



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



Original article

Socioeconomic disparities and COVID-19 vaccination acceptance: a nationwide ecologic study

Gil Caspi¹, Avshalom Dayan², Yael Eshal², Sigal Liverant-Taub³, Gilad Twig^{4, 5, 6, 7, 8}, Uri Shalit⁹, Yair Lewis¹⁰, Avi Shina^{4, 5, 8, **, †}, Oren Caspi^{2, 11, *, †}

¹) The Faculty of Electrical Engineering the Technion, Haifa, Israel

²) The B. Rappaport Faculty of Medicine, Technion, Haifa, Israel

³) Division of General Medicine, Medical Directorate, Israel Ministry of Health, Jerusalem, Israel

⁴) The Israeli Defense Forces Medical Corps, Israel

⁵) The Dr Pinchas Bornstein Talpiot Medical Leadership Program Sheba Medical Center, Ramat Gan, Israel

⁶) Sackler School of Medicine, Tel-Aviv University, Israel

⁷) Institute of Endocrinology Diabetes and Metabolism, Sheba Medical Center, Tel Hashomer, Israel

⁸) Department of Military Medicine, The Hebrew University, Jerusalem, Israel

⁹) The Faculty of Industrial Engineering and Management, Haifa, Israel

¹⁰) Maccabi Healthcare Services, Israel

¹¹) The Department of Cardiology, Rambam Health Care Campus, Haifa, Israel

ARTICLE INFO

Article history:

Received 17 February 2021

Received in revised form

13 May 2021

Accepted 20 May 2021

Available online 7 June 2021

Editor: A. Huttner

Keywords:

COVID-19

Heat map

Socioeconomic status

Vaccination percentage

Vaccine

ABSTRACT

Objective: To analyse the correlation between COVID-19 vaccination percentage and socioeconomic status (SES).

Methods: A nationwide ecologic study based on open-sourced, anonymized, aggregated data provided by the Israel Ministry of Health. The correlations between municipal SES, vaccination percentage and active COVID-19 cases during the vaccination campaign were analysed by using weighted Pearson correlations. To assess the adequacy of first dose vaccination rollout relative to the municipality COVID-19 disease burden, a metric termed the vaccination need ratio was devised by dividing the total number of active cases (per 10 000 people) by the vaccination percentage of the population over 60 in each municipality, and its correlation with the SES was examined.

Results: 23 days after initiation of the vaccination campaign, 760 916 (56.8%) individuals over the age of 60 were vaccinated in Israel with the first dose of the BNT162b2 COVID-19 vaccine. A negative correlation was found between the COVID-19 active case burden and the vaccination percentage of the study population in each municipality ($r = -0.47$, 95% CI -0.59 to -0.30). The vaccination percentage significantly correlated with the municipal SES ($r = 0.83$, 95% CI 0.79 to 0.87). This finding persisted but was attenuated over a 5-week period. A negative correlation between the vaccination need ratio and municipal SES ($r = -0.80$, 95% CI -0.88 to -0.66) was found.

Discussion: Lower COVID-19 vaccination percentage was associated with lower SES and high active disease burden. Vaccination efforts should focus on areas with lower SES and high disease burden to assure equality of vaccine allocation and potentially provide a more diligent disease mitigation. **Gil Caspi, Clin Microbiol Infect 2021;27:1502**

© 2021 European Society of Clinical Microbiology and Infectious Diseases. Published by Elsevier Ltd. All rights reserved.

* Corresponding author: Oren Caspi, Department of Cardiology, Rambam Health Care Campus and the B. Rappaport Faculty of Medicine, Technion, Haifa, Israel, POB 9602, Haifa, 31096, Israel.

** Corresponding author: Avi Shina, The Israel Defense Forces Medical Corps, Israel.

E-mail addresses: shina.avi@gmail.com (A. Shina), o_caspi@rmc.gov.il (O. Caspi).

† Both corresponding authors contributed equally to the manuscript.

Introduction

The coronavirus disease 2019 (COVID-19) pandemic had resulted in the deaths of over 3 million people worldwide by 16 April 2021 and has become a leading cause of mortality in adults. The rapid development of COVID-19 vaccines provides new hope

regarding our ability to control the pandemic [1–3]. However, while the availability of COVID-19 vaccinations is progressing globally, the pandemic is overwhelming health care system capabilities in some countries. Therefore, the limited rollout of vaccinations relative to the current COVID-19 burden mandates prioritization of the vaccination effort [4]. Currently, Israel, is one of the global leaders in vaccinating its population, making it a suitable case study for other countries as they form their vaccination strategies [5]. Many countries adopted strategies based on prioritizing elderly people, as they are at the greatest risk for severe COVID-19-related disease and mortality. In Israel, people over the age of 60, along with health care personnel, were the first to be offered the vaccine [6].

Prior survey studies suggested that vaccination percentages may be reduced among demographically defined groups of lower education and income levels [7]. Also, municipalities with a lower socioeconomic status (SES) may suffer from lower availability of health care resources, leading to poorer health and lower acceptance of public health care measures such as vaccines by their residents [8]. Concurrently, some of these populations from municipalities of lower SES and of rural locations are more severely affected by the COVID-19 pandemic worldwide [9–11]. The overarching hypothesis of our research is that populations with a lower SES are subject to a double hit risk in the setting of the current pandemic, a higher disease rate coupled with a lower vaccination acceptance.

Materials and methods

Study population

The mandatory Israeli National Health Insurance Act provides health coverage through one of the four national Health Maintenance Organizations (HMOs) to every Israeli resident. All HMOs use electronic medical records and provide COVID-19-related data and vaccination information to the Israel Ministry of Health. The national vaccination campaign was launched on 19 December 2020 in Israel, actively encouraging the population to receive the vaccine. All four national HMOs began to simultaneously vaccinate medical staff and residents older than 60 with the BNT162b2 COVID-19 vaccine across the country free of charge.

The study population consisted of the population of Israel. Included were nationally aggregated, anonymized open-source data of the COVID-19 disease incidence by municipality in Israel as well as the vaccinations given by age and municipality provided by the Israel Ministry of Health. In our database, there were 9 070 297 subjects of which 1 466 664 were aged over 60, residing in 1218 municipalities. After limiting our analysis to municipalities with a population of over 2000 also excluding 1034 municipalities (lack of COVID-19 active case data, SES ranking, vaccination data) 184 municipalities populated with 7 987 009 subjects were available for analysis. Of these, 1 338 751 subjects were older than 60, with 467 257 accumulated cases of COVID-19. A total of 1 371 506 subjects were vaccinated with the initial dose. Of these, 760 916 subjects were older than 60.

Socioeconomic status

The socioeconomic status (SES) scoring was based on the Israeli Central Bureau of Statistics (ICBS) scoring system. Accordingly, each place of residence, obtained from the Israeli Ministry of Interior, is ranked from lowest to highest SES. The score stratifies all municipalities according to multiple variables that might affect SES, such as age distribution, level of unemployment and available work force, education (the proportion of undergraduate students and

those entitled to a high school diploma), average income per capita and the proportion that receives income support. The SES data were processed from ICBS SES report 2017 (https://www.cbs.gov.il/he/mediarelease/doclib/2020/403/24_20_403t1.xlsx) and the rank of each municipality was used. The population data by age group in each municipality 2019 (https://www.cbs.gov.il/he/publications/doclib/2017/population_madaf/population_madaf_2019_1.xlsx) was taken from ICBS. Given that a municipality's population was updated 2 years ago, in some extreme cases the number of vaccinated persons over the age of 60 (currently counted) is higher than that found in the municipality's population.

To assess whether the vaccination percentage were related to SES, we evaluated the correlation between SES rank and vaccination rates in the at-risk population (aged over 60).

COVID-19 vaccination percentage and active disease burden

Data of active COVID-19 cases for each municipality were derived from the COVID-19 database of the Israeli Ministry of Health (MOH) (<https://data.gov.il/dataset/covid-19>). First-dose vaccinations by municipality and age group data were derived from a status report published by the Israeli MOH on the 12 January 2021 (<https://data.gov.il/dataset/covid-19/resource/12c9045c-1bf4-478a-a9e1-1e876cc2e182>). Only people aged >16 years were deemed eligible to be vaccinated. In the data provided by the Israeli MOH, values between 1 and 14 cases/vaccinations in a municipality were marked as '<15' without indicating the exact number, due to privacy requirements. In those cases, missing data imputation was performed by replacing '<15' with the lower bound of 1.

The COVID-19 active cases and vaccination data were reported in 279 municipalities in Israel. SES was reported in 196 out of the 279 municipalities. Vaccinations of people over the age of 60 were aggregated out of four age groups (60–69, 70–79, 80–89, 90+). We filtered out the municipalities that had more than one subgroup with missing data (<15) – and accordingly a total of 13 municipalities were omitted. Hence, our analysis was performed using data of 183 municipalities in Israel.

To generate a national heat map, colour coding of municipalities was conducted by ranking the relevant metric according to percentiles. The lower 20 and upper 80 percentile were colour coded in red and green, respectively. Colour coding was spectrally determined according to the relevant percentile.

The vaccination need ratio

To characterize the association between the COVID-19 active case burden, and the vaccination percentage of the population older than 60, we devised the vaccination need ratio (VNR). VNR is calculated by dividing the total number of active cases (per 10 000 people) by the rate of vaccination of the population over 60 in each municipality (*m*)

$$VNR = \frac{\text{Active Cases per 10,000 people}_{(m)}}{\% \text{ Vaccination of over 60 population}_{(m)}}$$

We examined the association between the municipal SES to the VNR.

Finally, we colour-coded the municipalities according to the VNR metric where municipalities at top 20 percentiles of VNR were coded in red (e.g. high number of active cases per 10 000 people and low rates of vaccination) and those in the bottom 20 percentiles were coded in green with range spectral coding of all other municipalities, accordingly. We applied our findings to create a heatmap.

Data availability

Map data are copyrighted by Mapbox contributors and are available from <https://vaccinations.covid19maps.org/>.

The institutional review board of the Israel Defense Forces Medical Corps reviewed the study and granted it a waiver due to the analysis of open-sourced anonymized aggregated data.

Statistical analysis

Continuous variables are presented as median \pm SD and categorical variables as numbers, percentages median with interquartile (IQR) range where appropriate. The correlation was analysed by using a weighted Pearson correlation (according to the municipality population over 60 from the total population over 60 from the evaluated municipalities) and the CI was calculated using a bootstrapping method with an alpha of 0.95. Basic arithmetic calculations were conducted using Python Pandas and NumPy. Statistical analysis was done using Python SciPy.

Results

At the time of analysis, the vaccination percentage of subjects over 60 in Israel was a median of 54.9% (IQR 43.5–66.7), and a total of 760,916 were vaccinated. The median of active cases per municipality was 64.6 (IQR 46.3–99.8) per 10 000 people. The ratio between the municipality's COVID-19 active disease burden, and the vaccination's percentage of 60+ population, was calculated to assess the vaccination need termed vaccination need ratio (VNR). The median VNR was 1.2 (IQR 0.76–2.41). Vaccination percentages strongly correlated with municipal SES ($r = 0.83$, 95% CI 0.79 to 0.87) as shown in Fig. 1A. This correlation persisted but was ablated over 5 weeks to $r = 0.72$, 95% CI (0.60 to 0.81) (Video S1). The vaccination percentage of the population over 60 negatively correlated with the COVID-19 disease burden measured as total active cases (per 10 000 people) in a municipality, $r = -0.47$, 95% CI -0.59 to -0.30 as depicted in Fig. 1B.

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.cmi.2021.05.030>.

We identified a significant negative correlation between municipal SES and the VNR, ($r = -0.80$, 95% CI -0.88 to -0.66). To

assess the geographical dispersion of the VNR across the country, a color-coded heatmap was generated portraying the VNR ranges between different municipalities (Fig. 2). The generated map demonstrated high VNR in northern Israel, the seam zones, and municipalities heavily populated with minorities.

Discussion

The current research identified a correlation between municipal vaccination percentages and SES. Furthermore, the need for vaccinations in municipalities (measured as the VNR) inversely correlated with the municipal SES. Finally, we generated a geographic heatmap highlighting areas of high VNR, allowing us to outline the need for vaccination in a geographical context and assisting policymakers in avoiding pockets of high COVID-19 morbidity and low immunity.

We found that municipalities with a lower SES suffer from a higher disease burden, yet their at-risk population has not been vaccinated against COVID-19 in the targeted rates. In Israel, like other countries, populations from lower SES and minorities suffer from lower accessibility and availability to health care resources. This leads to a reduced willingness to actively partake in recommended public health measures (social distancing, mask-wearing), putting these populations at an increased risk for COVID-19 infection. The reduced acceptance of these measures may further be augmented when introducing a vaccine based on novel technologies to the public potentially raising further objection and safety concerns.

The strengths of our study stem from the analysis of a nationwide, publicly available, aggregated dataset of COVID-19 morbidity and vaccinations in an ethnically heterogenous population, making our findings generalizable to other countries. Moreover, we were able to examine our findings over a five-week period enabling tracking of the vaccination efforts across municipalities. Thirdly, the timeliness of our findings is of temporal relevance to other countries. Moreover, our analysis was conducted prior to initiation of the protective effects of the vaccines expected to further widen the differences between municipalities with low and high SES. Fourth, a national diagnostic effort (a rate of over 12 tests/day per 1000 people) coupled with real-time monitoring of the vaccination percentage allow for an accurate and timely derivation of the VNR metrics. Our analysis is updated on our website (<https://>

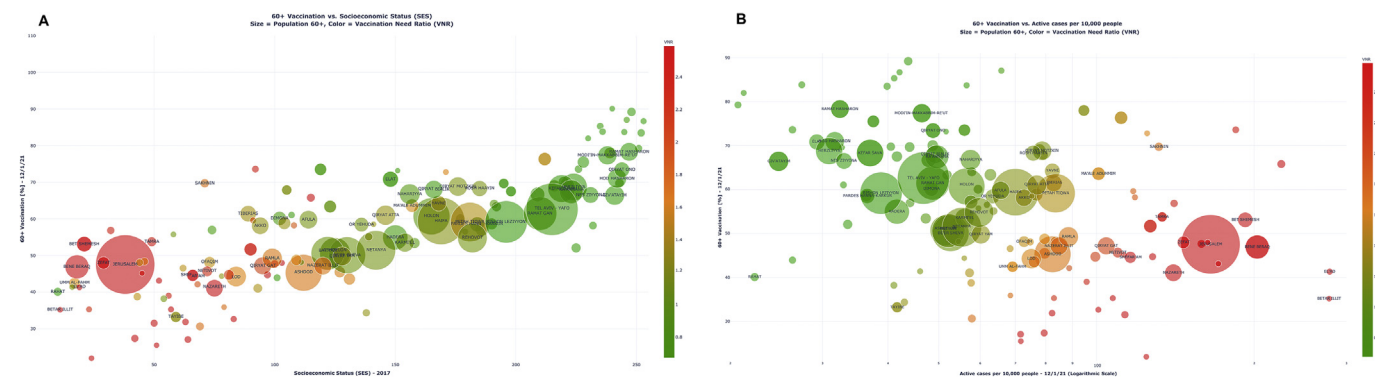


Fig. 1. (A) Correlation between vaccination of at-risk population and socioeconomic status (SES). A bubble chart depicting the association between the percentage of the vaccinated population over the age of 60 in a municipality and the municipality SES as ranked by the Israeli Central Bureau of Statistics, (higher rank means higher socioeconomic status). A strong positive correlation ($r = 0.83$, 95% CI 0.79–0.87) was found. (B) Correlation between vaccination of at-risk population and active COVID-19 cases. A bubble chart depicting the association between the percentage of vaccinated population over the age of 60 and the active COVID-19 cases (on a logarithmic scale) to the rate of the in each municipality. A moderate negative correlation ($r = -0.47$, 95% CI -0.59 to -0.30) was found. The bubble size is indicative of the size of the population than 60 while the spectral coding represents the vaccination need ratio-VNR (columns on the righthand side). Municipalities with a population older than 60 of less than 1000 are not displayed and only those with a total population of more than 30 000 are named in the chart.

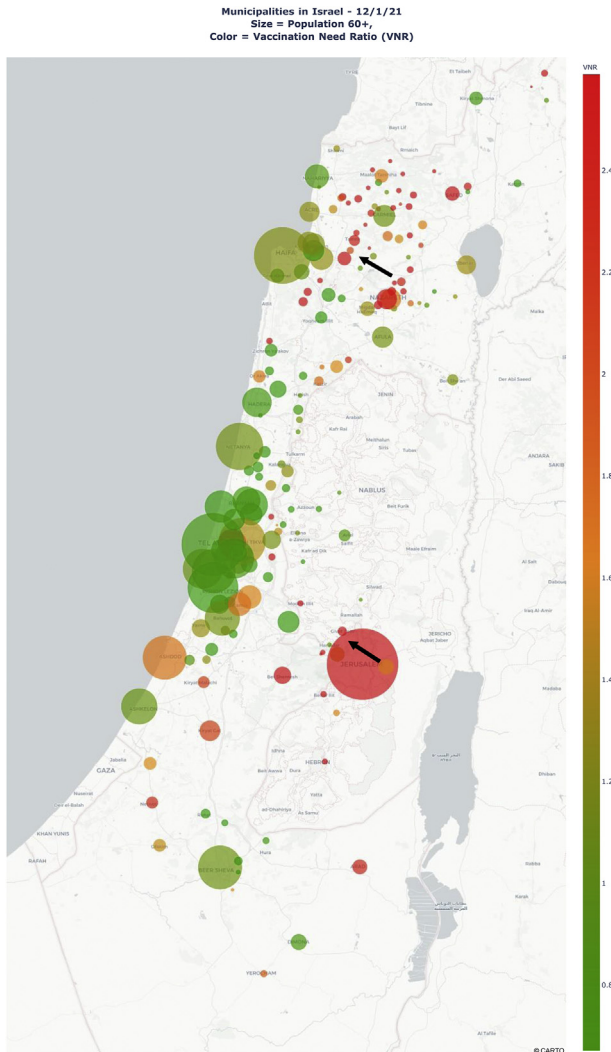


Fig. 2. Municipal nationwide vaccination need ratio (VNR) heat map. A heat map of Israel portraying the municipal nationwide VNR (colour coded) of the different municipalities. Arrow A and arrow B point to municipalities in northern Israel and the seam zone, respectively. Those municipalities have a VNR, which might be indicative of a forming geographical pocket of low immunity. The bubble size is indicative of the size of the population over the age of 60.

vaccinations.covid19maps.org/) enabling policymakers to track the effect of their actions.

Our study has limitations. SES is calculated differently in each country, though the national Israeli Central Bureau of Statistics classification correlative with metabolic disease [12] making our findings generalizable. Also, in this study, SES is used as an ecological variable and is not indicative of individual health, yet this is a more appropriate representation of its implication on municipal vaccination. We did not have available data regarding active disease burden of population over 60, or the disease severity of active cases within municipalities. As data were aggregated, we did not have available personal data regarding other COVID-19 risk factors, though older age is the most important risk factor for severe COVID-19 [13]. We were not able to remove the population aged over 60 who recovered or died from COVID-19 from the vaccination potential population in each municipality. However, at the time of analysis there were approximately 4000 COVID-19 related deaths and 5% of the population recovered from the disease in Israel. Finally, the analysis time point, three weeks following

the initiation of vaccinations in Israel, aimed to evaluate the vaccination, distribution and compliance but was not intended to evaluate vaccination efficiency.

Of note, the vaccine availability in Israel through the HMOs was equal between different municipalities, and vaccination is free to all residents. When faced with monetary and insurance barriers to health care which may exist in other countries, the need to directly target socio-economically disadvantaged populations is even more urgent. We confirm in a real-world setting, that prior concerns raised regarding vaccination acceptance in lower SES were warranted and should be addressed accordingly. Based on our findings, the Israeli Ministry of Health focused its vaccination effort on municipalities with lower SES, resulting in improved vaccination acceptance in those population.

In conclusion, as the initial vaccine rollout is limited, case numbers are spiking and more infectious COVID-19 strains are emerging, we urge policymakers to emphasize efforts of vaccination in municipalities with lower SES while using the suggested novel, metric, the VNR, to target the vaccination efforts. Geographic heatmap layering of the VNR can further assist in preventing pockets of regional decreased immunity.

Transparency declaration

Dr Caspi O received a research grant to fund this study by the Israeli Ministry of Health and the Ministry of Defense RDD&D. Shina A, Caspi G, Dayan A, Eshal Y, Lewis Y, Shalit U, Twig G and Liverant S have nothing to disclose. This study was funded through a research grant funded by the Ministry of Health Israel and the Ministry of Defense DDRD-Directorate of Defence Research & Development

Author contributions

Concept and design: Caspi G, Dayan A, Shina A, Caspi O. Acquisition, analysis, or interpretation of data: All authors. Drafting of the manuscript: Caspi G, Dayan A, Shina A, Caspi O; Validation of the results: Twig G, Liverant S, Lewis Y, Shalit U Critical revision of the manuscript for important intellectual content: All authors. Statistical analysis: Caspi G, Eshal Y, Dayan A, Twig G, Shina A, Caspi O. Journal Pre-proof Administrative, technical, or material support: Shina A, Dayan A, Caspi O, Caspi G. Supervision: Shina A, Caspi O, Caspi G, Eshal Y, Dayan A, Liverant S had full access to all the data of the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

References

- [1] Haynes BF. A new vaccine to battle Covid-19. *N Engl J Med* 2021;384:470–1.
- [2] Anderson EJ, Roupheal NG, Widge AT, Jackson LA, Roberts PC, Makhene M, et al. Safety and immunogenicity of SARS-CoV-2 mRNA-1273 vaccine in older adults. *N Engl J Med* 2020;383:2427–38.
- [3] Polack FP, Thomas SJ, Kitchin N, Absalon J, Gurtman A, Lockhart S, et al. Safety and efficacy of the BNT162b2 mRNA covid-19 vaccine. *N Engl J Med* 2020;383:2603–15.
- [4] Wood S, Schulman K. Beyond politics—promoting Covid-19 vaccination in the United States. *N Engl J Med* 2021;384:e23.
- [5] Ritchie H, Ortiz O, Beltekian D, Mathieu E, H J, B B, et al. Our world in data: coronavirus (COVID-19) vaccinations 2021. Available from: <https://ourworldindata.org/grapher/daily-covid-vaccination-doses-per-capita?tab=chart&stackMode=absolute&time=earliest..latest®ion=World>.
- [6] Lev B. EA Prioritization of COVID-19 Vaccines based on the recommendation of the COVID-19 vaccination committee-update 2. Jerusalem: Ministry of Health; 2020.
- [7] Lazarus JV, Ratzan SC, Palayew A, Gostin LO, Larson HJ, Rabin K, et al. A global survey of potential acceptance of a COVID-19 vaccine. *Nat Med* 2021;27:225.
- [8] Schaffer DeRoo S, Pudalov NJ, Fu LY. Planning for a COVID-19 vaccination program. *JAMA* 2020;323:2458–9.
- [9] Razai MS, Kankam HKN, Majeed A, Esmail A, Williams DR. Mitigating ethnic disparities in covid-19 and beyond. *BMJ* 2021;372:m4921.

- [10] Chung RY-N, Dong D, Li MM. Socioeconomic gradient in health and the covid-19 outbreak. *BMJ* 2020;369:m1329.
- [11] Emeruwa UN, Ona S, Shaman JL, Turitz A, Wright JD, Gyamfi-Bannerman C, et al. Associations between built environment, neighborhood socioeconomic status, and SARS-CoV-2 infection among pregnant women in New York City. *JAMA* 2020;324:390–2.
- [12] Twig G, Zucker I, Afek A, Cukierman-Yaffe T, Bendor CD, Derazne E, et al. Adolescent obesity and early-onset type 2 diabetes. *Diabetes Care* 2020;43:1487–95.
- [13] Petrilli CM, Jones SA, Yang J, Rajagopalan H, O'Donnell L, Chernyak Y, et al. Factors associated with hospital admission and critical illness among 5279 people with coronavirus disease 2019 in New York City: prospective cohort study. *BMJ* 2020;369:m1966.