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Evaluating University and Surrounding Area Factors Causing Variability in COVID-19 Vaccine Rates Among United States Universities

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Original Research

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Abstract

Objectives: The objectives of this study were to determine how university and surrounding area characteristics are associated with student vaccination rates and vaccine exemption stringency.
Methods: This study collected data from publicly available university-associated and government-associated websites. The university and surrounding area characteristics were evaluated to elucidate how they impact student vaccination rates and ease of exemption from vaccine mandates using statistical correlations and linear regression.
Results: Lower student-to-faculty ratios and stricter university exemption strategies were significantly correlated with higher vaccination rates. Schools that did not allow for personal exemptions to vaccine mandates had significantly higher vaccination rates as compared to schools without vaccine mandates. Certain university and surrounding area characteristics, such as regional location and surrounding area vaccination rates, might serve as underlying factors in inconsistent vaccination rates on university campuses.
Conclusions: Associations were seen between some of the explanatory variables and student vaccination rates. However, more research needs to be conducted to better understand how these discussed factors affect university vaccination rates. This will allow public health professionals to be more prepared as new health concerns arise in the future.

The COVID-19 pandemic, driven by the pathogen SARS-CoV-2, quickly rose in prevalence during the end of 2019 in China and decimated public health globally throughout 2020 and 2021. As a result, researchers around the world began to focus on mitigating the negative health impact of the pandemic. Successful vaccine development and testing was done at unprecedented levels and the vaccines were quickly rolled out to the public within the 2020 year.[1] Unfortunately, as the world fought against the virus with groundbreaking pandemic research and health and safety measures, multiple variants of SARS-CoV-2 continued to emerge and reduced the effects of the mitigation efforts. One of the issues experienced in the pandemic mitigation efforts has been the reluctance of the public in getting vaccinated causing the herd immunity threshold to become relatively unachievable.[2] Herd immunity generally is achieved only with high vaccination rates, the threshold estimated to be roughly 60-70%.[3] However, the combination of vaccination hesitancy and variant emergence has made this threshold an unlikely goal, as we adjust to a new normal of pandemic wave suppressions rather than longstanding herd immunity.[4]

Many institutions began to reopen, albeit with new safety precautions, in the fall of 2020 after undergoing lockdowns and heightened safety and health precautions. Universities across America have approached the pandemic with varying levels of student vaccine requirements during this period of heightened fear and safety concern. However, with every university varying in their approach to the vaccine requirements, different results emerge. There has been speculation regarding university decision-making and the ability to enforce proper safety regulations, including vaccination mandates, depending on university location due to politicization and legalities.[5] A study done by Ghaffarzadegan et al.[6] has shown that mandating COVID-19 vaccinations have substantially lowered COVID-19 cases at universities in the eastern and southeastern regions of the US and emphasizes the contrast between university rates of those who mandated versus recommended vaccinations. However, the study does not discuss that universities often have vaccine mandates that allow for exemptions for medical, religious, and sometimes philosophical or personal reasons; and the stringency of the exemption criteria can vary by university.

The objectives of this study were: 1) analyze various university and surrounding area factors to determine if these variables affect the on-campus vaccination rates; and 2) whether the vaccine mandate exemption stringency has a significant relation to factors associated with the respective

university and surrounding area. All vaccination rate data and other variables of interest were obtained from publicly available sources to analyze for correlations and other statistical relationships.

Methods

Data Collection

University information was collected from publicly available sources for a sample of 24 universities from all 4 Census regions of the country, the North, East, Midwest, and South. Our study included 6 schools per Census region. These 4 regions were chosen to represent the US as to allow for an initial examination to see if the geographic location of the university could impact student vaccination rates or exemption stringency. Surrounding area data for the universities selected was obtained through the U.S. 2020 Census (Table 1A). All data was made publicly available by the universities and sourced from official university websites or government databases. Student population (matriculated totals only) and student-to-faculty ratio data were obtained from each university's official

Table 1. Characteristics of universities included in study: (A) A collective table of universities utilized in this study along with corresponding information for each university; (B) A collective table defining the characteristics of the universities sampled (*N*=24)

(A) University variables

University	Student population	Student to faculty ratio	Student vaccination rate (%)	Mask mandate	Ease of vaccine exemption	Surrounding area vaccination rate (%)	Population density (pop/sq.mile)	Region
1	42 347	18:1	98	Hard	Hard	73	11874.0	West
2	39 075	20:1	98	Hard	Hard	56	6759.4	West
3	35 897	18:1	95	Hard	Easy	79	4389.7	West
4	33 359	18:1	94	Hard	Easy	71	4240.8	West
5	19 900	16:1	98	Hard	Hard	33	333.0	West
6	33 047	17:1	81	Hard	Easy	59	1797.5	West
7	22 273	6:1	96	Hard	Hard	68	18529.4	Northeast
8	48 000	9:1	99	Hard	Hard	63	29091.3	Northeast
9	45 901	17:1	87	Hard	N/A	52	8881.8	Northeast
10	12 060	6:1	98	Hard	Hard	48	7174.7	Northeast
11	9 948	6:1	99	Hard	Hard	60	10376.8	Northeast
12	26 552	6:1	96	Hard	Hard	66	11959.7	Northeast
13	48 153	15:1	95	Hard	Hard	73	4450.3	Midwest
14	61 369	19:1	73	Hard	Easy	56	4170.7	Midwest
15	43 064	16:1	88	Hard	Easy	58	3418.3	Midwest
16	21 000	6:1	97	Hard	Hard	53	10039.8	Midwest
17	45 540	17:1	93	Hard	N/A	74	3514.0	Midwest
18	52 331	17:1	88	Hard	Hard	54	206.6	Midwest
19	25 642	15:1	97	Hard	Hard	56	4546.2	South
20	30 101	13:1	93	Hard	N/A	57	2933.7	South
21	14 472	8:1	95	N/A	Easy	60	2266.5	South
22	24 649	20:1	52	N/A	N/A	25	1638.3	South
23	7536	6:1	93	Easy	N/A	52	3843.6	South
24	37 842	23:1	61	Easy	N/A	36	1653.7	South

(B) Characteristics of universities included in the study

Characteristic	Statistics	Description
School type Public Private	Number (%) 18 (75) 6 (25)	The primary funding source of the university
Student population	Mean (Range) 32502 (7536, 61369)	Total number of matriculated students
Student to faculty ratio	Mean (Range) 14:1 (6:1, 23:1)	Number of students for every 1 faculty member employed at the university

(*Continued*)

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Table 1. (*Continued*)

(B) Characteristics of universities included in the study		
Characteristic	Statistics	Description
Student vaccination rates (%)	Mean (Range) 95 (52, 99)	Number of enrolled students fully vaccinated (2+ doses)
Mask Mandate N/A Easy Hard	Number (%) 2 (8.3) 2 (8.3) 20 (83)	University mask requirements: No Mandate: no requirement Easy: only required in large indoor groups Hard: required indoors for everyone
Vaccine exemption stringency N/A Easy Hard	Number (%) 6 (25) 6 (25) 12 (50)	How easy it is to obtain a COVID–19 exemption: No Requirement: no vaccines are required Easy: religious, medical, and personal exemptions are considered Hard: only religious and medical exemptions are considered
Surrounding Area Vaccination Rate (%)	Mean (Range) 57.5 (25, 79)	Vaccination rate of the surrounding city or county depending on university location
Population Density	Mean (Range) 6587.1 (206.6, 29091.3)	Population of the surrounding city or county/land area based on the 2020 Census data
Region of the United States	6 universities/region	Regions are defined by the United States Census lines

website for the 2020 academic year. Student-to-faculty ratio was included in this analysis as we hypothesized that smaller class sizes and closer relationships with professors could encourage students to receive the vaccine. Vaccination rates, mask mandates, and ease of exemption information were obtained directly from the universities via official university COVID-19 dashboards and campus health and safety websites. The vaccination rates in the surrounding area were recorded from state- or local-level government COVID-19 dashboards. The surrounding area's population density was calculated from the US Census April 1, 2020 population results.[7] The surrounding area consisted of the city or county in which the designated university campus was located. All information utilized was the most recent available as of October 15, 2021. The websites and dashboards that were accessed to obtain university and local surrounding area data are undisclosed to preserve the anonymity of the universities utilized in this study.

Data Analysis

All tables were created within Microsoft Excel V 2102 (Microsoft, Redmond, WA). Pearson's correlation was initially used to determine the strength of the linear relationship between numeric variables of interest. Variables of interest for this correlation were student vaccination rates and the various university and surrounding area characteristics: student population, student-to-faculty ratio, surrounding area vaccination rates, and surrounding area population density (Table 2A). Independent variables with significant correlations ($P < 0.05$) were then assessed on their effect on student vaccination rates utilizing simple linear regression (Table 4A).

In addition to determining the relationship between student vaccination rates and the explanatory variables, statistical tests were performed to determine relationships between vaccine exemption stringency and explanatory variables: student vaccination rate,

Table 2. Correlations between explanatory variables and student vaccination rates and exemption stringency: (A) Pearson's correlation between explanatory variables and student vaccination rates; moderate correlations of high confidence (P<0.05, r=0.40-0.59) are bolded; (B) Spearman's correlation test between student vaccination rate, explanatory variables, and vaccine exemption stringency; moderate correlations of high confidence (P<0.05, *rho*=0.40-0.59) are bolded. Strong correlations of high confidence (P<0.05, *rho*=0.60-0.79) are bolded and underlined.

(A) Pearson's Correlation of explanatory variables and student vaccination rates		
Explanatory variable	*P* value	r
Student population	0.2871	–0.227
Student to faculty ratio	**0.005346**	**–0.55**
Surrounding area vaccination rate	**0.002282**	**0.593**
Surrounding area population density	0.06437	0.383
(B) Spearman's Correlation of student vaccination rate/explanatory variables and vaccine exemption stringency		
Explanatory variable	*P* value	rho
Student vaccination rate	**$\underline{7.05\ 10^{-6}}$**	**$\underline{0.78}$**
Student population	0.742	–0.071
Student to faculty ratio	0.068	–0.379
Surrounding area vaccination rate	0.422	0.172
Surrounding area population density	**0.011**	**0.511**

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student population, student to faculty ratio, surrounding area vaccination rate, and surrounding area population density. The strength and significance ($P<0.05$) of the monotonic association between exemption stringency and the explanatory variables was measured utilizing Spearman's correlation. Spearman's correlation was used with the variable exemption stringency because it includes 3 categories: N/A (not available), Easy, and Hard exemptions as defined in Table 1B (Table 2B). Kruskal-Wallis tests were then used to investigate for significant ($P<0.05$) relationships between explanatory variables and the 3 categories of vaccine exemption stringency (Table 3).

Multivariate logistical regression tests were chosen to analyze variable relationships to the 3 categories of vaccine exemption stringency. Each of the exemption categories was run as individual binary logistic regressions with surrounding area population density, with significance representing a higher likelihood of future predictive outcomes (Table 4B).

Strength of correlation tests were assessed with the designated correlation coefficient (r, rho) values: 0.00–0.19, very weak; 0.20–0.39, weak; 0.40–0.59, moderate; 0.60–0.79, strong; and 0.80–1.0, very strong. All regression tests assume a lack of multicollinearity of the explanatory variables and that there are no influential outliers in the data. A P value ≤0.05 was considered statistically significant in all correlations, Kruskal-Wallis tests, and regressions. All data analyses were conducted using R software version R-4.0.3.[8]

Table 3. Kruskal-Wallis test for significant difference between the explanatory variables and the exemption stringency groups; significant values ($P<0.05$) are bolded

Explanatory variable	*P* value
Student vaccination rate	**0.0007**
Student population	0.790
Student to faculty ratio	0.137
Surrounding area vaccination rate	0.161
Surrounding area population density	**0.0392**

Results

Six universities were selected from each designated census region, of which 18 (75%) were public schools and 6 (25%) were private schools. Most of the universities (91.3%) required masks as of October 15, 2021. While student vaccinations were not required in all universities, over half of the students at each university were vaccinated, with vaccination rates ranging from 52-99% (Table 1B).

Student Vaccination Rate Relationships

As described above, student vaccination rates at each university were analyzed in significance and strength of linear relationship with student population, student-to-faculty ratio, surrounding area vaccination rates, and surrounding population density. The student-to-faculty ratio and surrounding area vaccination rates were both significantly associated with student vaccination rates (P=0.005 and 0.002, respectively). A moderate negative association between student-to-faculty ratio and student vaccination rates was observed. Conversely, there was a moderate positive association between surrounding area vaccination rates and student vaccination rates (P = 0.006) (Table 2A). There were no significant associations found between student vaccination rates and either student population or surrounding area population density.

When student vaccination rates were compared to the ease of exemption using simple linear regression, it was found that schools were more likely to have higher vaccination rates if they only allowed medical and religious exemptions, thus classified in the "hard" exemption stringency group (P=0.003) (Table 4A). The range of vaccination rates for universities that did not have vaccine mandates or had mandates allowing personal exemptions were notably larger than the range of vaccination rates for the schools of the strictest exemption stringency (Figure 1). While there was not

Table 4. Summary tables from regressions: (A) Simple linear regression table comparing explanatory variables against the response variable: student vaccination rates; significance level of $P<0.05$ is bolded, minor significance of $P<0.1$ is underlined; (B) Summary of multivariate logistic regression for surrounding area population density and vaccine exemption stringency (P values).

(A) Simple linear regression for explanatory variables and student vaccination rates			
Explanatory variable	Coefficient	Confidence interval	*P* value
Ease of Exemption (reference: no vaccination requirement)			
Personal, religious, and medical	7.83	(–4.47, 20.14)	0.19972
Medical and religious only	**16.75**	**(6.09, 27.41)**	**0.00366**
Student to faculty ratio	**–1.19**	**(–1.99, –0.39)**	**0.00535**
Surrounding area vaccination rate	**0.55**	**(0.22, 0.88)**	**0.00228**
Region (reference: South)			
West	12.12	(–1.75, 26.09)	0.0832
Midwest	7.17	(–6.75, 21.09)	0.2956
Northeast	**14.00**	**(0.08, 27.92)**	**0.0488**

(B) Multivariate logistic regression of surrounding area population density and exemption stringency			
Explanatory variable	No vaccine requirement	Personal, religious, and medical exemptions	Religious or medical exemptions only
Surrounding area population density	0.23	0.93	0.27

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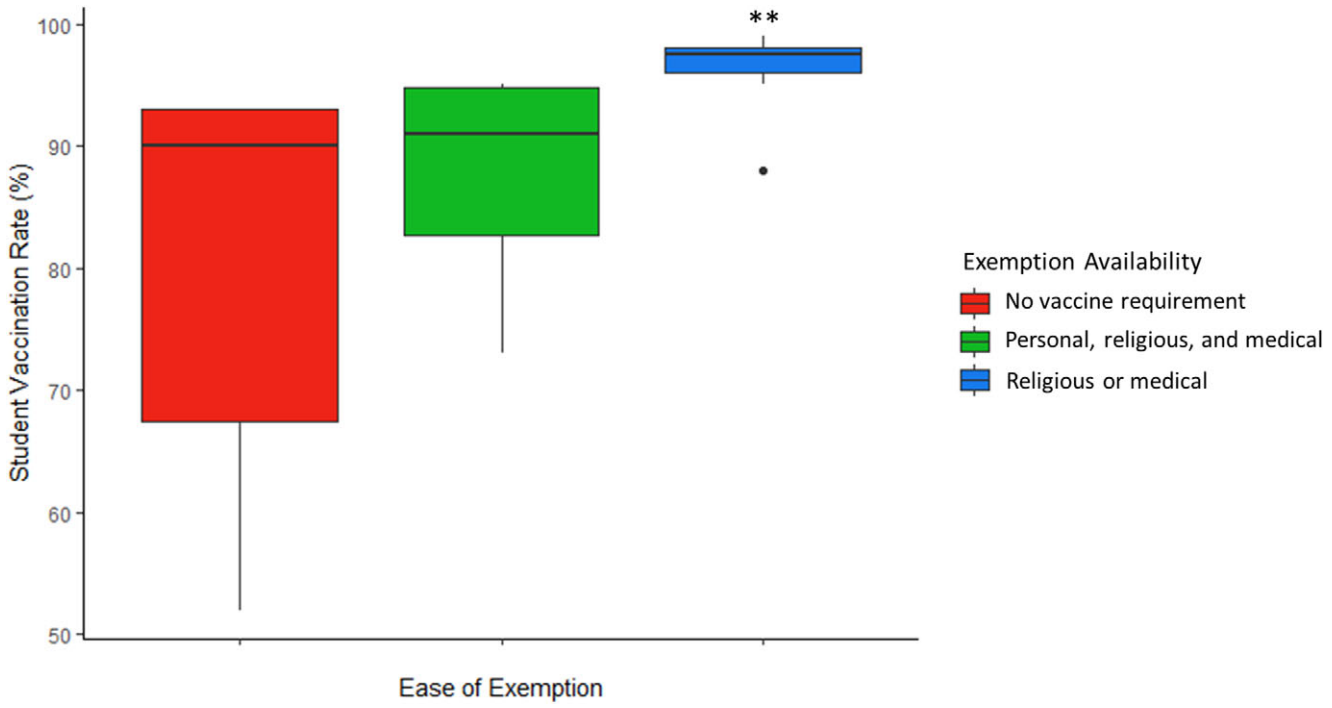

Figure 1. A comparison between ease of obtaining a vaccine exemption and student vaccination rates. Ease of exemption is ranked based on the type of exemptions accepted by the university.

a significant statistical relationship with the student population, a slightly negative linear trendline can be seen with a higher student population and lower vaccination rates (Figure 2a). A linear trendline also showed student vaccination rates decreasing as the student-to-faculty ratio increased, with a significant statistical relationship between the 2 factors as well ($P = 0.005$), validating the results from

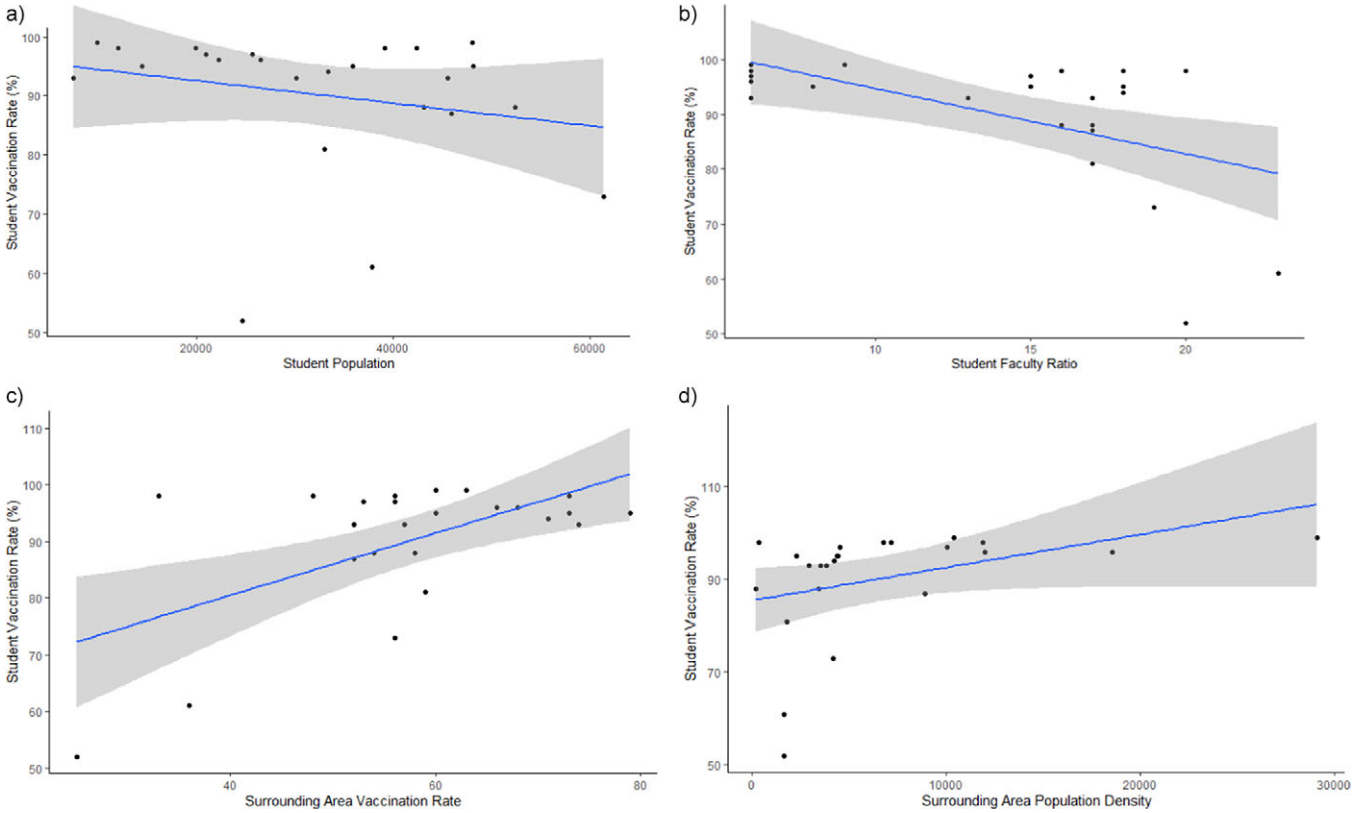

Figure 2. A comparison between explanatory variables and student vaccination rates. a) student population, b) student faculty ratios, c) surrounding area vaccination rate, and d) surrounding area population density.

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Pearson's correlation (Figure 2A and Table 4A). Schools located in cities or counties with higher vaccination rates were significantly more likely to have higher vaccination rates ($P = 0.002$) as is represented by a positive linear trendline in Figure 2c (Table 4A). The surrounding area population density also had a positive linear trend although the relationship was not statistically correlated (Figure 2d).

In Figure 3, the range of vaccination rates for the southern universities (Virginia, North Carolina, Oklahoma, Texas, Alabama, Louisiana) was notably much larger than the other regions. When statistically compared to this southern region in simple linear regression, there was a significant relationship ($P = 0.048$) between higher vaccination rates and universities located in the northeast (Pennsylvania, New York, Massachusetts, Connecticut, Rhode Island), and a slightly significant relationship ($P < 0.1$) with universities in the west (California, Colorado, Utah, Oregon) (Table 4A).

Ease of Exemption Relationships

Schools had a range of vaccine exemption options broken down into 3 categories, detailed in Table 1. Twenty five percent of the schools did not require vaccines, 25% of schools had an "easy" exemption stringency, allowing students to have religious, medical, and personal exemptions from obtaining the vaccines, and 50% of schools only considered medical or religious exemptions, causing their stringency to be categorized as "hard" (Table 1B). Factors associated with the 3 levels of vaccine exemption were analyzed for their correlations (Table 2B). There was no association between exemption stringency and student population (Figure 4a). When analyzed with student-to-faculty ratio, universities with the strictest exemption stringencies clearly had a lower median and interquartile range (IQR) of student-to-faculty ratio than the other exemption categories (Figure 4b). However, this was not significant based on Spearman's correlation (Table 2B). Further, when a Kruskal-Wallis test was performed, no significant difference in relationships was found between student-to-faculty ratios and exemption stringency groups (Tables 3 & 2B). Similar results can be seen in surrounding area vaccination rates, with the no vaccine requirement group having a lower IQR and median surrounding area vaccination rates when compared to the other categories; however, no statistical significance was found (Figure 4c, Table 2B). While surrounding area population density was significantly correlated to vaccination rates and had significant results from a Kruskal-Wallis test (Tables 2B and 3), the logistic regression showed it did not appear to have a significant effect on exemption stringency (Table 4B). However, figure 4d shows that the category of strict exemption stringencies had a higher IQR than the other categories. Figure 4e shows that the southern region had the most universities without a vaccination requirement, and the northeast had the highest number of universities with a strict exemption stringency; while the Midwest has a mix of results, all the universities sampled from the western region required a vaccination to varying degrees.

Discussion

Vaccine hesitancy has been a long-debated concern; it has existed since the introduction of vaccines in the 1700's. This skepticism peaked in the 1990's by the onset of false claims that MMR (measles, mumps, and rubella) vaccines gave children autism.[9] COVID-19 vaccines have been no exception to the controversy. Alongside general vaccination opposition, the COVID-19 vaccine has caused concerns with the speed of development, distrust of pandemic information, and fear of side effects.[10,11] The combination of vaccine hesitancy and universities reopening to in-person classes caused concern for student safety. Adding to this concern is that student's live in close quarters on or near their school's campus,

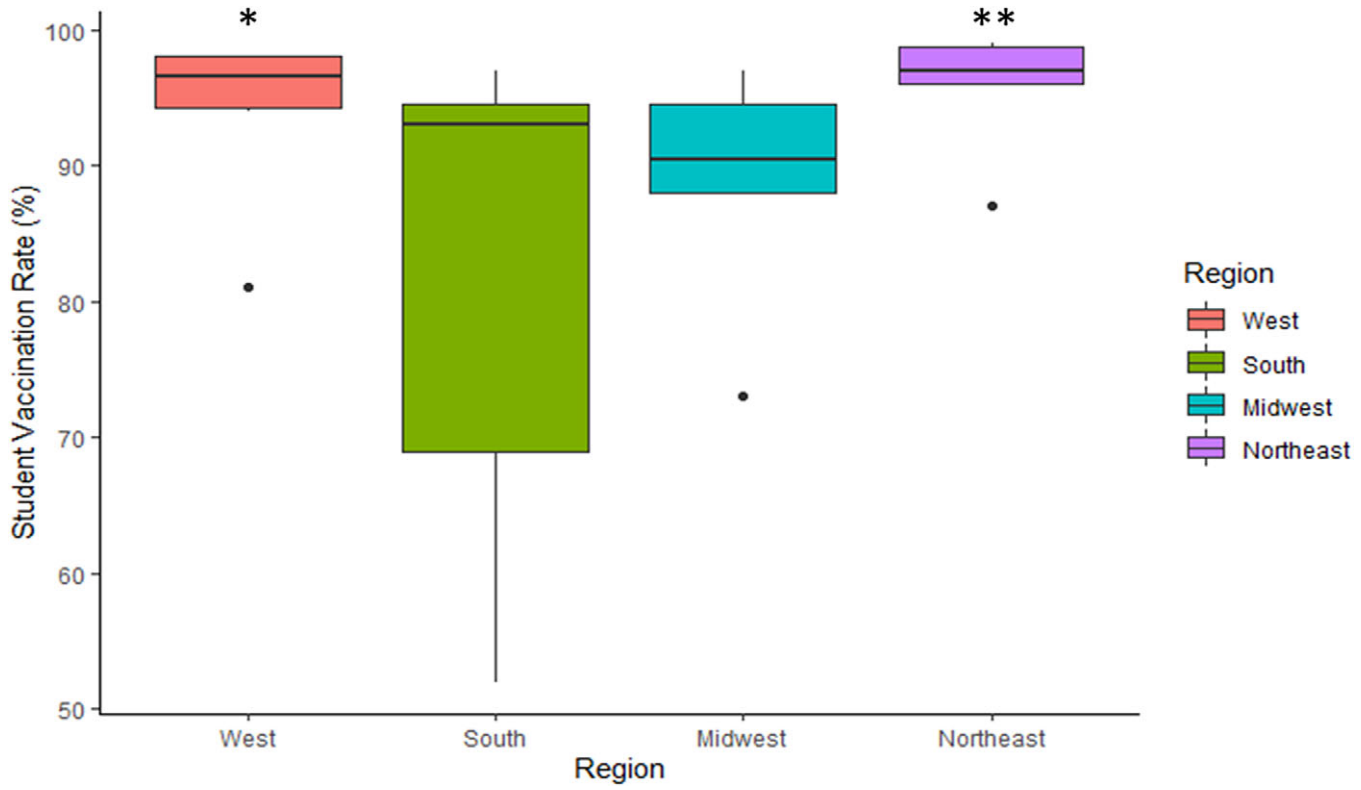

Figure 3. A comparison between the Census region in which each university is located and student vaccination rates.

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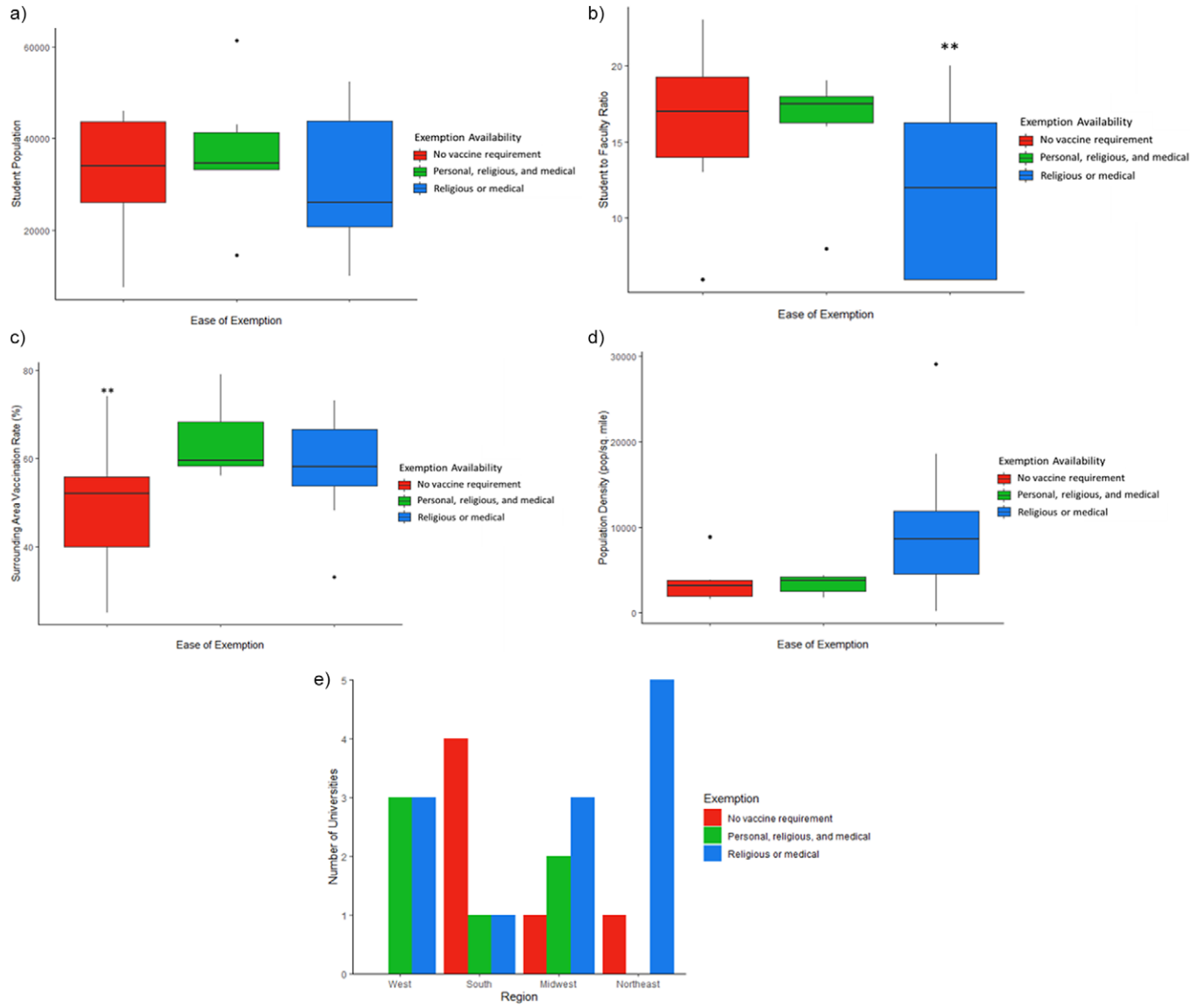

Figure 4. A comparison between explanatory variables and vaccine exemption stringency at sampled universities. Significant values (P<0.1) are marked with asterisks. a) student population, b) student to faculty ratio, c) surrounding area vaccination rates and d) population density, and e) region.

which could potentially elevate the spread of COVID-19. Studies have shown that variability in immunization has been a concern at US universities with other vaccinations, and that variability could be linked to a multitude of factors related to not only university inconsistencies, but other university characteristics such as location and exemption stringencies, as well as the student engagement and social norms.[12,13]

When looking at campus factors that potentially affected vaccination rates, schools with harder exemption stringencies were more likely to have higher student vaccination rates while universities that allowed for personal exemptions were not significantly different in vaccination rates than those that did not require vaccinations (Table 4A). This suggests that by allowing personal exemptions, the vaccine mandate was significantly less effective in enforcing compliance. A smaller student-to-faculty ratio was also associated with higher vaccination rates as well as harder vaccine exemption criteria. Smaller student-faculty ratios reflect the ability for interactions between students and faculty, as well as overall classroom engagement on college campuses.[14] Further, student engagement and influence by social norms have been shown to be a potential factor in vaccine hesitancy; students who interact regularly with peers whom they believe are vaccinated are more likely to be vaccinated as well.[13]

Another aspect of university life is engagement with the surrounding community. Population density has been shown to not only affect epidemic spread in cities but affect COVID-19 vaccination rates as well.[15–17] Residents of urban counties or counties with higher population density are more likely to be vaccinated than those of rural counties or counties with lower population density.[16,17] However relatively little is known about how these surrounding areas are potentially associated with university vaccinations. Low university vaccination rates were significantly associated with low surrounding area vaccination (Table 4A). This suggests a potential influence of surrounding areas on the university vaccination rates that should be continued to be studied.

Regionally, when compared to the South, Northeastern schools were significantly more associated with high vaccination rates (Table 4A). It's valuable to note that the South had the highest

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number of universities with no vaccine requirement (66%), while the Northeast had the largest number of universities with a strict exemption stringency (83%) (Fig 4e). While the data suggests a linear association, the reasoning is relatively difficult to address due to the amount of potential confounding factors.

One of these prominent factors is the political divide in the US. It is generally accepted that the Republican party has dominated within the Southern region since the 1970's.[18] Republican association has been linked to negative trends in vaccine perception, individual's intention to be vaccinated, and lower vaccination rates at the county level.[19,20] This relationship of political hesitancy could not only affect the regional rates, but potentially affect the perceptions of students attending universities in these counties. Within the US, the highest rate of vaccination hesitancy is within adults ages 18-25.[13] This is a safety concern not only for the young adult population on socially dense college campuses, but also for the country. Students can encourage viral transmission by travelling to and from their homes and universities or by attending social gathering activities.

This initial study presents several limitations. First, with the nature of publicly available information, this study was limited in the number and variety of universities included in the analysis. Many universities did not have vaccination information publicly accessible, and universities were often limited in the information publicly available about recent student statistics. With the evolution and spread of vaccination mandates, the vaccination rates at universities quickly rose, and website information may not have been up to date with vaccination rates, as rates quickly changed with enforcement of mandates at universities. Further, this study aimed to include data from the beginning of the Autumn 2020 semester, another constraint in the data acquisition process as many universities do not have historical pandemic records publicly available, causing the sample size to be relatively small. Additionally, this study uses a large geographic range with a relatively small sample size. While it is difficult to form concise conclusions based on region, this analysis provides an initial look at how student vaccination rates and vaccination exemption can change based on the school's geographic location. This can serve as a starting point for a more in-depth spatial analysis to better understand how universities and their surrounding areas can impact one another among pandemic-related factors, such as vaccination rates.

Overall, this study addresses potential concerns for the university communities and highlights the necessity for further research into not only how they are affected, but how these findings could be utilized to change the promotion of vaccines among young adults and reshape health and safety plans for universities in the future. The observations made in this study suggest further research needs to be performed to determine how factors associated with surrounding area characteristics could potentially affect university vaccination rates. Findings from this study can help public health professionals be prepared better as new infectious disease concerns arise in the future.

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Competing interests. The authors declare no competing interests.

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