Introduction

Effective vaccine-based containment strategies for SARS-CoV-2 require equitable coverage of communities at greatest risk of infection.\(^1\) Adapting a concept from HIV-prevention efforts,\(^2\) we examined the alignment of vaccination and SARS-CoV-2 risk in Massachusetts by creating and applying a vaccination-to-infection risk (VIR) ratio.

Methods

We aggregated community SARS-CoV-2 testing and vaccination data from the Massachusetts Department of Public Health and the Boston Public Health Commission from January 29, 2020, through June 24, 2021. Data were available for 293 distinct communities (278 cities and towns, and 15 Boston neighborhoods) with a cumulative population of 6,755,622 (98.6%). We adhered to Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines. This study involved the use of public anonymized data and was therefore designated as exempt by the Mass General Brigham Institutional Review Board.

We considered each community’s cumulative incidence of confirmed SARS-CoV-2 infections to be the best available indicator of future infection risk. We used 2 approaches to assess vaccination equity: VIR ratio and Lorenz curves. The VIR ratio was calculated for each community as the quotient of the number of fully vaccinated individuals divided by the cumulative number of confirmed SARS-CoV-2 infections. Communities with VIR ratios below the statewide mean have lower vaccination coverage relative to their infection risk. Lorenz curves, which assess equity in resource distribution,\(^3\) were used to describe vaccination relative to COVID-19 burden and calculate summaries of inequity (Gini index) and magnitude of vaccine reallocation required to achieve equity (Hoover index).

We used population estimates from the Massachusetts Department of Public Health and the American Community Survey to determine community age, race, and ethnic composition. Socioeconomic vulnerability was estimated using the Socioeconomic Status domain of the Social Vulnerability Index (census tract ranks aggregated by community). We fit a negative binomial model using robust sandwich estimators to assess associations between community VIR ratios and a priori-selected predictors: proportion 65 years or older (an early vaccination eligibility criterion), proportion identified as Black and/or Latinx individuals (<20% or \(\geq\)20%), quartile of socioeconomic vulnerability, and community size (<7500 or \(\geq\)7500 residents). Analyses were conducted in R, version 4.0.5 (R Foundation), and a 2-tailed \(P < .05\) was considered statistically significant.

Results

As of June 24, 2021, 649,379 (8.9%) SARS-CoV-2 infections had been confirmed in 6,755,622 residents of included communities, and 3,880,706 (57.4%) were fully vaccinated. Cumulative incidence of confirmed SARS-CoV-2 infection (minimum, 1.6%; maximum, 24.1%) and complete vaccination (minimum, 26.5%; maximum, 99.6%) varied considerably between communities.
The VIR ratio is calculated as the cumulative number of fully vaccinated individuals divided by the cumulative number of confirmed SARS-CoV-2 infections in each community reported from January 29, 2020, through June 24, 2021. Mean VIR by socioeconomic quartile: low, 0.18; low to moderate, 0.54; moderate to high, 5.40; and high, 2.99. Socioeconomic vulnerability was estimated using the Socioeconomic Status domain of the Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (SVI).
Communities with increased socioeconomic vulnerability had lower VIR ratios indicating less equitable vaccination relative to infection risk (Figure 1).

In multivariable analysis, decreased vaccination relative to infection risk was independently associated with increasing socioeconomic vulnerability (adjusted relative risk [aRR], 0.82 per quartile increase; 95% CI, 0.76-0.87; \( P < .001 \)) and when more than 20% of the community identified as Black and/or Latinx individuals (aRR, 0.73; 95% CI, 0.62-0.86; \( P < .001 \)). Improved community vaccine coverage was associated with higher community proportion of residents 65 years or older (aRR, 1.11 per 5% increase in proportion; 95% CI, 1.03-1.20; \( P = .007 \)) and community size fewer than 7500 residents (aRR, 1.48; 95% CI, 1.30-1.68; \( P < .001 \)).

Lorenz curves indicated considerable inequity, with an estimated Gini coefficient (1, complete equity; 0, complete inequity) of 0.51 between communities and 0.47 by race and ethnicity of individuals (Figure 2). An estimated 810 000 full vaccination courses would need to be diverted to undervaccinated communities to achieve equity.

### Discussion

In this cohort study, analysis of SARS-CoV-2 vaccination indicated structural disparity in vaccine distribution with lower vaccine coverage to infection risk in communities with increased socioeconomic vulnerability and larger proportions of Black and Latinx individuals. While a limitation of this study is that these analyses do not directly assess the mechanisms of disparity, Massachusetts prioritized large hospital systems and mass vaccination sites4 rather than strategies to mitigate structural racism recommended by others.5,6 In conclusion, disparities in vaccine coverage highlight ongoing inequities in the approach to COVID-19 and imperil efforts to control the pandemic.

---

**Figure 2. Lorenz Curves of Cumulative Proportion of Vaccination and COVID-19 Infection by Community and Individual Residents in Massachusetts**

- **Panel A:** Massachusetts communities
  - Gini index, 0.51
  - Hoover index, 0.21

- **Panel B:** Massachusetts residents
  - Gini index, 0.47
  - Hoover index, 0.35

Asian, Black, and Latinx residents, as well as residents of multiple and/or other races and ethnicities (including American Indian and Alaska Native, Native Hawaiian and Pacific Islander, and other and unspecified/unknown races) accounted for 62% of confirmed infections and 30% of full vaccinations. Cases and vaccinations reported from January 29, 2020, through June 24, 2021, are included. Socioeconomic vulnerability was estimated using the Socioeconomic Status domain of the Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (SVI).
ARTICLE INFORMATION

Accepted for Publication: July 23, 2021.
Published: September 17, 2021. doi:10.1001/jamahealthforum.2021.2666
Open Access: This is an open access article distributed under the terms of the CC-BY License. © 2021

Dryden-Peterson S et al. JAMA Health Forum.

Corresponding Author: Scott Dryden-Peterson, MD, MSc, Division of Infectious Diseases, Department of Medicine, Brigham and Women’s Hospital, 75 Francis St, Boston, MA 02115 (sldrydenpeterson@bwh.harvard.edu).

Author Affiliations: Division of Infectious Diseases, Department of Medicine, Brigham and Women’s Hospital, Boston, Massachusetts (Dryden-Peterson, Velásquez, Lockman, Ojikutu); Department of Immunology and Infectious Diseases, Harvard T.H. Chan School of Public Health, Boston, Massachusetts (Dryden-Peterson, Lockman); Botswana-Harvard AIDS Institute, Boston, Massachusetts (Dryden-Peterson, Lockman); Division of Global Health Equity, Department of Medicine, Brigham and Women’s Hospital, Boston, Massachusetts (Velásquez, Ojikutu); Department of Global Health and Social Medicine, Harvard Medical School, Boston, Massachusetts (Velásquez); Department of Public Health and Community Medicine, Tufts University School of Medicine, Boston, Massachusetts (Stopka); Tufts Clinical and Translational Science Institute, Boston, Massachusetts (Stopka); Department of Urban and Environmental Policy and Planning, Graduate School of Arts and Sciences, Tufts University, Medford, Massachusetts (Stopka); Department of Community Health, School of Arts and Sciences, Tufts University, Medford, Massachusetts (Stopka); Department of Medicine, Brigham and Women’s Hospital, Boston, Massachusetts (Davey); Division of Infectious Diseases, Massachusetts General Hospital, Boston (Gandhi, Ojikutu).

Author Contributions: Dr Dryden-Peterson had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: All authors.

Acquisition, analysis, or interpretation of data: Dryden-Peterson, Velásquez, Stopka, Ojikutu.

Drafting of the manuscript: Dryden-Peterson, Velásquez, Davey, Gandhi, Lockman.

Critical revision of the manuscript for important intellectual content: Dryden-Peterson, Velásquez, Stopka, Gandhi, Ojikutu.

Statistical analysis: Dryden-Peterson.

Obtained funding: Dryden-Peterson.

Other—provided guidance/feedback on spatial analyses: Stopka.

Other—literature review: Davey.

Conflict of Interest Disclosures: Dr Dryden-Peterson reported grants from the National Institutes of Health during the conduct of the study. Dr Velásquez reported grants from the National Institute of Allergy and Infectious Diseases during the conduct of the study and grants from the Unitaid endTB-Q trial outside the submitted work. Dr Gandhi reported personal fees from Merck and Gilead for serving on scientific advisory boards outside the submitted work. No other disclosures were reported.

Funding/Support: This work was made possible with help from the Harvard University Center for AIDS Research, a funded program of the National Institutes of Health (P30 AI060354); the National Institute of Allergy and Infectious Diseases (K08 AI147140, K24 AI131928, UMI AI069412); and the Dr Lynne Reid/Drs Eleanor and Miles Shore Fellowship at Harvard Medical School and the Burke Global Health Fellowship at the Harvard Global Health Institute (Dr Velásquez).

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Disclaimer: The contents of this manuscript are solely the responsibility of the authors and do not necessarily represent the official views of the National Institutes of Health or the institutions with which the authors are affiliated.

REFERENCES

1. Wrigley-Field E, Kiang MV, Riley AR, et al. Geographically-targeted COVID-19 vaccination is more equitable than age-based thresholds alone. medRxiv. Preprint posted online March 27, 2021. doi:10.1101/2021.03.25.21254272

2. Siegler AJ, Mouhanna F, Giler RM, et al. The prevalence of pre-exposure prophylaxis use and the pre-exposure prophylaxis-to-need ratio in the fourth quarter of 2017, United States. Ann Epidemiol. 2018;28(12):841-849. doi:10.1016/j.amepi.2018.06.005
3. Mody A, Pfeilfauf K, Geng EH. Using Lorenz curves to measure racial inequities in COVID-19 testing. JAMA Netw Open. 2021;4(1):e2032696. doi:10.1001/jamanetworkopen.2020.32696
4. Goralnick E, Kaufmann C, Gawande AA. Mass-vaccination sites—an essential innovation to curb the Covid-19 pandemic. N Engl J Med. 2021;384(18):e67. doi:10.1056/NEJMp2102535
5. Bibbins-Domingo K, Petersen M, Havlir D. Taking vaccine to where the virus is—equity and effectiveness in coronavirus vaccinations. JAMA Health Forum. 2021;2(2):e210213. doi:10.1001/jamahealthforum.2021.0213
6. Corbie-Smith G. Vaccine hesitancy is a scapegoat for structural racism. JAMA Health Forum. 2021;2(3):e210434. doi:10.1001/jamahealthforum.2021.0434