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Mobile health clinics for distribution of vaccinations to underserved communities during health emergencies: A COVID-19 case study

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ABSTRACT

Objectives: Mobile health clinics (MHCs) effectively provide healthcare to underserved communities. However, their application during health emergencies is understudied. We described the implementation of an MHC program delivering vaccinations during the COVID-19 pandemic, examined the program's reach to medically underserved communities, and investigated characteristics of vaccination uptake in order to inform the utility of MHCs during health emergencies.
Study design: The study observed COVID-19 MHC vaccination rates and factors associated with uptake between February 20th, 2021, and February 17th, 2022.
Methods: Prisma Health deployed six MHCs to underserved communities. We described the characteristics of individuals who utilized the MHCs and evaluated census tract-level community factors associated with use of the MHCs through generalized linear mixed effects models.
Results: The MHCs conducted 260 visits at 149 unique sites in South Carolina, providing 12,102 vaccine doses to 8545 individuals: 2890 received a partial dose, 4355 received a primary series, and 1300 received a booster dose. Among individuals utilizing the MHC, the median age was 42 years (IQR: 22–58), 44.0 % were Black, 49.2 % were male, and 44.2 % were uninsured. Black, Hispanic, and uninsured individuals were significantly more likely to utilize MHC services for COVID-19 vaccination. During periods when vaccines were limited, MHC utilization was significantly greater in communities facing access barriers to healthcare.
Conclusions: The high COVID-19 vaccination uptake at MHCs demonstrated that the MHC framework is an effective and acceptable intervention among medically underserved populations during health emergencies, especially when resources are scarce. The identified factors associated with vaccination uptake demonstrated that the MHCs had the greatest impact in higher-risk communities and can be used to inform allocation of such field-level interventions in future health emergencies.

1. Introduction

Through 2023, it is estimated that nearly 1.2 million American lives have been lost to the COVID-19 pandemic [1]. The death rate has been even more profound in rural communities and among Black and Hispanic Americans, who were twice as likely to die from COVID-19 during

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the first year of the pandemic [2–5]. These disparities have been fueled by inadequate access to essential resources throughout the pandemic, including testing, treatment, and vaccines [6–11]. Such inequities are not unique to COVID-19. Over the past century, emerging infectious diseases have significantly perpetuated disparities, with a high impact on underserved communities [12–14].

One of the most significant barriers to healthcare delivery is that of proximity. That is, getting providers and services closer to those patients who need to utilize them [15]. Mobile health clinics (MHCs) provide quality health care to vulnerable and underserved populations, and to communities with geographical burdens to access [15,16]. In 2020, there were an estimated 2000 MHC serving 7 million at-risk individuals in the US [17,18]. Estimates have shown that each MHC prevents an average of 600 emergency visits each year [19]. Racial and ethnic minority groups and rural communities, who are disproportionally impacted by lack of access to healthcare, are among the prime beneficiaries of MHCs [15,16,20,21].

MHCs are especially effective at reaching underserved communities during natural disasters and health emergencies [17,22]. From lead contamination of water supply [23] to delivery of COVID-19 testing kits and vaccinations [17,24–27], the mobility and flexibility of MHC allow for timely delivery of essential medical care to socioeconomically disadvantaged populations in emergency situations [15]. This is especially critical during phases of pandemics when essential resources are limited, as these phases correlate with periods of high transmission, morbidity, and mortality. For example, disparities in COVID-19 vaccination uptake among Black, Hispanic, and rural communities were highest during winter 2021 when vaccine supply was limited, yet this time-period corresponded to the greatest number of deaths throughout the pandemic [8,10,28,29].

Given that The COVID-19 pandemic intensified health disparities, particularly impacting structurally marginalized communities who face greater challenges during health crises and have limited access to healthcare, an understanding of effective distribution methods for delivery of essential resources to these communities is imperative [30]. However, studies evaluating the extent to which such communities utilize available medical services, and MHCs in particular, are lacking. Moreover, no studies have evaluated factors associated with utilization of MHCs for vaccination during health emergencies. Knowledge of these factors is ultimately necessary for the timely distribution of essential resources to underserved populations during critical phases of pandemics when such resources are limited [5,31,32]. COVID-19 will unlikely be the last pandemic in our lifetime [33]. It is very possible that high impact pathogens, including coronaviruses and influenza A viruses, will emerge and remerge [33]. Development of effective strategies for delivery of essential resources is therefore crucial to addressing health disparities during future health emergencies.

In this study, we describe the implementation of an MHC program in South Carolina (SC) for COVID-19 vaccine delivery of BNT162b2 (Pfizer-BioNTech), mRNA-1273 (Moderna), and Ad26.COV2.S (Johnson and Johnson-Jansen) vaccines authorized in the United States (US). Our aims are to 1) explain the implementation of and evaluate the effectiveness of MHCs in reaching medically underserved individuals and 2) examine individual and community-level characteristics that are associated with COVID-19 vaccination uptake via MHCs. Understanding these factors is important for maximizing the effectiveness of MHCs frameworks and thereby improving the delivery of essential resources to underserved communities during health emergencies [34].

2. Methods

2.1. Setting

2.1.1. South Carolina

The SC population faces significant health disparities in both infectious disease outcomes and chronic conditions. SC had the highest age-adjusted COVID-19 mortality rate on the East Coast and the 11th highest rate nationwide [35]. Several factors drove these outcomes. SC communities have higher uninsured (12.2 %) and poverty (14.6 %) rates compared to the national average, the 5th largest African American population (26.7 %), and the 17th largest population of residents living in rural areas (33.7 %) [36–38]. Furthermore, SC ranks in the bottom 10 states for percentage of individuals with an updated COVID-19 booster dose [39]. Taken together, these factors lead to a substantially greater risk of severe infectious disease outcomes.

2.1.2. Prisma Health

Prisma Health is the largest non-profit health care provider in SC, serving over 1.2 million patients annually. With funding from the Coronavirus Aid, Relief, and Economic Security Act, Prisma Health deployed a fleet of six MHCs in an effort to increase COVID-19 vaccination uptake in underserved communities in SC. Each MHC contained refrigerators to store vaccines and space for vaccination preparation and reconstitution. The MHC clinical team consisted of a director, site coordinator, nurses and vaccinators, pharmacist, registrars, and traffic directors. The first MHC unit was delivered on February 20, 2021, in Greenville County, SC. Between February and May of 2021, an additional 5 MHCs were rolled out to census tracts in the Upstate and Midland regions of SC.

2.2. Protocol for mobile health clinic events

Between February and May of 2021, site locations (census tract level) were chosen using data from social vulnerability index (SVI) [40] rankings and international and internal Prisma Health vaccination data. Locations were chosen based on highest SVI with lowest vaccination rates. Through this approach, the MHC team ensured data-driven decision making with an equity lens geared towards social disadvantage. If post-event analytics showed that uptake was low among underrepresented groups for a particular event, the MHC team engaged community leaders to help promote vaccine awareness in those areas. As vaccines became more widely available and accessible, MHCs were distributed based on community requests. In addition, the MHC team partnered with the SC Department of Education to reach communities with low vaccination uptake. The MHC also delivered vaccines to high schools in Greenville County and in Richland County, as well as homeless shelters, upon request. The MHC team also joined existing community events (including baseball games, farmers markets, and community festivals).

Once a census tract was chosen, site locations (i.e., parking for the MHC) was decided upon in collaboration with community leaders, including elected officials from city, county, and state representation. Upon choosing a location, the MHC team hosted virtual community meetings to promote the MHC and describe the logistics of the set up and what individuals should expect. For example, the presence of the National Guard for logistical operations. The MHC team utilized email listservs for community leaders and organizations to inform them of MHC location and educational information about the vaccine and COVID-19 (and included a link to MHC team email in order both provide additional information and for requesting an MHC), distribute promotional flyers, and further engage community partners to raise awareness on vaccine safety and effectiveness and to help schedule appointments. Weekly communications were conducted with SC Department of Health and Environmental Control (DHEC) to coordinate vaccine distribution throughout the state and help prevent redundancy with DHEC's mobile sites.

The MHC team, in collaboration with community leaders, identified high-traffic areas and events for placement of the MHC. This included faith-based organizations, homeless shelters, universities, schools, apartment complexes, and businesses. With the exception of events which distributed the one-dose Jansen/Johnson & Johnson (Ad26.COV2.S) vaccine, the MHC team returned to each site 21 days or 28 days after the first visit. If an individual received their first dose during a follow-up visit, then a 3rd visit was scheduled if there were at least 10 individuals in need of a second dose. Otherwise, individuals were provided information on where to obtain their second dose.

2.3. Study population

The study population consists of all individuals receiving a vaccine dose from one of Prisma Health's MHCs during one year from the vaccination start date (visits conducted between February 20, 2021, and February 17, 2022). Pre-registration was not required for vaccination. The following sociodemographic information was recorded for each individual: age, sex, race, ethnicity, address, and primary insurance. With each candidate, the MHC team discussed eligibility requirements, including vaccination history, adverse reactions to prior vaccinations and other allergies, along with additional information included in the registration form (Supplementary Material: Sections 2 and 3). The candidate then received the appropriate vaccine dose and given a vaccination card.

2.4. Community level variables

Demographic and socioeconomic variables, including age, sex, race, ethnicity, subpopulation size, median income, unemployment rate, and labor force participation were collected at the census tract level [41]. SVI is a quantitative indicator of vulnerability of communities to adverse consequences of natural disasters. It is based on socioeconomic status; household composition, including age, disabilities, and language; racial and ethnic minority status; and housing and transportation characteristics [42,43]. SVI for each census tract is structured as a percentile rank with higher values indicating greater vulnerability. Data is provided by the CDC's Agency for Toxic Substances and Disease Registry also at the census tract level [44]. Availability of medical resources at the zip code level was provided by the SC Center for Rural and Primary Healthcare (SCCRPH) [45]. This data, collected by the SC Department of Labor, Licensing, and Regulation (SCDLLR) and SC DHEC, includes the number of hospitals in a given zip code, the number of primary care practitioners (PCP) per 1000 residents, doctor of medicine or doctor of osteopathic medicine (MD/DO) per 1000 residents, uninsured population, mortality rate, and urban/rural classification of each zip code. Data related to number of vaccinations, cases, hospitalizations, and deaths at each zip code was obtained from Prisma Health. The demographic and socioeconomic covariates in these models were selected based on similar studies in the literature and data availability [46–48]. Healthcare access barriers were chosen based on consultation with SCCRPH.

2.5. Utilization of MHC through follow-up vaccine

This study also investigated the rate at which individuals returned to the MHC to receive a follow-up vaccine. Individuals are considered eligible for a second dose of vaccine if they received a first dose of an mRNA vaccine (BNT162b2 or mRNA-1273) and 21 days had passed since uptake of the first BNT162b2 dose or 28 days had passed since uptake of the first mRNA-1273 dose. We examined the utility of the MHC for the first and second doses based on MHC revisits in the same zip code (restricted to vaccine-eligible individuals). For instance, given an individual received a BNT162b2 or mRNA-1273 vaccine and the MHC returned to their zip code after enough time since the first dose passed, we checked whether the individual utilized the MHC upon its return.

2.6. Statistical analysis

We analyzed MHC data from February 20, 2021 to February 17, 2022 to investigate the characteristics of individuals who utilized the MHC for COVID-19 vaccination and identify associated individual and community level factors. Descriptive statistics of individuals are presented as median (inter-quartile range, IQR) for continuous variables and N (%) for categorical variables. Individuals were stratified by age, race and ethnicity, and sex. Age groups consisted of 12–17, 18–29, 30–44, 45–64, and 65 or older. Age groupings for 18 years of age and older have been used in previous research [34,49]. The 12–17 age group was also included since this group received MHC services once they were eligible for vaccination. Race and ethnicity were classified as Black, Hispanic, White, and races other than these categories. Site location type was categorized as church, corporate, homeless shelters, public K-12 schools, university, and other locations (supermarkets, clinics, community centers, wellness centers, and sports centers). Insurance type was classified as Medicare, Medicaid, private, and uninsured. Chi-square tests were used to examine the associations between these characteristics by vaccine dose.

Stratified negative binomial generalized linear mixed effects models (GLMM) were used to evaluate community-level factors associated with vaccination uptake at the census tract-level (details provided in the Supplemental Material). Individuals were stratified by demographic subpopulation: age (years; 12–17/18-54/55+), sex (female/male), race (white/non-white) and insurance status (insured/uninured). The outcome variable was defined as the total subpopulation count (e.g., uninsured white males aged 55+) receiving a vaccine from each mobile unit on each date. Subpopulation size in each census tract was included as an offset. Each model is adjusted for age, sex, race and ethnicity, insurance status group, vaccination month (February 2020, March 2020, …, February 2021), site category (church, corporate, homeless, K-12 school, university, other site), day of week (Friday, weekend, and other weekday), and zip-code based vaccination rate prior to MHC visit. Analyses were restricted to the first MHC vaccine delivery at each site. All continuous variables were standardized to mean of 0 and standard deviation of 1 for direct comparison. In all models, nested random effects were included for the census tracts in the zip codes. Additional details are provided in Section 1 of the Supplementary Material.

To evaluate the association between individual and community-level factors with MHC vaccination uptake during the period of limited vaccine availability, we separated the data into before and after March 31st, 2021. Beginning March 31st, all individuals 16 and older were eligible for COVID-19 vaccination [50]. Furthermore, COVID-19 vaccines started to become available in pharmacies, clinician offices, and other locations during this period [51], thus reducing access barriers that previously existed. To assess sensitivity to this cut-off date, we repeated these analyses using a cut-off date of May 10th, 2021. This date was chosen for several reasons. Half of US adults received at least 1 COVID-19 dose by April 18th, and all adults were eligible for vaccination nationwide on April 19th [51]. By April 23rd, many states began turning down COVID-19 vaccine shipments from the federal government due to low demand [51]. On May 10th, the US Food and Drug Administration approved vaccines for adolescents aged 12–15 years [51].

3. Results

3.1. Descriptive characteristics

Descriptive statistics for 8545 individuals receiving a vaccine dose from the MHCs are provided in Table 1. The median age among vaccinated individuals was 42 (IQR: 20–58). The plurality of people were 45–64 years of age (30.8 %), male (49.2 %), Black (44.0 %), and uninsured (44.2 %). The proportion of Black and uninsured individuals were substantially higher compared to the SC population (Table 1). Characteristics of individuals who utilized the MHC before and after cutoff dates (March 31st and May 10th, 2021) are shown in Table S1 in the Supplementary Material. A diagram showing the utilization of MHCs is given in Fig. 1, and the locations of MHC sites and the number of vaccines administrated in each census tract in the Upstate and Midlands regions are shown in Fig. 2.

Number of visits and vaccine uptake by site types, day of week, time

Table 1
Descriptive statistics for South Carolina (SC) population, and for individuals who utilized the mobile health clinics (MHCs) for COVID-19 vaccination during the 12-month period.

Characteristics	SC Population	MHC Vaccination Population
	N = 5,078,903	N = 8545
Median Age (IQR)	40	42 (20–58)
Age Group N (%)		
11 and under	724,223 (14.3)	135 (1.6)
12–17	389,524 (7.7)	1581 (18.5)
18–29	808,333 (15.9)	1152 (13.5)
30–44	936,706 (18.4)	1754 (20.5)
45–64	1,321,652 (26.0)	2631 (30.8)
65 and over	898,465 (17.7)	1292 (15.1)
Sex N (%)		
Female	2,709,991 (51.3)	4317 (50.5)
Male	2,572,643 (48.7)	4208 (49.2)
Unknown		20 (0.2)
Race/Ethnicity N (%)		
Black	1,389,333 (26.3)	3758 (44.0)
Hispanic	348,654 (6.6)	876 (10.3)
White	3,354,473 (63.5)	2621 (30.7)
Other	190,174 (3.6)	650 (7.6)
Unknown		640 (7.5)
Insurance N (%)		
Medicaid	1,061,809 (20.1)	710 (8.3)
Medicare	898,048 (17.0)	901 (10.5)
Private/Other	2,794,514 (52.9)	3159 (37.0)
Uninsured	528,263 (10.0)	3775 (44.2)

MHC: mobile health clinic; SC: South Carolina; IQR: interquartile range. Percentages may not add to 100% due to rounding.

of day, and month are presented in Table 2 for a 12-month period, and before and after March 31st, 2021. Over the course of one year, the MHCs made 260 site visits to 149 unique locations in 108 census tracts and 59 zip codes across 17 counties in SC. In total, 12,102 COVID-19 vaccine doses were provided to 8545 individuals. Of the 260 MHC site visits, 67 (25.8 %) were to churches, 6 (2.3 %) to homeless shelters, 15 (5.8 %) to universities, 48 (18.4 %) to K-12 schools, 51 (19.6 %) to corporate sites, and 73 (28.1 %) to other types of locations such as parks, wellness centers, community centers, and markets. The events were hosted on Monday-Thursday (n = 112; 43.1 %), Friday (n = 44; 16.9 %) and on the Weekend (n = 104; 40.0 %), and showed substantial differences in terms of visit frequency given that more than half of the MHC activities were on Friday, Saturday, and Sunday. Although the number of site visits increased after March 31st, vaccine uptake via MHCs substantially declined across all sites, likely because the demand for MHC was higher when resource supply was limited. The relative table for a cutoff date of May 10th' 2021, and total vaccinations at the first, second, and third or more site visits are given in Table S2 and Table S3, respectively.

Descriptive statistics of individuals based on vaccination status are given in Table 3. Of 8545 individuals, 2890 (33.8 %) received a partial dose (one dose of BNT162b2 or mRNA-1273 vaccines), 4355 received their primary series (first two doses of BNT162b2 or mRNA-1273 vaccines or one dose of Ad26.COV2.S vaccine), and 1300 received a booster (three doses of BNT162b2 or mRNA-1273 vaccines or a Ad26.COV2.S vaccine followed by an BNT162b2 or mRNA-1273 vaccines). Of 12,102 vaccines, 11,100 doses were mRNA vaccines (BNT162b2: 10,984 and mRNA-1273: 116), and 1002 doses were the Ad26.COV2.S vaccine. The median age of individuals who received a partial dose was 28 (IQR: 16–48), with 12–17 as the largest age group, compared to 43 (IQR: 24–58) for those with a primary series and 56 (IQR: 44–68) for those with a booster. In these groups, the largest age group was 45–64 years of age. The age distribution was significantly different based on different vaccination statuses ($p < 0.001$). Although the sex distribution of individuals receiving the partial dose (50.0 % female and 49.8 % male) and or primary series (48.2 % female and 51.4 % male) was similar, there was a significant difference in the distribution of male (40.5 %) and female (59.4 %) among those who received a booster dose ($p < 0.001$), showing that a significantly higher proportion of females received a booster dose than males. Among all vaccination statuses, the majority of individuals identified as Black (partial dose: 44.7 %; primary

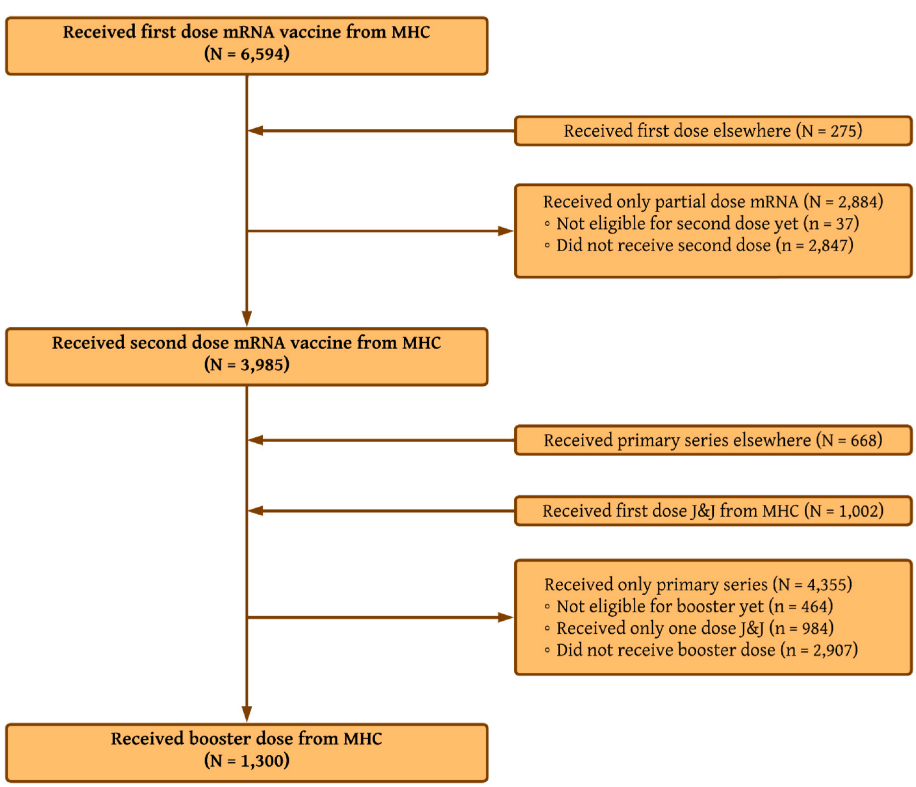

Fig. 1. The diagram of utilization of mobile health clinics (MHCs).

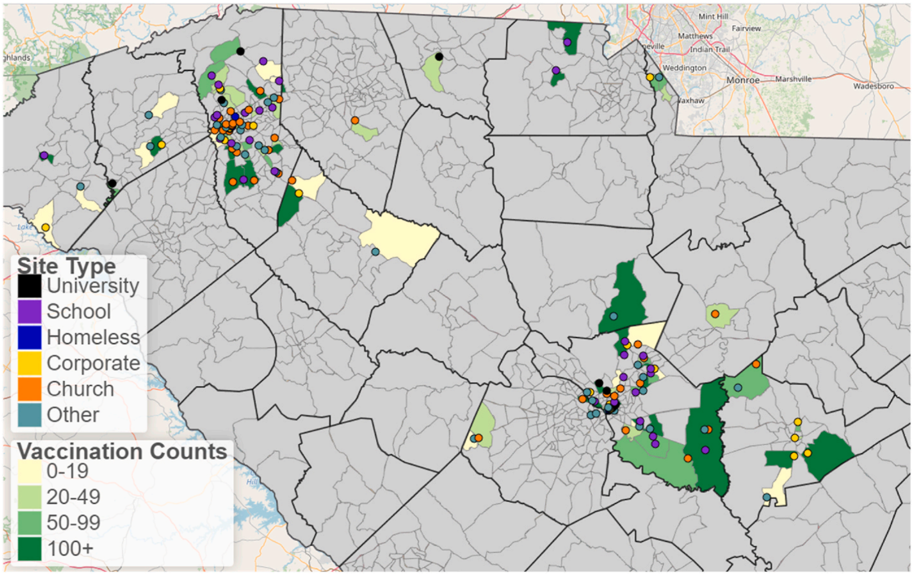

Fig. 2. MHC site visits map for COVID-19 vaccination in the Upstate and Midlands regions. The locations of sites are shown with points in different colors based on the site type, and the census tracts are colored based on the number of vaccines administrated in that census tract. County boundary lines are shown as thick black lines. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Site visits and Median (IQR) vaccination counts per site visit and at different site types (church, corporate sites, homeless shelters, k-12 schools, universities, and other locations), days of week (Monday to Thursday, Friday, and weekend), times of day (morning, afternoon, and evening), months (February 2021 to February 2022). Characteristics are presented for different vaccination term that is before and after March 31, 2021. P-values compare the significant difference on mean vaccine counts for each level of the categorical variable.

	Site Visits N (%)			Median (IQR) Vaccine Count per Visit		
	12-month	Before March 31	After March 31	12-month	Before March 31	After March 31
Site type				**(*P* < 0.001)**	(*P* = 0.194)	**(*P* < 0.001)**
Church	67 (25.8)	4 (36.3)	63 (25.3)	27 (16–48)	172 (108–252)	24 (13–43)
Corporate	51 (19.6)	1 (9.1)	50 (20.1)	26 (10–40)	301 (301–301)	26 (10–38)
Homeless	6 (2.3)	2 (18.2)	4 (1.6)	28 (22–114)	179 (160–198)	24 (17–27)
School	48 (18.4)	2 (18.2)	46 (18.5)	48 (24–82)	200 (184–217)	45 (24–77)
University	15 (5.8)	2 (18.2)	13 (5.2)	27 (21–58)	189 (147–231)	27 (17–36)
Other	73 (28.1)		73 (29.3)	12 (6–24)		12 (6–24)
Day of week				**(*P* < 0.001)**	(*P* = 0.080)	**(*P* <. 001)**
Monday-Thursday	112 (43.1)	1 (9.1)	111 (44.6)	24 (10–40)	301 (301–301)	27 (10–56)
Friday	44 (16.9)	2 (18.2)	42 (16.9)	28 (11–71)	179 (160–198)	23 (12–44)
Saturday/Sunday	104 (40.0)	8 (72.7)	96 (38.6)	24 (12–69)	199 (112–243)	23 (10 - 38
Time of day				(*P* = 0.127)	(*P* = 0.616)	(*P* = 0.056)
Morning	150 (58.1)	8 (72.7)	142 (57.5)	24 (12–47)	199 (112–243)	24 (12–43)
Afternoon	93 (36.0)	3 (27.3)	90 (36.4)	26 (12–42)	216 (179–258)	25 (11–40)
Evening	15 (5.8)		15 (6.1)	19 (4–45)		19 (4–45)
Unknown	2		2			
Month				**(*P* < 0.001)**	(*P* = 0.955)	**(*P* < 0.001)**
February, 21	2 (0.8)	2 (18.2)		126 (106–147)	126 (106–147)	
March, 21	9 (3.5)	9 (81.8)		230 (142–273)	230 (142–273)	
April, 21	23 (8.8)		23 (9.2)	44 (30–92)		44 (30–92)
May, 21	38 (14.6)		38 (15.3)	28 (20–43)		28 (20–43)
June, 21	50 (19.2)		50 (20.1)	16 (6–28)		16 (6–28)
July, 21	28 (10.8)		28 (11.2)	13 (11–40)		13 (11–40)
August, 21	27 (10.4)		27 (10.8)	18 (7–46)		18 (7–46)
September, 21	21 (8.1)		21 (8.4)	24 (9–32)		24 (9–32)
October, 21	30 (11.5)		30 (12.1)	26 (14–46)		26 (14–46)
November, 21	11 (4.2)		11 (4.5)	28 (12–39)		28 (12–39)
December, 21	7 (2.7)		7 (2.8)	31 (24–60)		31 (24–60)
January, 22	7 (2.7)		7 (2.8)	31 (23–34)		31 (23–34)
February, 22	7 (2.7)		7 (2.8)	17 (8–25)		17 (8–25)

Percentages may not add to 100% due to rounding.

series: 42.6 %; and booster: 46.8 %) followed by White individuals (27.6 %, 31.2 %, and 35.7 %), with a significant difference in race and ethnicity between vaccination statuses ($p < 0.001$). Those who received a partial dose or primary series were largely uninsured, with 50.7 % and 44.8 %, respectively. By contrast, this percentage decreased to 27.5 % for booster doses and there was a significant difference among insurance types based on vaccination status ($p < 0.001$). These results demonstrate the demand for vaccination among those with limited health care access,

Table 3
Descriptive statistics of individuals[a] based on vaccination status (partial: one dose of one dose of BNT162b2 or mRNA-1273 vaccine, primary series: two doses of BNT162b2 or mRNA-1273 vaccines, or one dose of Ad26.COV2.S vaccine, and booster dose: three doses of BNT162b2 or mRNA-1273 vaccines or one dose of Ad26.COV2.S and one dose of BNT162b2 or mRNA-1273 vaccines). P-values compare the significant difference between the levels of categorical variables and the vaccination status of individuals.

Characteristics	Partial N = 2890	Primary Series N = 4355	Booster Dose N = 1300	P-value
Median Age (IQR)	28 (16–48)	43 (24–58)	56 (44–68)	<0.001
Age Group N (%)				<0.001
5-11	112 (3.9)	23 (0.5)	0 (0)	
12-17	849 (29.4)	724 (16.6)	8 (0.6)	
18-29	523 (18.1)	563 (12.9)	66 (5.1)	
30-44	553 (19.1)	934 (21.4)	267 (20.5)	
45-64	602 (20.8)	1459 (33.5)	570 (43.8)	
65 and over	251 (8.7)	652 (15.0)	389 (29.9)	
Sex N (%)				<.001
Female	1446 (50.0)	2099 (48.2)	772 (59.4)	
Male	1437 (49.8)	2244 (51.4)	527 (40.5)	
Unknown	7 (0.2)	12 (0.3)	1 (0.1)	
Race/Ethnicity N (%)				**<.001**
Black	1292 (44.7)	1857 (42.6)	609 (46.8)	
Hispanic	342 (11.8)	493 (11.3)	41 (3.2)	
White	797 (27.6)	1360 (31.2)	464 (35.7)	
Other	230 (8.0)	333 (7.6)	87 (6.7)	
Unknown	229 (7.9)	312 (7.2)	99 (7.6)	
Insurance N (%)				**<.001**
Medicaid	377 (13.0)	307 (7.0)	26 (2.0)	
Medicare	178 (6.2)	466 (10.7)	257 (19.8)	
Private	869 (30.1)	1631 (37.5)	659 (50.7)	
Uninsured	1466 (50.7)	1951 (44.8)	358 (27.5)	

Percentages may not add to 100% due to rounding.
[a] Individuals with unknown characteristics are not included in the table.

particularly during earlier phases of the pandemic where supply was more limited.

A total of 6594 individuals received the first dose of the mRNA (BNT162b2 or mRNA-1273) vaccine. Of those, 5894 individuals had an opportunity and were eligible to receive the second mRNA dose (i.e., completion of primary series) through a follow-up MHC site visit in the same zip code. Of those eligible, 3439 (58.3 %) received the second mRNA vaccine dose. Characteristics of second dose-eligible individuals and their vaccination status are shown in Table 4. Individuals who received the second dose of vaccine had higher median age of 41 (IQR: 18–59) than those who did not get the second dose of vaccine 30 (IQR: 16–49); p < 0.001. Insurance type was also significantly different between the two groups ($p < 0.001$), with those on Medicare more likely to receive the second dose compared to Medicaid.

3.2. *Association between community-level factors and vaccination uptake from mobile health clinic*

When restricting to the first MHC site visit, the MHCs provided COVID-19 vaccines to 6200 individuals at their first MHC utilization. This population was used to analyze factors associated with MHC uptake. MHC conducted 149 first site visits to 37 churches (24.8 %), 22 corporate centers (14.8 %), 5 homeless shelters (3.4 %), 8 universities (5.3 %), 32 K-12 schools (21.5 %), and 45 other types of sites (30.2 %). Characteristics of individuals at the first site visits are shown in Table S4 in the Supplementary Material. The majority of events (94, 63.1 %) were hosted on weekdays and 55 (36.9 %) events occurred on the weekend. Characteristics of individuals used in the analysis is given based on 12-month period, and cutoff terms of March 31st, 2021, and May 10th, 2021.

Uptake per visit was highest among schools (median = 41, IQR: 21–63), followed by corporate sites (median = 34, IQR: 20–44), homeless shelters (median = 28, IQR: 27–142), universities (median = 27, IQR: 21–67), churches (median = 22, IQR: 13–38), and other sites (median = 12, IQR: 5–20). Overall, uptake was higher on Fridays (median = 25.5, IQR: 10–70) compared to other weekdays (median = 24.5, IQR: 12–44), and weekend (median = 22, IQR: 12–40.5). Vaccine uptake was highest in March 2021 (median = 216, IQR: 128–287) and in February 2021 (median = 126, IQR: 85–168).

Table 4
Descriptive statistics for individuals who were eligible for the second dose of an mRNA vaccine (BNT162b2 or mRNA-1273) when MHC visited a site within the same zip code of the initial visit. P-values compare the significant difference between the levels of categorical variables and the vaccination status of individuals.

Characteristics	Second mRNA Dose while eligible		**P-value**
	No	**Yes**	
	N = 2455	**N = 3439**	
Median Age (IQR)	30 (16–49)	41 (18–59)	**<.001**
Age Group N (%)			**<.001**
5-11	88 (3.6)	23 (0.7)	
12-17	730 (29.7)	723 (21.0)	
18-29	409 (16.7)	480 (14.0)	
30-44	471 (19.2)	664 (19.3)	
45-64	534 (21.8)	959 (27.9)	
65 and over	223 (9.1)	590 (17.2)	
Sex N (%)			0.783
Female	1261 (51.4)	1780 (51.8)	
Male	1187 (48.4)	1649 (47.9)	
Unknown	7 (0.3)	10 (0.3)	
Race/Ethnicity N (%)			0.100
Black	1143 (46.6)	1780 (51.8)	
Hispanic	299 (12.2)	1649 (47.9)	
White	647 (26.4)	10 (0.3)	
Other	193 (7.9)	1780 (51.8)	
Unknown	173 (7.0)	1649 (47.9)	
Insurance N (%)			**<.001**
Medicaid	313 (12.7)	242 (7.0)	
Medicare	163 (6.6)	406 (11.8)	
Private	706 (28.8)	1093 (31.8)	
Uninsured	1273 (51.9)	1698 (49.4)	

Percentages may not add to 100% due to rounding.

Estimated relative risks, and confidence intervals for each variable are presented in Fig. 3 and Table S5 in the Supplementary Material. During a 12-month period, individuals between 12 and 17 years of age, (RR = 2.01, 95 % CI: 1.64–2.45, $p < 0.001$), non-white (RR: 1.54, 95 % CI: 1.36–1.75, p < 0.001) and uninsured individuals (RR: 2.22, 95 % CI: 1.95–2.52, p < 0.001) were more likely to utilize the MHC compared to the reference groups of 55 or older, white, and insured individuals, respectively. On the other hand, census tracts with lower unemployment rate (RR: 0.89, 95 % CI: 0.80–0.99, p = 0.027) and higher labor force participation (RR: 1.13, 95 % CI: 1.01–1.27, p = 0.028) were associated with higher vaccine uptake. These results show persistent use of the MHCs by individuals that tend to be medically underserved, including racial and ethnic minority groups and uninsured individuals.

Prior to March 31st, 2021, non-white individuals were 1.93 (95 % CI:1.28–2.92, p = 0.002) times and uninsured individuals were 1.61 (95 % CI: 1.02–2.55, $p = 0.04$) times more likely to utilize the MHC for COVID-19 vaccination compared to the reference groups. Individuals from zip codes with lower PCP rates (RR: 0.65, 95 % CI: 0.46–0.92, $p = 0.015$) and lower MD/DO rate (RR: 0.58, 95 % CI: 0.38–0.89, $p = 0.012$) had lower vaccine uptake.

After March 31st, 2021, individuals aged between 12 and 17 years (RR = 2.09, 95 % CI: 1.72–2.56, p < 0.001), non-white (RR: 1.46, 95 % CI: 1.28–1.66, p < 0.001), and uninsured individuals (RR: 2.46, 95 % CI: 2.16–2.81, p < 0.001) were more likely to utilize the MHC. Census tracts with higher unemployment rates (RR = 0.89, 95 % CI: 0.79–0.99, p = 0.024) were associated with decreased vaccine uptake (i.e., higher employment rate associated with higher uptake). Estimated associations

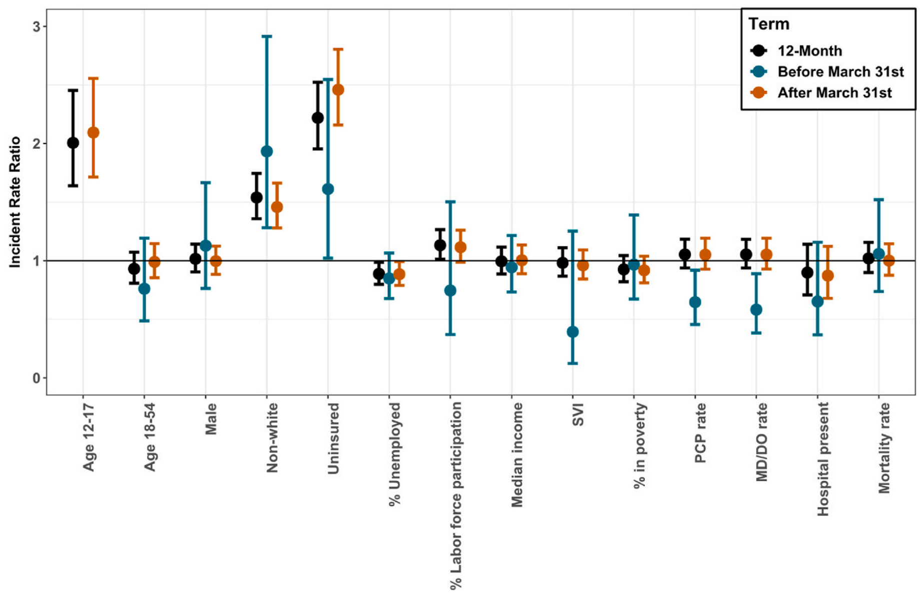

Fig. 3. Estimated relative risks for each factor (points) on vaccine uptake through MHC, and 95 % confidence intervals (lines) for 12-month period and before and after March 31st, 2021. Analysis population is the individuals utilized the MHC for the first time at the first site visits between February 20, 2021, and February 17, 2022. Subpopulations are stratified by age, sex, race, and insurance status. The negative binomial GLMM is adjusted for age group, sex, race, insurance status, site category, time of the week, time of the day, and vaccination rate in the zip code before MHC visit and total subpopulation size is used as an offset. The reference for age is age older than 55 years. In all cases, sex is female, race is White and insurance status is insured.

before and after the May 10th, 2021, cut-off date were similar (Table S6).

4. Discussion

The Prisma Health MHCs showed evidence of substantial improvement in access to COVID-19 vaccines in medically underserved communities. Starting from February 2021, Prisma Health's six MHCs provided over 12,102 vaccines to 8545 individuals over a one-year period. Our results show that the highest utilization of MHC services (via COVID-19 vaccine uptake) was from racial and ethnic minority individuals and individuals who have less access to medical resources. During the period of study, these populations were at high risk of severe COVID-19 outcomes yet less likely to be vaccinated [8,10,28,29]. Given the toll of the COVID-19 pandemic, our findings demonstrate that priority delivery of MHCs to medically underserved communities can substantially reduce health disparities for COVID-19 vaccination and in future health emergencies.

Similar to other MHC programs for COVID-19 vaccination in the state of Tennessee and city of Boston (Massachusetts) [52,53], we found that MHCs were highly utilized by racial and ethnic minority groups and medically underserved groups. Relative to the general SC population, the population of those who utilized MHC vaccination services were more racially and ethnically diverse and without insurance. Black and Hispanic populations constituted 44 % and 10.3 % of the population utilizing MHC services for COVID-19 vaccine delivery, despite constituting only 26.3 % and 6.6 % of the of the SC population, respectively. Importantly, a substantially higher proportion of uninsured individuals (44.2 %) utilized MHC services for COVID-19 vaccination compared to the general population (10.0 %). However, while uninsured individuals and those on Medicaid represented a greater share of individuals receiving their partial or primary series doses through the MHC, their representation among those receiving a booster dose substantially dropped. These findings highlight persistent barriers for racial and ethnic minority groups, the uninsured, and those on Medicaid. That is, the MHC may serve as an important initial source of healthcare access with a need to enhance consistency of access, such that MHC programs should consider the importance of their return visits and reconnecting with previous patients.

This study also found several community-level factors associated with the utilization of MHCs for COVID-19 vaccination. During early phases of vaccine distribution where supplies were limited, communities with lower availability of medical resources, including PCP and MD/DO per capita and lower hospital access, were associated with increased MHC utilization for COVID-19 vaccination. However, these variables were not significant predictors of MHC utilization once vaccines became widely available.

Our study provides preliminary information for region-based variables of importance. Given the mobility and flexibility of MHCs, our findings suggest that allocation of these units based on community-level factors can both maximize intervention uptake and minimize severe disease outcomes. Based on the results, communities with less access to healthcare and medical providers should be prioritized. Such strategic planning can improve both the timely delivery of essential medical care and health outcomes in socioeconomically disadvantaged populations during emergency situations [15]. This is especially critical during phases of pandemics when essential resources are limited, as these phases correlate with periods of high transmission, morbidity, and mortality. Age-based allocation of COVID-19 vaccines adopted by states nationwide lead to inequity in vaccination uptake, with lower rates in disadvantaged neighborhoods that were at an increased risk for severe COVID-19 infection and death [54–56]. Alternatively, prioritization based on both age and geographic region would have led to a substantial decrease in COVID-19 hospitalizations [54]. Our findings are consistent with these studies and demonstrate that incorporation of community-level features into the planning and distribution process for MHCs can substantially improve health outcomes during health emergencies.

Understanding and improving MHC utilization has substantial benefits beyond pandemics and future health emergencies. A recent review of MHCs in the United States found that such units were successful at increasing healthcare access, advancing health outcomes, and improving population health, with the added benefit of reducing cost burdens on the healthcare system [15]. MHCs have shown evidenced success in providing a variety of forms of care, including testing and treatment for Hepatitis C (HCV), human immunodeficiency virus (HIV), human papillomavirus vaccination (HPV) [57–62], treatment for opioid use disorder [63], cancer screenings [64], and prenatal care [65,66]. MHCs have been noted as a key strategy for increasing vaccine uptake, particularly in underserved communities [61,67,68]. Prior to the COVID-19 pandemic, mobile health clinics have been utilized to increase access to influenza vaccination [69–71], HPV [60–62], and routine child vaccines [67,72].

This study has several limitations and necessary extensions. We cannot establish causality between community-level factors and MHC utilization. To help establish this, future studies could incorporate additional individual level demographic, socioeconomic, and health care access data. Also, the number of individuals included in the analysis reduced from 6200 to 5887 due to having missing observations on variables. Importantly, strategies to ascertain community-level vaccine hesitancy should be employed. Even prior to the COVID-19 pandemic, the World Health Organization declared vaccine hesitancy a top ten global health threat [73]. Vaccine hesitancy is a complex problem caused by a broad array of multi-level factors [74] and will likely further perpetuate health disparities if unaddressed [75]. This is influenced by issues related to vaccine confidence, distrust in government and health institutions, issues of complacency and convenience, sociodemographic factors, structural barriers to care, and is further driven by perpetuation of misinformation [74,76–78]. To help address COVID-19 vaccine hesitancy, the Prisma Health MHCs and other institutions have distributed evidence-based information on vaccines, engaged with communities to promote vaccines among their networks, and offered financial incentives [79–81]. However, information on community-level vaccine perception was not recorded. Strategies including survey administration prior to MHC allocation, or the use of social media data, are potential approaches to ascertaining community-level vaccination strategies [82,83]. Given the strong association between vaccine hesitancy and distrust in health institutions, just the presence of MHCs can impact vaccine hesitancy in underserved populations by improving trust in healthcare and working with trusted community partners [15,18,74,75,78,84,85]. Since the vaccination through MHCs depend on a location-based administration, it is important to devise allocation methods for MHCs to certain locations, and investigate the community-level factors associated with vaccine uptake. Finally, vaccine uptake via MHCs substantially decreased throughout the study period, which is likely due to a combination of an increase in both the availability of vaccinations and vaccine hesitancy.

5. Conclusions

The COVID-19 mobile vaccination program was successful at vaccinating a large number of individuals, particularly those from socially disadvantaged and medically underserved communities. This demonstrates that 1) the MHC are reaching their intended (underserved) populations, and 2) there are factors that strongly predict utilization of MHCs that can be used to inform and improve allocation of MHCs during health emergencies. While over 2000 MHCs are estimated to currently operate in the United States, it is not possible to cover all underserved communities nationwide. It is therefore imperative to have protocols in place to maximize the effectiveness of these units with respect to increasing intervention utilization among underserved populations during health emergencies. Such protocols have potential to improve equity in intervention distribution and prevent additional infections and deaths among marginalized populations during infectious disease outbreaks.

Statement of ethical approval

This study was approved by the Institutional Review Board of Clemson University (Protocol #IRB2022-0150).

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Declaration of interests

This study was funded by the National Library of Medicine of the National Institutes of Health and the Center for Forecasting and Outbreak Analytics of the Centers for Disease Control and Prevention. The MHC program was supported by The Greenville County CARES Program as part of a Covid-19 Funding Program. LR, FG, IJ, KJB, AHL, and KKS received support from the National Library of Medicine of the National Institutes of Health (R01LM014193) during this study; LR, FG, KAH, KJB, AHL, and KKS received support from the Centers for Disease Control and Prevention (NU38FT000011). The funders had no role in the design, conduct, reporting of the study, or decision to submit for publication.

Evidence before this study

Emerging Infectious Diseases (EID) with high pandemic potential have substantially increased over the past 20 years and have disproportionately impacted underserved communities. During the Covid-19 pandemic, Black, Hispanic, and rural Americans faced a substantially greater risk of hospitalization and death. These disparities have been fueled by inadequate access to essential resources throughout the pandemic, including vaccines. Mobile health clinics (MHCs) are an effective and versatile tool for reducing health disparities through timely delivery of interventions to medically underserved communities. This is especially critical during phases of pandemics when essential resources are limited, as these phases correlate with periods of high transmission, morbidity, and mortality. For example, disparities in Covid-19 vaccination uptake among Black, Hispanic, and rural communities were highest during winter 2021 when vaccine supply was limited, yet this time-period corresponded to the greatest number of deaths throughout the pandemic. To maximize vaccination rates in underserved communities during pandemics in limited resource settings, it is imperative to both develop effective MHC programs and study factors associated with increased utilization.

Prior to the Covid-19 pandemic, MHCs have been noted as a key strategy for increasing vaccine uptake in underserved communities, including influenza vaccination, human papillomavirus (HPV) vaccination, and routine childhood vaccines. However, the study of MHCs for vaccine distribution during the Covid-19 pandemic, and particularly under resource constraints, are limited. We used the following search terms in PUBMED to identify the studies investigated the implementation of MHCs for Covid-19 vaccination: ((Mobile health clinic [Title]) OR (Mobile health unit [Title]) OR (Mobile health center [Title]) OR (Mobile clinic [Title]) OR (Mobile unit [Title]) OR (Mobile container [Title]) OR (Mobile center [Title]) OR (mobile health service [Title]) OR (mobile vaccination [Title])) AND ((vaccine [Title]) OR (vaccination [Title])) AND ((covid [Title]) OR (covid-19 [Title]) OR (sars-cov-2 [Title]) OR (census block [Title])). Of three search results, two studies investigated the demographic characteristics of individuals who utilized the MHCs for Covid-19 vaccination in Massachusetts and Tennessee. The third study evaluated the utility and effectiveness of MHCs for vaccination through written questionnaire upon their attendance to the MHC. However, no study evaluated the impact of demographic, socioeconomic, or health care access barriers on increased vaccination uptake via MHCs. Moreover, these study findings are aggregated across phases of the pandemic when vaccine supplies were both limited and abundant. Once vaccine availability was widespread, individuals could go to local pharmacies, primary care physicians, or other readily accessible health establishments to be vaccinated. Therefore, such aggregated results may be less useful for understanding factors contributing to MHC utilization during health emergencies. Such knowledge is critical for identifying and prioritizing high-risk communities for delivery of this essential but limited resource.

Added value of this study

This study demonstrates the effectiveness of MHCs in delivering a large quantity of vaccinations during public health emergencies and that individuals from socially disadvantaged and medically underserved communities utilize MHCs to a great extent. This demonstrates that 1) the MHCs are reaching their intended populations and 2) there are factors that strongly predict utilization of MHC utilization. When vaccines were first authorized for distribution and supplies were limited, Black, Hispanic, and uninsured individuals, along with individuals from communities with less access to health care resources, were more likely to utilize the MHCs. However, associations between MHC utilization for Covid-19 vaccination and health care access barriers were mitigated once vaccines became widely available. These results significantly improve understanding on how to leverage MHCs to provide interventions to medically underserved communities during pandemics, particularly when resources are in short supply.

Implications of all the available evidence

The ability of MHCs to provide timely interventions during the Covid-19 pandemic demonstrates their utility in improving health outcomes and reducing health disparities in medically underserved communities during health emergencies. With over 2000 MHCs estimated to be operating in the United States, it is imperative that institutions have protocols in place for distribution of their mobile clinics during public health emergencies, with an emphasis on increasing intervention utilization among underserved populations. This is especially critical during phases of pandemics when essential resources are limited, as these phases correlate with periods of high transmission, morbidity, and mortality. For example, disparities in Covid-19 vaccination uptake among Black, Hispanic, and rural communities were highest during winter 2021 when vaccine supply was limited, yet this time-period corresponded to the greatest number of deaths throughout the pandemic. The findings of this study, combined with existing evidence demonstrating the effectiveness of MHCs for delivery of vaccines and other intervention across a wide range of diseases, can be used to inform strategic allocation of MHCs to underserved communities during future health emergencies. Such strategies have the potential to improve equity in vaccine distribution (along with screening and treatment uptake) and prevent additional infections and deaths among marginalized populations during infectious disease outbreaks. While MHCs are also useful mechanisms for disseminating information on vaccination, future research should continue to focus on strategies for reducing vaccine hesitancy and disinformation to further increase the effectiveness of such mobile health clinic frameworks.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhip.2024.100550.

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