments.

The growing wealth gap between black and white families could also worsen disparate racial impacts as it relates to the intersection of energy, health, and poverty (147, 148). Energy transitions from fossil fuels to renewables such as wind and solar may also contribute to a growing gap because white-collar businesses and wealthier households are able to control and obtain financing for renewable energy, whereas poorer, minority populations are unable to grow their use of renewable energy technology because the cost is prohibitive and access is difficult given the cost, lack of social capital, and lack of education around renewables (130). African Americans have been historically excluded from opportunities for social and economic mobility, and, in the energy sphere, they are also unduly burdened. The literature has failed to explicitly acknowledge the racial divides in energy-related hardship related to cost, comfort, and efficiency and the protracted uptake of the cleanest energy technologies among minoritized groups. It is important to recognize how an increasing wealth gap will perpetuate energy insecurity, further impacting the ability of low-income and minority families to afford adequate energy. Identifying racially based injustices has been critical to advances in environmental justice, and here too, we see a potential for greater analysis of the racial disparities in energy insecurity and related health and social outcomes.

Energy Insecurity and the Global South

While this review has focused on energy implications in the U.S. and the Global North, many of the same issues are relevant to the Global South. Few articles discussed in this review use a framework of intersectionality to discuss the burden that inordinately affects marginalized populations around the world. Research on global household energy insecurity that uses environmental justice and intersectional frameworks could more adequately analyze this topic. In the Global South, millions of households lack adequate energy sources (149). It is vital that we find methods to expand modern energy services to reach more of the population (150). However, more systematically speaking, energy is dispersed unjustly and inequitably around the world (151, 152). Some populations have greater energy access than they need, while others do not have enough (8). We know that reducing carbon emissions worldwide is vital for addressing climate change, but it is also important to address the unequal distribution of energy sources. Health impacts from energy poverty in the Global South exist partially due to limited access to modern energy technologies. One example is the increased risk of COPD and heart disease from air pollutants that stem from cooking with biomass fuels rather than using electric or gas stoves (7, 19, 153, 154). Households using biomass cookstoves, for instance, face the dilemma of inhaling toxic pollutants from cooking or not eating—both of which have significant health implications. About one-third of the world, almost entirely in the Global South, relies on solid fuel sources such as wood and crop waste for cooking fuel (5, 7). Burning solid fuels for cooking creates indoor air pollution, which is significantly associated with stroke, ischemic heart disease, COPD, lung cancer, and pneumonia. The health impacts of solid-fuel cooking disproportionately impact women and children, who are exposed to higher pollution due to spending a larger amount of their time cooking than do men. Of the 1.3 million COPD deaths among women, about 511,000 are attributable to indoor cooking pollution. In contrast, of the 1.4 million COPD deaths among men, a much smaller proportion−173,000 cases—are attributable to indoor cooking pollution (7). Increasing the prevalence of and access to cleaner fuels for stoves around the world could significantly reduce these negative health outcomes.

In the same way that people of color in the U.S. disproportionately experience energy insecurity, people of color and those living in lower-middle-income countries (LMICs) around the world disproportionately bear the burden of an inequitable global energy system. Globally, people of color bear the burden of household energy insecurity. To this day, 1.3 billion people, most of whom live in Asia, Latin America, and Africa, lack access to modern energy services (155). Of the total number of people lacking electricity access worldwide, 41.3% of the people live in African countries, 28.5% live in India, 27.3% live in other Asian countries, and 2.2% live in Latin American countries (155). Countries of color are also more likely to shoulder the impacts of climate change, though they are less responsible for carbon emissions and environmental degradation, and their ability to withstand and rebuild from weather events is lower than higher-income countries (156).

Climate Change and Energy Insecurity

The literature reviewed here does not adequately demonstrate a thoughtful link to climate change that goes beyond the concepts of adaptation and mitigation. Future research should examine the impact that climate change will have on energy insecurity. We propose that the concepts of acute and chronic energy insecurity may allow future researchers to expand upon and better evaluate the effects of climate change on household energy. Climate change worsens the direct and indirect health outcomes of energy insecurity and exacerbates cumulative risk, such that those already experiencing energy insecurity are most affected by climate events because they are less able to prepare for, respond to, and recover from disaster events (157). Communities that are most vulnerable to daily hardships are also most vulnerable to the impact of weather events, and the disparity worsens with repeated shocks from climate change (156). For instance, mortality from heatwaves disproportionately affects older, minority, and low-income residents who are less equipped socially, economically, and physiologically to withstand high temperatures. After the 1995 Chicago heatwave, there was clear demographic disparity in mortality rates—lower-income and older people died at much higher rates than the rest of the population (48). These populations were much more vulnerable to heat stress due to living in decaying housing, lack of access to medical services, and social isolation (48). Without movement toward addressing the world's substandard housing, medical, and financial systems, natural disasters could continue to disenfranchise marginalized populations, intensifying and worsening existing stressors. Though some of the literature critically appraised in this review discusses weather events, the vast majority did not explicitly discuss climate change. Research should incorporate and explore the detrimental implications of climate change when evaluating energy insecurity in order to better prepare for future climate scenarios.

While vulnerable populations tend to be hit harder by climate change-related weather events all people are affected by climate change. Climate change-related energy insecurity issues, therefore, could impact anyone regardless of socioeconomic status (158). Severe weather events will lead to acute energy insecurity such as power outages that can affect anyone. More frequent heatwaves will significantly increase energy demand, the need for expanded energy systems, dependence on household air conditioning for entire populations (45, 93, 141, 142, 159). Power outages from heatwaves and storms can put anyone at risk of medical difficulties. Furthermore, storms are increasing in frequency and severity allover the world, putting people at risk of cut off energy access. And regardless of socioeconomic status, people resort to using emergency energy systems (e.g., generators) or non-energy methods during storms or disasters, which puts residents at risk of CO poisoning (160). It is difficult for residents with chronic illnesses to withstand acute energy insecurity from storm-related power outages (141, 161). As shown in these examples, energy insecurity, particularly acute energy insecurity, may become more prevalent for all people as climate change worsens. Notwithstanding the importance of the issue, a demonstrable gap in the literature exists, given that only one-third of the sources included in this review discuss climate change in relation to energy insecurity.

STRENGTHS AND LIMITATIONS

This review paper was inspired by a desire to comprehensively understand the predictors and outcomes of energy insecurity. The household energy literature spans many disciplines and research methods. As a result, we drew from a large interdisciplinary pool of research in order to capture enough relevant sources on this topic. The broad inclusion criteria allowed us to find articles that spanned many disciplines and methods to give us a realistic look at the full range of the household energy insecurity literature. Though the breadth of information about household energy is a strength, it was also challenging in that it demonstrated a clear lack of cohesion and systematic guidelines around research on household energy. Therefore, making connections and critiques across these fields of research and sources presented a formidable challenge, though we have done our best to synthesize the literature and draw conclusions from it. The papers vary significantly not only in focus but in scientific quality and rigor—some are more descriptive in nature, while others are more empirical. Many of the studies were not rigorously designed, and for the most part, the literature proved to be quite underdeveloped overall. This review did not assess for quality or eliminate studies on the basis of potential bias. The challenge of a highly dispersed evidence base led us to develop our heuristic model, which attempts to conceptually unify the literature on household energy and health.

CONCLUSION

When considering the substantial impact that inadequate household energy can have on population health, we recognize the need to adopt policies and practices that protect people from energy insecurity. This review sought to highlight how energy needs are important for all aspects of daily living and for protection against the effects of acute insecurities in the context of climate change. Climate change threatens life on earth as we know it, and our collective vulnerabilities to energy hardship need to be addressed with extreme urgency (162). By using energy insecurity as a framework for understanding the nexus of effects of unmet household energy needs, we can draw connections between the direct effects of inadequate household energy, such as hypertension from a cold home, and how social vulnerabilities and co-occurring hardships contribute to the problem. With this broader framework, we can begin to understand how policies that address food insecurity, housing insecurity, structural and institutional racism, neighborhood segregation, education inequality, income inequality, and so many other social issues, will also affect energy insecurity and together impact population health. Studying the energy–health–justice nexus through the lens of acute and chronic energy insecurity presents a novel and innovative direction for public health research, advocacy, and policy that can be used to improve the health of people in the U.S. and around the world.

AUTHOR CONTRIBUTIONS

SJ, SS, and DH contributed to the conception and design of the review, performed the analysis, contributed to manuscript revision, response to comments from reviewers, read and approved the submitted version of the review, and all accountable of all aspects of the review, including its accuracy and integrity. SJ organized the database and wrote the first draft of the manuscript. SS and DH wrote sections of the manuscript.

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REVIEW
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Intersectional Stigma and Multi-Level Barriers to HIV Testing Among Foreign-Born Black Men From the Caribbean

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Testing is the entry point into the HIV care continuum that includes linkage to and retention in prevention services, and adherence to prevention strategies, including repeat HIV testing. Despite US policy approaches to expand HIV testing to diverse clinical care and community settings, disparities in HIV testing among Black populations persist. Foreign-born (FB) Black persons from the Caribbean have higher annual rates of HIV diagnosis and a higher percentage of late-stage HIV diagnosis, compared with US-born Black persons; and most HIV infections among FB Blacks are among men. In this article, we provide an overview of HIV testing barriers among FB Black men who engage in HIV risk-taking behaviors (e.g., condomless sex with male and/or female partners of unknown HIV serostatus). Barriers to HIV testing for both FB and US-born Black men, include HIV stigma (anticipated, perceived, internalized), low perceived HIV risk, medical or government mistrust, and perceived low access to testing resources. We examine beliefs about masculinity and gender roles that may perpetuate heteronormative stereotypes associated with perceptions of low HIV risk and barriers to HIV testing. We also discuss the impact of recent immigration policies on accessing HIV testing and treatment services and how intersectional stigmas and structural forms of oppression, such as racism, prejudice against select immigrant groups, and homophobia that may further amplify barriers to HIV testing among FB Black men. Finally, we review comprehensive prevention approaches, and suggest innovative approaches, that may improve the uptake of HIV testing among FB Black men.

Keywords: intersectional stigma, foreign born, Caribbean men, HIV testing barriers, stigma-reducing interventions

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INTRODUCTION

In the United States (US), foreign-born (FB) persons, defined as individuals who were born outside the continental US and its territories, and naturalized citizens, comprise only 13% of the country's population, yet FB individuals face barriers to accessing health care that may lead to poorer HIV disease outcomes (1, 2). FB persons account for 16% of new HIV infections in the US (2); however, FB Blacks from the Caribbean and Africa have higher annual rates of HIV diagnosis, and late-stage HIV diagnosis, compared to US-born Blacks and FB Whites, thus highlighting disparities due to race and immigration status (3, 4). FB Black men who engage in HIV risk-taking behaviors, including men who have condomless sex with female and/or male partners of unknown serostatus, often reside in metropolitan areas with high HIV prevalence and are less likely to test for HIV than other groups with similar HIV risk behaviors (5, 6).

Universal HIV testing, coupled with regular testing among groups that engage in HIV risk-taking behaviors, is a foundational element of HIV control. Since 2006, the Centers for Disease Control and Prevention (CDC) has recommended universal screening for HIV, and that individuals who engage in HIV risk behaviors should test at least annually, with additional screening as warranted based on risk behavior (7–10). Testing is the entry point to the HIV continuum of care that includes diagnosis, linkage and engagement in HIV medical care, and initiation and adherence to HIV antiretroviral therapy (ART) to achieve viral suppression (10). The UNAIDS, WHO, and the US through the National HIV/AIDS Strategy have set goals for 2020 to improve diagnosis rates among people living with HIV (PLWH), initiate therapy, and achieve viral suppression; all include the goal of having 90% of PLWH aware of their serostatus (11, 12).

Increasing the proportion of persons with HIV aware of their serostatus is the goal of the UNAIDS 90-90-90 treatment target in 2020 (13) but subgroup disparities in HIV testing undermine achieving this goal. For populations with HIV risk-taking behaviors, regular testing is critical, given that most individuals reduce HIV transmission risk behaviors following an HIV diagnosis, that early ART treatment reduces risk of transmission to sexual and drug using partners by lowering viral load, and at an individual level lowers risk for AIDS-defining illnesses and death (14). Additionally, improved screening and detection of HIV at the community level leads to lowered community viral load and a reduced proportion of persons in a potential partner pool with detectable viral load (15), ultimately reducing societal-level suffering and costs associated with HIV/AIDS (16). Despite policy approaches to expand HIV testing to diverse clinical care settings, to implement "opt out" procedures for integrating HIV testing into other standard screening approaches, and to mount community-level campaigns to increase awareness about the importance of HIV screening, disparities in HIV testing among Black populations, especially Caribbean men, persist (17–19).

In Brooklyn, New York (NY), which has the largest Caribbean community in the US, the highest percentage (33%) of new HIV diagnoses are among FB Caribbean individuals, 75% of whom are men (20). New York City (NYC) recently achieved the 90% HIV testing federal goal (21); however, HIV screening among FB Black men with HIV risk-taking behaviors remains suboptimal. Numerous studies have found that late HIV testing is common among FB individuals from the Caribbean (3, 22, 23). Risk factors that adversely affect HIV testing among Black men with HIV risk behaviors, including FB Black Caribbean men, are complex and comprise individual, interpersonal, and structural-level barriers. For example, gender norms surrounding masculinity may impact sexual stereotypes (and associated behaviors) placed on Black men who have sex with men (MSM), along with HIV/STI testing behavior and communication (24, 25). Indeed, culturally oppressive heteronormative gender roles and ideologies perpetuate transmission risk associated with masculinity (26, 27). In addition to oppressive gender norms ascribed to Black men surrounding HIV transmission risk, individual barriers to testing include low perceived risk, endorsing HIV conspiracy beliefs, and perceived low access to testing (26, 27).

Since the inception of the global HIV/AIDS pandemic, there has been a parallel pandemic of stigma and discrimination fueled by blaming the "dangerous infected other" (28). Dr. Jonathan Mann called this the "third level of the AIDS pandemic" (29, 30) and stated that "discrimination is found not only to be [sic] tragic results of the AIDS pandemic, but to be the root societal cause of vulnerability." HIV stigma, distinct from HIV discrimination, is the ascription of negative attitudes, beliefs and stereotypes about PLWH as undesirable due to fears of contagion, death, or affiliation with "spoiled identity" (31) that diminishes social status, health and wellbeing and produces harmful social consequences (32, 33) and health disparities (33). Fears of loss of privacy, social support and being ostracized due to HIV stigma have had a negative impact on preventive behaviors [e.g., condom use or anti-retroviral therapy (ART) adherence] and has hampered the uptake of HIV testing (34, 35). Internalized HIV stigma has been associated with sexual transmission risk behaviors, including condomless sex (36, 37) and lower likelihood of regular HIV testing (38, 39). HIV screening among FB Black men is influenced by HIV stigma, primarily as it relates to having prejudiced attitudes toward PLWH that perpetuates fears of the social consequences with an HIV diagnosis (40).

Guided by an understanding of intersectional stigma and an ecological model of social determinants of health, this review explores how FB Black Caribbean individuals who inhabit multiple and intersecting stigmatized identities face additional barriers to HIV testing (41, 42). In this review, we also examine gaps in HIV testing initiatives and describe potential novel approaches to lessen barriers and intersectional stigma and develop sustainable HIV testing, treatment, and care programs for this marginalized priority population.

FB PERSONS WITH HIV IN THE US

FB persons with new HIV diagnoses, compared with newly diagnosed HIV-positive US-born persons, have different group characteristics due to factors related to their immigration pathway, education, health status, local social networks, and the specific risk factors that characterize the global HIV epidemic (5, 23, 43, 44). FB persons with HIV include skilled workers and students pursuing college or graduate training, while other FB persons have become naturalized citizens or immigrate because they have family members that are US citizens or have strong social networks in place in the US (2). The most vulnerable FB individuals with HIV are those that come as undocumented migrants, asylum seekers or refugees who, based on their vulnerable status, have been exposed to political or discriminatory violence due to sexual orientation; some also experience sexual abuse and HIV exposure (45, 46). How vulnerable FB immigrants arrive in the US also impacts how they access health information, insurance, and health care, increasing for some the risk of HIV exposure (47, 48).

Until recently, there was little information about FB Black persons because they were often subsumed under the singular racial category of being "Black." Ojikutu, Nnaji et al. argued that "All Black People Are Not Alike" in HIV surveillance data and that to explore the epidemiological diversity and more accurately identify HIV prevalence within Black immigrant subgroups, we must disaggregate racial categories by country of birth (23). Thus, grouping US-born and FB Blacks into a single homogeneous racial category masks important sociocultural, linguistic and historical differences that influence health behaviors but also ignores the important impact that migration can have on FB Black's health-seeking behaviors, including HIV testing (49).

HIV INFECTION AMONG FB CARIBBEAN BLACKS

HIV disproportionately affects FB Black men in the US who engage in HIV risk behaviors (2–5, 50, 51). In a modeling analysis, the CDC projected that approximately 4,275 FB persons with HIV could immigrate each year to the US (95% CI, 966-5768 persons), assuming that mostly healthier persons would be able to immigrate and that a more accurate prediction may be the lower end of the confidence interval (2, 52). With regard to Caribbean countries of origin, Haiti and Jamaica had the second and eighth highest total number of HIV diagnoses among FB and permanent residents in the US, respectively. California, Florida, NY, and Texas have the highest numbers of FB persons diagnosed with HIV and highest percentages of overall HIV cases in the US (3). In 2016, FB Black individuals from the Caribbean accounted for 22% of new HIV diagnoses in the US, and 70% of those new diagnoses were among FB MSM compared to 75% of US-born men who acquired HIV through MSM contact (2); and 39% of new infections were attributable to heterosexual behavior compared to 27% among US-born persons (2, 3). One study found that Black West Indian men were less likely than were US-born Black men to report non-regular partners (53). Using data from the NYC HIV surveillance registry and American Community survey, another study determined that 61% of FB infections occurred in the US (51); and that the likelihood of the acquisition of HIV in the US was higher for FB males than FB females (68 vs. 50%), and higher for FB MSM (76%), thus highlighting the urgency to promote HIV prevention among new immigrant groups (51).

FB BLACK MEN AND MULTI-LEVEL BARRIERS TO HIV TESTING

Late HIV testing is common among immigrants from the Caribbean (3, 4, 6, 22, 23, 43). Despite late presentation to HIV care, studies have shown that among FB persons there was no difference in retention in care or virologic suppression compared to US-born persons (54). In the US, factors that account for disparities in HIV screening among Black men with HIV risk behaviors (5, 55–57), including FB Black Caribbean men, are increasingly known (6, 22). Disparities in HIV testing among both US-born and FB Black men with HIV risk behaviors are associated with poor socioeconomic status and greater income inequality (58), poor access to health services (59), decreased access to HIV screening and treatment services (60), delayed health screening (61), and lower engagement with existing social services and related prevention services (62–64). However, numerous studies have noted that differences in HIV testing patterns between FB Black and US-born Blacks are also influenced by nativity (5, 23, 43). Lower levels of HIV testing among FB Black men with HIV risk behaviors, as compared to their US-born male counterparts, is also influenced by differential access to HIV testing and knowledge of how to access testing, lower health insurance coverage (65), and lower familiarity with the US health care system (6). In a recent assessment of 875 Black men with HIV risk behaviors in Brooklyn who reported multiple female partners and condomless sex in the past 6 months, 76% were FB Blacks and only 51% reported HIV testing in the past year (56). Reasons for low HIV testing rates among FB men have included privacy concerns and misconceptions about HIV transmission (66). Another study found that barriers to HIV testing for recent vs. long term immigrants were also due to health access, fatalism and anticipated HIV stigma (6). Among FB Black men with HIV risk behaviors, the benefit of testing more frequently than annually is unknown (67) and warrants investigation, especially since Caribbean men are likely to acquire HIV in the US. Multi-level factors related to immigration status may further undermine FB Black men's access to HIV screening in the US (**Table 1**).

Structural and Policy-Level Factors

A policy-level factor that undermines access to HIV testing for FB Black persons was the removal of HIV testing at US points of entry, which was an unintended consequence of the repeal of the 22-year HIV immigration ban in 2010 (69, 70). The HIV immigration ban, which was first instituted in 1987, prevented non-US citizens with known HIV diagnoses from entering the country (71). The ban permitted the exclusion, removal or deportation of PLWH from the United States. Although the repeal of the HIV immigration ban was considered a watershed moment in eliminating HIV stigma and exceptionalism for PLWH in the US, that repeal of the ban may have inadvertently created more missed opportunities for early diagnosis (69). The repeal of the ban eliminated mandatory HIV testing as part of the physical examination and consequently removed access to free screening at all United States' points of entry. Following the repeal of the ban, the rate of HIV infection among FB individuals rose, especially among persons from the Caribbean. One study found that between 2011 and 2015, the highest rates of HIV infection (8.4%) were among Caribbean men (18).

Two other policy-level barriers to HIV testing for immigrants are restrictions to access Medicaid, and anti-immigrant, anti-Black racism and HIV criminalization laws (72). In the US, legal immigrants are restricted for 5 years after their arrival from accessing federal health benefits, such as Medicaid (73). For the FB Black man unaware of his serostatus, a 5-year delay in access to Medicaid and HIV screening increases the likelihood of HIV transmission. For a FB Black man living with HIV, 5 years without access to antiretroviral therapy could be devastating

TABLE 1 | Multi-level factors influencing HIV screening among FB Black men with HIV risk behaviors.

Individual	Community	Policy
• Fear of social consequences of an HIV diagnosis/loss of confidentiality (e.g., discrimination) • Lack of familiarity with US health care system • Distrust of the medical care system and government • Low perception of personal HIV risk and inadequate knowledge about HIV transmission and testing	• High HIV-associated stigma • Prejudice/stereotypes toward PLWH and groups with HIV risk behaviors • Normative distrust in the medical care system • Available testing venues are not advertised/communicated, especially in Creole or languages other than Spanish • Low normative expectations of HIV screening/Gender normative expectations regarding screening • Clinics are female spaces • Real men don't go to doctors	• No HIV testing at US points of entry • No access to Medicaid for 5 years after immigration • Lengthy immigration process • HIV criminalization laws and fears of deportation • Low access to free and confidential/anonymous testing in venues where FB Black men are likely to interface • Few health promotion opportunities emphasize the importance of HIV screening

Health outcomes associated with improved screening	→ Greater likelihood of viral suppression; less risk behavior; improved quality and length of life	→ Decreased risk of HIV transmission to partners	→ Lower community viral load/proportion with suppressed viral load

**Adapted from the NIMHD Minority Health and Health Disparities Research Framework (68).*

to his health. The lengthy process for establishing residency or citizenship status to legally work or access health care can further delay access to health care and HIV testing (73). Breanne Palmer (74) argues that anti-immigrant and anti-Black racism in the US legal system has resulted in a disproportionate mass criminalization and deportation of Black immigrants from the Caribbean, compared to immigrants of other races (75). Using public records on US Deportation proceedings in immigration courts, Palmer found that 20.3% of FB individuals deported for committing a crime were Black (74).

Another legal scholar, found that under the illegal NYC "stop and frisk" policy those racially profiled were mostly Black and Latino men, and 98% were deported and 75% of those deportees were male (76). Tanya Golash-Boza (76), whose research focuses on Caribbean populations, found that 10% of deportees in the US were Jamaican, who make up only 2% of legal permanent residents. Police cooperation with Immigration and Customs Enforcement (ICE) in non-sanctuary cities under President Trump's administration has fostered ambivalence and mistrust of the police in Black immigrant communities (77–80). There is evidence that some migrants underutilized HIV testing resources because of misconceptions about immigration laws and that seeking care or a positive test could result in deportation (81, 82). HIV criminalization laws that broadly penalize alleged or perceived non-disclosure of, and exposure to, HIV and non-intentional HIV transmission with incarceration can be an even more detrimental policy-level barrier to HIV screening (83, 84) among FB Blacks because being convicted of a crime can be grounds for deportation. And those deported may likely have even fewer HIV prevention resources available in their home countries.

Societal-Level Factors

Societal barriers to HIV testing that are specific to FB Black men include anti-immigrant bias, oppressive heteronormative gender roles, and masculine ideologies. Studies have found that xenophobia undermines mental health; however, little is known about xenophobia as a social determinant of health. In an integrative review of the literature, Suleman et al. (85) found that, globally, xenophobia is a "political threat" that can have a deleterious impact on the health and wellbeing of immigrant communities. A well-documented example of stigmatizing or ostracizing a population is the US medical, political, and social response to Haitian-Americans and Haitian immigrants during the 1980s and 1990s when HIV/AIDS was more of a death sentence (86–89). Anti-immigrant rhetoric in the US in the past and present strives to stigmatize and alienate people from other countries. The anti-immigrant racism that resurfaced prior to the 2016 presidential election and became manifest in new discriminatory policies are thought to limit access to health resources and increase racial and ethnic health disparities among immigrant groups and undocumented persons (90). Morey (91) argues that "immigration policy is also 'health policy'" and:

> "*When immigration policy responds to the worst sentiments of anti-immigrant bias with punitive action, disparity-inducing health consequences follow. When this happens, the vision of Healthy People 2020 of "a society in which all people live long, healthy lives" is compromised. We must recognize how the xenophobic and racist underpinnings of the current anti-immigrant environment contribute to widening health disparities (91).*"

Oppressive, heteronormative gender roles and masculine ideologies are key structural barriers to HIV testing among FB Black men (92). Indeed, oppressive beliefs about masculinity, heteronormativity, and heterosexism have been found to be barriers to HIV testing, not only for gay and bisexual men, but also for heterosexual men (39, 93). Gender norms within the Black Diaspora are strikingly similar and create both barriers and facilitators to HIV testing that could include: a man's fear of losing his marriage and ability to provide for his family with a positive HIV test result; fear of being blamed for the spread of HIV; internalized feelings of shame; the perception that clinics are a female space and that "real men" don't go to doctors because

it highlights their weakness instead of stoicism and self-reliance; threats to masculinity due to fears that a positive HIV screen might curtail their sexual prowess; and/or being exposed for infidelities, or philandering behavior (94). Mburu et al. argued that HIV stigma "threatened masculine notions of reputation and respectability, independence and emotional control, while it amplified men's risk-taking" and influenced men's participation in HIV services (95). In many African communities, to reveal that one is sick is a stigmatized identity, which extends beyond the individual to the family (96). The stigmatizing sick self is perceived as more severe for men due to the association of sickness as the antithesis of masculine strength (97). Mburu et al. (95) also found that seeking HIV prevention services, or any type of health care, meant that they publicly accepted the stigmatized sick role. Community-level interventions that fostered contact or visibility with the disaffected groups and targeted negative stereotypes have proved effective in reducing HIV stigma and homophobia (98).

Community-Level Factors

Community-level factors that impact HIV testing for both FB and US-born Black men include HIV-associated stigma (99–103), low normative expectations regarding HIV testing (53, 104), and endorsement of HIV conspiracy beliefs and medical and/or government mistrust (66, 105) that are rooted in historical societal abuses, which create distrust in HIV screening services and higher refusal rates when routine testing is offered (106, 107). However, distinct to FB Black men, there is the challenge of assimilating to US culture and society that may similarly create barriers to access to health prevention screening (108–110), including HIV testing. The process of migrating to another country and cultural system is stressful and often impacts community health outcomes (111–113), including HIV risk behaviors and low HIV screening (114). Losing access to protective social networks are thought to be driving factors of increased vulnerability to HIV infection (115–117). Migrants have fewer economic, cultural and psychosocial resources and often experience difficulty coping with stressful changes of living in another country, which may increase sexual risk behaviors (6). One study found that FB and US-born differences in HIV test-seeking and HIV prevention services are likely due to FB status and the loss of protective, pre-migration sexual networks (49). A study in Canada among Muslim immigrants found that longer time spent in a new country increased knowledge but decreased likelihood of HIV testing (118).

Acculturation has been found to be a key driver in HIV-related sexual behaviors and among immigrants (50, 114, 119–122). A systematic review and subset meta-analysis (119) found that immigrants with high levels of acculturation was associated with condomless sex, sexually transmitted infections (STIs), multiple partners and early sexual debut. They also found that gender moderated the relationship between acculturation, condomless sex, and STIs, and that the relationship between acculturation and condomless sex also varied across different ethnic groups (119). Despite these findings, a key limitation of this study is that most studies examined focused on Hispanics and Latinx samples or female immigrants. Saint-Jean et al. (50) found that the challenges of acculturation in the US and poverty have placed Caribbean-born Black immigrants at higher risk of substance abuse and HIV infection. Despite these challenges, other research has also shown that social integration and political empowerment for some Caribbean communities, including the Haitian and Jamaican communities in NY, has fostered wellbeing (123, 124).

Individual-Level Factors

Individual-level factors known to lower HIV screening among FB Black men include: lower knowledge of HIV transmission, lower perception of personal or partner HIV risk, reservations or fears about breaches of confidentiality, and potential societal consequences, lack of knowledge about where and how to access testing, speaking a language other than English, low income, no regular provider due to a lack of familiarity with US healthcare system, and recent immigration (6, 125, 126). English-language proficiency is also a known barrier to accessing HIV testing and health care in general (127). Francophone and Haitian immigrants in Brooklyn face greater challenges to accessing health care because of less English fluency and undocumented status (128). Language and cultural barriers can make it harder for many FB individuals to access information about HIV prevention and where to access HIV screening (129). Second, FB Black men are less likely to have a usual source of care or to utilize general preventive care services (130, 131), and are therefore less likely to have routine HIV screening offered, with the exception of men who are currently incarcerated and receive mandatory HIV screening (132, 133). A lack of familiarity with how to navigate the US health care system and system of Medicaid entitlements is another key barrier to accessing HIV prevention and screening services (134).

INTERSECTIONAL STIGMA

Building on the pioneering theory of *intersectionalities* (135, 136), the framework of intersectional stigma links exposure to oppression with experiences of stigma (137). Individuals with anticipated, perceived, enacted, or internalized HIV stigma often inhabit various marginalized social identities; and have exposure to multiple forms of oppression, known as intersectional stigma. Forms of privilege and oppression intersect with HIV (138, 139), and other stigmatized social identities, such as race and ethnicity, nationality, gender identity, sexual orientation, sexual practices, mental health, and addictions that may increase the cumulative burden of psychological distress (140), contribute to poor clinical outcomes (141) and create disparities in HIV screening (141, 142), especially among Black men (143, 144). However, stigmatized identities have often been analyzed in isolation, ignoring the convergence of intersecting forms of stigma or multiple stigmatized identities that is the reality for many individuals and groups (145). FB Black gay and bisexual men at-risk of acquiring HIV who have low levels of HIV screening (141, 142) may experience layered or intersectional oppression due to racism, anti-immigrant bias, homophobia, and HIV discrimination at work, home, in their communities, as well as while accessing healthcare and HIV screening services.

Racism: Being a Black, Cis-gender Man

FB Black men experience perceived or anticipated racial or ethnic discrimination in health care settings (61, 146). The influence of perceived racism on HIV testing is not well understood and studies have found mixed results. For example, some studies have found that perceived everyday racism or beliefs in racialized conspiracy theories may improve the likelihood of HIV testing, while other studies have found that perceived healthcare-specific racial discrimination or government/medical mistrust is not a major barrier contributing to the sub-optimal frequency of HIV testing (105, 106, 147, 148). One study found that perceived racism was not inherently detrimental and that it may increase the likelihood of HIV testing and early detection of HIV infection. A clinic-based study in North Carolina found that 90% of the sample had experienced perceived racism and that it was associated with higher odds of HIV testing (147). Alternatively, perceived racism and medical mistrust were found to undermine PrEP awareness and uptake in Black compared to White gay and bisexual men (149). Racial discrimination has also been found to predict lower adherence to HIV treatment (150). One study found that conspiracy beliefs related to pre-exposure prophylaxis (PrEP) were reported more frequently among Black men and transgender women who have sex with men compared to their White counterparts, and that there is an urgent need to address racial medical mistrust so that individuals at risk will understand the potential benefits of PrEP, a highly effective biomedical strategy for HIV prevention (151).

Racism and Xenophobia: Being a Black Caribbean Man

Anti-immigrant rhetoric before and after the 2016 presidential campaign fueled xenophobic fears that worsened racial and ethnic disparities, especially among Black undocumented immigrants (91). The anti-immigrant campaign slogan, "Build the wall" supported enthusiasm for the implementation of stringent immigration policies along the US-Mexico border and the Executive Order 13769, entitled Protecting the Nation from Foreign Terrorist Entry into the United States, which was also known as the Muslim ban (152, 153). Research suggests that community-level prejudice and xenophobia also increased mortality among immigrant groups (154). Most studies have focused on hate crimes (155–158), especially among transgender and gender-nonconforming individuals (159–161), or police violence and Black Lives Matter before and after the 2016 election (162–165). Seminal studies are now reporting that anti-immigrant policies and sociopolitical stressors are impacting maternal health. Two studies found an association between preterm births among US Latina women and the 2016 presidential election (90, 166, 167).

The global HIV/AIDS pandemic prompted a dubious epidemic of discrimination and racial prejudice. Nations experiencing the pandemic have blamed the "other"—those foreigners or marginalized groups within their society—in order to relocate the source of the deadly contagion safely outside the boundaries of the national identity. In 1988, Dr. Jonathan Mann (30) referred to this process of "shifting the blame" onto the "outsider" as the Third *Level* of the AIDS epidemic. The first level was (and continues to be) the "silent" and undetectable suffusion of HIV infection; followed by the inevitable second tier, which is the visible physical manifestation of the disease syndrome. The third level of the AIDS epidemic is defined as the concurrent epidemic of "blame" and "accusation" (87), in which the "social, cultural, economic, and political reactions to AIDS…[is]… as central to the global AIDS challenge as the disease itself" (30). These social beliefs and fears of contagion, and its causal transmission have resulted in the social control, surveillance, and stigmatization of those infected and afflicted, compromising their right to public health and civil liberties. Today, there is a dearth of research on the intersection of xenophobia, racism and HIV stigma or HIV testing; however, we could speculate that there continues to be an epidemic of blaming the foreign other. More research is needed to explore the impact of anti-immigrant bias on perceived HIV stigma and low HIV testing.

Homophobia and Racism: Being a Black, Gay, or Bisexual Man

Since the beginning of the HIV epidemic in the US, homophobia has been central to the parallel pandemics of stigma and discrimination (168). However, understandings and experiences of homophobia vary across cultures. Studies have also found a synergism with racism and minority sexual orientation status. Layered or intersecting stigmas due to racism, homophobia, and HIV have made those individuals who are "triply cursed" reluctant to pursue HIV testing (169, 170). In several studies, researchers found that implicit racist and homophobic biases among health care providers may limit access to PrEP among those patients most in need. A study among medical students found that a prevention paradox in their lack of willingness to prescribe PrEP was inconsistent with patient risk and may have been impacted by implicit racial bias (171). Using data from the Urban Men's Health Study, another study found that the combination that racism and minority sexual orientation status has impacts on Black MSM's encountered everyday racism, and thus Black MSM have a less positive experience with the gay community than their White counterparts (172).

A similar study found that Black MSM encounter racism and a less positive experience within the gay community than their White counterparts, suggesting that racism may shape the extent to which gay community affiliation serves as a protective factor against HIV for Black MSM (173). In a qualitative study in Boston (MA) and Jackson (MI), Cahill et al. (149) found evidence that providers and health departments are not adequately addressing medical mistrust among Black gay and bisexual men and other MSM. Black HIV-positive MSM who experienced greater racial discrimination were found less likely to achieve viral suppression compared to Latino HIV-positive MSM (174). Identifying particular sources of perceived racism in health care settings or circulating conspiracy discourses in the Caribbean immigrant community would help to tailor HIV testing strategies for FB Black men.

APPROACHES TO REDUCE STIGMA OF HIV TESTING

UNAIDS recommends that every nation's HIV response should include specifically targeted programs to reduce stigma (175). A review of stigma interventions (176) shows that stigma can manifest on multiple levels, including the intra-personal (e.g., individual-level interventions that aim to reduce the impact of stigma by changing behavior, attitudes, or psychosocial outcomes), interpersonal (e.g., small group-level interventions among individuals who may or may not share the same stigma status, such as HIV serostatus discordant couples), and structural-level (e.g., mass media, change in government or institutional policy). Stigma-focused interventions have generally been delivered in-person; while demonstrating efficacy, these interventions have been implemented on a relatively small scale (177). HIV prevention interventions that include Black MSM have included stigma as an intervention topic (178–180) and a growing number of eHealth interventions have been developed for Black MSM (178, 181, 182) but few interventions have addressed intersectional stigma (169, 183). To date, there are few effective interventions for cis-gender, gay or bisexual FB Black Caribbean immigrant men to promote HIV testing (18). We conducted a review of evidence-based interventions and identified six interventions, ranging from individual to community-level, which target different determinants of HIV prevention and testing, some of which also address stigma.

Self-Testing

To date, few effective interventions exist for FB Black-Caribbean immigrants to promote HIV testing (18). HIV self-testing via the OraQuick In Home HIV Test does not require interfacing with a clinical setting and has been found to increase self-testing in cohort studies and clinical trials (184, 185). Self-testing for HIV is hypothesized to also reduce the impact of HIV stigma and possibly HIV conspiracy beliefs on testing behaviors (186, 187). However, the prohibitive cost of OraQuick limits its sustainable use in resource-poor settings where many live below the federal poverty line. In addition, the high false-negative rate and inability to detect acute HIV infection are limitations of OraQuick (188). An alternative stigma reduction strategy for HIV self-testing is via Dried Blood Spot (DBS) self-collection kits (189). DBS home collection is currently used for research and clinical purposes to improve access to HIV testing in low-resource settings where access to healthcare and advanced lab techniques are limited (190, 191). DBS self-collection is becoming more common in the US and has been used successfully for self-collecting blood samples for laboratory-quantified viral load among MSM (192). DBS self-collection may become a lower-cost option for collecting blood and mailing the specimen for laboratory-based HIV testing.

Health Education in the Clinic

Health education interventions can inform both stigmatized and non-stigmatized groups about health issues and reduce perceived stigma by normalizing educational information as part of a general health care visit. A study by Armstrong et al. (193) found that low income Black and Latino men who received the educational intervention reported lower sexual risk and greater sexual health knowledge and health behaviors three months after the intervention. A part of the aforementioned educational intervention is to "teach back," where the provider teaches the patient health information and then asks the patient to explain what they learned. Healthcare practitioners routinely include "teachable moments" during routine visits to educate patients.

Aung et al. argue that provider-initiated testing and counseling may be the most promising because they foster trust in both the provider and in health systems (82).

Individual Counseling

Counseling and referral for social support services can be used to provide basic prevention information to screen for unmet needs related to housing, mental health services, and substance use care, and can facilitate navigation to these services (194, 195). These approaches address the HIV screening determinants of HIV transmission and prevention knowledge, address gaps in access to HIV prevention information in this group, and can address gaps in care for unmet service needs. Contact with PLWH is another established and evidence-based strategy to reduce HIV stigma because it can dismantle harmful stereotypes and generalizations that perpetuate fear and misunderstanding (42).

Active Recall

Brief screening reminders ("active recall") can promote regular HIV testing (196). In a randomized controlled trial of MSM receiving STI services in Australia, brief automated reminders to engage in testing increased HIV/STI screening to 64% as compared to 30% in a comparison group. A recent review of interventions using this approach revealed no methodologically rigorous evaluations among men with HIV risk behaviors (196). Thus, there is a need to conduct HIV prevention research with FB Black men, and other at-risk populations, to determine the feasibility of automated reminders for health screening. If feasible, this methodology would be cost-efficient (e.g., it is automated and would not require much human effort; the cost per text is low or included in most phone data plans), highly scalable (e.g., most individuals have a mobile phone), and sustainable.

Male Social Spaces

Barbershops are a natural site for the conduct of health programs on stigmatized issues, including HIV testing. Most FB Black men with HIV risk-taking behaviors are likely to visit a barbershop on a regular basis. In addition, barbershops are typically located in the customer's own neighborhood, allowing public health efforts to focus on prioritization of high-risk geographic areas. Barbershops are trusted community venues for men, and since Black men are less likely than other subgroups to be exposed to more traditional sources of HIV information, such as clinical settings and faith-based organizations (197, 198), they may be more likely to interface with a barbershop than a clinical care setting. Studies have demonstrated the feasibility of partnering with barbershops for HIV prevention efforts, as described in a recent review (198). A recent community-based study in NYC demonstrated success in developing barbershop alliances

for recruiting Black men (including 35% FB Black men) for HIV testing programs (199). Thus, partnering with barbershops may be a viable community level approach to increase HIV testing uptake.

Access to Healthcare Services

Changes in healthcare policy can serve as a structural-level intervention by increasing access to care on a population level. Recent changes in legislation have increased access to healthcare, including the Affordable Care Act (2010), to reduce the number of uninsured individuals. In 2015, the Centers for Medicare & Medicaid Services (CMS) expanded HIV testing coverage to individuals between the ages of 15 and 65 years (200); however, this does not include undocumented immigrants. The Ending the Epidemic (ETE) federal initiative aims to reach groups living with, or at-risk for, HIV with testing and treatment initiatives (201). A recent report by AIDS United (202) provided a framework through which the ETE could effectively reach populations at highest risk of HIV infection, including documented and undocumented immigrants; this included recommended policy changes to include undocumented immigrants in federal HIV testing programs, such as CMS. It is important to note that some changes in healthcare policy have been the result of lobbying by individuals, groups, or corporations, which shows that those who lobby for health care rights can be a catalyst for change in access to services, including HIV testing (203).

Community-Level Campaigns

Mass media campaigns serve to educate and expose populations to conditions or topics that may be stigmatizing. However, some community-wide media health education campaigns have inadvertently been stigmatizing. A review of US STI prevention and testing mass media campaigns published between 2000 and 2014 cited stigma as the first issue that can impact STI testing and treatment (204). The review found that the campaigns reached 66% of their target populations, on average, and were feasible for reaching at-risk or high-risk populations who may not be reached via the healthcare system or similar services. The authors reported common elements of effective mass media campaigns: obtaining feedback from the target audience to understand the needs of the population and appropriate health messaging; having a theoretically based design; training media staff who run the campaign and interact with the population; reaching the target population with culturally informed messaging through multiple venues such as online, apps, magazine ads, and public transportation billboards; establishing or using existing community partnerships that will provide the services (HIV/STI testing, counseling, etc.) and funds to offer "swag" (e.g., branded condoms, lip balm, t-shirts) in order to legitimize and promote the campaign brand; continual process evaluation to adapt and improve the campaign in real-time; conducting an outcome evaluation to measure the public health impact (e.g., HIV testing rates at specified partner locations before, during, and after the campaign); and continued financial support (via grants or fundraising) to maintain the campaign and its impact. A notable finding from this review was that many of the campaigns did not have rigorous evaluation designs (i.e., no control condition), which is critical to measuring the relative success of a public health campaign.

HIV prevention interventions that include Black MSM have included stigma as an intervention topic (178–180) and a growing number of eHealth interventions have been developed for Black MSM (178, 181, 182), but few interventions have addressed intersectional stigma (169, 183). Stigma-focused interventions have generally been delivered in-person and have been implemented on a relatively small scale (177). In order to address various forms of stigma (e.g., homophobia and racism), on a structural level, stigma-focused interventions must reach much larger populations, as well as collaborate with community coalitions including churches (205, 206). As an example, Frye et al. (207) conducted a rigorous randomized cluster-design trial of community-level intervention on HIV stigma, homophobia, and HIV testing in Black-Caribbean neighborhoods in NYC and found a 350% increase in HIV testing in that neighborhood compared to a control community. Another example of addressing HIV testing on a structural level is by reaching at-risk and high-risk individuals online or via apps. In 2018, Grindr.com implemented an HIV testing reminder system on its site (208) and included HIV status for members to self-identify (e.g., HIV negative, HIV positive, undetectable). Grindr has become as nearly ubiquitous in the MSM community as Facebook is in the general population and could function as an HIV prevention platform, thus reducing stigma associated with testing and with sexual orientation. Similarly, Black MSM and FB Black men may be encouraged to test through mobile apps developed for supportive healthcare interactions and facilitation (209, 210).

Role of Faith-Based Community

Sanders and Ellen (205) suggest that addressing structural-level issues in communities may reduce racism and poverty more quickly and efficiently. For example, including federal HIV prevention funding for African American community coalitions, including churches, is one way to address racial/ethnic disparities in access to HIV testing and care (205). A review of HIV testing initiatives in Black churches found that, although testing is becoming more available at churches, there is a great need for collaboration between faith-based organizations and public health entities to increase HIV testing and linkage to care (206, 211). Another example to address racial/ethnic HIV testing disparities by involving Black churches is spurring Youth movements through social media; with support from church leadership, Youth movements could help to normalize HIV testing in churches, and consequently reduce HIV testing stigma.

Gender-Transformative Interventions

Gender-transformative interventions (GTI) "seek to reshape gender relations to become more gender equitable through approaches that 'free both men and women from the impact of destructive gender and sexual norms'" (92, 212). Gender within the GTIs is considered as a key social determinant of men's health and has largely focused on understanding masculinity as a set of normative beliefs that is fluid and modifiable. A systematic

review of gender-transformative health interventions targeting HIV-related outcomes found 9 out of 11 interventions resulted in statistically significant reductions in sexual risk behaviors and 11 out of 12 violence reduction interventions found statistically significant changes toward gender equality (213). Participants in the pioneering One Man Can Program in South Africa (92) reported greater willingness to pursue HIV testing and fewer concerns about the stigma associated with HIV testing.

CONCLUSION

In the US, foreign-born (FB) Black men from the Caribbean with HIV risk-taking behaviors are disproportionately affected by HIV. This disparity, in part, is driven by disparities in HIV screening. Known barriers to HIV testing, such as perceived, anticipated, internalized HIV stigma, low perceived risk, endorsing HIV conspiracy beliefs, and perceived low access to testing are common among FB Blacks. Similarly, established social determinants of sickness and disease that stem from systematic forms of privilege and oppression (e.g., such as poverty, gender inequality, unemployment and limited access to education, quality health care and health promotion information) also undermine the ability of FB Blacks to engage in early testing, care and treatment (3, 4). However, more attention is needed to address the combined impact of layered social stigmas on disparities in HIV screening. And less is known about the links between heteronormative masculine gender roles and ideologies, intersectional stigma and HIV risk. Stigmatized identities have often been analyzed in isolation, but the reality is that intersecting forms of stigma or stigmatized identities seldom operate alone. Caribbean-born, Black gay, bisexual, or heterosexual men living with or at-risk of HIV experience exponential internalized stigma and oppression due to racism, anti-immigrant bias, and homophobia, as well as discrimination at work and in their communities while accessing healthcare and HIV screening services. More culturally responsive research is needed to explore the impact of intersecting stigmas on HIV testing and address the critical gap of HIV risk and poor clinical outcomes across the HIV continuum of care in this priority population.

AUTHOR CONTRIBUTIONS

TT developed the topic area and wrote sections of the manuscript. SH wrote sections of the manuscript and provided feedback. JD reviewed and provided feedback on several versions of the manuscript.

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frontiers in Public Health

ORIGINAL RESEARCH
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Associations Between Maternal Community Deprivation and Infant DNA Methylation of the SLC6A4 Gene

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Introduction: Poverty is negatively associated with health and developmental outcomes. DNA methylation (DNAm) has been proposed as a mechanism that underlies the association between adversity experienced by mothers in poverty and health and developmental outcomes in their offspring. Previous studies have identified associations between individual-level measures of stress and adversity experienced by a mother during pregnancy and infant DNAm. We hypothesized that independent of individual stresses, a mother's community-level deprivation while she is pregnant may also be associated with DNAm among the genes of her offspring that are related to stress response and/or development.

Methods: Pregnant mothers ($N = 53$) completed assessments that measured stress, adversity, and mental health. To evaluate community-level deprivation, mothers' addresses were linked to census-level socioeconomic measures including a composite index of deprivation that combines multiple community-level indicators such as income and highest level of education received. Infant buccal cells were collected at about age 4 weeks to measure DNAm of candidate genes including *NR3C1*, *SCG5*, and *SLC6A4*, which are associated with the stress response and or social and emotional development. Multivariable models were employed to evaluate the association between maternal community deprivation and infant DNAm of candidate genes.

Results: No significant associations were identified between maternal community-level deprivation and the methylation of *NR3C1* or *SCG5*, however, maternal community-level deprivation was significantly associated with higher mean methylation across 8 CpG sites in *SLC6A4*.

Conclusion: This study identified an association between community-level measures of deprivation experienced by a mother during pregnancy and DNAm in their offspring. These findings may have implications for understanding how the community context can impact early biology and potential function in the next generation.

Keywords: community, deprivation, epigenetics (DNA methylation, histone modifications), poverty & inequality, prenatal

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INTRODUCTION

The lifestyle and health of a mother during pregnancy can significantly affect offspring health. For example, exposure to maternal depression and anxiety is related to increased behavioral reactivity and cortisol levels in infants and is associated with reduced gray matter in the frontal cortex (1). Prenatal maternal stress is also associated with increased risks of psychopathology; decreased cognitive, linguistic, and play abilities; behavioral problems; and increased heart rate in infants (1, 2). Prenatal depression has been associated with increased cortisol levels in infants and altered neurobehaviors (3). Additional research has begun to uncover the long term effects a mother's pregnancy experience has on the life of the child as he or she grows older (4). In addition to individual maternal adversity and mental health, a mother's community, neighborhood, and social environments are also associated with infant and child development. Poverty during early childhood can lead to structural differences in brain development and related deficits in academic achievement (5, 6).

One proposed mechanism linking the maternal social environment to biologic changes in the offspring is epigenetics. Epigenetics refers to chemical modifications to chromatin, such as the binding of methyl groups to DNA, that regulate genomic transcription and may be sensitive to early environmental signals (4). For example, studies have shown increased exposure to parental stress is associated with changes in DNAm in infants (7). To associate maternal and early adversity to infant DNAm, prior studies have employed both epigenome-wide and candidate gene approaches, with a focus on genes involved in the neuroendocrine response and neurodevelopment (2, 8, 9). Evidence also suggests that differences in DNAm at certain genes is associated with development and behavior (10). However, prior studies have focused primarily on individual-level, rather than community-level adversity and the association with infant DNAm.

Community disadvantage may lead to changes in DNAm that can have functional consequences to cognitive and behavioral health that persist into adulthood. At the community-level, disadvantage can mean increased food insecurity, violence, and housing instability, all factors disruptive to early development (11). Two recent studies support a relationship between community disadvantage and DNAm at genes in the pathways of stress reactivity, inflammation and neurodevelopment (12, 13). These community-level effects appear to be independent of individual socioeconomic factors, suggesting that community deprivation has deleterious effects that extend beyond individual circumstances. The epigenetic response to community disadvantage is linked to structural brain differences in regions that impact executive function and emotional regulation (13).

The purpose of this study was to determine the association between community deprivation and offspring DNAm at loci in the regulatory regions of candidate genes. Three candidate genes were selected based on prior research and associations between maternal stress and mental health in pregnancy and infant DNA methylation. The Nuclear Receptor Subfamily 3, Group C, member 1(*NR3C1*) glucocorticoid receptor has been well studied due to its essential role for modulating the stress response through regulation of the hypothalamic-pituitary-adrenal (HPA) axis. Prior research has shown that methylation of this gene is associated with psychosocial stress and a variety of stress-related disorders (14). These associations have been observed for stress experienced across the life-course. DNA methylation in the Solute Carrier Family 6, Member 5 (*SLC6A4*) serotonin transporter gene has been associated with exposure to adversity such as maternal depression and childhood trauma (15). In addition to associations with maternal adversity, this receptor is essential for socio-emotional and behavioral development and has been shown to be epigenetically modified in people who experience major depressive disorder. Less evidence exists regarding the role of the Secretogranin V (*SCG5*) gene in either a response to stress and adversity or infant development. The *SCG5* gene encodes a chaperone protein that is widespread in neuroendocrine tissues and, notably, high maternal prenatal distress has been associated with lower offspring DNA methylation and *SCG5* gene expression (8). Differential infant DNAm of these candidate genes attributed to a mother's prenatal experience may underlie health consequences to the infant, such as delayed development.

MATERIALS AND METHODS

Study Population

We conducted this analysis within the Pregnancy and Infant Development (PRIDE) Study. Participants from the PRIDE Study were enrolled from the Every Child Succeeds (ECS) early childhood home visiting program in the Greater Cincinnati, Ohio area. The program provides home visiting services to mother-child dyads in seven counties in southwest Ohio and Northern Kentucky. All mothers in the program are low income, single, or have other psychosocial risks. Women who enroll prenatally receive weekly, bi-weekly, or monthly visits depending on their gestational week. After the infant is born, the home visits continue until the child is age 3 years, and include regular developmental screening beginning at age 4 months. The women participating in the PRIDE Study cohort were required to be English speaking, 18 years of age or older, and between 12 and 35 weeks gestation. Eligible participants were referred to the PRIDE Study by ECS home visitors. All procedures of the PRIDE Study were approved by the Institutional Review Board at Cincinnati Children's Hospital, and mothers provided informed consent for their and their infant's participation.

Study Visits

Two home visits were conducted for the PRIDE Study. The first home visit was conducted prenatally during the second or third trimester of pregnancy and the second home visit was conducted postnatally when the infant was age 3–5 weeks. At the first visit, informed consent was obtained, data on maternal stress, adversity, and social support during childhood and pregnancy were collected, and a hair sample was collected. The purpose of the second home visit was to measure infant neurobehavior and to collect buccal cells from infants for DNAm analysis.

Directed Acyclic Graph

Directed Acyclic Graphs (DAGs) are used to display hypothesized relationships and causal pathways. In a DAG, an arrow connecting one variable to another represents causation. Therefore, if there is not an arrow directly connecting two variables, there is not a causal association. DAGs are especially helpful for identifying confounding factors and for reducing biases that may occur when variables are inappropriately added to statistical models (16). We developed a DAG to guide statistical modeling of the association between maternal community deprivation and infant DNA methylation (**Figure 1**) utilizing available measured covariates including household income, mother's age, self-identified race, and Adverse Childhood Experience Scale (ACE) score, and identified maternal stress and social support as potential mediators.

MEASURES

Deprivation Index

We identified census tracts in which each mother lived based on her address at study enrollment. For each census tract, a deprivation index was calculated. The deprivation index combines community-level indicators including the following factors: fraction of people receiving assisted income, fraction of people who graduated from high school, median income, fraction of people with health insurance, fraction of people living in poverty, and fraction of vacant housing in the community (17, 18). The deprivation index ranges from 0 to 1, where 1 indicates greater deprivation. For the present analyses, deprivation index was evaluated both continuously and dichotomously where a deprivation index above the median (0.32) was designated "high deprivation" and below the median was designated "low deprivation."

Additional Individual-Level Measures

Adversity was measured by a variety of self-assessments during the prenatal study visit. The Adverse Childhood Experience Scale (ACE) is a 10-question assessment of physical and emotional abuse and neglect (19). The Edinburgh Postnatal Depression Scale (EPDS) (20) is used to measure maternal depressive symptoms and has been validated for use prenatally (21). The Perceived Stress Scale (PSS) is the most widely used measure of perceived stress and measures the degree to which situations in one's life are appraised as stressful (22). The Interpersonal Support Evaluation List (ISEL) is a 40-item assessment that gives an overall score of support and has four subscales including appraisal, tangible, self-esteem, and belonging (23).

Additional variables included infant sex, maternal age (years) at the time of enrollment, self-reported race (black, white, other), income level ($<$\$25,000, $\geq$\$25,000), high school education (yes/no), and residence distance from major roadways (meters).

DNA Methylation

DNA was extracted from infant buccal cells collected during the postnatal visit. Pyrosequencing was used to quantify DNAm

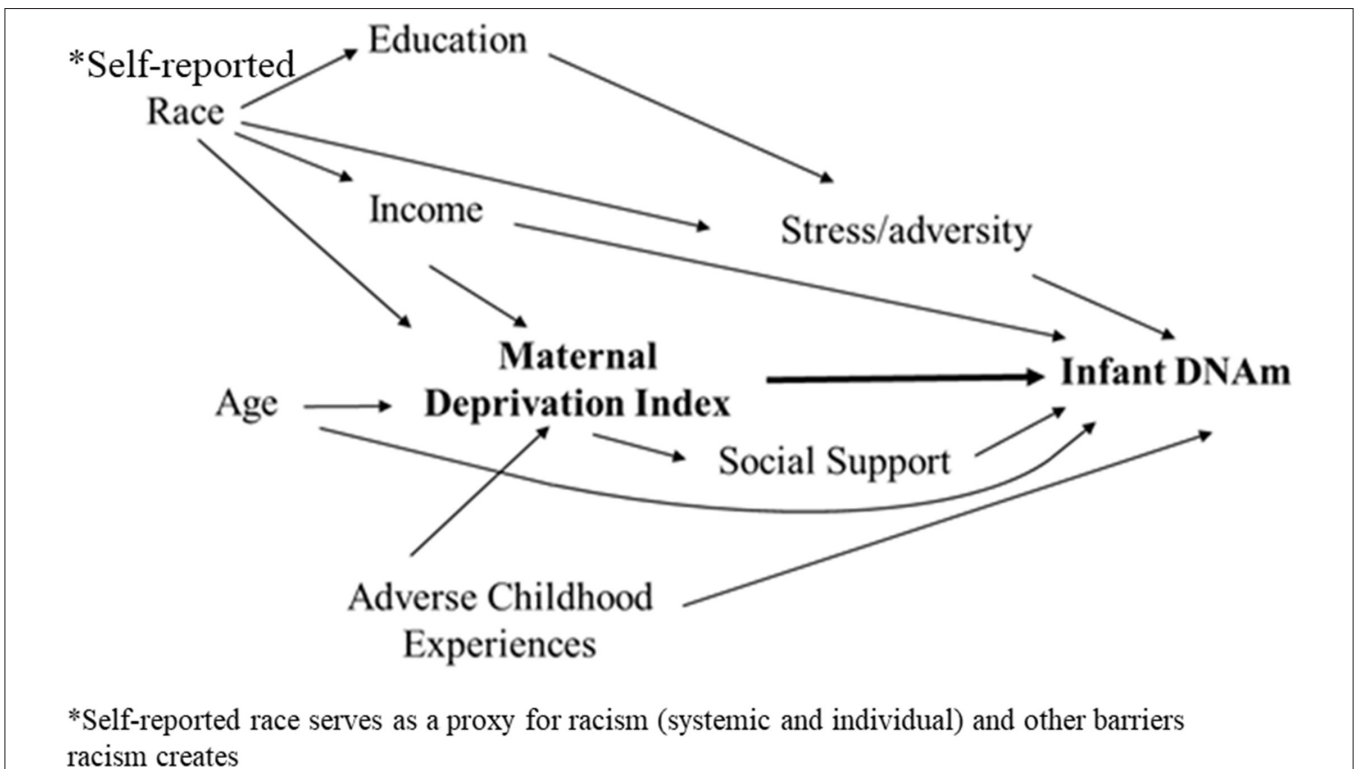

FIGURE 1 | Directed Acyclic Graph displaying the hypothesized association between maternal deprivation index and infant DNA methylation.

TABLE 1 | Bisulfite pyrosequencing primers.

***NR3C1* 1F Assay 2** chr5: 143,404,013-143,404,147[a] (- strand)	
PCR primer forward (5′ biotinylated)	GTTGTTATTAGTAGGGGTATTGG
PCR primer reverse	AACCACCCAATTTCTCCAATTTCTTTTC
Pyrosequencing primer	CAACTCCCCCACTCCAAACCC
Targeted CpG sites 1–5	chr5: 143,404,124; 143,404,121; 143,404,114; 143,404,099; 143,404,091
***NR3C1* 1F Assay 1** chr5: 143,404,011-143,404,097[a] (- strand)	
PCR primer forward	AGTTTTAGAGTGGGTTTGGAG
PCR primer reverse (5′ biotinylated)	AAAACCACCCAATTTCTCCAATTTCTT
Pyrosequencing primer	GAGTGGGTTTGGAGT
Targeted CpG sites 6–10	chr5: 143,404,075; 143,404,073; 143,404,063; 143,404,057; 143,404,043
***SLC6A4* Assay** chr17: 30,236,070-30,236,156[a] (- strand)	
PCR primer forward	GTATTGTTAGGTTTTAGGAAGAAAGAGAGA
PCR primer reverse (5′ biotinylated)	AAAAATCCTAACTTTCCTACTCT TTAACTT
Pyrosequencing primer	AAACTACACAAAAAAACAAAT
Targeted CpG sites 1–5	Chr17: 30,236,070; 30,236,087; 30,236,101; 30,236,125; 30,236,156
***SCG5* Assay** chr15: 32,934,005-32,934,025[b] (- strand)	
PCR primer forward	GGGTTGTTTTTAGGTGAGTATAGTTTTGAT
PCR primer reverse	CTCAATACTCCCTTCCCCTTAC
PCR primer-nested forward (same as forward)	GGGTTGTTTTTAGGTGAGTATAGTTTTGAT
PCR primer-nested reverse (5′ biotinylated)	AACCTCCACCTCAAAAATTTTAACA
Pyrosequencing primer	GGTGAGTATAGTTTTGATG
Targeted CpG sites 1–4	Chr15: 32,934,005; 32,934,009; 32,934,016; 32,934,025

[a]*Chromosomal coordinates for PCR and sequencing are based on UCSC Genome Browser Human Dec. 2013 (GRCh38/hg38) Assembly.*
[b]*Chromosomal coordinates for PCR and sequencing are based on UCSC Genome Browser Human Feb. 2007 (GRCh37/hg19) Assembly.*

of the *NR3C1*, *SLC6A4*, and *SCG5* genes and methylation was measured in Beta-values that indicated percent methylation (**Table 1**). The Beta-values were converted to M-values with a logit transformation. Cell type heterogeneity was evaluated from an additional sample of infant buccal cells collected at the same time as the DNA and then placed in phosphate-buffered saline. Cells were spun and examined under a microscope to determine the proportion of various cell types. It was found that 99% of the cells were epithelial indicating no need for statistical adjustments for cell type composition.

Statistical Analysis

For the present analyses, deprivation index was evaluated both continuously and dichotomously. Participant characteristics were compared between the high and low deprivation groups, comparing means (or medians for variables with non-normal distributions) for continuous variables and frequencies and percentages for categorical variables. Normality was assessed for continuous variables using a Shapiro Wilk Test, and a Welch's two sample *t*-tests was used to identify statistically significant differences between the high and low deprivation groups. When the data were not normally distributed, a Wilcoxon Signed-Rank Test was used. Chi Squared and Fisher's Exact tests identified the statistical associations between categorical variables and high and low deprivation groups. Associations between maternal characteristics, adversity measures, social support, and continuous deprivation index were analyzed using simple linear regression.

A multivariable general linear model was used to examine the association between the deprivation index of the mother and infant DNAm. Guided by the DAG, we adjusted the model for mother's age, household income, mother's self-reported race, and mother's ACE score. A potential interaction between deprivation and infant sex (male/female) was investigated by including a multiplicative interaction term in the multivariable model and using stratification. All statistical analyses were completed using R software. Associations with $p \leq 0.05$ were considered statistically significant.

RESULTS

We enrolled 56 participants in this phase of the PRIDE Study. Of these, 53 participants completed both the prenatal and the postnatal study visits. Mothers identified themselves as white (38%), black or other race (62%), and Hispanic (6%). Eighty-seven percent of mothers were employed, 51% had a household income of <$25,000, and 79% had no college experience. The distribution of the deprivation index of the sample was generally higher than the overall distribution of the deprivation index across the Greater Cincinnati area. Sociodemographic variables did not significantly across deprivation groups, except self-reported race ($p < 0.0001$) (**Table 2**). No individual-level adversity measures were significantly associated with deprivation index, including the EDPS, PSS, and ISEL, administered during home visits.

In an unadjusted model, a mother's deprivation index during pregnancy was significantly associated with infant DNAm of *SLC6A4* ($\beta = 3.31$, $p = 0.02$). Adjusting for maternal age, the association remained statistically significant ($\beta = 2.81$, $p = 0.03$). Adjusting for household income, race, and the mother's ACE score, the association was no longer statistically significant ($\beta = 2.17$, $p = 0.10$) (**Table 3**). Although there was not a statistically significant interaction ($p > 0.05$), as we were underpowered to identify interactions, in stratified analyses the association between maternal deprivation during pregnancy and methylation of *SLC6A4* was smaller among males ($\beta = 1.87$, $p = 0.39$) compared to among females ($\beta = 3.69$, $p = 0.14$). There were no statistically significant associations observed between maternal deprivation index and DNAm of *NR3C1* or *SCG5* ($\beta = 3.23$ ($p = 0.76$) and $\beta = 3.77$ ($p = 0.37$), respectively, in unadjusted models).

DISCUSSION

We identified an association between mothers' community level deprivation index while she was pregnant and infant DNAm

TABLE 2 | Maternal characteristics, adversity measures, and measures of support are summarized with linear regression coefficients for the association between each and a continuous measure of the deprivation index as well as means (standard deviations) for continuous variables and the number (percent) for categorical variables presented by the deprivation index variable split at the median.

		Deprivation	
	β	High (≥0.32)	Low (<0.32)
Maternal characteristics			
Age, yrs	0.49	22.35 (3.83)	21.19 (2.65)
Self-reported Race*			
White	Ref	7 (35%)	13 (65%)
Black/Other	7.85	19 (59%)	13 (41%)
Hispanic			
Yes	−7.91	1 (50%)	1 (50%)
No	Ref	25 (50%)	25 (50%)
Employed			
Yes	1.08	24 (53%)	21 (47%)
No	Ref	2 (29%)	5 (72%)
Household income			
<$25,000	Ref	15 (56%)	12 (44%)
>$25,000	−2.43	11 (48%)	12 (52%)
Education			
No college experience	Ref	21 (50%)	21 (50%)
Some college/Bachelor's	−0.69	5 (50%)	5 (50%)
Distance from major roadway, meters	0	2,285 (2,276)	3,366 (4,122)
Adversity Measures			
ACE scores			
<3	Ref	18 (51%)	16 (48%)
≥3	0.97	8 (44%)	10 (56%)
EPDS			
<10	Ref	14 (45%)	17 (55%)
≥10	1.72	12 (57%)	9 (43%)
PSS			
Low	Ref	12 (52%)	11 (48%)
Moderate/High	0.34	14 (50%)	14 (50%)
Cortisol	−0.09	16 (55%)	13 (45%)
Social support			
Appraisal	−0.6	22.12 (5.35)	24.77 (5.33)
Tangible	−0.31	21.04 (7.87)	23.35 (4.77)
Self-Esteem	−0.02	21.92 (4.66)	22.35 (4.42)
Belonging	0.04	22.04 (7.00)	22.08 (6.78)

**No variables were statistically significantly different by levels of deprivations, except for race (P < 0.0001).*

TABLE 3 | Unadjusted and adjusted models illustrating relationship [beta values (*p*-value)] between maternal community deprivation and mean infant DNAm of *SLC6A4*.

Variable	Unadjusted	Adjusted I	Adjusted II
Deprivation index	3.31 (0.023)	2.81 (0.03)	2.17 (0.10)
Maternal age		0.17 (0.06)	0.16 (0.11)
Household income			0.45 (0.61)
Self-reported race			0.24 (0.91)
Mother's ACE score			0.01 (0.55)

of *SLC6A4* gene. The association remained after adjustment for maternal age. Although the association was attenuated and no longer statistically significant after additional adjustment for household income, race, and mother's ACE score, the effect was still evident; statistical significance may have been impacted by our small sample size. While there was not a significant interaction between deprivation index and infant sex, the effect in females was 2-fold the effect in males suggesting a potential heterogeneity of effects that should be tested in a larger sample.

No statistically significant associations were identified for CpG sites in *NR3C1* and *SCG5*.

The *SLC6A4* gene encodes the serotonin transporter (5-HTT), which is essential for the reuptake of the neurotransmitter serotonin, facilitating communication between neurons (9). 5-HTT transports serotonin from the synaptic cleft to the presynaptic neuron (24). Serotonin is a chemical compound that modulates many behavioral and neuropsychological processes, and dysregulation of receptors has been associated with psychiatric disorders (25). Previous research has demonstrated an association between prenatal maternal depression and DNAm of the *SLC6A4* gene (9). Therefore, DNAm and related silencing of 5-HTT expression may disrupt normal neuropsychological processes. Alterations in 5-HTT availability may increase risk for later emotional problems such as depression (26).

The observed association between early adversity in the environment and infant DNAm aligns with several prior studies. Specifically, a 2013 study reported a significant relationship between adversity experienced during infancy and preschool and DNAm in adolescents (7). In addition, another study showed that individuals from at-risk populations who experienced significant stress from their early life experiences had greater DNAm of the *SLC6A4* gene (27). Maternal depression during pregnancy has also been associated with offspring *SLC6A4* DNAm, suggesting a potential impact on longer term emotional development (9).

Our study contributes to fledgling literature that examines the relationship between prenatal community-level deprivation and differential offspring DNAm. In one study, it was shown that an increase in one standard deviation of deprivation was associated with significantly higher DNAm of the *MEG3* gene in infants (28). In two other studies, community disadvantage was linked to significant differences in DNAm at genes controlling stress reactivity, inflammation, and neurodevelopment (12, 13). The current study adds *SLC6A4* to the list of genes involved in stress response, and more broadly, behavioral and neuropsychological processes that may have regulatory differences by community context. This information suggests that the multitude of factors at the community level can have a potent impact on offspring biology with potentially, long-term consequences.

The study had several limitations. First, the sample size precluded detection of anything other than large effects. Therefore, it is possible that other, more modest associations between community deprivation and CpG sites of other genes existed and will be important to examine in larger studies.

Second, although several measures were taken regarding the experience and health of the mother before and during pregnancy, many other factors including nutrition and pollution of the environment in which the pregnant mother and infant lived may affect DNAm and were not measured in the present study. These variables could modify the identified association and should be investigated further. We also did not have the power to investigate potential mediation and effect modification of this association.

There were also important strengths to this study. First, the longitudinal study design permitted prenatal assessment of community deprivation characteristics followed by a neonatal measurement of offspring DNAm. Second, the study examined these associations within a low-income, urban cohort that was representative of families who participate in early childhood prevention programs for high-risk families. The study population permits generalization to the large system of early childhood home visiting programs serving families throughout the United States. Although all the mothers had high sociodemographic risk, there was still variation in the index of deprivation enabling estimation of the effect on DNAm. Third, the study uniquely investigated the effect of community context on offspring epigenetic mechanisms. This work provides insight into how community variation, even within lower income communities, can impact early biology. Together, the study design, biologic plausibility of candidate gene selection, and strong effect size after controlling for several covariates, suggest a potential association that warrants replication in larger studies.

We identified a novel association between the deprivation of the maternal community during pregnancy and infant methylation of DNA at the *SLC6A4* gene. Given the role of *SLC6A4* in social and emotional health, DNAm of *SLC6A4* may underlie some of the association between maternal community deprivation and development in infants. Further research is necessary to replicate these findings.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Cincinnati Children's Hospital Medical Center. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KB and AF conceived and designed the study and supervised the study. KD conceived the statistical approach and preformed the statistical analysis and wrote the manuscript. LD supervised the statistical analyses. KY performed developmental testing on all study visits and critically reviewed analyses. All authors contributed to the article and approved the submitted version.

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Potential Effects of the COVID-19 Pandemic on Future Birth Rate

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Here, we examine the potential effect of the COVID-19 pandemic on future birth rates. This highly contagious disease originated in China, and rapidly spread worldwide, leading to extensive lockdown policies being implemented globally with the aim of containing the infection rates and its serious attendant consequences. Based on previous extant literature, this paper overviews the potential demographic consequences of the current progressively widespread epidemic on conception and fertility as driven by the data obtained during similar prior incidents. In general, epidemics manifest a common pattern as far as their impact on population, which is remarkably similar to natural disasters, i.e., a steep decline in birth rates followed by gradual increases and then followed by a baby boom. Additionally, we have also depicted how economic conditions, mental health, fear, and mortality may also influence future birth rates.

Keywords: COVID-19, pandemic, demography, birth rate, fertility

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INTRODUCTION

The coronavirus disease-2019 (COVID-19) is an infectious disease caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which was first reported in December 2019 in Wuhan, People's Republic of China. To date, the spread of this disease has been extremely rapid throughout the world (1), and the World Health Organization (WHO) declared COVID-19 as a Public Health Emergency on January 30, 2020. By March 11, 2020, COVID-19 was declared as a global pandemic by the WHO, and has since continued to spread at an accelerated rate. At the time of writing, more than 50.5 million cases have been reported across 213 countries and territories, and have ultimately resulted in more than 1.26 million deaths (November 9, 2020; (Source: Johns Hopkins University Coronavirus Resource Center; https://coronavirus.jhu.edu/map.html). The virus generally spreads between persons during close contact, most often through small droplets produced by sneezing, coughing, and talking. It can also spread by touching contaminated surfaces followed the touching of the face, nose, and eyes with unwashed hands. Since no licensed vaccines or specific antiviral treatments are currently available for COVID-19, some initiatives such as spatial distancing restrictions and lockdowns across the world have been strictly imposed to prevent the spread of the virus and reduce the magnitude of the pandemic.

As a result of the transmission control efforts, more than two-thirds of the world population have experienced lockdown measures, lasting from weeks to months, and thereby affecting family and social lives, as well as imposing a substantial burden on mental health (2). Thus, in addition to the physical health effects of the virus in those persons infected, the pandemic is also causing detrimental social and mental health effects, which in turn can influence fertility, conception, gestation, and birth. Furthermore, different propagation patterns of the COVID-19 pandemic as occurring in different countries and even in regions within countries may also in turn lead to other consequences, the latter related to different socio-economic conditions, healthcare facilities and access, and financial stability (2). Thus, the impact of the pandemic on conception, pregnancy, and birth will likely greatly differ in advanced and emerging economies.

INFLUENCES OF COVID-19 PANDEMIC ON FERTILITY RATE WORLDWIDE

The Socio-Economic Impact of the COVID-19 Pandemic

The impact of the lockdown may vary from country to country, and it is likely to increase global poverty and inequalities (3–6). Millions of individuals are unable to work because of complete or partial lockdown, and unemployment rates have exponentially risen. Consequently, individuals from all walks of life have been afflicted by the financial fluctuations and economic uncertainty during the outbreak, and the situation has led to economic recession and increased psychological stress (2). The World Bank projects that the COVID-19 pandemic will cause a contraction of 7% in GDP across the globe in 2020 and, while severely affecting all countries, the impact on unemployment will vary. According to estimates by the International Labor Organization (ILO), the lower-middle income countries (LMICs) (16.1%) experienced greater levels of working hour losses than those sustained by higher income countries (HICs) (13.9%) in the second quarter of 2020.

The Impact of Socio-Economic Circumstances on Fertility Rates

Studies suggest that fertility rates are affected by economic recession and poverty (7) with country-specific poverty rates across both emerging and developed economies leading to further variation in fertility rates (8). USA experienced a decline in birth rates during the great economic recession in 2008, and the trend was sustained till the first half of 2009, whereas the birth rates in 2007 were the highest recorded for the prior two decades. A study carried out by Pew Research Center in October 2009 in USA reported that 14% (ages 18–34) and 8% (ages 35–44) of those surveyed were still planning to postpone having a child due to the prior financial downturn (9). Other factors such as the availability of contraception, and women educational attainment levels (9) may also influence the fertility rates differently across HICs and LMICs. Therefore, the economic recession caused by the COVID-19 pandemic may impose a long-term impact on fertility rate, even after the pandemic has abated or been resolved.

The Impact of Anti-COVID-19 Measures on Fertility Rates in HICs

The economic crisis that resulted from COVID-19 pandemic along with unemployment, increase in domestic violence, and limited access to the healthcare sector in the antenatal period can also affect birth rates. The United Nations predicted that in 114 LMIC, 47 million women will be unable to access modern contraceptives due to lockdown measures and will lead to 116 million unwanted babies. In addition, 3.3 million unintended pregnancies are estimated in the USA. However, this unwanted baby boom will not be a major concern for developed economies according to the United Nations.

Fertility is usually reported as the Total Fertility Rate (TFR), indicative of the average number of children per woman. A TFR of ∼2.1 children per woman is termed the Replacement Fertility Rate. The TFR has been below the replacement rate in most developed countries since 1950. The unique circumstances imposed by the pandemic are likely to affect TFR, particularly in developed economies, where the population susceptibility to economic changes appears to exert increased impact on reproductive decisions (10, 11). Moreover, in HICs the fertility rate is greatly influenced by higher women educational levels, which again may impact the birth rates in high economies during COVID-19 pandemic (12). The desire to conceive a baby is also somewhat dependent on the childcare outsourcing in HICs, and fertility is also maintained in this way. The inaccessibility to childcare outsourcing services during COVID-19 pandemic could also impact the birth rates to some extent in higher socioeconomic settings (12).

According to a survey among ovulation and pregnancy test kit customers ($n = 132$) in the USA, many couples have expressed reluctance to conceive babies in such adversity (13). The survey also reported that the supply of ovulation and pregnancy test kits decreased and the demand of emergency contraception increased in May 2020, whereas, there was a spike in the demand of pregnancy and ovulation test kits early in March 2020 (13) suggesting that less individuals are trying to become pregnant. Though the survey in the USA, which included only a limited number of participants, may not accurately represent all the actual scenarios, another survey in Italy involving highly educated participants (∼64% graduate) found that most of them were not planning to conceive during the COVID-19 crisis (14). Their sex lives as well as planning for parenthood have been substantially influenced during COVID-19 pandemic (14) by a number of reasons like worries about future economic difficulties, fear of getting infected, complications during pregnancy, shortage of healthcare workers, and disease clusters in hospitals. Conversely, a minority of individuals may be more inclined to conceive during the lockdown (14). This is likely due to enhanced couple intimacy opportunities in the context of working from home or furlough during lockdown, emergent desire to bring about a change in their life, and the need for positive emotional support during the COVID-19 pandemic (15). Again, the study also revealed that the desire for parenthood during the pandemic was more prevalent among the higher age group (31–46 years) which may be another reason for the fluctuation of fertility rates.

The aforementioned study concerning family planning among 1,482 Italian respondents (944 males and 538 females) reported that, before the COVID-19 pandemic, 268 participants were planning to have children and the other 1,214 showed no interest in planning for babies. However, during the pandemic, 100 of the 268 abandoned their plans for fear of becoming infected ($n = 28$), fear of the consequences of pregnancy ($n = 58$), and fear of economic difficulties ($n = 58$). In contrast, 140 among the 1,214 participants indicated that they were now planning to have children during the pandemic. The reasons for such changes in opinion included having more free time ($n = 36$), increased couple interactions ($n = 26$), wishing to bring about some changes in the couples' lives ($n = 70$), and need for positivity ($n = 56$). Notwithstanding, there was an overall reduction in frequency of sexual intercourse during the pandemic (14). In another study ($n = 2,009$) carried out by the Guttmacher Institute in the USA, 40% women reported having changed their plan to not have a child during pandemic (16). The study also reported that lower-income women (36%) were more likely to have trouble and delays in having access to contraception and birth controls than higher-income women (31%) during the pandemic.

The Impact of Anti-COVID-19 Measures on Fertility Rates in LMICs

If we re-examine the consequences of a pandemic on TRF, although a baby boom, i.e., a remarkable sudden increase in the birth rates when compared to normal rates, is unlikely to occur in western countries despite economic problems, psychological distress, household stress, and shortage of health services, controlling the anticipated baby boom is impracticable among individuals in low-middle income countries (LMIC). Moreover, in LMICs (e.g., India and Bangladesh), the impact of COVID-19 on fertility appears to be quite different. While socioeconomic factors are intimately related to risk awareness as related to pregnancy during a pandemic, and therefore highly educated sectors of the population in LMIC are unlikely to plan family expansion during this situation, some cases of conception may still occur (12). For instance, prolonged lockdown may result in a large number of women or men not having access to various forms of contraception, also a major determinant of baby booms after an epidemic has occurred. The Ipas Development Foundation, which focuses on contraception and abortion in India, an LMIC of Southeast Asia, estimated that about 1.85 million women were unable to gain access to abortions between March and May 2020 (17). Another organization in the same country, Reproductive Health Service reported that about 25 million people were unable to access contraception in May 2020 during lockdown. Among all other less privileged sectors of the population in LMIC, the lack of access to birth control services is further apparent, and likely to result in millions of unintended pregnancies, unsafe abortions, and maternal deaths (18). Moreover, during the lockdown women are not able to go to the clinics for their regular check-ups and pregnancy tests, and consequently, they are not always able to prevent unintended pregnancies. Additionally, the practice of family planning is comparatively low among illiterate individuals due to poverty and lack of education and resources in LMICs (19). Such individuals do not have clear concepts and awareness about proper spacing between pregnancies, usage of condoms, and of female contraceptive methods (20, 21). As a result, unintended pregnancies are unlikely to be reduced among this group. Due to the lockdown, individuals are in their houses with their partners and because of job losses or interrupted work-related activities, the increased time spent at home will further escalate the possibility of a baby boom in rural areas during this pandemic.

The Possible Direct Impacts of COVID-19 on Fertility Rates

Few unresolved or poorly understood factors could also significantly affect the fertility rate during any pathogenic outbreak. Given the 1918 influenza pandemic as an example, pregnant women were the hardest hit among all infected individuals, but the reason behind such observations are still a subject of debate (22–24). Since many factors regarding COVID-19 remain still poorly understood, the chance of direct impact of SARS-CoV-2 (the causative agent of COVID-19) on both male and female fertility cannot be excluded. SARS-CoV-2 binds to the Angiotensin Converting Enzyme-2 (ACE-2) receptors to enter the cells of human body. Several hypotheses have pointed the presence of ACE-2 receptors on male Leydig cells and female ovaries as the possible thread to directly affect human fertility (25, 26). Therefore, how differently COVID-19 affects male and female fertility *per se* is not yet clear, and as a result, the actual impact of SARS-CoV-2 on overall fertility cannot entirely be incorporated into accurate estimates of future TFR (20, 21). In addition, the knowledge gap about the vertical transmission of the SARS-CoV-2 virus, along with the inability to universally diagnose asymptomatic patients remains another concern to consider the direct impact of COVID-19 pandemic on fertility rate (27). If SARS-CoV-2 is vertically transmitted from asymptomatic mother to child, the assumption on COVID-19 not affecting pregnancy outcomes or birth rates may be misleading. Furthermore, embryology laboratory personnel who is infected and asymptomatic can contaminate the gamete/embryo during manipulation required for *in vitro* fertilization (IVF) and thus can affect the fertility rate unknowingly. These unknown factors and certainly many others that remain unaccounted may influence professional societies recommendations (10), as well as lead to public opinion shifts regarding pregnancy decisions.

The Impacts of COVID-19-related Morbidity and Mortality on Fertility Rates

Additionally, the death rate of COVID-19 may adversely impact TFR; however, considering that COVID-19 mortality rates are particularly elevated among older individuals and those with underlying chronic disease, the overall direct effect of mortality is likely to be minor on TFR. We should point out that historical evidence from high mortality events such as wars, diseases, famines, heatwaves, and storms typically have an immediate negative effect on fertility rates, whereby mortality affects fertility by both a replacement effect and a hoarding effect. By replacement (or volitional) effect, we indicate compensation for birth loss (i.e., a response by couples to plan for a new baby because they have lost one), especially evidenced in societies where extended families living together are the norm, and where

children are valuable for their support in their parents' old age and for their economic contribution to the family. A significant rise in stillbirths was observed during the ongoing pandemic in UK, India and Nepal and the study carried out among 20 thousand women in nine hospitals across Nepal revealed about 50% increase in stillbirth rates due to inaccessibility to health facilities and antenatal support (28). This suggests that the global fertility rate could be also influenced by replacement effect more specifically in developing countries. By hoarding effect, we signify expected mortality risk of offspring by their parents (i.e., a response by couples to expected mortality of their offspring which causes them to plan for more babies) (29, 30).

CORRESPONDENCE BETWEEN COVID-19 AND OTHER PRECEDING EPIDEMICS

A large number of deadly disasters have previously occurred in the world history. From influenza epidemics to COVID-19, all have taken hundreds of thousands of lives. Studies have shown that such high fatality disasters lead to a decline in births in the several months that follow such events. The Great Finnish Famine (1866–1868) killed more than 0.2 million people in Finland (i.e., 10% of the country population). The birth rate during the epidemic was lower compared to the period 1801–1850 (31). The birth rate later markedly increased shortly after the famine ended. The Spanish flu (1918) is the most destructive flu pandemic in modern history and killed 50 million people worldwide. A unique feature of this virus was the high death rate among young adults aged 20–40 years (32). There were no significant changes noticed in fertility rates between 1913 and 1918, and the fertility rate was at its lowest in 1919. However, in 1920, a baby boom occurred in European countries including Norway, Sweden, and the UK. This surge in natality was identified as reflecting the tendency of many couples rushing to wed and then conceive children after surviving the epidemic (33, 34). A surge in fertility rate was also observed 9–12 months after the Great Kanto Earthquake in Japan (1923). Experts suggested that victims of the disaster sought motherhood because of child loss in the earthquake (35).

More recently, studies suggest that fertility rates also declined during the Severe Acute Respiratory Syndrome (SARS) epidemic (2003) and the Zika virus outbreak (2015–16). In a study carried out in Taiwan that compared to pre-SARS period, the market share for childbirth health services dropped in medical centers (5.2%) and regional hospitals (4.1%) with reduced cesarean rates during the peak SARS period (36). The Ebola epidemic in Africa killed 50% of infected individuals, spread by means of bodily fluids, and had a case fatality rate up to 70%. During and after the Ebola epidemic, the birth rate declined, but after the announcement of several countries as being Ebola-free, the birth rate temporarily rose. For instance, in Liberia, a sharp decline in birth rates was observed during the first 6 months from the beginning of the Ebola outbreak, whereas a 33% rise was reported for 5 months in the 17 months preceding the outbreak (37, 37, 38).

In **Figure 1**, we depict monthly fluctuation (percent change in monthly birth rate after outbreak) from the start of the SARS, Zika, and Ebola epidemics in Hong Kong (2002), Brazil (2015), and West Africa (2016). After several months (8–12 months) of the epidemics, a reduction in birth rates was apparent and was followed by a noticeable upward trend in the birth rates that lasted well into 20 months after the beginning of each of these epidemics.

Overall, these observations indicate that during all these three recent epidemics, the birth rates decline immediately after the epidemic and recover or further surpass pre-epidemic levels within a year and thereafter. The reclamation of fertility took place mainly because of the replacement effect and the hoarding effect. The loss of family members, relatives, or friends appeared to result in replacement fertility. Additionally, the fear of existence and insecurity influenced the hoarding effect (39). The baby boom after the Spanish flu pandemic was because many women had experienced mortality directly (i.e., loss in their own family) or indirectly (observed death in neighborhood or community). Therefore, the birth rates vary during epidemics and pandemics in different regions because of the different factors influencing birth rates.

DISCUSSION

A recent demographic study estimated that the total number of COVID-19 infections is four times larger than the number of confirmed cases. As mentioned, if SARS-CoV-2 exerts a direct effect on either male or female fertility, the impact of such asymptomatic infections on birth rates could be augmented, and yet unless universal testing is instituted for detection of all asymptomatic cases, the attributable factor to such decline in fertility and consequently birth rates would not be identified. At present, and with very limited evidence, it is somewhat difficult to predict whether and how COVID-19 will affect birth rates. However, considering factors such as changes in socio-economic conditions, mental health, mortality rates, and direct effects of the virus on fertility, and incorporating lessons learned from the previous pandemics, it would be reasonable to postulate that the COVID-19 pandemic may significantly affect future birth rates with long-term effects.

The aforementioned cross-sectional study in Italy, reported that 37.3% had abandoned intentions of having a baby due to the future economic climate, but also that 4.3% had tried to achieve pregnancy (9). Therefore, this change to family planning will to some extent mitigate each other, and the birth rate after 9 months (Bertillon effect) will not be as pronounced due to the counterbalancing effects of these two factors. After an initial reduction, it is expected that birth rates will rise again due to the aforementioned mortality replacement and hoarding effects. However, more precise estimates of the birth rates are unknown because previous studies of epidemics suggest a range from 0.25 to 2 births being added per each death toll in the course of 1 to 5 years after an epidemic. The reduction of 1 birth in 1918 during Spanish flu, was followed by an increase of 1.5 conception 1 year later and resulted in a baby boom (32, 37). This suggests that the COVID-19 pandemic is also very likely to influence the global fertility rate significantly.

The economic recession seems to be a major regulator for affecting the birth rates differently across countries with different

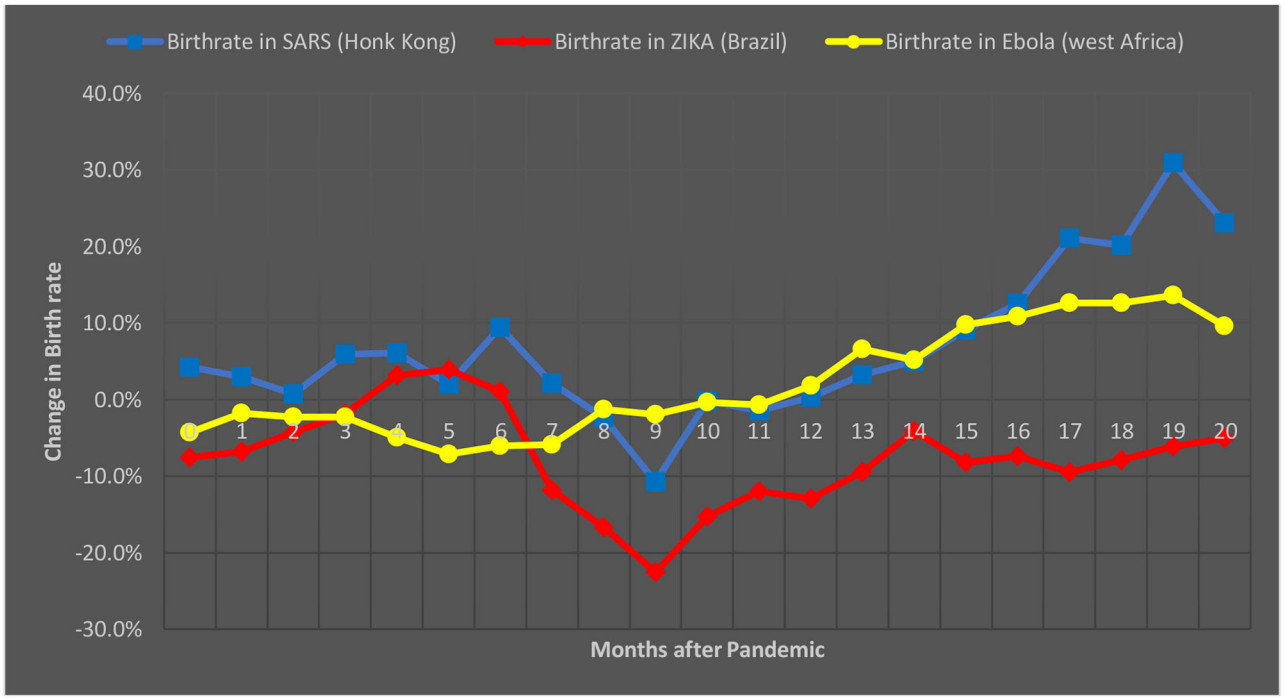

FIGURE 1 | Change in birth-rate in months after the start of three recent epidemics, namely SARS, Zika, and Ebola (Source: The Economist; Institute for Family Studies).

socioeconomic settings. Moreover, since every country has unique characteristics in terms of literacy, family planning, rate of disease spread, mortality, and morbidity, different trajectories in fertility and birth rates are anticipated. Again, the countries will start recovering their normal economic state after the pandemic has abated which will also differ from one country to another. The recovery period thus may also significantly influence the global fertility rates for long term in different manners across HICs and LMICs.

Furthermore, the availability of contraception and health care facilities during the pandemic appear to affect the fertility rates greatly in LMICs than HICs. Therefore, a short-lasting drop followed by a later sudden rise in birth rates due to the pandemic is expected to normalize rapidly in developed economies, while a much more variable pattern should emerge in LMICs. And thus, governments in LMICs should ensure the emergency supports to avoid unintended baby boom in such countries during ongoing pandemic. The health agencies should monitor and record the factors associated with undesired events like stillbirth and prevent these from happening again. Moreover, lessons learned from the COVID-19 pandemic should be executed to avoid any future similar circumstances caused by outbreaks or other natural disasters.

CONCLUSION

The COVID-19-related pandemic is negatively impacting human welfare in many domains, and as a result, birth rates are likely to be affected, albeit differentially in developed economies and in LMICs. While initial reductions in birth rates are likely, it is overall expected that a rebound of such rates will take place. Consequently, LMIC governments can play an important role in preventing undesirable baby booms by implementing measures, such as ensuring continued access to family planning centers, and instituting informative public education campaigns.

DATA AVAILABILITY STATEMENT

The original contributions generated for the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MU and DG conducted the complementary literature searches and reviews. MU, AB, and YA wrote the initial draft of the manuscript. YA conceived the study design. MG and DG edited and revised the manuscript. All authors approved the final manuscript.

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frontiers in Public Health

ORIGINAL RESEARCH
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Association of Night Sleep Duration and Ideal Cardiovascular Health in Rural China: The Henan Rural Cohort Study

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Introduction: We aimed to explore the association between night sleep duration and ideal cardiovascular health (ICH) among Chinese rural population.

Methods: In all, 35,094 participants were included from the Henan Rural Cohort study. Information on sleep was collected using the Pittsburgh Sleep Quality Index. The ICH scores were evaluated. The associations between night sleep duration and ICH were examined using both linear regression and logistic regression models.

Results: The mean night sleep duration for all participants was 7.75 ± 1.28 h. Compared with those with night sleep duration of 7 to <9 h by using linear regression model, a significant decrease in ICH scores was observed for participants with shorter [−0.077 (−0.131, −0.024)] and longer [−0.079 (−0.121, −0.036)] night sleep duration. Compared with 7 to <9 h, longer sleep duration [0.919 (0.851, 0.992)] were associated with decreased odds of ideal CVH.

Conclusions: Shorter and longer night sleep duration are negatively associated with ICH among rural population. This suggests that it may be beneficial to include night sleep duration assessment in cardiovascular risk screening.

Keywords: ideal cardiovascular health, health behaviors, health factors, night sleep duration, rural population

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INTRODUCTION

Cardiovascular disease (CVD) is now the leading cause of premature mortality and disability both worldwide (1, 2) and in China (3). There are the heavy social burdens of disease due to CVD in China (4). In 2010, ideal cardiovascular health (ICH) was defined as the simultaneous presence of four ideal health behaviors including ideal smoking status, ideal body mass index (BMI), ideal physical activity, and ideal diet and four ideal health factors including ideal smoking status, ideal total cholesterol (TC), ideal blood pressure (BP), and ideal fasting plasma glucose (FPG) in the absence of CVD history by the American Heart Association (AHA) (5). Prospective studies consistently indicated that individuals with higher number of ICH metrics have lower risks of CVD events, hypertension, type 2 diabetes mellitus, cancer and all-cause mortality (6–11).

In the past few years, several studies have evaluated the relationship between night sleep duration and the occurrence of hypertension (12), diabetes (13), CVD (14–18). However, most previous studies considered single cardiovascular risk factors. A National Health and Nutrition Examination

Survey among US adults, reported that both shorter and longer sleep duration were associated with decreased odds ratio of ICH and lower mean cardiovascular health scores (19). However, for a population with limited resources, such as the rural population, limited work has assessed the association between night sleep duration and cardiovascular health. Hence, we performed the current study based on data from the Henan Rural Cohort. This study aimed to explore the association between sleep duration and cardiovascular health in rural individuals.

METHODS

Study Design and Participants

The Henan Rural Cohort, was established in Henan Province, China during 2015–2017. A total of 39,259 people were included in the cohort study with a response rate of 93.7%. The details of this cohort have been described elsewhere (20). In current study, 39,223 participants with complete information on sleep information were included. Then, the participants were further excluded if they: (1) were diagnosed with coronary heart disease (n = 1,732); (2) were diagnosed with stroke (n = 2,639); (3) missed the necessary information in the present study (n = 99). Finally, 35,049 adults were included in the study.

Written informed consent was obtained from all participants. The study was approved by the "Zhengzhou University Life Science Ethics Committee" [Ethics approval code: [2015] MEC (S128)].

Data Collection

Data on participants' demographic characteristics, lifestyles, behaviors, dietary patterns (FFQ), individual history of diseases and medication use were collected using standard questionnaire through face to face interviews by well-trained research staff. Weight and height were measured twice in light clothing with shoes off and recorded to the nearest 0.1 kg and 0.1 cm, respectively, and we calculated the average of the two measures. Body mass index (BMI) was computed as body weight (kg) divided by height square (m^2) based on the measurement. Blood pressure was measured three times by electronic sphygmomanometer (Omron HEM-7071A, Japan) in the right arm in a sitting position after at least 5 min rest. There were 30 s intervals between the three measurements. Venous blood samples were collected from subjects after an overnight fast of at least 8 h and stored in −80°C cryogenic refrigerator before analysis. The fasting blood glucose (FBG) was analyzed via glucose oxidative method (GOD-PAP) by ROCHE Cobas C501 automatic biochemical analyzer. Total cholesterol was measured by Roche Cobas C501 automatic biochemical analyzer.

Ideal Cardiovascular Health Scores

We used the AHA definitions of ICH (5). Each ICH metric was categorized as ideal and non-ideal according to the following criteria: ideal TC, TC < 5.18 mmol/L untreated; ideal FPG, FPG < 5.6 mmol/L untreated; ideal BP, SBP <120/DBP< 80 mm Hg untreated; ideal smoking status, never a smoker; ideal physical activity, physical activity ≥150 min/week of moderate intensity or ≥75 min/week of vigorous intensity or ≥150 min/week of moderate-vigorous intensity combination; ideal BMI, BMI < 25 kg/m^2; ideal diet, ≥ 4 components. In addition, ICH was defined according to the American Heart Association's 2020 Strategic Impact Goals as follows: the simultaneous presence of 4 ideal health behaviors (ideal smoking status, ideal BMI, ideal PA, and ideal diet) and 4 ideal health factors (ideal smoking status, ideal TC, ideal BP, and ideal FPG) in the absence of a history of CVD. The healthy diet score was made some adaptations as appropriate. Healthy diet score was calculated by adding the number of diet components, including fruits and vegetables ≥500 g/d; fish ≥200 g/week; soybean products ≥125 g/d; red meat < 75 g/d; drinking tea. Ideal diet was defined as healthy diet score ≥4 components (21).

We calculated the ICH score by summing up the number of ideal metrics for each participant, ranging from 0 to 7, and participants were classified as having ideal CVH (≥5) and non-ideal CVH (0∼4) (5). Ideal health behaviors (IHB) scores and ideal health factors (IHF) scores were calculated by summing the total number of IHB metrics and IHF metrics, respectively, both ranging from 0 to 4.

Night Sleep Duration

Night sleep duration was evaluated by using the Pittsburgh Sleep Quality Index (PSQI) (22). Information on sleep was taken from answers to the following questions: (1) "What time have you usually gone to bed?" (bedtime), (2) "How long (in minutes) has it taken you to go to sleep each night during the past month?" (sleep latency), and (3) "What time have you usually gotten up in the morning?" (getting up time). Furthermore, we calculate the interval between bedtime and getting up time as night sleep duration. Night sleep duration was categorized as <6 h (shorter night sleep duration), 6 to <7 h, 7 to <9 h (reference), and ≥9 h (longer night sleep duration) (19).

Statistical Analysis

Multivariable linear regression model was conducted to examine the association between night sleep duration and ICH scores. Beside the linear regression model, logistic regression model was used to further examine the association between night sleep duration and ideal CVH (ICH scores ≥5). A range of potential confounders were adjusted, including age (<40, 40–60 or ≥60 years), sex (men or women), educational level (primary school or illiteracy, junior high school, or high school or above), income (<500, 500–1,000 or ≥1,000 RMB per month) and drinking (no drinking or current drinking). Results were expressed as increased ICH scores and 95% confidence intervals (95%CIs) or odds ratio of ideal CVH associated with night sleep duration. The potential modification effects of sex, age, education level, income and drinking were examined by adding an interaction term into the adjusted model. All statistical analyses were performed by STATA 15 for Windows and R version 3.6.3.

RESULTS

Characteristics of the Participants

The characteristics of the study participants by ICH groups are presented in **Table 1**. Of all 35,049 participants, 21,353 (60.92%)

TABLE 1 | Characteristics of the participants.

Variables	Total (n = 35,049)	Ideal CVH (n = 13,005)[a]	Non-ideal CVH (n = 22,044)[b]	p
Age (years, mean ± SD)	54.74 ± 12.28	51.25 ± 12.98	56.80 ± 11.351	<0.001
Sex				<0.001
Men	13,696 (39.08)	3,404 (26.17)	10,292 (46.69)	
Women	21,353 (60.92)	9,601 (73.83)	11,752 (53.31)	
Marital status				0.018
Married/cohabiting	31,611 (90.19)	11,793 (90.68)	19,818 (89.90)	
Unmarried/divorced/widowed	3,438 (9.81)	1,212 (9.32)	2,226 (10.10)	
Education level				<0.001
Primary school or illiteracy	15,128 (43.16)	5,227 (40.19)	9,901 (44.91)	
Junior high school	14,304 (40.81)	5,573 (42.85)	8,731 (39.61)	
High school or above	5,617 (16.03)	2,205 (16.96)	3,412 (15.48)	
Income				<0.001
<500	12,169 (34.72)	4,336 (33.34)	7,833 (35.53)	
500	11,623 (33.16)	4,260 (32.76)	7,363 (33.40)	
1,000	11,257 (32.12)	4,409 (33.90)	8,648 (31.07)	
Smoking				<0.001
No smoking	25,630 (73.13)	11,380 (87.50)	14,250 (64.64)	
Current smoking	9,419 (26.87)	1,625 (12.50)	7,794 (35.36)	
Drinking				<0.001
No drinking	27,078 (77.26)	11,203 (86.14)	15,875 (72.02)	
Current drinking	7,971 (22.74)	1,802 (13.86)	6,169 (27.98)	
BMI (kg/m2 mean ± SD)	24.79 ± 3.56	22.84 ± 2.76	25.94 ± 3.48	<0.001
Night sleep duration, h				<0.001
<6	2,160 (6.16)	738 (5.67)	1,422 (6.45)	
6 to <7	5,671 (16.18)	2,103 (16.17)	3,568 (16.19)	
7 to <9	23,558 (67.21)	8,913 (68.54)	14,645 (66.44)	
≥9	3,660 (10.44)	1,251 (9.62)	2,409 (10.93)	
Mean night sleep duration, h	7.75 ± 1.28	7.75 ± 1.24	7.76 ± 1.30	0.500

SD, standard deviation; Income, per capita monthly income, RMB per month; BMI, body mass index; [a]ICH scores ≥ 5; [b]ICH scores, 0∼4.

were women and the mean age was 54.74 ± 12.28 years. A total of 13,005 participants (37.11%) showed Ideal CVH (ICH scores ≥5) and nearly half were classified as intermediate overall CVH. The mean night sleep duration for all participants was 7.75 ± 1.28 h. Lower mean age and BMI, higher income, higher proportion of women, and married/cohabiting were observed among those with ideal ICH compared to non-Ideal ICH participants. Participants with ideal CVH tended to be non-smokers and non-drinkers. The prevalence of those who slept 7 to <9 h was 67.21%, and the prevalence of shorter sleep (<6 h) was 6.16% and longer sleep (≥9 h) was 10.44%. In the different ICH groups, the proportion of those who slept 7 to <9 h with ideal CVH was significantly higher than those with non-ideal CVH, while participants who were shorter sleep or longer sleep with ideal CVH were lower than those with non-ideal CVH.

Associations Between Night Sleep Duration and ICH

Differences were significant in all ICH metrics when stratified by the reported night sleep duration (**Table 2**). The results of multivariable logistic regression models showed the odds ratios (and 95%CIs) of each ICH metrics which was associated with night sleep duration scores in **Figure 1**. After adjusting for potential confounders, shorter night sleep duration was strongly related with total cholesterol, BMI and smoking. A strong association between longer night sleep duration and ICH metrics was observed in physical activity and blood pressure. In the linear regression models, we found a consistent association between shorter and long night sleep duration and decreased ICH scores both in the unadjusted and adjusted models. After adjusting for potential confounders, a significant decrease was observed in ICH scores for participants with shorter [−0.077 (−0.131, −0.024)] and longer [−0.079 (−0.121, −0.036)] night sleep duration, compared with those with night sleep duration of 7 to <9 h. In the multivariable logistic regression models, compared to the participants who slept 7 to <9 h, OR (95%CI) for ideal CVH among those with shorter night sleep duration was 0.853 (0.777, 0.936) in the unadjusted model and the effect was slightly attenuated with an adjusted OR (95%CI) of 0.929 (0.844, 1.023). An association between longer night sleep duration

TABLE 2 | Prevalence of the ICH metrics by night sleep duration.

ICH metrics	Total, n (%)	Night sleep duration, n (%)				*p*
		<6	6 to <7	7 to <9	≥9	
TC						<0.001
Ideal	23,779 (67.85)	1,394 (64.54)	3,738 (65.91)	16,202 (68.77)	2,445 (66.80)	
Non-ideal	11,270 (32.15)	766 (35.46)	1,933 (34.09)	7,356 (31.23)	1,215 (33.20)	
BP						<0.001
Ideal	14,019 (40.00)	907 (41.99)	2,390 (42.14)	9,437 (40.06)	1,285 (35.11)	
Non-ideal	21,030 (60.00)	1,253 (58.01)	3,281 (57.86)	14,121 (59.94)	2,375 (64.89)	
FPG						0.013
Ideal	24,931 (71.13)	1,530 (70.83)	4,045 (71.33)	16,836 (71.47)	2,520 (68.85)	
Non-ideal	10,118 (28.87)	630 (29.17)	1,626 (28.67)	6,722 (28.53)	1,140 (31.15)	
Smoking						<0.001
Ideal	25,630 (73.13)	1,420 (65.74)	3,949 (69.63)	17,558 (74.53)	2,703 (73.85)	
Non-ideal	9,419 (26.87)	740 (34.26)	1,722 (30.37)	6,000 (25.47)	957 (26.15)	
physical activity						<0.001
Ideal	32,031 (91.39)	1,975 (91.44)	5,259 (92.73)	21,599 (91.68)	3,198 (87.38)	
Non-ideal	3,018 (8.61)	185 (8.56)	412 (7.27)	1,959 (8.32)	462 (12.62)	
BMI						0.017
Ideal	19,094 (54.48)	1,129 (52.27)	3,053 (53.84)	12,851 (54.55)	2,061 (56.31)	
Non-ideal	15,955 (45.52)	1,031 (47.73)	2,618 (46.16)	10,707 (45.45)	1,599 (43.69)	
Diet						0.034
Ideal	167 (0.48)	9 (0.42)	41 (0.72)	101 (0.43)	16 (0.44)	
Non-ideal	34,882 (99.52)	2,151 (99.58)	5,630 (99.28)	23,457 (99.57)	3,644 (99.56)	

ICH, Ideal cardiovascular health; TC, total cholesterol; BP, blood pressure; FPG, fasting plasma glucose; BMI, body mass index (kg/m^2).
Ideal diet was defined as healthy diet score ≥ 4 components.

and decreased odds of ideal CVH [unadjusted 0.853 (0.793, 0.918) and adjusted 0.919 (0.851, 0.992)] was also observed (**Table 3**). When examining the IHB scores and IHF scores as a continuous variable, the decreased IHB scores was associated with shorter night sleep duration [−0.063 (−0.091, −0.035)] and longer night sleep duration [−0.030 (−0.052, −0.008)] in the adjusted model, and similar results were observed that the decreased IHF scores increased associated with shorter night sleep duration and longer night sleep duration were −0.056 (−0.098, 0.014) and −0.048 (−0.081, −0.015) after adjusting (**Supplementary Table 1**).

Interaction Analyses of Night Sleep Duration and ICH

In **Table 4**, it is shown that the association between night sleep duration and cardiovascular health was modified by age, sex, income, educational level, and drinking. Stronger associations between shorter night sleep duration and increased ICH scores were present among men participants, who were 40 to <60 years, non-drinkers and with high education level. Conversely, stronger associations between longer night sleep duration and increased ICH scores were present among women who were aged ≥60 years, low income, with low education level, and non-drinker.

DISCUSSION

To the best of our knowledge, this is the first study to examine the effect of night sleep duration on ICH among rural adults. The proportion of those who slept 7 to <9 h with ideal CVH were higher than those with non-ideal CVH, while participants who with shorter sleep or longer sleep with ideal CVH were lower than those with non-ideal CVH. There was a strong correlation between shorter night sleep duration and ICH metrics including total cholesterol, BMI and smoking, and a strong association between longer sleep and ICH metrics was observed in physical activity and blood pressure. Shorter (<6 h) and longer night (≥9 h) sleep duration were significantly associated with decreasing ICH scores, IHB scores and IHF scores, and longer sleep duration were associated with decreased odds of ideal CVH.

Currently, evidence for the adverse effect of sleep duration on ICH is limited in China or elsewhere in the world. In a National Health and Nutrition Examination Survey among US adults, shorter and longer sleep duration were associated with decreased odds ratio of ICH and lower mean cardiovascular health scores (19). The MORGEN study found that those individuals who slept 6 h or less had a 15% higher risk of CVD incidence and a 23% higher risk of CHD incidence compared with people who slept 7–8 h (23). Some studies found a U-shaped association between sleep duration and CVD (24–26). Similar results were found in our study, and our results completed the association between

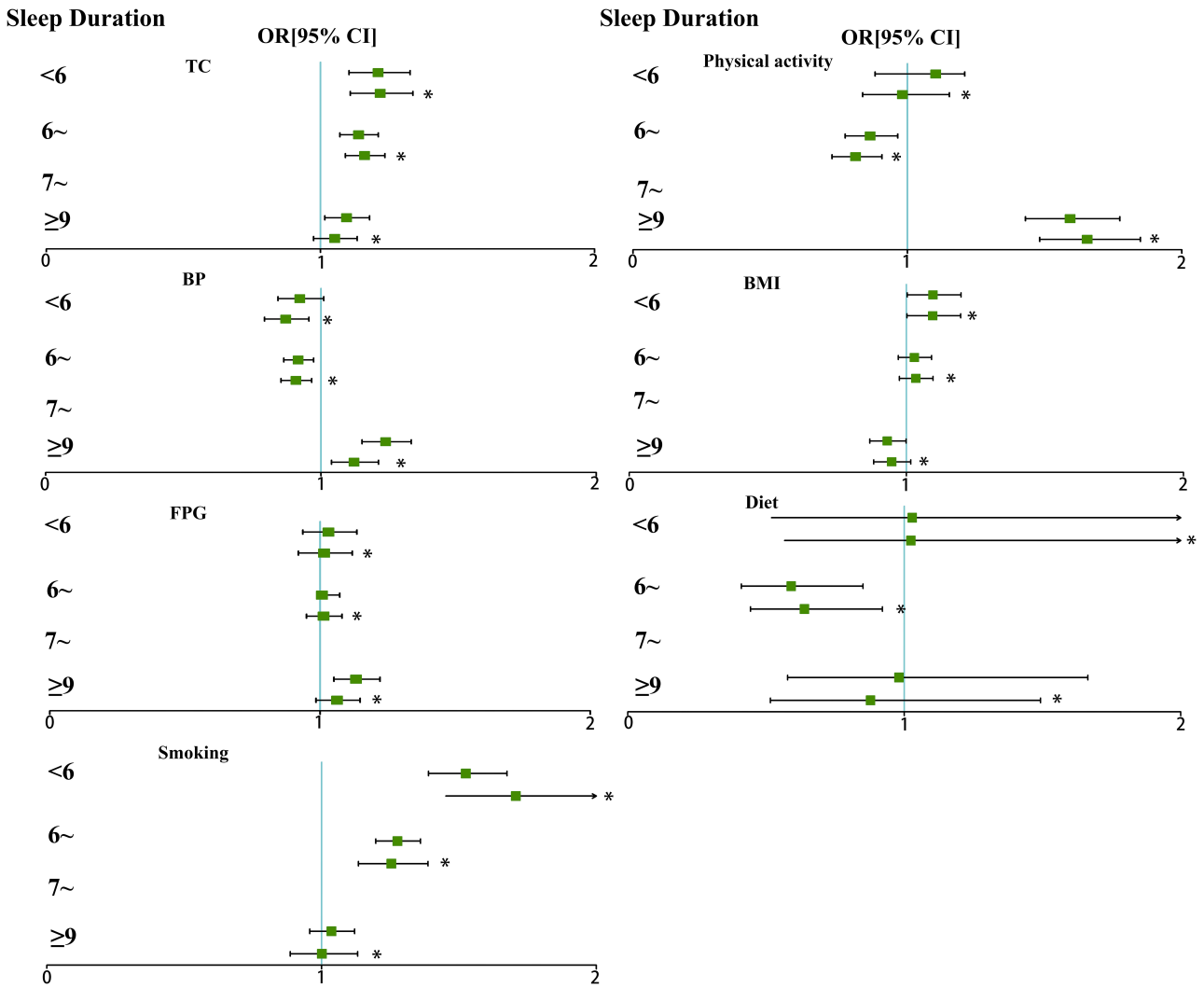

FIGURE 1 | Odds ratio of ICH metrics (and 95%CI) associated with night sleep duration. *Potential confounders were adjusted, including age, sex, educational level, income and drinking.

TABLE 3 | Association between night sleep duration categories and increased ICH scores and odds ratio of ideal CVH.

Night sleep duration	Increased ICH scores (95%CI)				OR (95%CI)			
	Model 1[a]	*p*	Model 2[b]	*p*	Model 1[a]	*p*	Model 2[b]	*p*
<6	−0.143 (−0.200, −0.086)	<0.001	−0.077 (−0.131, −0.024)	0.005	0.853 (0.777,0.936)	0.001	0.929 (0.844, 1.023)	0.133
6 to <7	−0.052 (−0.089, 0.014)	0.007	−0.022 (−0.057, 0.013)	0.219	0.968 (0.912, 1.028)	0.295	1.004 (0.943, 1.069)	0.892
7 to <9	0 [Reference]		0 [Reference]		1 [Reference]		1 [Reference]	
≥9	−0.128 (−0.172, −0.083)	<0.001	−0.079 (−0.121, −0.036)	<0.001	0.853 (0.793, 0.918)	<0.001	0.919 (0.851, 0.992)	0.031

Ideal CVH, ICH scores≥5; ICH, Ideal cardiovascular health; CI, confidence interval; OR, odds ratio.

[a]*Model 1: Unadjusted.*

[b]*Model 2: Adjusted for demographic factors of age, sex, education level, income, and drinking.*

night sleep duration and ICH among Chinese rural population, and the correlation intensity between shorter and longer duration of night sleep and ICH of the rural population is stronger than that of the developed countries. However, other studies have shown that long sleep duration has a protective effect on CVD or has non-significant associations (27). The effect estimates are not comparable due to differences in exposure and outcome assessments. Therefore, more studies are needed in the future

TABLE 4 | Results of stratified analyses for the association between night sleep duration and ICH scores.

Interaction term	Night sleep duration [increased ICH scores (95%CI)]			
	<6	6 to <7	7 to <9	≥9
Gender				
Men	−0.118 (−0.204, −0.033)	−0.025 (−0.082, 0.033)	[Reference]	−0.073 (−0.114, −0.001)
Women	−0.020 (−0.087, 0.047)	0.002 (−0.042, 0.045)	[Reference]	−0.087 (−0.138, −0.036)
Age				
< 40	−0.184 (−0.381, 0.012)	−0.147 (−0.255, −0.040)	[Reference]	−0.059 (−0.183, 0.064)
40–60	−0.094 (−0.168, −0.020)	−0.020 (−0.069, 0.030)	[Reference]	−0.077 (−0.148, −0.005)
≥60	0.004 (−0.082, 0.090)	0.007 (−0.051, 0.064)	[Reference]	−0.115 (−0.174, −0.057)
Income				
<500	−0.046 (−0.138, 0.046)	−0.022 (−0.083, 0.039)	[Reference]	−0.124 (−0.191, −0.058)
500	−0.137 (−0.232, −0.042)	−0.017 (−0.078, 0.044)	[Reference]	−0.081 (−0.156, −0.005)
1,000	−0.064 (−0.158, 0.031)	−0.056 (−0.119, 0.007)	[Reference]	−0.043 (−0.127, 0.040)
Education level				
Primary school or illiteracy	−0.017 (−0.072, 0.039)	−0.016 (−0.107, 0.076)	[Reference]	−0.098 (−0.170, −0.026)
Junior high school	−0.100 (−0.185, −0.015)	−0.073 (−0.128, −0.018)	[Reference]	−0.133 (−0.208, −0.058)
High school or above	−0.249 (−0.393, −0.105)	−0.031 (−0.119, 0.056)	[Reference]	0.052 (−0.081, 0.185)
Drinking				
No drinking	−0.068 (−0.131, −0.006)	−0.027 (−0.067, 0.013)	[Reference]	−0.094 (−0.141, −0.047)
Current drinking	−0.096 (−0.204, 0.012)	−0.039 (−0.115, 0.038)	[Reference]	−0.048 (−0.147, 0.051)

Income, per capita monthly income; RMB per month; ICH, Ideal cardiovascular health.

to provide more solid and robust evidence for the relationship between night sleep duration and ICH.

The biological mechanism for sleep and CVH likely differs from the association between sleep duration and ICH previously described, which may have multiple pathways. Night sleep duration is independently associated with several ICH metrics. In our findings, after adjusting for potential confounders, there was a strong correlation between shorter night sleep duration and ICH metrics including total cholesterol, BMI and smoking, while the association between longer sleep and ICH metrics was observed in physical activity and blood pressure. Prior literature has demonstrated that sleep duration was independently associated with several CVH metrics, such as BMI (28) hypertension (26) and hyperlipidemia (15). Abnormal lipid profiles have been reported as a possible mechanism in individuals who sleep for a long duration (29). Compared to a long sleep duration, a short sleep duration is associated with several correlates. Studies have found that short sleep shows better morbidity prediction (30). We further found that stronger effects of shorter night sleep duration and increased ICH scores were present among men participants, who were 40 to <60 years, non-drinkers and with high education level and the associations between longer night sleep duration and increased ICH scores were present among women who were aged ≥60 years, low income, with low education level, and non-drinker. In the USA data, long sleep duration was associated with stroke, especially in older people (31). The elderly are prone to sleep disorders, and their sleep duration is not guaranteed, which may lead to a stronger correlation between sleep duration and ICH in the elderly. In addition, we found that the association between shorter or longer night sleep duration and increased ICH scores existed only among non-drinkers. It also suggested that proper night sleep duration is better for cardiovascular health without drinking alcohol.

Taken together, sleep duration represents an important direction of cardiometabolic health risk. Future studies need to better describe the mechanisms by which sleep duration and other sleep metrics lead to morbidity. How to properly integrate sleep into seven ICH metrics and identify and refine interventions to better ameliorate this risk. At the same time, healthy sleep should be a consideration in the clinical care of patients with heart disease. Sleep may be one of the indicators used to describes the health of the cardiovascular system. Unhealthy night sleep duration is a modifiable risk factor and can provide targets for population intervention.

Our study had several strengths. Firstly, the relatively large sample size of rural population in China, as well as adjustments of a wide range of potential confounding factors, ensuring the reliability of the analysis. Secondly, to our best knowledge, few studies paid attention to the rural populations, who accounted for a large proportion of the Chinese population and had particular life styles including sleep habits. In addition, most subjects in our research are middle-aged and elderly people, which can better represent the current age structure of the Chinese rural population. Nevertheless, several limitations should also be considered. Firstly, these findings come from a cross-sectional study, rather than a prospective cohort design, thus do not accurately describe causality. Secondly, sleep duration data are self-reported and may have recall biases. However, previous studies have shown relationship between self-reported

sleep duration and objective sleep duration measured by polysomnography or actigraphy (32). Therefore, the results of relatively large rural epidemiological study could reflect the prevalence of ICH in rural areas of China to some extent.

CONCLUSIONS

There was a strong correlation between shorter night sleep duration and ICH metrics including total cholesterol, BMI and smoking, and a strong association between longer sleep and ICH metrics was observed in physical activity and blood pressure. Shorter (<6 h) and longer night (≥9 h) sleep duration were significantly associated with decreasing ICH scores and decreased odds ratio of ideal CVH. This study suggests that it may be beneficial to include night sleep duration assessment in cardiovascular risk screening. Future research should explore the causal relationship between night sleep duration and ICH.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Zhengzhou University Life Science Ethics. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XWu: investigation, data curation, methodology, formal analysis, visualization, and writing-original draft. XL and ZZ: investigation, data curation, writing-review, and editing. WL: investigation, validation, writing-review, and editing. SS and TA: investigation, writing-review, and editing. CW: conceptualization, methodology, investigation, validation, supervision, funding acquisition, project administration, and writing-original draft. XWa: data curation, methodology, writing-review, and editing. YL: conceptualization, methodology, writing-review, and editing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.606458/full#supplementary-material

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Strategies to Address COVID-19 Vaccine Hesitancy and Mitigate Health Disparities in Minority Populations

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Beyond the complex logistical task of prioritizing, distributing and safely storing millions of doses of COVID-19 vaccines, state and local governments must simultaneously devise and carry out transparent plans that center equity and overcome the barriers to vaccination facing minority communities. Using insights gleaned from four focus groups conducted with health care and social service professionals serving minority communities in New York State as well as from existing research on vaccination, our results emphasize that vaccine hesitancy and access barriers—particularly within minority communities—pose significant hurdles to achieving widespread uptake of COVID-19 vaccines. Overcoming barriers requires community-engaged campaigns that acknowledge and address the historical injustices and on-going inequities that drive distrust within communities of color, emphasize understandable and culturally appropriate messages that directly address people's concerns about vaccine safety and access, and tap existing community infrastructure to make full use of trusted voices to deliver timely and accurate information about vaccines. Given emerging data and changing conditions, campaigns must also be self-reflective and adaptive, assessing progress and outcomes and reevaluating strategies as needed. However, above all, primary goals should remain focused on transparency, equity and building trust.

Keywords: vaccine hesitancy, COVID-19, health disparities, community-engaged campaigns, health equity

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INTRODUCTION

The COVID-19 pandemic has delivered many sobering lesson–among the most pressing the need to confront disparities in COVID-19 outcomes in minority communities[1]. Disproportionate rates of infection and death from COVID-19 within communities of color have laid bare the tragic consequences of systemic and pervasive inequities in medical care and working,

[1]While we recognize that the terms used by members of different communities to refer to themselves vary, to simplify comparisons of COVID-19-related data to existing U.S. Census data, we use the term Black in this article in place of the full U.S. Census category "Black or African American alone", and we use the term Hispanic to refer to the full Census category "Hispanic or Latino." For the same reason, we use the term White to refer to individuals identified in the Census as "White alone, not Hispanic or Latino."

living, and environmental conditions (1). While some states successfully contained early waves of COVID-19, the policies, institutions and cultural forces responsible for underlying systemic racial-ethnic inequities remain and threaten to find new expression as states carry out unprecedented mass-vaccination campaigns (2, 3). Beyond the enormously complex logistical task of distributing and safely storing millions of doses of vaccine, each state must simultaneously take steps to address vaccine hesitancy. Vaccine hesitancy impacts many demographic groups in America, but especially minority groups, whose experiences and viewpoints are shaped by legacies of past medical abuses, contemporary health care and criminal justice disparities, and unequal burdens of the COVID-19 pandemic.

The discussion below draws on existing research on vaccine hesitancy and disparities as well as on focus group comments from health care and social service professionals doing work related to community health serving minority communities in New York State. We focused on these professional groups as they have knowledge of communities' health behaviors and concerns, play key roles in vaccine delivery and information, and often serve as trusted sources for health information. The four focus groups, described in greater detail in **Table 1**, were conducted in August 2020 and organized around four locations: Long Island, Brooklyn/Queens, Syracuse, and Buffalo. **Table 2** lists the primary questions related to vaccine concerns and barriers posed in the focus groups and key themes that arose in discussions. Taken together, existing research and these voices offer a compelling argument that efforts to address vaccine hesitancy must be multi-faceted, prioritize community engagement, and address the systemic inequities shaping people's experiences and viewpoints. This perspective article is based on a prior report made available in October 2020 (4), but includes updated recommendations to reflect new challenges facing equity goals in COVID-19 vaccination campaigns, and to contribute to the evidence base.

UNDERSTANDING VACCINE HESITANCY

Vaccine hesitancy refers to delays in the acceptance of or outright refusal of vaccines and is driven by attitudes toward a given vaccine, or the disease it is meant to prevent, as well as the difficulties one faces in trying to get the vaccine. A now-common phenomenon, vaccine hesitancy is context specific[2], with reasons that vary by vaccines and groups (5, 6). Often motivated by feelings of disconfirmation by government and other elites to the felt needs and concerns of the public and perceived infringement of personal choice, vaccine hesitancy can also stem from cultural suspicions within some religious, ethnic and racial groups as illustrated by resistance to measles, mumps, and rubella (MMR) immunization within ultra-Orthodox Jewish communities in New York (7, 8). Black people and Hispanics in the United States also are more skeptical of MMR vaccine benefits and rate the risk of side effects higher than Whites (9). In Latin American immigrant communities, barriers to vaccine uptake include questions about the necessity of vaccinations, a lack of guidance by health care providers, a lack of insurance or access to health care, and concerns about side effects and safety (10). Within Black communities, vaccine hesitancy is associated with a longstanding and justified distrust of the medical community based on past experiments such as the Tuskegee syphilis study, as well as contemporary inequities in access to health care and in health outcomes (11). Underscoring the importance of this history, the Tuskegee experiments were spontaneously mentioned by participants in each of the focus groups as an enduringly salient legacy for black people. A participant in the Syracuse group working with newly resettled refugee communities also emphasized that large cultural barriers between western medicine and some refugee communities contribute to distrust and would likely pose barriers to vaccination.

Several national polls conducted in early-mid 2020 found approximately one-quarter to one-third of Whites and nearly half of black people and Hispanics appeared unwilling to be vaccinated against COVID-19 (12–15). However, more recent data indicate that public opinion is changing as vaccines are distributed. One survey reported that Black respondents who had gotten a vaccine or wanted to get one as soon as possible rose from 20% in December 2020 to 35% in January 2021; the number wishing to "wait and see" declined from 52 to 43%. Similarly, Hispanic respondents who reported getting a vaccine or wanting to get one as soon as possible rose from 26 to 42%; the number wishing to "wait and see" declined from 43 to 37% (16). Vaccine decision-making is an ongoing process, and it is critical to address recently documented disparities in Black and Hispanic Americans' access to quality information on how vaccines are developed and tested (17, 18).

Practical and logistical factors also present substantial hurdles to vaccination and drive hesitancy in minority communities–including lack of health insurance and/or access to a regular source of care, difficulty scheduling health care visits around employment or care-giving responsibilities, transportation, and language barriers. Several such barriers were noted by focus group participants (see **Table 2**). Some states have sought to reduce access barriers in their vaccine distribution so far, but in certain cases have run into unanticipated complications, highlighting how barriers can emerge at many points in access. As one telling example, New York state placed vaccination sites in minority neighborhoods hit hardest by COVID-19 to facilitate access for community members, but found that wealthy Whites from other areas were taking a large share of appointments, until the state began limiting early access to some sites to only local residents (19, 20).

CENTERING EQUITY IN ALLOCATION STRATEGIES REQUIRES BUILDING TRUST

Several states and localities have integrated equity strategies in their vaccine distribution plans, including using community social disadvantage indicators in allocate vaccines more equitably

[2]Many of the reasons for vaccine hesitancy discussed here focus on the U.S. social and historical context. There may be some parallels in other nations and some of the recommendations that follow may apply to other national contexts as well. Cross-national comparisons may shed additional light on vaccine hesitancy, however such comparisons are beyond the scope of this piece.

TABLE 1 | Focus group format, recruitment, and participants.

Focus group formats	**All focus groups were conducted via Zoom, lasting ∼90 min, during August 2020**
Recruitment	This convenience sample was recruited in partnership with Healthcare Association of New York State (HANYS). HANYS sent a broad notification about the study to members involved with community health work. Individuals indicating interest in participating were connected to the project team and provided details and Zoom invites. Some individuals who received the initial notification may have shared with others in their professional network, some of whom may have joined the group. Participants were asked to join groups according to where in NY State they practiced, and sites were selected to reflect multiple regions of the state • Long Island, a downstate largely suburban location, had 4 participants • Brooklyn/Queens, a downstate urban location, had 9 participants • Syracuse, an urban/suburban location in central upstate, had 7 participants • Buffalo, a primarily urban location in western upstate, had 11 participants
Participants' descriptions of their professional roles included:	Community health educator, community health worker, community health worker manager, civil rights organization board member, health care administration and management, health coordinator for early childhood education program, non-profit and/or social service administration, city development planner, non-profit and/or social service administration, nurse practitioner, nurse, nutritionist
Participants' descriptions of communities they work with referenced:	The following racial-ethnic-nativity groups: Caucasian, African American/African descent/Black, Latino/Hispanic (some specifying Spanish-speaking), Native American, Asian (including specific mention of Chinese, Korean, Bangladeshi, and Indian communities), Caribbean (including specific mention of Jamaican communities), Arab/Middle Eastern, immigrants, newly settled refugees Age ranges referenced included young children through seniors

(21, 22). However, the ability of these plans to achieve equity goals depends critically on early engagement and trust-building. Consider, for instance, examples from the 2009 H1N1 pandemic. H1N1 vaccination rates were characterized by racial-ethnic disparities roughly on par with those for seasonal flu vaccines, with the lowest coverage among African Americans (23). Researchers who studied the H1N1 campaign in Los Angeles described substantial challenges based on underlying distrust of government and community-generated informal messaging that framed H1N1 vaccines as a conspiracy to harm minority community members. In offering lessons learned from the Los Angeles campaign, they concluded, "The key to a successful emergency response relies on trust building and collaboration with community partners in the preparedness phase.…" If public health authorities do not make "significant efforts to understand and address the issues of trust and disparities that exist at baseline," they continued, "inequities will continue in the context of an emergency response" (24).

Our focus groups underscored these issues, highlighting how perceptions of a "rushed" vaccine interact with minority communities' experiences of historical and ongoing inequities in health care as well as contemporary movements for racial justice. Participants in each focus group agreed enthusiastically with the need to collaborate early and establish trust. As one participant from Brooklyn/Queens put it: "We have institutions that come into communities and kind of rain their benevolence down on the community instead of making the community a trusted, invested partner from the very beginning. … I think you get the community involved early, often and make them invested in the process and invested in the success." Another participant from Long Island emphasized the importance of early, systematic education of key constituencies about the vaccine-development process: "[Don't] just come to me with, 'Hey a vaccine and it's ready', but educate me along the way so that I can have buy-in to it.... Because if you wait until you get a vaccine, forget about it. They don't trust the process."

ADDRESSING VACCINE HESITANCY THROUGH INTERVENTIONS

Our focus groups were conducted shortly after the large, early outbreak in New York City and during a period when media outlets regularly reported on controversial promises of vaccines by Election Day. When asked to describe concerns in the communities they serve, professionals in our focus groups most commonly cited efficacy, safety and trust, although some also mentioned complacency about the disease as a potential barrier for some subsets of teenagers or young adults. The European Union's Centers for Disease Prevention and Control (ECDC) emphasizes the importance of transparency when designing interventions to address the root causes of hesitancy and highlights three general areas where transparency should be improved: (1) basic information about how vaccines work, (2) the procedures for testing and licensing, as well as efficacy and side effects, and (3) conflicts of interest/trust in motives. These three areas align well with the responses from our focus groups (6).

Basic Information

Some people hesitate to vaccinate because they misunderstand how vaccines work. This could be addressed with more basic information about vaccines presented at various education levels to accommodate varying levels of literacy. The current situation with COVID-19 is rife with seemingly contradictory information about what is necessary to produce a safe and effective vaccine, particularly with respect to the speed of vaccine development. The resulting confusion was mentioned in all four focus groups and is reflected in the comments of one focus group participant from Long Island: "We're getting saturated and inundated with information. Misinformation, correct information, who knows what kind of information. You don't know what is what. So you hear that it takes 18 months to do a vaccine. And now you're hearing that, poof, a vaccine can be done in less than that and … it's like, who's gonna get to the finish line first? I'm not sure if

TABLE 2 | Primary questions and key themes of responses.

Participants were asked to address two primary sets of questions. Listed below are the key themes that emerged from these group discussions.

Question	Key themes
Concerns about vaccines:	
What are some of the biggest concerns that members of your community have about a COVID-19 vaccine?	• Varied concerns related to safety and side effects, with particular emphasis on how the speed of vaccine development and political pressure could potentially compromise vaccine safety/efficacy (LI, B/Q, S, B) • Changing information, mixed messages, and misinformation about vaccines and virus itself driving distrust (LI, B/Q, S, B) • Justified distrust based on historical medical abuse (Tuskegee experiment, experimentation under slavery, as well as other cases) and on-going disparities (LI, B/Q, S, B) • Teenagers and young people not feeling as vulnerable to disease and may therefore be less motivated to take vaccine (LI, B/Q, S) • Black Lives Matter movement as an important context for understanding vaccine concerns (LI, S) • Cultural barriers between western medicine and some refugee communities leading to miscommunication and distrust (S) • Concerns about being among the first groups (either as essential workers or communities with high COVID-19 rates) when side effects will be least known (LI) • Vaccine trials may not include adequate representation of racial-ethnic groups or individuals with preexisting conditions (B)
What do you think are the best strategies for addressing concerns and making people feel more comfortable taking a COVID-19 vaccine?	Groups noted central importance of: • Linguistically and culturally appropriate messages delivered by trusted partners who believe in vaccine (B/Q, S, B) • Early engagement before vaccines are available and education along the way (LI, B/Q) Points on message content: • Acknowledging and having open and honest conversations about past abuses and ongoing disparities and making clear intentions and plans to do better (B/Q, S) • Attending to age/generational differences in message content (B/Q, B) • Clear information on what was done to speed up vaccine testing/production to address concerns about speed (B/Q) When asked to suggest trusted partners, participants noted: • Places of worship (LI, B/Q, B), Health care providers (LI, B/Q, S), Local community-based organizations (e.g., immigration assistance, domestic violence support (LI, B/Q, B), Service fraternities and sororities (LI, B), Young activists in communities (B/Q), Shelters (LI), Mutual aid networks (B/Q), Unions (B/Q), Sports leagues (B/Q), Higher ranking individuals within school system (S), County health officials (S) When discussing how to deliver messages, participants noted: • Ethnic news outlets and media, including social media (LI, B/Q, B) and radio (B/Q, LI)
Access barriers to vaccination:	
What are the biggest logistical and practical barriers that people are likely to face in getting the vaccine?	Transportation (LI, B/Q, S), Child care (LI, S), Time and scheduling around work (B/Q, S), Potential distribution sites that are unequally distributed across a city, participants noted this as a barrier with testing that might emerge with vaccine sites as well (B/Q)
What would be the best strategies for distributing a vaccine?	• Have messages in plain language that are accessible to persons with disabilities, and include messaging strategies that don't require internet (B) When discussing possible distribution sites, participants noted: • Chain drug stores (LI, B/Q, S, B), Places of worship (LI, B/Q, S), Schools (LI, B/Q, S), Health centers (B/Q), Community-based organizations (B/Q, B), Public libraries (B/Q, B), Shelters (B/Q), Public housing (B/Q), Parks (B/Q), and using mobile vaccine units (B) • Some participants (LI, S) voiced concerns that vaccines delivered in some sites or by some organizations might be perceived as linked to delivery of in-kind benefits or services, which could make some groups feel obligated to accept vaccinations, e.g., if vaccines are delivered at a site that also serves as a food bank, etc.

the one who get[s] to the finish line first is going to be the most effective one because it should have taken 18 months. . . ."

Testing/Licensing and Efficacy/Side Effects

Clearly communicating the procedures for testing and licensing a COVID-19 vaccine will be particularly important given the media's focus on the speed of vaccine testing. Participants across all four groups emphasized the special need to create trust on the subject of testing, as indicated by this participant from Brooklyn/Queens: "There's a distrust about the vaccines and no matter what happens, or how much outreach is done, unless we can get a clear message across that the vaccines are tested, [that] they're worthwhile, it's not going to work. And this mad rush to get a vaccine in right away is not going to help." Involving minority communities in vaccine trials and vaccine preparation work would help foster trust that the vaccine's effectiveness and potential side effects have been adequately studied. Transparency about efficacy and risk is challenging, but there are several relevant recommendations from the ECDC, including emphasizing (1) "there is no such thing as a 'perfect' vaccine which protects everyone who receives it AND is entirely safe for everyone," (2) "Effective vaccines . . . may produce some undesirable side effects which are mostly mild and clear up quickly," and (3) "It is not possible to predict every individual who might have a mild or serious reaction to a vaccine, although there are a few contraindications to some vaccines" (25).

Conflicts of Interest/Motives/Trust

The ECDC emphasizes the need to communicate about concerns arising from the profit motives of pharmaceutical companies. In the context of U.S. race relations, there will need to be further culturally sensitive efforts to build trust in medicine and vaccines for minority, immigrant and disadvantaged communities that are often marginalized from services and have been subjected to historical medical abuse or mistreatment. This was underscored in strong terms by one of our focus group participants from Long Island: "We have such a long history in this country being experimented on unwillingly or without informed consent, and I know that we are all taught that and it's … almost embedded in our culture. We all know about Tuskegee, we all know what happened to the slaves. We're not taught that in school but taught that by our own. And so when you talk about vaccines and when you talk about getting them, someone always brings it up. And so there's an inherent mistrust." The participant went on to describe having heard that Black students might be among the first to return to school and continued: "Why [are] we always the first one[s] that they want to experiment on? Then it goes back to, 'Because our lives don't matter.' And so with the Black Lives Matter movement … building momentum now and COVID hitting at the same time... I think the numbers willing to take the vaccine will even be lower than the polls say." People want to know that sources they trust endorse the vaccine. These sources may be inside or outside of the healthcare system and could take the form of community health workers, educators, patient advocates, community leaders, pharmacists, neighbors, health departments and trusted voices on social media. Good information delivered by trusted sources empowers members of the public to advocate for themselves and their loved ones. A participant from Brooklyn/Queens said understanding and responding to the "historical narrative" will be essential to successful vaccination messages that resonate in Black and other minority communities: "When we talk about vaccination, the idea of being a guinea pig is quite important … This is how we have to approach vaccination, in particular the Black community, but I think there's also additional ripple effects into other minority groups as well."

Despite the fact that generalized trust in society and institutions is lower in minority communities, most people, regardless of race or ethnicity, trust people they know and have a history with—an esteemed member of their community or their own doctor—more than government health authorities and pharmaceutical companies (26, 27). Participants across all four groups emphasized that community-engaged vaccination strategies for COVID-19 will be essential to change attitudes and reduce access barriers in minority communities and preventing further COVID-19 health disparities. As one participant from the Syracuse focus group put it, there needs to be "an honest open conversation that's held in communities across the state about the disparities in health care and acknowledging … what has gone wrong, what this moment has shown us has gone wrong." This conversation, the Syracuse participant noted, is especially relevant amid the broader social reckoning highlighted by the Black Lives Matter movement. "It almost seems like, you know, the blame is placed on the … marginalized community for not believing in medicine, when in actuality it's been the medical industry that has mistreated them."

DISCUSSION AND RECOMMENDATIONS

In recent months, multiple COVID-19 vaccines have received emergency authorization in the U.S. and have begun to be distributed to groups defined in early phases of states' distribution plans. Despite this rapidly evolving situation, key themes that emerged in the focus groups still ring true. Justified distrust remains a central challenge, as does frequently changing information, now related to vaccine eligibility, supply, and efficacy against new strains. Although many states featured equity goals in their vaccine distribution plans (22), among the 27 states reporting racial-ethnic information in COVID-19 vaccination data, vaccination rates among Whites are three times higher than those for Latinx persons and twice as high as those for African Americans (28). These sobering numbers highlight the challenge of achieving equity, as well as why it is vital for state and local governments to regularly assess outcomes, diagnose problems, and correct course as needed.

At the time the focus groups were completed in August 2020, it was clear that above all else states' efforts to center equity in their COVID-19 vaccine strategies should begin as soon as possible, ideally well in advance of the vaccine distribution program, be multi-faceted and prioritize community engagement. Key recommendations our group made previously included: establishing vaccine equity task forces with diverse membership reflecting community leaders and public health representatives; capitalizing on existing community structures to foster community engagement; developing vaccine up-take campaigns that directly address communities' concerns and social justice contexts; and making use of diverse communication channels. Here we update several of our recommendations to reflect current conditions.

First, beyond establishing vaccine equity task forces, states and localities should integrate several practices that are likely to increase chances of success and lasting improvement in health disparities. **Task forces should define clear objectives and specific metrics** that can be used to assess progress and identify and address barriers when progress has been insufficient (29). Implementing this practice will require making available data on vaccinations that can be broken down by multiple dimensions of inequity, including race-ethnicity, socioeconomic status, and geography, among others. States and localities should work to **maximize communication and collaboration between equity task forces and other related task forces**, such as those working on vaccine distribution and implementation, so equity goals can be centered through all parts of vaccine campaigns. This may be particularly important if states and localities must quickly react to contingencies to avoid vaccine spoilage. Without careful planning, the urgency inherent in these contingencies may pose barriers to achieving equity. Additionally, and importantly, states and localities should build on COVID-19 related task forces and the bright light that the current pandemic has shone on

systemic racism and health disparities to **develop sustainable infrastructure for health equity and justice**. Michigan has been highlighted as a promising example on this point as their gubernatorial administration has used current momentum around COVID-19 disparities to convene a Black Leadership Advisory Council to advise the governor long-term on legislation that perpetuates race inequality and support for Black arts and community groups, and a Poverty Task Force, tasked with helping to develop an anti-poverty agenda for the state (30, 31).

Second, beyond engaging with trusted community organizations and leaders, **states and localities should support community organizations with needed funds and resources** so they can expand their work to address vaccine equity. The importance of community engagement and building on existing community structures has been widely recognized at both the federal and state/local levels (22, 32), however it is also important not to lose sight of the heavy burden that many community organizations are already shouldering as they support communities facing multiple hardships of the pandemic, including food insecurity, unemployment and of course the disease itself. Particularly in our Brooklyn/Queens focus group, participants shared that their organizations were already stretched so thin addressing their communities' increased needs during the pandemic that supporting vaccine efforts could pose a significant challenge. Michigan has again been cited as a promising example on this point as their vaccine equity task force has solicited applications to rapidly fund promising initiatives from community organizations (29).

Third, vaccine up-take campaigns already face significant hurdles as they attempt to address communities' concerns about vaccine safety and efficacy in culturally appropriate ways that address social justice contexts. The vaccine shortages and shifting eligibility criteria that characterize the current state of COVID-19 vaccination in the U.S. only make building that trust more challenging, particularly in communities that have traditionally been marginalized from services. While supply and distribution conditions are rapidly shifting and increased vaccine supply may soon alleviate some of this pressure, **states and localities should nonetheless build on existing partnerships and messaging strategies to provide culturally sensitive information about vaccine supply and eligibility as well**.

DATA AVAILABILITY STATEMENT

The data is not available for sharing to protect participants' identities.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University at Albany, SUNY, Institutional Review Board. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

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KS, TH, and TP contributed to the development of the protocol and conducted the focus groups. KS and TH were primarily responsible for the review of the literature. All authors contributed to the writing of the paper.

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GENERAL COMMENTARY
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Commentary: Strategies to Address COVID-19 Vaccine Hesitancy and Mitigate Health Disparities in Minority Populations

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Keywords: COVID - 19, machine learning, vaccines, datasets, adverse reactions

A Commentary on

Strategies to Address COVID-19 Vaccine Hesitancy and Mitigate Health Disparities in Minority Populations
by Strully, K. W., Harrison, T. M., Pardo, T. A., and Carleo-Evangelist, J. (2021). Front. Public Health 9:645268. doi: 10.3389/fpubh.2021.645268

1. INTRODUCTION

This commentary builds upon the article recently published by Strully et al.(1), which highlights vaccine hesitancy particularly among minority groups and proposes strategies to mitigate this serious setback in combating the pandemic. In light of the surging third wave of COVID-19 due to more virulent variants, the aim of this commentary is to generate further discussion and debate on the urgent need to focus efforts in making available datasets for prediction of adverse reactions from COVID-19 vaccinations. The goal of achieving herd immunity is at the moment hampered by anti-vaxxers and general skepticism from the unvaccinated arising from concerns regarding the safety of COVID-19 vaccines. With a publicly-available COVID-19 vaccine adverse reaction dataset, the machine learning community would be able to conduct predictive analytics studies and develop prediction tools to allay fears of adverse reactions based on the individual health backgrounds of the potential vaccine candidates, and this could arguably increase the confidence of the unvaccinated to get vaccinated.

As of 11 June 2021, more than 175 million cases of COVID-19 affecting 219 countries and territories have resulted in more than 3.7 million deaths (Worldometer Report). This COVID-19 outbreak, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), was first identified in Wuhan (Hubei, China) in December 2019 and has since swept across the entire globe, turning COVID-19 into a full-blown global pandemic by March 2020 (WHO), which is expected to cause up to $2 trillion in global GDP losses (UN News Report).

As countries scramble to secure vaccines to inoculate their citizens as a means of ending this pandemic, reports of adverse events arising from the urgent rush to mass vaccinate are being reported across the globe. As reported in the Business Insider (2), the Guardian (3), and CNN (4) on 12, 14, and 15 March 2021, respectively, a number of reports from major news sites have highlighted that more than a dozen countries have now suspended the use of a particular brand of COVID-19 vaccine due to severe adverse events. As such, rapid identification of patterns and trends relating to COVID-19 vaccine adverse events is beyond crucial, particularly from the use of computer-based simulations and modelling. In this vein, though data scientists are keen to assist, the large majority are sidelined due to the lack of detailed COVID-19 vaccine adverse event datasets. Although a

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handful of datasets related to COVID-19 vaccine adverse events are available, none of them contain any useful patient-level data such as reported symptoms and/or medical histories of the patients or are highly geographically-constrained in terms of their data source (5). If such datasets with detailed patient information are made available, a number of critically needed machine-learnable tasks would immediately become possible:

1. Prediction of susceptibility to adverse events based on health attributes such as physiological indicators, bloodwork, and/or medical history;
2. Prediction of the likelihood of fatalities due to adverse events;
3. Prediction of short-term versus long-term forms of adverse events that require hospitalization;
4. Prediction of adverse events probabilities across different vaccine brands for high-risk patients.

Apart from contributing to COVID-19 vaccination buy-in, such a system would also be beneficial to global vaccination programs against other vaccine-preventable infectious diseases. As highlighted by Salman (6), there is still a very significant shortfall in vaccine adverse events monitoring and reporting worldwide. Although improving COVID-19 vaccination acceptance is currently a crucial global agenda, the application of machine learning to the analysis and potential reduction/prevention of adverse effects of susceptible groups of vaccine recipients will remain a critical agenda for all routinely-administered vaccines. In order to materialize such a machine learning approach for vaccine safety monitoring, some potential ways forward may include:

- A globally-accessible central vaccine adverse events data repository with high quality datasets that are maintained and curated professionally [see for example (7)];
- A standardized and homogeneous data format for reporting adverse events [see for example (8)];
- Automated scheduled analysis and reporting of adverse events *via* machine learning approaches [see for example (9)];
- Incentives and competition-based data mining of adverse events by the machine learning community [see for example (10)].

Hence, detailed patient-level data related to COVID-19 vaccine adverse events that are rapidly made openly available is key for the application machine learning to the safe roll-out of COVID-19 vaccinations globally. The solution would need the concerted efforts of all nations to agree to contribute their patient data to a central vaccine adverse events repository (managed by the WHO?) in a timely manner that is made accessible to the public in real-time. This should perhaps become of the main global goals in order to bring the COVID-19 pandemic under control through safer mass vaccinations augmented by machine learning. Importantly, the advancements made in the application of machine learning to COVID-19 vaccine safety monitoring would be highly relevant and easily extended to other routinely administered vaccines for the same purpose. Therefore, these efforts would not only have a temporary contribution in overcoming the current pandemic but will continue to benefit the global vaccination program against other infectious diseases well beyond COVID-19.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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ORIGINAL RESEARCH
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Hispanic/Latino Acculturation Profiles and Telomere Length: Latent Class Analysis on a Nationally Representative Sample

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Background: Acculturation profiles and their impact on telomere length among foreign-born Hispanics/Latinos living in the United States (US) are relatively unknown. The limited research available has linked acculturation with shortened telomere length.

Objectives: To identify acculturation profiles among a US representative sample of Hispanics/Latinos and to then examine telomere length differences between profiles.

Methods: We conducted a latent class analysis among a non-institutionalized US-representative sample of Hispanics/Latinos using the 1999–2002 National Health and Nutrition Examination Survey (N = 2,292). The latent variable of acculturation was assessed by length of time in the US and language used as a child, read and spoken, usually spoken at home, used to think, and used with friends (i.e., Spanish and/or English). Telomere length assessed from leukocytes was used as the distal continuous outcome.

Results: We identified five profiles: (1) low acculturated [33.2% of sample]; (2) partially integrated [18.6% of sample]; (3) integrated [19.4% of sample]; (4) partially assimilated [15.1% of sample]; and (5) assimilated [13.7% of sample]. Acculturation profiles revealed nuanced differences in conditional probabilities with language use despite the length of time spent in the US. While telomere length did vary, there were no significant differences between profiles.

Conclusion: Profiles identified revealed that possible life-course and generational effects may be at play in the partially assimilated and assimilated profiles. Our findings expand public health research using complex survey data to identify and assess the dynamic relationship of acculturation profiles and health biomarkers, while being among the first to examine this context using a person-centered approach.

Keywords: acculturation, telomere length (TL), latent class analysis (LCAs), Hispanic (demographic), complex survey data, Latino (Hispanic)

INTRODUCTION

Acculturation is a dynamic process by which individuals, often immigrants, enter into a new host culture (1, 2) that has both indirect and direct effects on behavior and biology (3, 4). A particular biological marker or biomarker of interest are telomeres—caps of tandem repeat nucleotide sequences at the end of chromosomes that help protect cellular information during replication. The caps diminish as cells divide. As such, telomere length has been used as a biomarker of cellular aging or senescence (5–7). This diminishment has been used to predict accelerated senescence and senescence-associated diseases that increase morbidity and mortality in specific population profiles (8–13), and may be affected by the acculturative process (14).

Senescence-associated diseases include cardiometabolic disorders (e.g., type II diabetes), neurodegeneration (e.g., Alzheimer's and Parkinson's disease), and some types of cancers (15–17). Moreover, the common factors associated with telomere shortening in both animal and human studies are lifestyle and stress. Lifestyle and demographic factors including physical activity, diet, and nicotine use, as well as socioeconomic status have been linked to telomere length (7, 11, 18). A possible mechanistic pathway is that stress causes an oxidative response that affects humans at a cellular level, whereby cells dividing more frequently shorten telomeres and cause apoptosis at higher rates (6, 15). The stressful process of acculturation has been found to have a shortening effect on telomere length (14), and therefore acculturation may be associated with shortened telomeres. Other environmental factors and exposures that have been associated with telomere length may be directly and indirectly related to acculturation; these include biological ancestry categorized by race/ethnicity, poverty, and the built environment of—and environmental exposures from—neighborhoods (19, 20).

Acculturation has been associated with negative health consequences among Hispanics/Latinos (21–24) and other underrepresented groups such as African Americans (25–27). Acculturation may then further exacerbate health disparities in already-vulnerable groups. Among Hispanics/Latinos acculturation has been historically measured by language use. One longstanding validated linguistic acculturation measure is the Short Acculturation Scale for Hispanics (SASH), originally developed by Marin and colleagues (28) and recently validated by Hamilton and colleagues (29). While linguistic acculturation is used as a powerful measure to ascertain an individual's strategy to separate, integrate, marginalize, or assimilate into a new culture in the United States (US) (2, 30), it is unknown how the process is directly related to health biomarkers like telomere length.

Our study builds upon the limited research on acculturation and telomere length, especially among US Hispanics/Latinos. We used latent class analysis (LCA) to, first, identify acculturation profiles among US Hispanics/Latinos based on a nationally representative sample. Our second objective was to examine if differences in telomere length among identified Hispanic/Latino acculturation profiles existed. We proposed that at least three heterogenous profiles of acculturation would be identified. We hypothesized that telomere length would be significantly different between the identified acculturation profiles. We based our hypothesis on a study by Ruiz and colleagues (14) focused on a cohort of Mexican-American pregnant mothers' telomere length as it related to acculturation, discrimination, depression, and their levels of psychosocial stress. Ruiz and colleagues (14) reported a strong relationship between shortened telomere length and mothers' latent variables of negative affect from stressful experiences and acculturation strategies oriented toward US host culture, especially when compared to newly immigrated mothers.

MATERIALS AND METHODS

LCA refers to a person-centered technique used to identify unobservable, or latent, profiles within a population (31, 32). We conducted LCA using the National Health and Nutrition Examination Survey (NHANES) US Hispanic/Latino adult (18 years old and older) sample from the 1999–2002 cycles. Hispanic/Latino was operationalized based on NHANES defined race/ethnicity variables that self-identified as Mexican American and Hispanic. The 1999–2002 NHANES cycles allowed us to assess the impact of multiple acculturation factors on mean leukocyte telomere length. The 1999–2002 sample includes useable data from 2,292 Hispanic/Latino participants with acculturation questionnaire data and telomere length data. The Institutional Review Board assessed the research protocol, and as no human participants were involved in this study no approval was necessary. The secondary data analyzed from the 1999–2002 NHANES cycle are publicly available from the Centers for Disease Control and Prevention—National Center for Health Statistics database (https://wwwn.cdc.gov/nchs/nhanes/Default.aspx). A detailed description of the sampling methods and study procedures is available elsewhere (33). Sampling weights were included in all analyses to adjust for survey non-response and sample selection probabilities for the 1999–2002 cycles. Primary sampling units and stratum variables were included to account for the NHANES complex sampling design. All data and analytical files are available upon reasonable request.

Measures

Acculturation

We developed our acculturation latent variable from length of time in the US and language used among Hispanics/Latinos, i.e., Mexican American and other Hispanics. Other Hispanics, as reported in the NHANES, were participants that identified as Hispanic not of Mexican descent. Length of time was split into four categories: (1) <1 year; (2) 1 – <5 years; (3) 5 – <10 years; and (4) 10 years or more (34–36). Language specific questions were modeled after the SASH, which was originally developed by Marin and colleagues (28). The NHANES acculturation questionnaire gauged language used in the context of: (1) as a child; (2) for reading and speaking; (3) at home; (4) to think; and (5) with friends. Response options for all language used questions were: (1) only Spanish; (2) more Spanish than English; (3) both equally; (4) more English than Spanish; and (5) only English.

Telomere Length

NHANES collected blood from participants to conduct biomarker and other biological analyses. Telomere data were

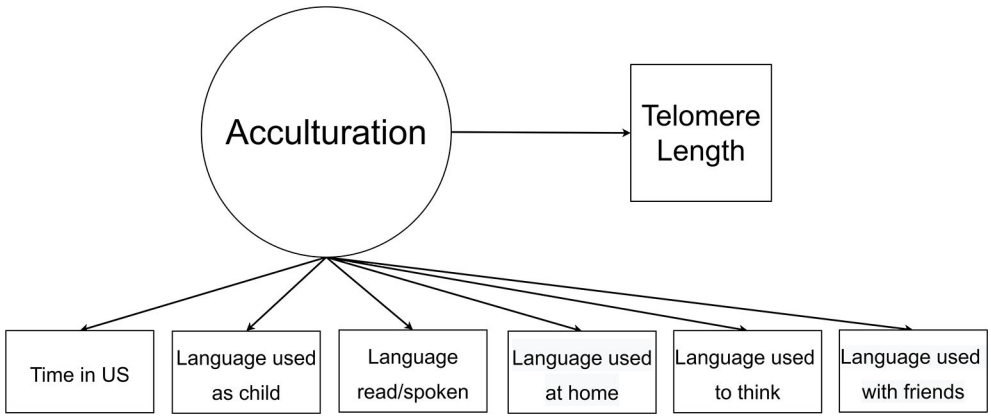

FIGURE 1 | Latent class analysis model of acculturation where the circle represents latent variable and rectangles represent observed indicator variables.

only publicly available during the 1999–2002 NHANES cycles. Telomere length was assessed from leukocyte assays performed using a quantitative polymerase chain reaction method to measure length relative to standard reference DNA or T/S ratio. See Needham and colleagues (11) for greater detail on lab assay techniques.

Sociodemographic and Lifestyle Descriptive Variables

Variables such as gender/sex (i.e., male and female), US citizenship (i.e., no or yes), less than a high school education (i.e., no or yes), smoked at least 100 cigarettes in lifetime (i.e., ever-smoker), and moderate physical activity over the past 30 days (i.e., no or yes) were assessed as descriptives for our sample due to their associations with telomere length (14, 19). Hispanic/Latino composition (i.e., Mexican American or other Hispanic) and citizen of the US (i.e., no or yes) were also assessed.

Latent Class Analysis

The latent or unobserved variable of acculturation was based on six observed acculturation variables and the distal continuous outcome of telomere length (see **Figure 1**). We conducted our LCA with Mplus 8.6 (Muthén & Muthén) using a robust maximum likelihood estimator and automatic BCH approach. The automatic BCH method—a modification of the approach developed by Bolck, Croon, and Hagenaars (37)—was used to estimate mean telomere length within each profile and compare differences between profiles.

We used a model comparison approach to determine the number of classes. A one-class model up to a seven-class model was subsequently calculated. The one-class model was calculated to assess fit indices and compare with subsequent models. To assess model fit and reliability, we used Bayesian information criterion (BIC), sample-size-adjusted-BIC (ssaBIC), and entropy (i.e., acceptable quality of classification). We evaluated all models based on fit indices and their practical and theoretical considerations.

RESULTS

The weighted sample was on average ∼40 years of age and equal across gender/sex, with male participants accounting for 49.9 and females 50.1%. The Hispanic/Latino sample was also almost equally weighted between Mexican Americans (50.7%) and other Hispanics (49.3%). Most of the sample were citizens of the US (61.6%) and had more than a High School degree or GED (54.9%), with a mean family poverty income ratio of 2.04. Much of the weighted sample had not smoked more than 100 cigarettes in their lifetime (56.7%), nor engaged in at least moderate physical activity over the past 30 days (64.4%). The Hispanic/Latino mean telomere length was 1.08 T/S ratio. For more details about participant characteristics (see **Table 1**).

Table 2 has the Hispanic/Latino weighted sample acculturation profile. Most participants lived in the US for 10 years or more (60.7%). The largest proportions of the sample used Spanish only as a child (60.2%), to read and speak (29.7%), at home (42.9%), to think (42.0%), and with friends (35.7%).

Latent Class Analysis of Acculturation

The five-class model with low BIC, ssaBIC, and high entropy of 0.891, as well as the most practical and theoretical considerations, was favored (see **Table 3**).

Class 1, or the *low acculturated profile* (33.2% of sample), with mean telomere length of 1.043, was composed of Hispanics/Latinos that had the highest conditional probabilities of being in the US <10 years. Class 1 had the highest conditional probabilities of using Spanish only during childhood (100%), to read and speak (88.0%), at home (99.6%), to think (99.8%), and with friends (96.4%).

Class 2, or the *partially integrated profile* (18.6% of sample), with mean telomere length of 1.102 had a high conditional probability of being in the US more than 10 years (65.5%). Class 2 had the highest conditional probabilities of using more Spanish than English (but not using Spanish exclusively) to read and speak (75.8%), at

TABLE 1 | Descriptive statistics of weighted participant sample ($N = 2,292$).

	Frequency (weighted %)	Weighted frequency (SE)
Sex/gender		
Male	1,092 (49.9)	11,518,928 (1,110,137)
Female	1,200 (50.1)	11,585,213 (1,273,746)
Hispanics/Latinos		
Mexican Americans	1,875 (50.7)	11,704,451 (1,276,076)
Other Hispanics	417 (49.3)	11,399,691 (2,134,279)
Citizen of the US ($n = 2,277$)		
No	906 (38.4)	8,816,781 (1,275,864)
Yes	1,371 (61.6)	14,164,806 (1,379,033)
Less than high school education ($n = 2,287$)		
No	933 (54.9)	12,651,015 (1,296,845)
Yes	1,354 (45.1)	10,373,192 (1,133,168)
Ever-smoker ($n = 2,284$)		
No	1,302 (56.7)	13,058,383 (1,411,389)
Yes	982 (43.3)	9,986,520 (1,055,595)
Moderate physical activity over past 30 days ($n = 2,289$)		
No	1,152 (64.4)	14,876,583 (1,646,121)
Yes	737 (35.6)	8,207,544 (821,444)

		95% CL for Mean	
	Mean (SE)	Lower	Upper
Age	40.0 (0.592)	38.8	41.2
Family PIR ($n = 2,060$)	2.04 (0.061)	1.92	2.17
Telomere length	1.08 (0.023)	1.03	1.13

PIR, poverty income ratio; SE, Standard Error.

TABLE 2 | Acculturation measure responses of weighted participant sample ($N = 2,292$).

	Frequency (weighted %)	Weighted frequency (SE)
Length of time in the US		
Less than 1 yr in US	72 (8.1)	1,123,041 (284,563)
More than 1 yr, less than 5 yrs	198 (16.4)	2,275,944 (421,384)
More than 5 yrs, less than 10 yrs	194 (14.8)	2,055,003 (266,954)
More than 10 yrs	882 (60.7)	8,409,529 (1,432,145)
Language used as child		
Spanish only	1,477 (60.2)	13,649,132 (1,747,330)
More Spanish than English	236 (10.4)	2,364,162 (277,464)
Both equally	207 (10.7)	2,412,563 (293,549)
More English than Spanish	178 (8.1)	1,834,010 (251,671)
English only	175 (10.6)	2,403,690 (263,529)
Language used to read and speak		
Spanish only	797 (29.7)	6,732,782 (1,005,467)
More Spanish than English	456 (20.0)	4,529,867 (666,345)
Both equally	413 (20.2)	4,580,644 (449,177)
More English than Spanish	413 (19.9)	4,508,553 (526,949)
English only	196 (10.2)	2,317,946 (296,526)
Language used at home		
Spanish only	1,082 (42.9)	9,700,915 (1,588,146)
More Spanish than English	227 (9.7)	2,196,353 (305,020)
Both equally	304 (15.1)	3,419,966 (407,984)
More English than Spanish	271 (12.1)	2,736,351 (335,478)
English only	390 (20.2)	4,582,019 (406,487)
Language used to think		
Spanish only	1,046 (42.0)	9,446,896 (1,455,867)
More Spanish than English	215 (8.8)	1,985,948 (23,815)
Both equally	328 (15.8)	3,561,690 (319,875)
More English than Spanish	210 (9.2)	2,057,699 (287,652)
English only	466 (24.2)	5,449,538 (496,264)
Language used with friends		
Spanish only	965 (35.7)	8,076,402 (1,230,584)
More Spanish than English	244 (9.7)	2,203,670 (401,562)
Both equally	411 (21.0)	4,762,837 (490,468)
More English than Spanish	248 (12.7)	2,867,081 (343,425)
English only	406 (20.9)	4,726,388 (414,047)

SE, Standard Error.

home (38.3%), to think (34.5%), and with friends (41.5%). The vast majority (86.1%) of this class used Spanish only as a child.

Class 3, or the *integrated profile* (19.4% of sample), with mean telomere length of 1.084 had a high conditional probability of being in the US more than 10 years (86.1%). Class 3 had the highest probabilities of using Spanish and English equally to speak as a child (28.3%), to read and speak (74.6%), at home (58.7%), to think (64.4%), and with friends (74.0%).

Class 4, or the *partially assimilated* (15.2% of sample), with mean telomere length of 1.108 had the highest conditional probability of being in the US more than 10 years (93.2%). Class 4 had the highest conditional probabilities of using more English than Spanish to speak as a child (35.5%), to read and speak (81.1%), at home (49.4%), to think (37.5%), and with friends (47.8%).

Class 5, or the *assimilated* (13.7% of sample), with mean telomere length of 1.101 had the second-highest conditional probability of being in the US more than 10 years (83.6%). Class 5 had the highest conditional probabilities of using only English to speak as a child (68.9%), to read and speak (68.9%), at home (100%), to think (99.9%), and with friends (97.4%). See **Table 4** for full detail of the latent class conditional probabilities.

Mean Telomere Length Across Latent Classes

Telomere length by profiles were compared. The automatic BCH approach revealed that the equality test of means across classes for the overall differences was not significant ($x^2 = 4.54$, $df = 4$, $p = 0.34$). See **Appendix** for **Supplementary Table 1** for between class mean comparisons.

DISCUSSION

Our study using a nationally representative sample identified five profiles of Hispanic/Latino linguistic acculturation and their respective telomere length. In using the five SASH items in conjunction with time spent in the US we were able to

TABLE 3 | Latent class analysis fit criteria of acculturation and telomere length models.

Model	BIC	ssaBIC	Entropy
One-class solution	35576.764	35503.688	-
Two-class solution	28410.596	28261.268	0.944
Three-class solution	26075.609	25850.030	0.929
Four-class solution	25309.857	25008.025	0.906
Five-class solution	24869.397	24491.313	0.891
Six-class solution	24801.132	24346.796	0.898
Seven-class solution	24823.808	24293.220	0.897

BIC, Bayesian information criteria; ssaBIC, sample size adjusted BIC.

create more dynamic profiles based on the acculturative process. The acculturative process involves language and behavioral norm acquisition from prolonged contact with the host culture (2, 30). US Hispanics/Latinos have been reported to have various acculturation strategies that include marginalization (i.e., rejection of both native and host culture), segregation (i.e., non-integration into the host culture), enculturation, integration, or assimilation (24, 38–40). Enculturation is often operationalized as reintegration or relearning of an individual's native culture (24). Integration is the process where an individual adopts aspects of the host culture without the loss of their native culture (1). Assimilation is the process where the individual replaces aspects of the native culture with those adopted from the host culture (1). The process of assimilation in the acculturative process can be a source of high psychosocial stress due to feelings of otherness and discrimination (34, 40, 41), as well as the lifestyles changes that lead to a loss of social support and unhealthy behaviors (23, 42, 43). The psychosocial effects are prominent in subsequent generations, as protective health behaviors and support structures from the native culture diminish. Moreover, Hispanic/Latino groups are reported to experience worse health outcomes as they become more similar to their US counterparts (24).

Language serves as a primary factor to integration into a new host culture (28). For instance, in reviewing the low acculturated (Class 1) profile of US Hispanics/Latinos that almost exclusively used Spanish regardless of time spent living in the US, two patterns emerged in this profile that will require further examination. First, the low acculturated profile had an approximate conditional probability of 34% to be in the US <1 year and between 1 and <5 years, which would explain the Spanish only linguistic acculturation. Newly arrived immigrant groups will learn the host country's culture and language, or that is the expectation of the host country for the newly immigrated (1, 2, 44). Second, the highest conditional probability of time spent in the US, was 47% on 10 years or more. The high conditional probability of being in the US for a decade or longer in juxtaposition of Spanish only linguistic acculturation may be indicative of low acculturation due to marginalized or segregated individuals as described by Berry (1, 44). The low acculturated profile represented the largest subgroup across all identified profiles.

While it is difficult to ascertain whether persons are marginalized and segregated in our study, it should be noted that low acculturated individuals have been reported to experience worse mental health outcomes (38). The effect of low acculturation and telomere length is less clear. Some studies have found linear associations with lower acculturated groups and decreased telomere length when compared to more acculturated or assimilated groups (45, 46). Specifically, a study by Ruiz and colleagues (14) reported that among pregnant Mexican mothers there is a complex association between low acculturation and decreased telomere length in the presence of psychosocial stress. Inversely, a study among Mexican women in the US reported that among the high acculturation group, longer telomeres were associated with increased percentage body fat but reported no association with low acculturated women (47). In our study, while we found that the low acculturated group had the lowest mean telomere length, it was not significantly different from all other acculturation profiles. Future studies must consider other factors from joint pathologies or other disease etiologies, in addition to environments that may facilitate acculturation strategies such as marginalization or segregation.

Nevertheless, environmental data from built-environmental features, community compositions, and neighborhoods were not available for use in our model, but we must acknowledge their role in linguistic acculturation. Discrimination and discriminatory policies that may be linguistically biased must also be considered to understand low acculturation in context of segregation and marginalization in an environmental context (1, 2, 30). The neighborhood environment, however, may have protective or detrimental effects to the newly introduced immigrant's health based on individual and family language usage (48–50). Neighborhood racial and ethnic composition may also have a role in linguistic acculturation, and their selected acculturation strategy (51, 52).

By contrast, the partially integrated (Class 2) spoke more Spanish than English and were more likely than the low acculturated class to have lived in the US 10 or more years (65.5% conditional probability). The integrated (Class 3) was comprised of Hispanics/Latinos living in the US 10 or more years that used English and Spanish equally, at home, to think, to read and speak, and with friends. The integrated profiles may indicate biculturalism or adaptive profiles. While the integrated profiles are often adaptive, there are some mental and physiological health concerns. Hispanics/Latinos in this adaptive bicultural process adopt customs and language norms that will benefit their integration into the larger US culture (24, 38, 40). Issues concerning identity are at the crux of this process as the degree to which Hispanics/Latinos have a choice to enculturate, integrate, or assimilate is unknown as are the health consequences.

Most individuals (57.8%) in the integrated class used at least some English during childhood—although a plurality (42.2%) of them solely spoke Spanish during this period of their lives. More than two-fifths (42.2%) of people in this class used Spanish

TABLE 4 | Conditional probabilities of 5-class solution from latent class model ($N = 2,282$).

	Class 1: Low acculturated 33.2% ($n = 757$)	Class 2: Partially integrated 18.6% ($n = 424$)	Class 3: Integrated 19.4% ($n = 442$)	Class 4: Partially assimilated 15.1% ($n = 346$)	Class 5 Assimilated 13.7% ($n = 312$)
Length of time in the US					
Less than 1 yr in US	0.113	0.081	0.000	0.000	0.000
More than 1 yr, less than 5 yrs	0.231	0.112	0.051	0.068	0.164
More than 5 yrs, less than 10 yrs	0.182	0.152	0.088	0.000	0.000
10 yrs or more years	0.473	0.655	0.861	0.932	0.836
Language used as child					
Spanish only	1.000	0.861	0.422	0.161	0.017
More Spanish than English	0.000	0.115	0.231	0.196	0.053
Both equally	0.000	0.023	0.283	0.221	0.103
More English than Spanish	0.000	0.000	0.024	0.355	0.138
English only	0.000	0.000	0.040	0.067	0.689
Language used to read and speak					
Spanish only	0.880	0.038	0.006	0.000	0.000
More Spanish than English	0.120	0.758	0.053	0.019	0.000
Both equally	0.000	0.195	0.746	0.133	0.037
More English than Spanish	0.000	0.010	0.149	0.811	0.275
English only	0.000	0.000	0.046	0.037	0.689
Language used at home					
Spanish only	0.996	0.416	0.065	0.050	0.000
More Spanish than English	0.003	0.383	0.096	0.023	0.000
Both equally	0.001	0.082	0.587	0.160	0.000
More English than Spanish	0.000	0.028	0.184	0.494	0.000
English only	0.000	0.091	0.068	0.273	1.000
Language used to think					
Spanish only	0.988	0.425	0.054	0.006	0.000
More Spanish than English	0.007	0.345	0.074	0.032	0.000
Both equally	0.005	0.185	0.644	0.028	0.000
More English than Spanish	0.000	0.041	0.116	0.375	0.001
English only	0.000	0.004	0.112	0.559	0.999
Language used with friends					
Spanish only	0.964	0.189	0.018	0.000	0.000
More Spanish than English	0.022	0.415	0.029	0.021	0.003
Both equally	0.011	0.260	0.740	0.122	0.003
More English than Spanish	0.003	0.088	0.145	0.478	0.020
English only	0.000	0.047	0.068	0.380	0.974
Telomere length					
Mean T/S ratio (SE)	1.043 (.033)	1.102 (.037)	1.084 (.034)	1.108 (.033)	1.101 (.031)

SE, Standard Error.

only as a child. The integrated class indicated possible language use change over time. Interestingly, even though the conditional probability of using more English than Spanish to think was highest for this class, a majority of people (55.9%) in the partially assimilated (Class 4) reported using English only to think. The partially assimilated (Class 4) were those with the highest likelihood of living in the US 10 or more years and using more English than Spanish but not exclusively English to read and speak, at home, and with friends. The partially assimilated class illustrated the importance of social context for language use, as many individuals continued to use Spanish frequently in their lives despite reporting English use for thinking. The assimilated (Class 5) were those living in the US 10 or more years and had the highest conditional probability to speak only English as a child. The majority of the assimilated exclusively spoke English only as a child, to read and speak, at home, to think, and with friends.

Assimilation in first generation individuals can be stressful, compared to subsequent generations (24, 53). The process of

assimilation in subsequent generations is often classified as either congruent or dissonant between parents and children (54). The assimilated classes from our findings could be indicative of second or subsequent generations of Hispanics/Latinos in our sample. Findings suggest a generational effect in the partial assimilation (Class 4) and assimilation (Class 5) as the profiles have an overall lower probability of using Spanish and a higher probability of speaking more English as children, respectively, to other profiles. The partially assimilated primarily had a higher probability of speaking more English than Spanish as children (i.e., 35.5% conditional probability). To contrast, the assimilated profile had the highest probability to speak English only as children (68.9% conditional probability).

Overall, using our LCA on a US representative sample of Hispanic/Latinos we identified heterogenous classes of acculturation that may reveal differences in experiences and processes, which were theoretically suggested in the literature. Linguistic acculturation can be a powerful indicator of risk, but more may be needed to detect telomere length differences between subgroups. While various reasons can be attributed as to why significant telomere differences were not detected, linguistic acculturation may be indicative of other psychosocial stressors and adaptive strategies. For instance, while language can be a source of insecurities and discrimination it can also be key to facilitate equitable access to healthcare and mental health services. In context of our findings, the largest subgroup was low acculturated with almost exclusive Spanish use while having lived in the US for 5 or more years. This may be indicative that a large proportion of US Hispanics/Latinos speak only Spanish, which may affect their access and quality of health services. Nonetheless, linguistic interventions will not be enough to mitigate the possible disparity. Spanish interpreters or translated health materials are a start but literacy and cultural empathy are critical to intervene or prevent excess risk by incorporating customs, norms, and behaviors that are conducive to health among US Hispanics/Latinos. To mitigate disparities and promote health equity, future studies must collect environmental and community data, as well as biomarkers of risk to create more comprehensive models. These comprehensive models may be used to confirm if profiles from our findings remain consistent or detect telomeric differences. Telomere differences may be indicative of increased morbidity and mortality among certain subpopulations (55). As such, the importance of detecting telomere length by acculturation may, for instance, be the critical difference in identifying cancer risk or preventing cancer among Mexican Americans (56). Lastly, in using more comprehensive person-level approaches we can model risk contextually to not only understand syndemic vulnerabilities—the synergy of disease outcomes interacting with comorbid conditions, as well as other social, cultural, biological, and environmental determinants in context of human rights (57)—but to also help develop tailored interventions and prevention programs for those at increased risk from among the most at-risk (24, 47, 53, 54).

LIMITATIONS AND STRENGTHS

Our study had four major limitations. The first was that the data, although nationally representative, were cross-sectional; therefore, we were unable to examine changes within the sample over time. Still, various published studies and reports have demonstrated that the data are of acceptable quality (11–13, 58). Second, acculturation is a complex, dynamic multidimensional process. Acculturation measures that exclusively use linguistic measures to assess the process have been critiqued (30, 53). Nonetheless, the validated SASH measure serves as a measure to assess a facet of acculturative strategies (29). Third, the telomere data were not from the current NHANES as they are only accessible from the 1999–2002 cycles. The fourth limitation concerns the meaningfulness of telomere length data in health outcomes research. While telomere research continues to be refined, the interpretation of telomere length and outcomes on morbidity and mortality are less direct (11–13, 59) and may explain why no significant telomere length differences were detected. Although more advanced methods from a manual BCH auxiliary regression approach in Mplus (37) would allow us to test the effects of covariates on classes, we would not be able to test differences of telomere length by class. Additionally, the manual approach would not permit us to test telomere length differences between profiles.

Our study also possessed notable strengths, as it is among the first to focus on acculturation and telomere length, a complex biomarker of senescence and risk. We used the most current techniques for available software packages to assess acculturation profiles and biological processes using complex survey design data of US Hispanics/Latinos. Future research will incorporate multiple acculturation factors beyond language measures to assess its impact on health biomarkers in the context of syndemic vulnerability and risk. A syndemic and latent variable approach will be critical as various factors co-occur and synergize to affect biological processes occurring in tandem without a priori categorization to capture person-centered contexts.

CONCLUSION

We identified five Hispanic/Latino acculturation profiles at possible differential risk of shorter telomere length, but no significant telomere length differences emerged. Specifically, our findings will contribute to the emerging literature on the relationship between acculturation profiles and associated biomarkers of health and disease. Our findings and approach provide a way to identify groups most at-risk in already vulnerable subpopulations. Through this work we can understand contextual risk, as well as develop prevention programs and targeted health interventions among US Hispanic/Latino groups. The implications of this research will be to examine the dynamic effects of acculturation using comprehensive models of risk biomarkers to develop prevention programs in order to mitigate health disparities and move toward health equity.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: https://wwwn.cdc.gov/nchs/nhanes/Default.aspx.

AUTHOR CONTRIBUTIONS

FM: conceptualization, data curation, methodology, formal analysis, visualization, roles, writing—original draft, and writing—review and editing. PM: roles, writing—original draft, conceptualization, and writing—review and editing. KV: conceptualization and writing—review and editing. JC: resources, roles, writing—original draft, supervision, and validation. AN: roles, writing—original draft, writing—review and editing, supervision, and validation. FW: project administration, resources, software, supervision, writing—review and editing, and validation. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.640226/full#supplementary-material

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