Spring 5-2023

Prevalence of SARS-Cov-2 Antibodies by Rural-Urban Residential Status in Texas

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BS HUMAN BIOLOGY, The University of Texas at Austin, 2021

Presented to the Faculty of The University of Texas

School of Public Health

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF PUBLIC HEALTH

THE UNIVERSITY OF TEXAS
SCHOOL OF PUBLIC HEALTH
Houston, Texas
May 2023

PREFACE

I completed my Bachelor of Science in Human Biology at The University of Texas at Austin. During my time there, I minored in sociology. Upon graduation, I decided my new educational endeavor would be my master's in public health, as it combined my love for traditional science and my interest in the social sciences. My time at The University of Texas Health Science Center at Houston School of Public Health has greatly cultivated my professional interests.

I am personally motivated to make healthcare more accessible to rural individuals because I grew up low-income in a small town. With the COVID-19 pandemic and vaccines becoming a central theme in misinformation and reduced health literacy amongst rural individuals, I was personally interested to see if rural individuals are less protected against the virus. Understanding these health disparities will hopefully allow public health officials to create targeted interventions.

ACKNOWLEDGMENTS

Words cannot express my gratitude to my thesis advisor, Dr. Sarah Messiah, for her invaluable patience, feedback, and guidance. I also could not have undertaken this journey without my academic advisor, and member of my thesis committee, Dr. Melissa Harrel, who generously provided her knowledge and expertise. Additionally, this endeavor would not have been possible without the generous support from the Texas CARES team, specifically Dr. Eric Boerwinkle, Lindsay Padilla, Jessica Ross, Dr. Michael Swartz, Yashar Talebi, and my fellow graduate research assistants.

I am also grateful to my professor, Dr. James Hixon, for his guidance and feedback as I prepared my proposal. Special thanks should also go to my classmate Katie Clark for her editing help, feedback sessions, and moral support.

I am thankful for my dear friend, Kyleigh Stalker, for her years of support and encouragement in my professional and personal life. Lastly, I would be remiss in not mentioning my family, especially my mother, Colleen Ellis, my sister, Cayley Ellis, my sister and her husband, Ashton, and Wyatt Langford. My grandmother, Anna Streuly, and my aunt and uncle, Vitalia and Troy Streuly, supported me. Their belief in me has kept my spirits and motivation high throughout my educational career.

PREVALENCE OF SARS-COV-2 ANTIBODIES BY RURAL-URBAN RESIDENTIAL STATUS IN TEXAS

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Understanding the health disparities associated with SARS-CoV-2 antibody status across Texas is essential. These differences can guide healthcare professionals and local public health officials to identify vulnerable populations needing COVID-19 prevention and treatment resources. This study aims to contribute to the literature by determining if rural and urban geographical locations are disproportionately impacted by SARS-CoV-2 infection and vaccination in the state of Texas. I utilized the Texas Coronavirus Antibody REsponse Survey (Texas CARES), a large ongoing prospective population-based survey among 5–90-year-olds from the Texas general population that began collecting seroprevalence data in October 2020 (1). Participants in the survey are currently offered a series of 4 SARS-CoV-2 antibody tests over 12+ months or about every three months. The cohort provided the data needed to describe the prevalence of SARS-CoV-2 antibodies from both natural and vaccine-induced infection and vaccination status. Additionally, each county in Texas was categorized as either rural or urban, and each participant was described as residing in a rural or urban setting based on their mailing address. Chi-square analysis determined any statistical differences in seroprevalence (positive/negative) by rural and urban status.

Texas CARES utilizes two antibody blood tests. The S test, or COVID-19 Antibodies, Spike Protein detects antibodies from a past COVID-19 infection and/or vaccination (positive range 08-2500U/mL). The N test or SARS-CoV-2 Total Antibodies detects antibodies from a past COVID-19 infection (positive range > 1.0). Rural participants had a higher percentage of positive N test results for their first (T1, October/2020) and their fourth (T4, July/2022), 37.00% and 65.40%, respectively. In contrast, urban participants had seropositivity of 20.19% and 55.33% for T1 and T4 N test respectively. Therefore, more rural individuals had antibodies from a natural infection at that point in time than urban individuals. Both rural and urban individuals had a 97% seroprevalence for their T4 S test, indicating nearly all individuals have some degree of protection against COVID-19.

Nearly three-fourths of urban participants were fully vaccinated (45.18%) or fully vaccinated and boosted (30.28%). About half of rural participants were fully vaccinated or fully vaccinated (37.74%) and boosted (16.28%). Within the rural population, 27.32% of participants are not vaccinated, compared to 11.41% of unvaccinated participants in urban counties.

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BACKGROUND

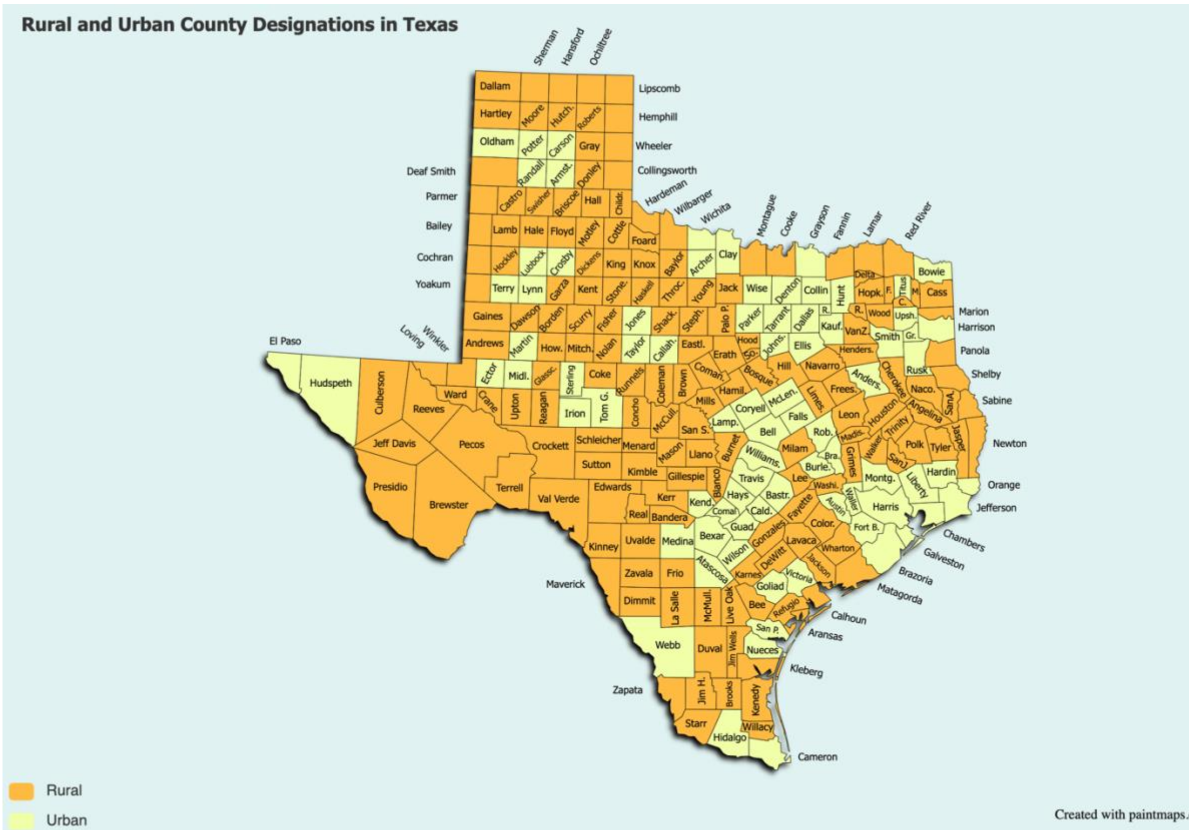
Literature Review

As of March 2023, over 103 million confirmed cases of COVID-19 have been reported in the United States (2). The Centers for Disease Control and Prevention (CDC) among others have tracked SARS-CoV-2 antibody serostatus in the United States but this has occurred primarily in anonymous samples (e.g., blood draw and blood bank sites). Individuals can gain seroprevalence through a natural infection of SARS-CoV-2 or vaccination. There remains limited literature on how COVID-19 vaccination and the prevalence of SARS-CoV-2 antibodies differ by rural and urban residential status in Texas.

Rural and Urban Counties in Texas

The state of Texas ranks second nationally in SARS-CoV-2 infection with over 6.4 million cases (2). Texas has an estimated population of 29,527,941 as of 2021, with 3,035,014 rural residents (10.27%) (3). It should be noted that no universal definition of rural or urban is used widely in biomedical literature (4). Texas CARES (the data source for this thesis) follows the definition of rural and urban used by the Health Resources and Service Administration (HRSA), an agency under the U.S. Department of Health and Human Services. Figure 1 demonstrates all 254 Texas counties, how they fall into rural and urban definitions, and their distribution across the state.

Figure 1: Rural and Urban County Designations in Texas*



Please note that there is no standardized definition for rural or urban. The definitions used for rural and urban as defined by the Health Resources and Service Administration (HRSA) (5).

Health Disparities in Rural Communities

Health disparities across socioeconomic status, ethnicity, and rural-urban communities have been well documented in the United States. For instance, urban Texans' average per capita income in 2020 was $56,302, compared to $45,120 in rural Texas (6). The poverty rate in rural Texas is 15.8%, whereas the urban poverty rate is 13.2% (6). Only 15.2% of urban Texans lack a high school diploma, compared to 18.9% of rural Texans (6).

Education level also varies across urban and rural areas, with 32.3% of urban Texans and 17.8% of rural Texans holding college degrees as of 2020 (Table 1) (6). Moreover, rural communities are disproportionately affected by chronic disease disparities including diabetes (7), heart disease (8), cancer, and stroke (9), which puts them at higher risk of morbidity and mortality related to COVID-19 illness compared to urban communities (10). Reducing these numerous disparities has been an overarching goal of public health professionals in the US (11).

Table 1: Texas Rural-Urban Demographics as of 2020*

	Urban	Rural
County count	30	224
Poverty rate	13.2%	15.8%
Per-capita income	$56,302	$45,120
Lack high school diploma	15.2%	18.9%
Completed college	32.3%	17.8%

**Data compiled from the U.S. Department of Agriculture Economic Research Service from 2020* (6).

Texas faces multiple challenges regarding healthcare access (12). Rural communities face disproportional obstacles regarding healthcare access (13). According to federal authorities, 75% of Texas counties have health professional shortages and/or are in a medically underserved field (12). Rural individuals often live miles away from the nearest medical facility; therefore transportation can be an issue, especially for elderly individuals who may no longer feel comfortable driving far distances (12). There is also a lack of physicians, nurses, and medical staff who can easily communicate in Spanish and providers who are not trained in specific cultural competencies (12). Without enough providers, patients may fail to learn about their health adequately, making them susceptible to insufficient health literacy (12). In addition to these challenges, nearly one-fifth of rural Texans do not have any form of health insurance, and as a result, they may avoid or delay care due to medical costs (12).

Vaccination Disparities

Murthy et al. demonstrated disparities in COVID-19 vaccination coverage, and that vaccination coverage, COVID-19 incidence and mortality are higher in rural versus urban communities (14). It is recognized that rural populations tend to be older, uninsured, live far away, and are, therefore, more likely to have untreated medical conditions, which place them at higher risk for adverse COVID-19 outcomes and fewer vaccinations (14). The CDC conducted a county-level vaccination analysis among Americans older than 5 years of age who received their first dose of the Pfizer-BioNTech, Moderna, or Johnson & Johnson vaccine from December 2020-January 31, 2022 across all 50 states and the District of Columbia (14). Despite increased access to COVID-19 vaccines, between December 2020-April 2021, rural-urban vaccination disparities increased more than twofold through January 2022, with rural counties with first-dose vaccination coverage of 58.5%, compared to 45.7% in December 2020-April 2021 and urban counties 75.4%, compared to 45.7% in December 2020-April 2021 (15). The CDC suggests this difference is due to several factors, which include vaccine hesitancy, challenges accessing health care, and variations in personal views of the seriousness of the COVID-19 pandemic (14). Adults in rural areas were nearly three times as likely to report that they “definitely won’t” get a COVID-19 vaccine than urban adults (16). Parents in rural areas are twice as likely to state that their child "definitely won't" get a COVID-19 vaccination compared to urban communities (16).

Public Health Significance

Understanding the seroprevalence of SARS-CoV-2 antibodies can inform public health efforts as the pandemic reaches endemic status. This study examines how rural and urban statuses across the state of Texas have been impacted by SARS-CoV-2 infection. It is essential for healthcare providers and policymakers to consider the barriers rural Texans may face, as healthcare providers remain a trusted source of vaccination and health information for patients (14). Targeted efforts are critical to increasing vaccine confidence to address gaps in vaccination coverage between urban and rural communities (14). Addressing these barriers to healthcare and vaccination in rural areas is vital to achieving vaccine equity and decreasing COVID-19-related illness and death, especially as more variants emerge. Targeted efforts are critical to increasing vaccine confidence to address gaps in vaccination coverage between urban and rural communities (17). Addressing these barriers to healthcare and vaccination in rural areas is vital to achieving vaccine equity and decreasing COVID-19-related illness and death, especially as more variants emerge.

Hypothesis, Research Question, Specific Aims or Objectives

The extent of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection and how it varies between rural and urban populations remains unclear. The long-term goal of this analysis was to inform the public health efforts for COVID-19, the disease caused by SARS-CoV-2. The overall objective was to strengthen the understanding of SARS-CoV-2 antibody serostatus by rural-urban residential status in Texas. To achieve this goal, I tested the central hypothesis that the SARS-COV-2 seroprevalence and would be higher in urban counties, and I suspect urban individuals to have higher vaccination rates. By examining these differences, I aim to form accurate estimates of seroprevalence that can inform policy-making decisions relevant to SARS-CoV-2. To address the gap in knowledge regarding differences in seroprevalence by geographical location and evaluate the central hypothesis I propose the following two specific aims:

Aim 1: Estimate the prevalence of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) antibody serostatus in the state of Texas by rural-urban residential status.

Texas ranks second in SARS-CoV-2 infection with over 2.71 million cases. Texas has also seen a disproportionate rate of death across the state. Rural populations in Texas intersect with large border and immigrant populations who are disproportionately impacted by COVID-19 morbidity and mortality (18). I utilized the Texas Coronavirus Antibody REsponse Survey (Texas CARES), a large ongoing prospective population-based survey among 5–90-year-olds from the Texas general population that began in October 2020. This epidemiological cohort provided the data needed to identify the presence of SARS-CoV-2 antibodies from both natural and vaccine-induced infection. A chi-square test determined if there was a statistically significant difference between the expected frequency of antibody status and the observed antibody status across the geographical location. This aim also utilized descriptive statistics to understand the cohort better.

Aim 2: Estimate the prevalence of vaccination (partial, full, boosters) in the state of Texas by rural-urban residential status.

Vaccinations are one of the only public health tools for preventing morbidity and mortality from COVID-19 infections (19). A chi-square test determined if there was a statistically significant difference between the percentage of vaccinated rural individuals and the percentage of vaccinated urban individuals. A statistical difference between the two geographical categories may highlight areas of weakness in the state's vaccination efforts. Providing a targeted approach toward COVID-19 prevention for certain communities is vital. Addressing the current gaps in knowledge of the prevalence of SARS-CoV-2 antibodies among rural and urban populations in Texas, the proposed study will provide a better understanding and information for new strategies for reducing individual risk and the population prevalence of COVID-19.

METHODS

Study Design

Texas CARES is an ongoing statewide seroprevalence project with nearly 90,000 participants which began enrollment in October 2020 (1). The survey is designed to assess antibody status amongst the participants at four different time points (1). The survey collects information such as the participant's demographic, COVID-19 infections, COVID-19 symptoms, co-existing conditions, mental health changes, and academic performance. Once the volunteer completes the survey, they receive a text message with a confirmation and order number, which allows them to receive a free antibody blood test at their local Clinical Pathology Laboratory (CPL) location (20). The Institutional Review Board approved all protocols at the University of Texas Health Science Center at Houston (20).

Study Subjects

The project includes 90,000 Texas adults (aged 20-80 years) and children (6 months-19 years). Volunteers were recruited via Federally Qualified Health Centers (FQHCs), community clinics, Texas state employees, educators, and social media campaigns, amongst others (20). Study subjects were recruited regardless of vaccination status, previous infections, and across education levels, socioeconomic status, and ethnicities for the most accurate estimation of seroprevalence in Texas. All participants signed a participation consent form prior to filling out their survey.

Data Collection

A large epidemiological cohort, Texas CARES, provided the data needed to identify the presence of SARS-CoV-2 antibody status from both natural and vaccine-induced infection. Each Texas CARES participant completed the survey at four different time points. Each survey collects information such as the participant's demographic, COVID-19 infections, COVID-19 symptoms, co-existing conditions, mental health changes, academic performance, and more. Following the survey, the participant gave blood tests that detect antibodies resulting from vaccination and/or previous infection. Each blood test is completed at least 90 days apart, and the survey must be completed as close to the time of the blood test as possible. After blood collection, CPL analyzes the blood sample and reports the results to the Texas CARES team. Texas CARES utilizes two different antibody tests. The first test "COVID-19 Antibodies, Spike Protein" (S Test) and detects antibodies from a past COVID-19 infection and/or vaccination (positive range is 0.8-2500 U/mL). The second test is the "SARS-CoV-2 Total Antibodies" (N Test) which detects only antibodies from a past COVID-19 infection (any result of 1.0 or higher is positive). The results come to the Texas CARES team as positive or negative based on the number of antibodies present in the participant's blood.

Given the information collected in the survey, the participant's home address was used to categorize participants into rural and urban designations. Texas CARES follows the definition of rural and urban used by the Health Resources and Service Administration (HRSA), which provides a guide for classifying counties into the two categories (5). In addition to rural and urban designations, participants were also assigned into vaccination categories. Categories include fully vaccinated, fully vaccinated and boosted, not vaccinated, or partially vaccinated. Full vaccination is defined as two weeks after the second dose of an mRNA COVID-19 vaccine, two weeks after a second dose of the Novavax COVID-19 vaccine, or two weeks after you get a single dose of the Janssen/Johnson & Johnson COVID-19 vaccine (21).

Data Analysis

Texas CARES biostatisticians retrieved all data from Redcap, a web-based application developed to capture data for clinical research and create databases and projects. Descriptive statistics were used to characterize the sample by rural and urban counties (Table 2). These characteristics include race, ethnicity, county designation, and age. Antibody test results were pulled from the first survey (T1; October/2020) and the fourth survey (T4; July/2022). A chi-square test of independence was used to see if there was a statistically significant difference between the antibody status of rural and urban populations (Table 3). Vaccination status was also analyzed with a chi-square test to compare rural and urban population differences (Table 5).

All statistical tests were conducted by myself using STATA, version 14 (22). STATA generated the Pearson chi-square value and the corresponding p-value. A significance value of 0.05 was used. A calculated p-value that is less than or equal to 0.05 indicates there is sufficient evidence to conclude that the observed distribution is not the same as the expected distribution, therefore there is a relationship exists between the categorical variables. Due to the large sample size, missing values were removed and excluded during the analysis. Of the participants who completed both T1 and T4, 1,223 participants were excluded from the analysis due to not having an address or county on file, making it impossible to designate rural or urban status. 51 participants were also excluded because the address provided was not in the state of Texas.

RESULTS

The final analytical sample included 38,436 participants. Of those individuals, 6.22% lived in a rural county and 93.78% live in an urban county. A summary of the descriptive statistics of these participants can be found in Table 2. 90.88% of participants were white and 87.43% were non-Hispanic. The age distribution of the cohort can be found in Table 2, with 28.75% of participants between the ages of 60-69 years old.

Table 2: Summary of Descriptive Statistics for All Participants

Descriptive Category		n (%)
Race		
	American Indian or Alaskan Native	115 (0.30)
	Asian	1,660 (4.32)
	Black	559 (1.45)
	Hawaiian or other Pacific Islander	47 (0.12)
	Missing/other	651 (1.69)
	Multiracial	475 (1.24)
	white	34,929 (90.88)
Ethnicity		
	Hispanic	3,609 (9.39)
	Missing	1,223 (3.18)
	Non-Hispanic	33,604 (87.43)
County Designation		
	Rural	2,390 (6.22)
	Urban	36,046 (93.78)
Age (years)		
	20-29	725 (1.89)
	30-39	4,179 (10.87)
	40-49	7,328 (19.07)
	50-59	8,600 (22.37)
	60-69	11,049 (28.75)
	70-79	6,099 (15.87)
	80-89	445 (1.16)
	90-99	11 (0.03)

Table 3 summarizes antibody test results from all participants analyzed in this cohort. The seroprevalence was 21.24% for the T1 N test, meaning at that point in time, 21.24% of participants had antibodies from a current or past COVID-19 infection (Table 3). For the T1 S test, seroprevalence was 95.52%, meaning most participants have COVID-19 antibodies from either a natural infection or a vaccination (Table 3). During the fourth test, T4, the N test, and S test seroprevalence was 55.96% and 99.12%, respectively (Table 3).

Table 3: Summary of Antibody Test Results for All Participants (T1 = October/2020, T4 = July/2022)

Descriptive Category		n (%)
T1 N Test Diagnosis		
	Negative	30,268 (78.76%)
	Positive	8,162 (21.24%)
T1 S Test Diagnosis		
	Negative	1,632 (4.48%)
	Positive	34,829 (95.52%)
T4 N Test Diagnosis		
	Negative	16,927 (44.04%)
	Positive	21,509 (55.96%)
T4 S Test Diagnosis		
	Negative	338 (0.88%)
	Positive	38,098 (99.12%)

COVID-19 Antibodies, Spike Protein (S-Test): detects antibodies from a past COVID-19 infection and/or vaccination (positive range 08-2500U/mL)
SARS-CoV-2 Total Antibodies (N-Test): detects antibodies from a past COVID-19 infection (positive range > 1.0)

T1 N test diagnosis, T1 S test diagnosis, T4 N test diagnosis, and T4 S test diagnosis all resulted in a P-value of < 0.0001. In addition to the chi-square p-value, Table 4 includes the breakdown of rural and urban individuals and the percentage that tested negative and positive respectively. 99.17% of urban individuals and 98.37% of rural individuals were S test seropositive (Table 4).

Table 4: Comparison of Blood Test Diagnosis by Rural-Urban Residential Status (T1 = October/2020, T4 = July/2022)

Test Type	n (%)	n (%)	Chi2	P-Value
T1 N Test Diagnosis				
	Negative	Positive		
Rural	1,505 (63.00)	884 (37.00)		
Urban	28,763 (79.81)	7,278 (20.19)		
			Chi2(1) = 378.442	P < 0.001
T1 S Test Diagnosis				
	Negative	Positive		
Rural	191 (8.69)	2,006 (91.31)		
Urban	1,441 (4.21)	32,823 (95.79)		
			Chi2(1) = 92.090	P < 0.001
T4 N Test Diagnosis				
	Negative	Positive		
Rural	827 (34.60)	1,563 (65.40)		
Urban	16,100 (44.67)	19,946 (55.33)		
			Chi2(1) = 378.442	P < 0.001
T4 S Test Diagnosis				
	Negative	Positive		
Rural	39 (0.63)	2,351 (98.37)		
Urban	299 (0.83)	35,747 (99.17)		
			Chi2(1) = 16.552	P < 0.001

COVID-19 Antibodies, Spike Protein (S-Test): detects antibodies from a past COVID-19 infection and/or vaccination (positive range 08-2500U/mL)
SARS-CoV-2 Total Antibodies (N-Test): detects antibodies from a past COVID-19 infection (positive range > 1.0)

Natural infection antibodies also increased over time, with T1 N test diagnosis showing 20.19% of urban individuals and 37.00% of rural individuals had antibodies from natural infection (Table 4). Whereas for T4 N test diagnosis, 55.33% of urban individuals and 65.40% of rural individuals have detectable antibodies from a previous natural infection (Table 4).

Of the rural participants, 37.74% are fully vaccinated, and 16.28% are fully vaccinated and boosted (Table 5). 18.66% of rural participants are partially vaccinated, and 27.32% are not vaccinated. The urban participants have a 45.18% full vaccination rate, and 30.28% are fully vaccinated and boosted (Table 5). 13.13% of urban participants are partially vaccinated, and 11.41% of urban participants have not received any covid vaccines (Table 5). There was a significant difference between rural and urban status as vaccination status (p-value <0.001).

Table 5: Comparison of Vaccination Status by Rural-Urban Residential Status

	n (%) Fully Vaccinated	n (%) Fully Vaccinated and Boosted	n (%) Not Vaccinated	n (%) Partially Vaccinated	Chi2	P-Value
Rural	902 (37.74)	389 (16.28)	653 (27.32)	446 (18.66)		
Urban	16, 286 (45.18)	10,916 (30.28)	4,112 (11.41)	4,732 (13.13)		
					Chi2(3) = 686.1202	P < 0.001

Full vaccination is defined as two weeks after the second dose of an mRNA COVID-19 vaccine, two weeks after a second dose of the Novavax COVID-19 vaccine, or two weeks after you get a single dose of the Janssen/Johnson & Johnson COVID-19 vaccine.

DISCUSSION

In this study of 2,390 rural Texans and 36,046 urban Texans, rural and urban individuals had a 99.12% seroprevalence for their T4 S test. This seroprevalence indicates nearly all individuals have some protection against COVID-19 (Table 4). The calculated total seroprevalence is similar to the December 2021 CDC estimate of 94.7% seropositivity (23). There are currently a limited number of studies surrounding rural-urban communities and SARS-CoV-2 seroprevalence, specifically in the United States. A 2023 study estimates a 96.00% total SARS-CoV-2 seropositivity across 76 rural households in eastern Uganda, as compared to the T4 seroprevalence of 98.37% found in this study (24). As of February 2023, the Office for National Statistics, which is the executive office of the United Kingdom's Statistics Authority found that seropositivity from either vaccination or natural infection in England was 77.7%, Wales was 79.5%, Northern Ireland was 74.5%, and Scotland was 79.8% (25). These percentages are noticeably lower than the seropositivity calculated in this thesis. These differences could be due to sampling differences. The study from the UK used randomly selected blood samples, whereas Texas CARES is a population-level convenience sample of 90,000 participants.

As of March of 2023, 54.02% of rural participants are fully vaccinated, or fully vaccinated and boosted, and 75.46% of urban individuals are fully vaccinated, or fully vaccinated and boosted. These findings line up with previous studies that found that rural populations are less vaccinated than urban individuals. According to a 2021 study, as of August 11, 2021, 45.8% of adults in rural counties had been fully vaccinated, compared to 59.8% in urban counties (26). Although this study found similar vaccination rates, with rural being a lower percentage than urban, it should be noted that the COVID-19 booster became available in September 2021, which could explain the differences in these values (27).

These values indicate a substantial difference in vaccination rates across rural-urban communities. Vaccination is an essential tool to prevent morbidity and mortality from COVID-19 (19). Given the vast difference between rural and urban vaccination rates, one proposed method for increasing vaccination rates amongst rural individuals includes mandates (26). The analysis of rural and urban differences is important because although it is widely understood that health disparities exist across rural-urban populations, there have been limited studies of SARS-CoV-2 antibodies across this specific demographic.

These results can help inform current public health policies, health interventions, vaccination plans, and more. Considering that COVID-19 vaccinations have been available since late 2020, it is essential to understand why individuals choose not to get vaccinated. Researchers from the Learner Center of Public Health at Syracuse University found that the lower vaccination rates amongst farming and mining-dependent counties found an association with lower education, less access to physicians, and a higher share of votes for former president Donald Trump (26). Understanding the reasoning behind these differences can assist in tailoring public health practices and interventions to increase vaccination rates among rural communities. Public health implications of this research include a greater focus of reducing vaccine misinformation and barriers to healthcare. Further research should continue to monitor the seroprevalence of SARS-CoV-2 antibodies, specifically focusing on vulnerable communities.

CONCLUSION

Results show that rural participants have more antibodies from natural infections than urban participants for T1 (October/2020) and T4 (July/2022). Nearly all (99.12%) Texas residents tested positive for antibodies from either a vaccine or natural infection during their fourth test (T4, July/2022) have some amount of seroprevalence. Results show that nearly three-fourths of urban and half of rural participants are fully vaccinated or fully vaccinated and boosted. Further analysis from the Texas CARES project will allow for seroprevalence and vaccination estimates over time.

Strengths of the current study include the large cohort the data is drawn from, as large sample sizes allow for a more precise estimate of the current prevalence of COVID-19 antibodies (28). The limitations of the present study are that Texas CARES relies on a population-level convenience sample. Although this sample is large, diverse, and spread across the state, participants chose to participate in the study, which may result in selection bias. Future research should investigate the root cause of the differences between seroprevalence and vaccination rates within the urban and rural demographic. Ultimately, it is essential to understand these differences to allow public health officials to alter their COVID-19 efforts.

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