

Original article

Fighting a pandemic: sociodemographic disparities and coronavirus disease-2019 vaccination gaps—a population study

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Abstract

Background: Data suggest lower coronavirus disease-2019 (COVID-19) vaccination coverage among minority and disadvantaged groups. We aimed to identify interactions between sociodemographic factors associated with vaccination gaps.

Methods: This population study used Israeli National COVID-19 data (extracted: 10 May 2021). The analysis comprised 6 478 999 individuals age ≥ 15 years with aggregated area-level data on sex and age distribution and no COVID-19 history. We estimated vaccination hazard and cumulative incidence using the Fine and Gray competing risk model.

Results: Older age and higher socioeconomic status (SES) were associated, with step-wise higher cumulative vaccination rates (age 20–24: 67%, age ≥ 75 : 96%; SES 1–3: 61%, 4–5: 74.2%, 6–7: 82%, 8–10: 87%). We found the lowest vaccination rates in Arab (65%) and Ultra-Orthodox Jewish (54%) areas. SES modified the association in Arab neighbourhoods, with higher coverage than in the non-Orthodox Jewish reference group in SES 1–3 [adjusted hazard ratio (HR) = 1.06; 95% confidence interval (CI): 1.02–1.11], and gradually lower coverage in higher SES classes (SES 6–7: HR = 0.83; 95% CI: 0.79–0.87). Vaccination rates were also higher among younger Arabs (≤ 45 years) compared with age counterparts in the reference population group (age 25–34: HR = 1.18; 95% CI: 1.12–1.28) and lower than the reference group among Arabs age ≥ 45 years. Among Ultra-Orthodox Jews, vaccination HRs remained below one across age and SES classes.

Conclusions: Age and SES modified the association between population group and vaccination coverage. Identifying the interplay between sociodemographic characteristics and the underlying explanations may improve targeted efforts, aimed at closing vaccination coverage gaps and mitigating COVID-19.

Key words: COVID-19, vaccine, equity

Key Messages

- Lower vaccination coverage was reported among minority and disadvantaged groups.
- In this population study among nearly 6.5 million Israelis aged 15 years and older, age, socioeconomic rank and minority status were key determinants of vaccination, with generally lower rates in low-socioeconomic status (SES) areas and areas with minority predominance.
- Nevertheless, the associations between age and SES with vaccine coverage differed by population group.
- Compared with the reference majority group, vaccine coverage was consistently lower in Ultra-Orthodox Jewish areas and paradoxically higher among young and low-SES Arab community members.
- Our study demonstrates the importance of identifying interactions as the basis for targeted efforts to maximize vaccination coverage and increase equity. Further research aimed at identifying the underlying barriers to vaccination will help implement better-designed and -focused interventions.

Introduction

Minority ethnicity/race and socioeconomic deprivation are associated with higher coronavirus disease-2019 (COVID-19) burden and worse prognosis.^{1,2} These disproportionate effects on disadvantaged groups accentuate preexisting social and structural inequalities.^{3,4} Drawing from experience,^{5,6} concerns regarding vaccination disparities, particularly during early deployment of limited supplies, arose while vaccines were still under study.⁷ Advisory boards such as the World Health Organization Strategic Advisory Group of Experts on Immunization and the US Committee on Equitable Allocation of Vaccine for the Novel Coronavirus recommended prioritizing vaccine allocation based on biological and social vulnerability.^{3,8}

The messenger RNA BNT162b (Pfizer-BioNTech) vaccine was the first to receive a Food and Drug Administration (FDA) emergency use authorization on 11 December 2020. On 19 December 2020, Israel launched its national immunization campaign with the BNT162b2 vaccine administered in two doses 21 days apart.⁹ By that time, 373 509 COVID-19 cases out of a population of more than 9 million were detected.¹⁰

Persons aged 60 years or older, people at risk due to pre-existing morbidity and health care workers were among the first vaccinated. By mid-January 2021, the eligibility age was lowered to 45 and by 4 February, the vaccine was offered to all from age 16. The contributors to Israel's successful initial vaccine rollout were discussed by Rosen *et al.* and included country-, health system- and vaccine-specific factors.¹¹

Early data suggested lower vaccination rates among the Israeli Arab minority and Ultra-Orthodox Jewish population groups and variation in vaccine coverage across socioeconomic status (SES) among the 60+ population segment.^{12,13} Both above-mentioned studies relied on municipal aggregated data without examining further factors

that might explain these findings. Disparities in COVID-19 vaccination rates were recently reported in the USA.¹⁴ The factors driving these gaps may differ between populations. The latest infection surges, driven by the severe acute respiratory syndrome corona virus-2 (SARS-Cov-2) variants highlight the importance of vaccination for reducing transmission rates and the burden of hospitalizations and severe disease. The identification of specific sociodemographic characteristics and their interplay related to COVID-19 vaccination is important for informed decision making to maximize equity alongside efficiency in reaching this goal. We, therefore, aimed to identify interactions between sociodemographic characteristics associated with lower vaccination coverage.

Methods

This population study combined anonymized individual-level data from the Israeli COVID-19 National surveillance Database (extracted: 10 May 2021), and sociodemographic data published by the Israeli Central Bureau of Statistics (ICBS; updated throughout 2019). ICBS published data were aggregated by the smallest published geospatial units (referred to as 'area' hereafter) representing relatively homogeneous neighbourhoods, comprising 3000–5000 inhabitants or the entire population for small localities (<10 000 inhabitants).¹⁵ The Sheba Medical Center Institutional Review Board approved the study.

Study population

Data on area, sex, and age distribution existed for 2895 areas (99% of areas in localities permanently inhabited by at least 40 adults). Data on age were available in 5-year groups, 15–19 being the youngest group relevant for vaccination from the age of 16. The analysis population

included 6 779 750 residents, 15 years and older, with complete age and sex distribution data. We deducted the number of COVID-19 cases before 19 December 2020 from each area population (300 751 individuals in total). Compared with the general population, pre-vaccination COVID-19 cases were younger and more likely to reside in Arab and Jewish Ultra-Orthodox areas and to belong to lower SES classes ([Supplementary Table S1](#), available as [Supplementary data](#) at *IJE* online).

Variable definition

We used ICBS indexes for periphery (2015 version) based on standardized distance between residence locality and a central economic centre,¹⁶ and for SES based on demography, education, occupation and standard of living.¹⁷ Population group (Arab minority, Ultra-Orthodox Jews, Orthodox Jews, other) was determined at area level according to population group predominance in the area. The proportion of Arab inhabitants in areas labelled 'Arab' was particularly high [median = 98.4%; interquartile range (IQR): 79.5–99.6%].

Statistical analysis

Time to vaccination was the primary endpoint. We used the Fine and Gray model¹⁸ for estimating vaccine cumulative incidence and sub-distribution hazard while accounting for competing SARS-CoV-2 infection, precluding subsequent vaccination. Age-adjusted cumulative vaccination incidence rates are presented for the 60–64 age group included in the first vaccination priority group. Time was defined as days between 19 December 2020 and first dose administration (event of interest), or positive COVID-19 polymerase chain reaction (PCR) test (competing event) or censoring for end of follow-up at the data extraction date (10 May 2021). Data preparation included augmentation by event type (vaccination, infection or censoring) within time, area, sex and age-group strata (see [Supplementary material](#) for method details, available as [Supplementary data](#) at *IJE* online). We also examined cause-specific hazard censoring on a competing event. The proportional hazard assumption was tested based on weighted Schoenfeld residuals in cause-specific models. Whereas the hypothesis of zero correlation with time rank was rejected for all predictors due to large numbers, a visual inspection of graphs satisfied the assumption with correlations ranging between –0.07 and 0.01 ([Supplementary Methods](#), available as [Supplementary data](#) at *IJE* online). Age groups above 44 years were outliers, with correlations between –0.2 to –0.1, reflecting higher vaccination priority earlier in the campaign. We computed age-adjusted cumulative infection

rates (the competing event) by sociodemographic characteristics, with Cox proportional hazard models as 1-infection-free survival. We first present the result of an analysis without interactions (main effect model) and then repeat the analyses adding each interaction, separately, to the main effect model. Effect modifiers considered included SES, age, sex, population density and pre-vaccination infection rate. Data were analysed with SAS 9.4 (SAS Institute, Cary, NC).

Results

During the follow-up period, 5 001 535 individuals received at least one COVID-19 vaccine dose and 4 709 981 (94%) received two doses. Cumulative vaccination rates among vaccine-eligible men (73.8%) and women (73.6%) were similar ([Supplementary Figure S1](#), available as [Supplementary data](#) at *IJE* online).

The age distribution of the analysis population varied by sociodemographic characteristics ([Supplementary Table S2](#), available as [Supplementary data](#) at *IJE* online). Accounting for the competing SARS-Cov-2 infection risk, older age was associated with higher cumulative vaccination rates, by 10 May 2021 reaching 96% for age ≥ 75 and 67% for age 20–24 ([Figure 1a](#)). The multivariable-adjusted hazard ratio (HR) for age ≥ 75 years was 3.24 [95% confidence interval (CI): 3.14–3.34; reference = 20–24; [Table 1](#)]. The corresponding cumulative SARS-Cov-2 infection rates are presented in [Figure 1b](#).

Comparing population groups, we found the lowest vaccination rates in areas predominantly populated by Ultra-Orthodox Jews or by the Arab minority (54% and 65%, respectively, vs 78% in the reference group comprising mostly non-Orthodox Jews; [Supplementary Table S3](#), available as [Supplementary data](#) at *IJE* online). Comparable age-adjusted cumulative incidences are presented in [Figure 2a](#). The adjusted HR for Ultra-Orthodox Jews was 0.7 (95% CI: 0.68–0.72) and was 0.96 (95% CI: 0.94–0.98) for Arab communities ([Table 1](#)). Areas populated by Ultra-Orthodox Jews also had the highest competing SARS-CoV-2 infection rates (30%), whereas the rates in areas predominantly inhabited by Arabs (17%) were only slightly higher than among the reference group (15%; see [Figure 2b](#) for age-adjusted comparable cumulative rates).

Areas with Arab minority or Ultra-Orthodox Jews had lower median SES (1–3 for both compared with 6–7 for the reference population group) and were absent from the highest (8–10) SES classes. Lower SES was associated with stepwise lower age-adjusted cumulative vaccination rates ([Figure 2c](#); see [Figure 2d](#) for the corresponding cumulative infection rates). Crude vaccination coverage ranged between 61% in SES classes 1–3 (82% in ages 60–64) to

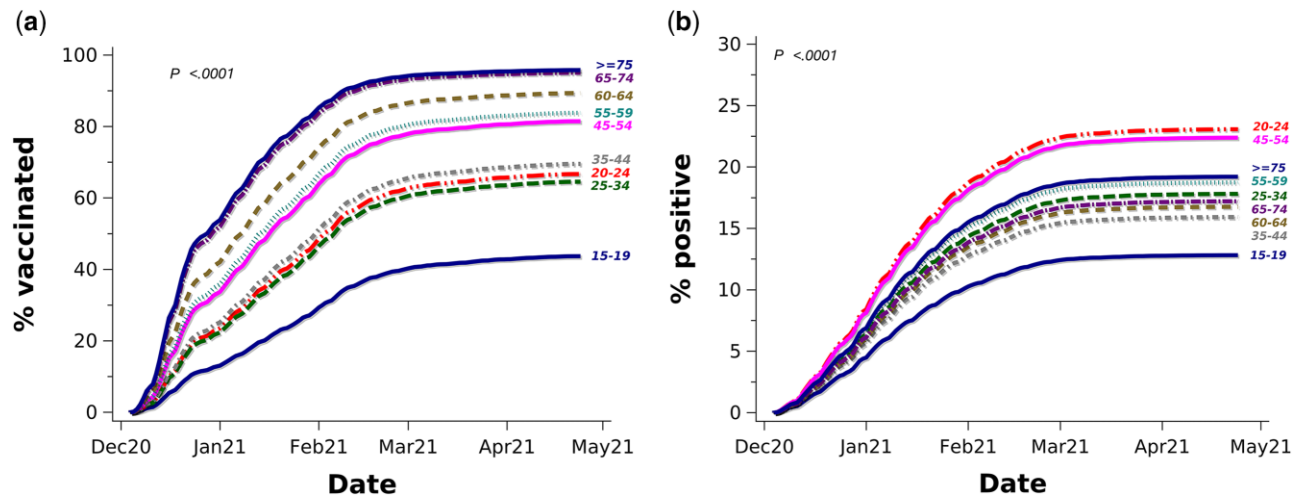


Figure 1. Cumulative vaccination incidence (a) and competing SARS-CoV-2 infection (b) rates by age group. Percentages (%) of vaccinated refer to cumulative incidence/100 accounting for the competing COVID-19 infection risk. % positive refers to cumulative SARS-CoV-2 infection rate/100 based on Kaplan-Meier infection-free survival.

Table 1 Multivariable-adjusted vaccination hazard ratios among 6 478 999 individuals aged 15 years and older

Characteristic (reference category)	HR	(95% CI)
Men (women)	1.06	(1.06–1.07)
Age, years (20–24)		
15–19	0.52	(0.50–0.54)
25–34	0.93	(0.91–0.95)
35–44	1.08	(1.05–1.11)
45–54	1.51	(1.47–1.55)
55–59	1.71	(1.67–1.76)
60–64	2.18	(2.12–2.24)
65–74	3.10	(3.01–3.20)
≥75	3.24	(3.14–3.34)
Population group (other)		
Arabs	0.96	(0.94–0.98)
Orthodox Jews	0.95	(0.90–1.00)
Ultra-Orthodox Jews	0.70	(0.68–0.72)
SES class (1–3)		
4–5	1.24	(1.21–1.28)
6–7	1.67	(1.63–1.72)
8–10	2.05	(1.98–2.11)
Locality population (<2000)		
2000–99 900	0.84	(0.82–0.87)
100 000–499 900	0.80	(0.77–0.82)
≥500 000	0.75	(0.72–0.79)
Population density population/km ² (<746)		
746–3064	1.02	(0.99–1.04)
3064–11 137	1.00	(0.97–1.04)
>11 137	0.95	(0.92–0.99)
Periphery (central)		
Very central	1.03	(1.01–1.06)
Peripheral	1.07	(1.05–1.09)
Very peripheral	1.00	(0.97–1.02)
Past SARS-CoV-2 infection rates % ^a (<0.011)		
0.011–0.383	1.50	(1.45–1.55)
>0.383	1.71	(1.66–1.77)

Model without interactions.

CI, confidence interval; HR, hazard ratio; SES, socioeconomic status.

$P < 0.0001$ for all.

^aPast SARS-CoV-2 infection rates refer to the % of area population infected up to 19 December 2020, categorized by tertiles.

82% in classes 6–7 (95% in ages 60–64) and 87% (97%) in classes 8–10. This vaccination rate gradient persisted, following adjustment, with an HR of 2.05 (95% CI: 1.98–2.11) for the highest SES (8–10) areas (reference = 1–3), which also had the lowest concurrent age-adjusted COVID-19 infection rate (Figure 2d). Vaccination coverage was higher in smaller localities (Figure 2e). The competing infection rates for the smallest (population < 2000: 15%) and largest (population ≥ 500 000: 23%) localities (see age-adjusted rates in Figure 2f) portray a reversed trend. Areas with larger households on average also had lower vaccination rates (for age-adjusted rates see Supplementary Figure S2, available as Supplementary data at *IJE* online).

Considering known SARS-CoV-2 infections prior to vaccination rollout, the multivariable-adjusted vaccination incidence rate was 71% higher (95% CI: 66–77%) in areas in the upper pre-campaign infection rate tertile than in the lowest tertile. Repeating the analysis with cause-specific models yielded similar results (Supplementary Table S4, available as Supplementary data at *IJE* online).

Examining interactions, male and female Ultra-Orthodox area residents had significantly lower adjusted vaccination rates than the reference population group (HR = 0.71; 95% CI: 0.68–0.74 and HR = 0.69; 95% CI: 0.66–0.72, respectively), whereas Arab area residents had only slightly lower (for women) or similar (for men) rates (Supplementary Figure S3, available as Supplementary data at *IJE* online). Vaccination rates in Arab areas varied by SES. The rate was higher in the lowest classes 1–3 (adjusted HR = 1.06; 95% CI: 1.02–1.11), and lower than in the same SES reference group, in higher classes (Figure 3). HRs for Arab neighbourhoods increased with increasing age up to age 25–34 (HR = 1.18; 95% CI: 1.12–1.23) and were lower than in the reference group from age 45 onwards (Figure 4). In areas populated mainly by Ultra-Orthodox Jews, HRs remained below 1.00 across SES classes and age groups. The interaction of population groups with population density was less consistent (Supplementary Figure S4, available as Supplementary data at *IJE* online).

No significant interaction was found between SES and sex (Supplementary Figure S5, available as Supplementary data at *IJE* online) but the SES gap widened with older age, (Supplementary Figure S6, available as Supplementary data at *IJE* online) and in areas with lower population density (Supplementary Figure S7, available as Supplementary data at *IJE* online). Examination of effect modification by pre-vaccination campaign infection rates showed adjusted HRs ranging from 0.55 (95% CI: 0.50–0.62) in the lowest tertile to 1.00 (0.98–1.03) in the upper infection rate tertile in Arab neighbourhoods, and from 0.29 (0.24–0.35) to 0.75 (0.73–0.78), respectively, in Ultra-Orthodox Jewish

neighbourhoods. The gap between the lowest and higher SES classes was larger in areas with low pre-vaccine infection rates (Supplementary Figure S8, available as Supplementary data at *IJE* online).

Discussion

In this nationwide study among nearly 6.5 million Israeli residents aged 15 years and older, we found vaccination rates to be independently associated with age, SES, locality size, population group and prior area SARS-Cov-2 infection rates.

Older age, in the current study, was associated with higher vaccine coverage. This cannot be explained merely by longer accessibility, as the vaccine was offered from the age of 16 within less than 2 months, and the vaccination rate gradient persisted into age groups included in the first vaccination round. COVID-19 risk perception by older adults and targeted campaign efforts may provide additional explanations. Our finding of higher vaccination rates in areas experiencing higher past infection rates supports this assumption.

Arabs, the largest minority in Israel, constitute 21% of the population¹⁹ and Ultra-Orthodox Jews constitute 12.5%.²⁰ These distinct social groups, comprising together more than a third of the Israeli population, suffered particularly high COVID-19 burden compared with other population groups. Lower COVID-19 vaccination rates among these groups are congruent with lower adult seasonal influenza vaccine rates and contrast with high rates of routine childhood vaccines among Arabs.^{12,13,21} The reasons for vaccination disparities are complex. Financial barriers, however, are less relevant for the COVID-19 vaccine, offered cost-free in Israel as in other countries.¹¹

Another possible explanation is vaccine hesitancy. An international survey conducted in June 2020 found 71.5% of 13 426 people from 19 countries to be at least somewhat likely to get vaccinated.²² Factors associated with higher acceptance rates included older age, female sex and higher income, education, risk perception and trust in government and vaccine efficacy.^{22,23} Political leaning was a risk factor in the USA for reduced vaccine acceptance.²⁴ Greater COVID-19 burden among disadvantaged groups may reinforce mistrust and vaccine hesitancy.²⁵ Reduced uptake for past vaccines and hesitancy for COVID-19 vaccines were reported for ethnic minorities in the UK.²³ In a survey conducted in October 2020, in a sample of Israelis aged 30 years or older, 41% of Arab women and 23% of Arab men rejected the COVID-19 vaccine altogether, compared with 17% and 8% of Jewish women and men, respectively.²⁶ In the current study, lower personal risk perception in Ultra-Orthodox Jewish areas with the lowest pre-vaccine infection tertile may explain their particularly low vaccine coverage.

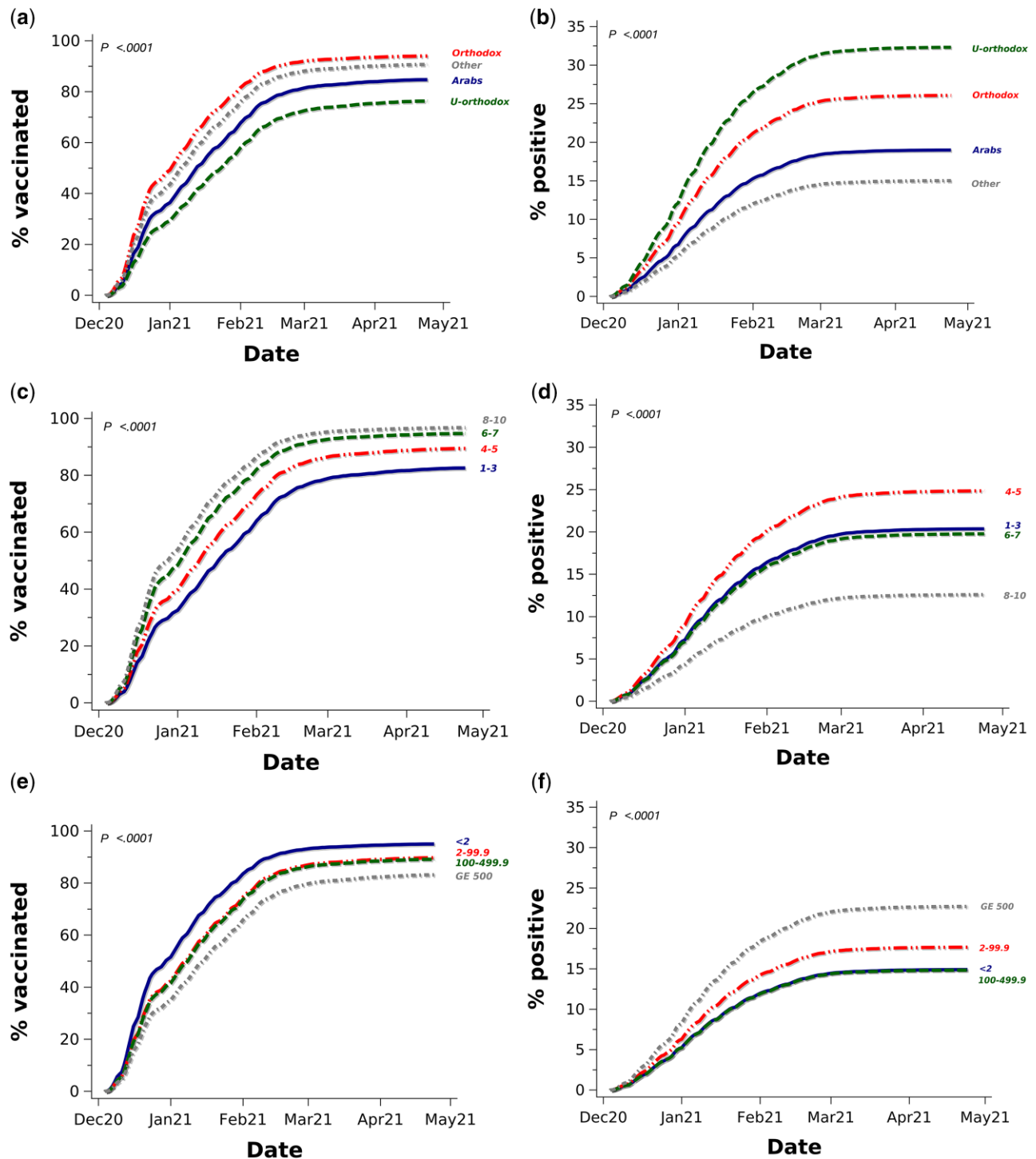


Figure 2. Age-adjusted cumulative vaccination incidence and age-adjusted competing SARS-CoV-2 infection rates by population group [(a), (b), respectively], socioeconomic status [(c), (d)] and locality population size in thousands [(e), (f)] in those aged 60–64 years. GE denotes greater than or equal to. Percentages (%) of vaccinated refer to cumulative incidence/100 accounting for the competing COVID-19 infection risk. % positive refers to cumulative SARS-CoV-2 infection rate/100 based on Kaplan-Meier infection-free survival. Results are presented for the 60–64 age slice for comparability.

The links between social groups and SES are interlaced. Our findings suggest that there may be different explanations for lower vaccination coverage in areas with predominantly Arab minority or Ultra-Orthodox Jewish inhabitants.

Among Ultra-Orthodox Jews, less likely to be vaccinated across the SES scale, higher SES had a mitigating effect. Conversely among Arab communities, lower SES was associated with higher vaccination rates, and lower rates,

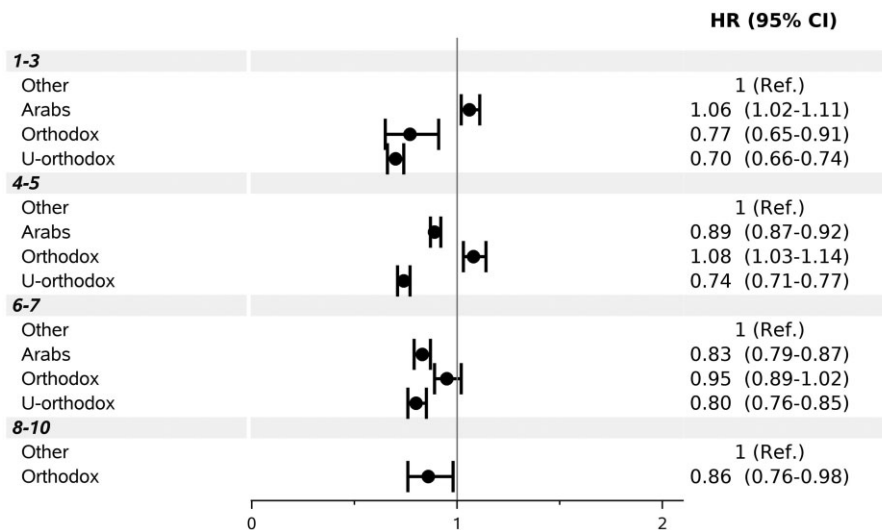


Figure 3. Multivariable-adjusted hazard ratio (HR) and 95% confidence interval (CI) under socioeconomic class and population group interaction. Ref. denotes reference. P for interaction <0.0001 .

compared with the reference group, were limited to the highest area SES for this group (classes 6–7). Age was another effect modifier. Higher vaccine rates among younger and lower rates among older individuals compared with the reference group in Arab communities may stem from lower education and health literacy among older generations²⁷ or work-related incentives among younger ones.

Disinformation may be more important where official information is restricted. Facebook as the main information source independently predicted vaccine hesitancy among health care workers in Italy.²⁸ The Israeli Ultra-Orthodox Jewish society is diverse; their closed communities shun external influences. Internet use among them reached 66% during the COVID-19 pandemic, but 85% of the Ultra-Orthodox filter content inconsistent with strict religious observance.²⁰ Alternative information sources used by these communities could channel unfounded concerns about the vaccine, particularly regarding fertility. Older and less Hebrew-proficient Arab community members may be more exposed to such sources, in spite of governmental campaigns providing reliable language and culturally congruent information through a variety of media.

The use of nationwide population data and accounting for competing infection risk are strengths of the current study. Several limitations however deserve noting. A previous study briefly reporting lower vaccination rates among Arab and Ultra-Orthodox Jewish population groups categorized mixed cities as Jewish.²⁰ Our definition of sociodemographic characteristics, based on the smallest geospatial units and relatively uniform by definition, remains ecological and deserves consideration while interpreting results. This observational study could not determine the direct cause for lower uptake in any specific area, and residual

confounding by factors not considered in the current study may exist. Targeted surveys on hesitancy and vaccination barriers employing in-person interviews may provide additional insight into possible barriers.

Missing information on non-COVID-19 related deaths resulted in censoring at data extraction date rather than at actual death. Assuming an average of 4500 deaths/month among the vaccine candidate population, we expect 22 500 deaths in total (0.3% of the candidate population) and the bias to be negligible.

The Fine and Gray model used in this study is not without limitation. Whereas this model provides a useful way for predicting cumulative incidence and the association of covariates with the cumulative incidence in the presence of informative censoring by a competing risk, it may be less suitable for causal inference.²⁹ It was also observed that the sum of cumulative incidence estimated by the model might exceed 1.00 under specific circumstances.³⁰ The similar results obtained from a cause-specific Cox model, in which concurrent infections were treated as censoring events rather than as competing risks, support the validity of using the Fine and Gray model in this study.

In conclusion, our study demonstrates the importance of extending beyond a top-level view for identifying specific groups that might benefit from tailored interventions to increase vaccination rates. Revealing combinations of characteristics linked to reduced vaccination rates may also shed light on the underlying causes, and help funnel limited resources more efficiently.

The Israeli experience demonstrates that unrestricted vaccine availability cannot guarantee equity. As the totality of minority and disadvantaged groups may represent a non-negligible portion of the society, understanding and

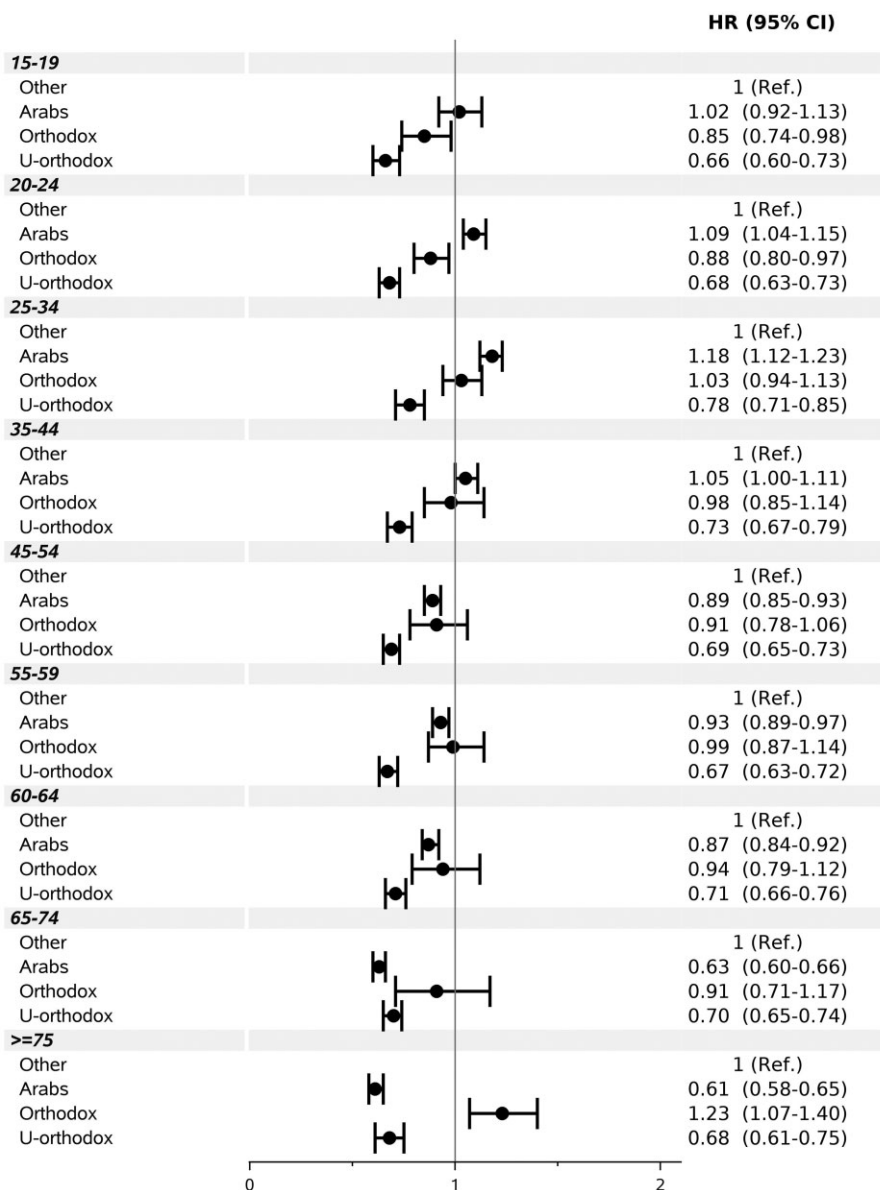


Figure 4. Multivariable-adjusted hazard ratio (HR) and 95% confidence interval (CI) under age and population group interaction. Ref. denotes reference. *P* for interaction <0.0001.

addressing disparities is not only a prerequisite for equity but also key to curtailing transmission by vaccination. Disparities between social groups may persist, as demonstrated by our study, despite a proactive approach including outreach by local clinics, language, culturally adapted vaccine information and support of religious leaders.^{11,31} Vaccination gaps are society dependent. Our results highlight the importance of identifying local factors associated with lower vaccine coverage and understanding the interplay between factors for improving targeted efforts, aimed at closing vaccination coverage gaps and mitigating COVID-19.

This study is based on data from the Israeli COVID-19 National Database and sociodemographic data published

by the Israeli Central Bureau of Statistics [<https://www.cbs.gov.il>]. Aggregated COVID-19 data by area are available on the Israel Ministry of Health website [<https://data.gov.il/dataset/covid-19>]. SAS code of interest will be shared upon request.

Supplementary Data

Supplementary data are available at *IJE* online.

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Author Contributions

All authors contributed to the study concept and design. A.Z. and M.B. were responsible for data acquisition and preparation. M.B. and I.N. performed the statistical analyses. M.B., A.Z., A.H. and O.K.L. contributed to data interpretation. The first draft was written by M.B., and all authors commented on previous versions of the manuscript and approved the final version.

Conflict of Interest

None declared.

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