Differences in COVID-19 vaccination in the province of Ontario across Health Regions and socio-economic strata

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# Abstract

The COVID-19 pandemic continues to be a worldwide public health concern. Although vaccines against this disease were rapidly developed, vaccination uptake has not been equal across all the segments of the population. In particular, it has been shown that there have been differences in vaccine uptake across different segments of the population. However, there are also differences in vaccination across geographical areas, which might be important to consider in the development of future public health vaccination policies. In this study, we examined the relationship between vaccination status (having received the first dose of a COVID-19 vaccine), and different socio-economic and geographical factors. Our results show that between October of 2021 and January of 2022, individuals from underrepresented communities were three times less likely to be vaccinated than White/Caucasian individuals across the province of Ontario in Canada, and that in some cases, within these groups, individuals in low-income brackets had significantly higher odds of vaccination when compared to their peers in high income brackets. Finally, we identified significantly lower odds of vaccination in the Central, East and West Health Regions of Ontario within certain underrepresented groups. This study shows that there is an ongoing need to better understand and address differences in vaccination uptake across diverse segments of the population of Ontario that the pandemic has largely impacted.

# Keywords

Covid-19, vaccination, survey, socio-economic factors, visible minorities.

# Background

As of May of 2023, there have been 765 million confirmed cases of COVID-19 around the world, including 6.8 million deaths1. Although this disease is no longer categorized as a global health emergency by the World Health Organization (WHO)2, there is ongoing concern due to continued transmission, surges in cases and deaths due to new variants3, and weaknesses in health systems around the world that could be exploited by a novel virus or another public health emergency in the future4.

In particular, a major weakness that has received attention during the pandemic has been related to inequalities in vaccine uptake. The rapid development of vaccines against COVID-19 initially brought the hope of a rapid end to the pandemic due to the start of vaccination campaigns in certain parts of the world toward the end of 20205–8) but inequalities in vaccine uptake made these pharmaceutical interventions ultimately unable to replicate the success of the smallpox vaccination program, which was crucial to control this disease9.

This problematic is a multifaceted issue resulting from a combination of factors, among which are failed public health measures10, inequality in vaccine access between high- and low-income countries11,12, and vaccine hesitancy13. Furthermore, it is well established that this issue has affected in particular individuals in certain underrepresented groups (e.g., Black, Asian, or Indigenous) as well as individuals with socio-economic disadvantages14–20.

Reasons given for this inequality have included medical mistrust due to systemic medical racism16,21, mistrust in vaccines14, and the influence of conspiracy theories21–23. However, it is important also to consider that vaccination uptake can be influenced by geographical (spatial) factors. In this regard, differences in COVID-19 vaccination rates have been associated with varied regional attitudes towards vaccination24, spatial differences in vaccine access and supply, vaccination location availability, and lack of prioritization of areas where vulnerable groups reside7,25. Other studies have also shown heterogeneity in vaccine uptake within small governmental administrative units such as counties26–29, and that accounting for geographical differences in vaccination can help predict patterns of booster uptake30.

However, such analyses have been carried out mostly in territories outside of Canada, where available studies have been focused in certain cities (such as Toronto31, or Montreal32), or have explored differences at a province-wide level18. Therefore, there is a need for studies that explore spatial differences in vaccination within the Canadian territory and that consequently, can help identify disparities that need to be addressed within specific areas in each province.

This need is especially important in the case of Ontario, the most populated province of Canada. Between 2007 and 2019, Ontario managed healthcare access to its inhabitants using 14 intra-provincial divisions called the Local Health Integration Networks (LHINs), which aimed to provide an integrated health system for the province. However, this approach was complex, bureaucratic, and resulted in excessive expenditures, disparities in mortality rates, the deterioration of certain performance indicators such as wait times and hospital readmissions, fragmented electronic health systems, the decline of performance indicators, and inequities in health services access33–37. Therefore, with the intent of better organizing and delivering care in late 2019 the provincial government eliminated the LHINs and incorporated the areas covered by them into six larger Health Regions (North East, North West, Central, Toronto, West, and East)35.

Because of the relatively recent adoption of the Health Region model and its alignment with the onset of the COVID-19 pandemic, there is a need to analyze if there are ongoing disparities in health access under this approach that need to be addressed before they are exploited by a new disease or public health threat. In this regard, previous research has highlighted disparities in the level of activity of each Health Region38. Therefore, analyzing differences in vaccination uptake within the Health Regions and can help identify which socio-demographic groups are the most vulnerable and what areas of the province deserve special attention by decision-makers.

Therefore, in this study we aim to understand the differences in vaccination uptake between the different Health Regions of Ontario between October of 2021 and January of 2022. By including socio-economic factors in our analysis, we aimed to identify in which groups these differences were significant in order to provide an assessment of the current state of healthcare access in Ontario.

# Methods

## Data and Methods

We used data from the *Survey of COVID-19 related Behaviours and Attitudes*, a repeated cross sectional survey focused on the Canadian province of Ontario that was commissioned by the Fields Institute for Research in Mathematical Sciences and the Mathematical Modelling of COVID-19 Task Force under ethical guidance from the University of Toronto (under protocol 00043317), and which ran between September 30th, 2021 and January 17th,2022. The survey collected socio-economic information from participants (Table 1), their location (nearest municipality, as shown in [Figure 1](#fig-map)), the date of access to the survey, and asked information on vaccination status by using the question “Have you received the first dose of the COVID vaccine?”, with possible answers “yes” and “no”. The original dataset contained 39,029 observations.

By design, the survey allowed respondents to exit at any time and deployed the questions randomly. This resulted in 84% of the observations having multiple missing answers or being incomplete due to participants leaving the survey at different stages. Therefore, we selected 6,343 observations that were labelled as “complete” in the dataset and that had answers for all covariates considered in our analysis. Later, we matched the city of each observation with its corresponding LHIN and Health Region, and removed observations from areas with low representation (254 observations corresponding to the North West and North East Health Regions). After all the preliminary analyses, the total number of observations used for analysis was 6,236 and included the East, Central, Toronto, and West Health Regions covering between October 1st,2021 and January 17, 2022. The original dataset, clean dataset, and details on the data cleaning process are described in detail in the [GitHub repository](https://github.com/aimundo/Fields_COVID-19/) for this paper.

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| A picture containing map, atlas, text  Description automatically generated  Figure 1: Geographic representation of the data collected by the Survey of COVID-19 related Behaviours and Attitudes, collected by the Fields Institute in Ontario. Municipalities from where survey participants provided answers appear as points, color indicates number of observation obtained from each city. The Health six Regions are color-coded and labelled sequentially. Internal boundaries within certain Health Regions indicate areas previously covered by the Local Integrated Health Networks (LHINs). |

## Statistical analyses

We used a logistic regression model to examine the impact of the Health Regions in vaccination rates while considering the socio-economic factors and months covered by the survey (Table 1) and certain interactions (Race and Health Region and Race and income), as previous studies have shown that socio-economic factors and their interactions are significant predictors of intent of vaccination and vaccination status39–41. Because we identified differences in representativity between the survey data and the estimates from the Census, we used an iterative proportional fitting procedure (*raking*)42 to correct the data using data from the Census and Health Region population totals; and fitted the regression model to the uncorrected and corrected data. Details regarding the correction can be found in the Appendix. All analyses were conducted in R 4.2.2 using the packages survey43,tidyverse44, quarto45, modelsummary46, and gtsummary47.

# Results

## Sample Characteristics

Table 1 shows the characteristics of the data from the Fields COVID-19 survey used for analysis. The sample contained 6,236 observations, from which 24.8% (1,547) corresponded to individuals that reported not having received the first dose of the vaccine. Vaccination rates ranged between 71-79% across all household income brackets, age groups, Health Regions, and the months considered in the survey. However, the highest vaccination rates in each category were reported by individuals in the highest income bracket (79%), those between 16 and 34 years of age (77%), individuals that lived in the East Health Region (77%), and during January of 2022 (78%). Between racial/ethnic groups, the highest vaccination rate was reported by White/Caucasian individuals (84%), against vaccination rates between 63-66% reported in the case of Arab/Middle Eastern, Black, Indigenous, Latin American individuals, and those that reported belonging to “Other” racial groups, which included Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere.

## *Table 1: Descriptive Statistics of the Fields COVID-19 Survey (by Vaccination Status)*

| **Variable** | **no**, N = 1,5471 | **yes**, N = 4,6891 | **p-value**2 |
| --- | --- | --- | --- |
| **Income (CAD)** |  |  | <0.001 |
| 60000 and above | 542 (21%) | 1,996 (79%) |  |
| 25000-59999 | 347 (25%) | 1,046 (75%) |  |
| under 25000 | 658 (29%) | 1,647 (71%) |  |
| **Age Group** |  |  | 0.002 |
| 16-34 | 645 (23%) | 2,117 (77%) |  |
| 35-54 | 411 (24%) | 1,305 (76%) |  |
| 55 and over | 491 (28%) | 1,267 (72%) |  |
| **Health Region** |  |  | 0.3 |
| Toronto | 593 (26%) | 1,709 (74%) |  |
| Central | 372 (26%) | 1,083 (74%) |  |
| East | 236 (23%) | 783 (77%) |  |
| West | 346 (24%) | 1,114 (76%) |  |
| **Month** |  |  | <0.001 |
| October | 469 (27%) | 1,263 (73%) |  |
| November | 376 (28%) | 980 (72%) |  |
| December | 181 (24%) | 565 (76%) |  |
| January | 521 (22%) | 1,881 (78%) |  |
| **Race** |  |  | <0.001 |
| White/Caucasian | 354 (16%) | 1,871 (84%) |  |
| Arab/Middle Eastern | 111 (34%) | 220 (66%) |  |
| Black | 159 (34%) | 303 (66%) |  |
| East Asian/Pacific Islander | 94 (19%) | 404 (81%) |  |
| Indigenous | 112 (37%) | 194 (63%) |  |
| Latin American | 99 (34%) | 195 (66%) |  |
| Mixed | 177 (30%) | 411 (70%) |  |
| Other3 | 315 (34%) | 606 (66%) |  |
| South Asian | 126 (21%) | 485 (79%) |  |
| 1n (%) | | | |
| 2Pearson's Chi-squared test | | | |
| 3Southeast Asian, Filipino, West Asian,  and minorities not identified elsewhere according to the Census. | | | |

## Multivariate Regression

[Figure 2](#fig-models) presents the estimates (as odd ratios) from the logistic regression models for vaccination status using the socio-demographic factors collected by the survey, and their interactions. Generally speaking, lower odds of vaccination were identified in both cases in individuals characterized by a low household income, or that identified as part of underrepresented groups. However, the magnitude of the estimates differed between the uncorrected and corrected models and more importantly, there were differences in the statistical significance of certain estimates before and after the correction. Specifically, the uncorrected model showed significant differences in vaccination odds between the age groups considered, the East Health Region, Latin American individuals with a household income under CAD 25,000, and Indigenous individuals living in the Central Health Region ([Figure 2](#fig-models),B) but these were deemed non statistically significant after the correction.

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| Figure 2: Coefficient estimates and confidence intervals for the uncorrected model. Only statistically significant interaction terms are shown. Full interaction terms can be found in Supplementary Figures A-3 and A-4. |

However, significantly lower odds of vaccination were identified in the corrected model for those with a household income under CAD 25,000 (OR=0.37, CI=[0.27,0.51]) and those with an income between CAD 25,000 and 59,999 (OR=0.58, CI=[0.42,0.81]). Additionally, individuals who identified as Arab/Middle Eastern, Black, Latin American, of mixed background, or that belonged to other racial groups (a category that included Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere), had significantly lower odds of vaccination than those in the White/Caucasian group (ORs and CIs=0.28 [0.16,0.51], 0.27 [0.16,0.45], 0.40 [0.21,0.76], 0.53 [0.30,0.92], 0.23 [0.15,0.36]). Additionally, individuals that reported living in the Central and West Health Regions had higher odds of vaccination than those in the Health Region of Toronto (ORs and CIs=1.61 [1.10,2.34], and 1.59 [1.16,2.19], respectively).

Interestingly, individuals in underrepresented groups with a household income below CAD 25,000 had higher odds of vaccination (when compared to those with a household income above CAD 60,000). This held true in the case of Arab/Middle Eastern individuals (OR=34, CI=[1.70,6.79]), Black individuals (OR=3.81, CI=[2.05, 7.09]), and those in other racial or ethnic groups (OR=3.19, CI=[2.00,5.09]). Additionally, individuals with an income between CAD 25,000 and 59,999 in the Arab/Middle Eastern and other racial or ethnic groups also had higher odds of vaccination than their high-income peers (ORs and CIs=6.96 [2.67,18.16], and 3.5 [1.85,6.62]).

Finally, the place of habitation affected the odds of vaccination for certain underrepresented groups, as significantly lower odds of vaccination were identified for the interaction between Health Region and race in the case of Black individuals in the Central Health Region (OR=0.39, CI=[0.2,0.75]), Arab/Middle Eastern individuals in the East Health Region (OR=0.41 [0.17, 0.98]), and in the Indigenous and mixed groups in the West Health Region (ORs and CIs=[0.31 [0.14, 0.7] and 0.38 [0.19, 0.76], respectively).

# Discussion

In this study, we hypothesized that differences in COVID-19 vaccination uptake were present between the Health Regions between late 2021 and early 2022. Our goal was to determine which socio-demographic groups could be impacted by these disparities in order to provide decision-makers with information that could be used to develop policies focused on reducing or eliminating these differences and ensuring that the Health Region model is able to fulfill its mission of improving health access for all Ontarians.

Our results show that indeed, there were differences in vaccination odds across Ontario in certain socio-demographic groups. Specifically, those who identified as Arab/Middle Eastern, Black, Latin American, having mixed racial or ethnic background, or that belonged to other groups not explicitly included in the survey (Southeast Asian, Filipino, West Asian, and minority groups not identified elsewhere) had vaccination odds that were between a third and a half of that of individuals that identified as White or Caucasian ([Figure 2](#fig-models)). These results are consistent with previous studies that have shown lower vaccination rates in individuals with the same socio-demographic characteristics18–20,48.

Lower vaccine uptake in the socio-demographic groups indicated above may be influenced in part, by vaccine hesitancy and refusal, which have been associated in underrepresented Canadian individuals with concerns on vaccine safety, effectiveness, and experiences of racial discrimination in health settings41,49–51. However, it has been shown that structural barriers also play an important role in vaccination uptake. In the case of underrepresented individuals, such barriers include complex scheduling systems, language barriers, lack of adequate public transportation, and lack of accessible vaccination sites52. In this regard, it is interesting to note that vaccination venues were scarce in low socio-economic areas that had the highest burden of COVID-19 in Toronto and other regions of Ontario around the time covered by the survey7,53, and that pharmacies in the Peel region (an area identified as a “hotspot” with high numbers of essential workers and multigenerational households) could not keep up with vaccine demand54. This suggests that the observed differences are associated with disparities in vaccine access that were present during the period covered by the survey.

Interestingly, whereas overall self-reported vaccination rates were found to be statistically significantly lower in various underrepresented groups when compared to White/Caucasian individuals, the change in odds of vaccination within certain racial groups and income strata was actually positive, in contrast to the White/Caucasian group, where vaccination odds decreased in income brackets below CAD 60,000 (Supplementary Figure A-5). Specifically, individuals in low income brackets that belonged to Arab/Middle Eastern, Black, or other minority groups had higher odds of vaccination that their peers with an income above 60,000 CAD.

This result is likely reflects in part the fact that individuals in underrepresented groups tend to perform occupations that have been deemed as “essential” in the context of the pandemic55,56, which include workers in the areas of grocery stores, gas stations, warehouses, distribution, and manufacturing, all being occupations for which an income within the significant brackets identified in the analysis is to be expected. In Ontario, these workers had priority for COVID-19 vaccination57; and there is evidence of interventions by vaccination staff in certain parts of the province to encourage vaccination uptake by these individuals54. These facts, combined with evidence of increased trends in vaccination in this group elsewhere58, suggest that the type of occupation of individuals in underrepresented groups played an important role in increasing the odds of vaccination.

However, the results also indicate that the place of habitation affected the odds of vaccination for certain underrepresented groups (interaction term of Health Region and Race, [Figure 2](#fig-models),B). Specifically, this held true in the case of individuals identifying as Indigenous or with mixed racial background in the West Health Region, Black individuals in the Central Health Region, and Arab/Middle Eastern individuals in the East Health Region [Figure 2](#fig-models). For these individuals, vaccination odds were lower when compared to the Toronto Health Region (Supplementary Figure A-6). We indicate next some contributing factors that might help provide context to these results.

First, in this case it is useful to analyze the data considering the LHINs in each Health Region, because most studies in the literature focused on Ontario use the LHINs as the base of their analyses. The West Health Region covers the area previously occupied by the Hamilton Niagara Haldimand Brant, South West, and Waterloo Wellington LHINs, whereas the East Health Region covers the area of the former Champlain and Central East LHINs. Previous research has identified health disparities in these (mostly rural) regions, such as unequal distribution of primary care providers, increased mortality, and low pharmacist availability59–61.

Furthermore, there is an ongoing challenge for the health system of the province with regard to personalized healthcare for marginalized individuals. For example, the West Health Region has only two Aboriginal Health Access Centres (community-led primary healthcare organizations focused on First Nations, Métis, and Inuit communities) to provide care to an estimated 100,000 Indigenous individuals living in the area62. Lack of access to personalized healthcare affects individuals that may mistrust the traditional healthcare system due to systemic racism or oppression, which is known to be the case for Indigenous and Black individuals in Canada, as these rationales have been associated with observed lower vaccination rates among these groups63,64. Taken together, this suggests that healthcare disparities specific to these underrepresented groups in certain parts of the province impacted vaccination uptake, and highlights the need of investments in the Health Regions focused on resources, infrastructure, and specially personnel that can deliver personalized care to marginalized communities, as it has been shown that such efforts have improved trust in vaccination in underrepresented groups elsewhere65.

There are some limitations to the present study. First, the data collection design, which allowed respondents to withdraw from the survey at any point, and that deployed the questions in a random manner resulted in an elevated number of missing observations without a definite pattern and complicated the implementation of sensitivity analyses. Therefore, we focused on entries that had complete answers, and corrected the data using population-wide information from the Census. More granular corrections would be needed to obtain more accurate estimates. For example, our analysis identified higher odds of vaccination in the Central and West Health Regions, but in this case these differences are likely to be driven by the proportion of White/Caucasian individuals, who had higher vaccination rates than other racial groups. Correcting for each racial/ethnic group in each Health Region can provide a more accurate estimation of region-wide vaccination rates but unfortunately, at the moment this correction cannot be implemented as such stratification is has not been implemented in the Census.

Additionally, our analysis did not consider the North West and North East Health Regions, due to the low number of entries from these areas in the survey ([Figure 1](#fig-map)). Low representation is expected as these regions as they only account for 5% of the total population of Ontario. However, these areas have the highest proportion of Indigenous inhabitants62. In the context of personalized care, there is a need to collect data that focuses on these Health Regions where additional health disparities might be present and possibly understudied.

The results in this study are based on self-reported data, where bias might be present. However, in the context of COVID-19, it has been shown that good agreement exists between self-reported and documented vaccination status66, we believe that our data was able to provide a valid sample of vaccination uptake in the province. This is supported by the statistically significant higher vaccination odds that were identified for January of 2022 in the model, which are consistent with province-wide trends reported by Public Health Ontario (which show a 4% increase between early December and January, in contrast to a 2.5% increase between October and November67); however, the short time window constitutes essentially a “snapshot” view of the evolution of the disease, and additional data would be needed to obtain estimates per racial/ethnic group over time across all Health Regions that can help inform the existence of other health disparities.

Nonetheless, the results presented here can serve as a starting point to motivate the collection of robust longitudinal data that can be used to quantify geographical and temporal differences within vulnerable segments of the population, and that can be used to inform the development of adequate public health policies within the province of Ontario or across other provinces in Canada that aim to minimize disparities in health access.

# Conclusion

The implementation of the Health Regions in Ontario aimed at reducing the bureaucratic complexity and health disparities identified under the LHIN model. However, there are currently multiple challenges that need to be addressed to ensure that the new model can improve healthcare for the inhabitants of the province. First, the fact that each Health Region now covers a large geographical area that was served by multiple LHINs in the past creates a complex socio-demographic landscape that is different in each case due the different levels of rurality and representation of equity-deserving groups that are now within each Health Region. So far, the evidence collected during the COVID-19 pandemic indicates that differences in vaccination uptake are associated to a lack of infrastructure and resources that can adequately support personalized care to marginalized individuals. In the near future, health decision-makers will need to consider the implementation of policies that are focused on addressing this problematic.

Moreover, the recent nature in the adaption of the Health Region poses a challenge for researchers in the acquisition of data and information that can be used to analyze the performance of the new model. From one side, the Health Regions have not been incorporated as part of Census data (LHINs were considered before in the Census), and this impact the amount and level of detail of available information. On the other hand, evaluations of the Health Region model are at the moment not considered in the Annual Reports of the Auditor General of Ontario, which was critical in the past to identify limitations in the LHIN model. Currently, the only demographic information available for each Health Region is provided by Ontario Health (the agency that administers the Health Regions) but this information only provides general estimates that do not allow for detailed analyses of performance indicators (such as hospitalizations, readmissions, and trends in chronic disease incidence) between the Regions. Therefore, there is a pressing need for open data that can be used by researchers and decision-makers to examine the performance of the Health Region model.

The Health Region model will only by successful if it ensures that healthcare improves across all segments of the population of Ontario, particularly in the event of a future public health emergency or pandemic where so far, based on the experience of the COVID-19 pandemic, underrepresented individuals have been disproportionately affected.

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# Conflicts of Interest

The authors declare no conflict of interest.

# References

1. World Health Organization Coronavirus (COVID-19) Dashboard. Accessed May 11, 2023. <https://covid19.who.int/>

2. Rigby J, Satija B. WHO declares end to COVID global health emergency. *Reuters*. Published online May 8, 2023. Accessed May 11, 2022. <https://www.reuters.com/business/healthcare-pharmaceuticals/covid-is-no-longer-global-health-emergency-who-2023-05-05/>

3. Nations U. WHO chief declares end to COVID-19 as a global health emergency. *UN News*. Published online May 5, 2023. Accessed May 11, 2022. <https://news.un.org/en/story/2023/05/1136367>

4. Mackey K, Ayers CK, Kondo KK, et al. Racial and ethnic disparities in COVID-19related infections, hospitalizations, and deaths. *Annals of Internal Medicine*. 2021;174(3):362-373. doi:[10.7326/m20-6306](https://doi.org/10.7326/m20-6306)

5. Microbe TL. COVID-19 vaccines: The pandemic will not end overnight. *The Lancet Microbe*. 2021;2(1):e1. doi:[10.1016/s2666-5247(20)30226-3](https://doi.org/10.1016/s2666-5247(20)30226-3)

6. Davis CJ, Golding M, McKay R. Efficacy information influences intention to take COVID-19 vaccine. *British Journal of Health Psychology*. 2022;27(2):300-319. doi:<https://doi.org/10.1111/bjhp.12546>

7. Bogoch II, Halani S. COVID-19 vaccines: A geographic, social and policy view of vaccination efforts in ontario, canada. *Cambridge Journal of Regions, Economy and Society*. Published online November 2022. doi:[10.1093/cjres/rsac043](https://doi.org/10.1093/cjres/rsac043)

8. Tanne JH. Covid-19: FDA panel votes to authorise pfizer BioNTech vaccine. *BMJ*. Published online December 2020:m4799. doi:[10.1136/bmj.m4799](https://doi.org/10.1136/bmj.m4799)

9. Kayser V, Ramzan I. Vaccines and vaccination: History and emerging issues. *Human Vaccines &amp$\mathsemicolon$ Immunotherapeutics*. 2021;17(12):5255-5268. doi:[10.1080/21645515.2021.1977057](https://doi.org/10.1080/21645515.2021.1977057)

10. Li Q, Wang J, Tang Y, Lu H. Next-generation COVID-19 vaccines: Opportunities for vaccine development and challenges in tackling COVID-19. *Drug Discoveries & Therapeutics*. 2021;15(3):118-123. doi:[10.5582/ddt.2021.0105](https://doi.org/10.5582/ddt.2021.0105)

11. Gerretsen P, Kim J, Caravaggio F, et al. Individual determinants of COVID-19 vaccine hesitancy. Inbaraj LR, ed. *PLOS ONE*. 2021;16(11):e0258462. doi:[10.1371/journal.pone.0258462](https://doi.org/10.1371/journal.pone.0258462)

12. Yamey G, Garcia P, Hassan F, et al. It is not too late to achieve global covid-19 vaccine equity. *BMJ*. Published online March 2022:e070650. doi:[10.1136/bmj-2022-070650](https://doi.org/10.1136/bmj-2022-070650)

13. Nafilyan V, Dolby T, Razieh C, et al. Sociodemographic inequality in COVID-19 vaccination coverage among elderly adults in england: A national linked data study. *BMJ Open*. 2021;11(7):e053402. doi:[10.1136/bmjopen-2021-053402](https://doi.org/10.1136/bmjopen-2021-053402)

14. Willis DE, Andersen JA, Bryant-Moore K, et al. COVID-19 vaccine hesitancy: Race/ethnicity, trust, and fear. *Clinical and Translational Science*. 2021;14(6):2200-2207. doi:[10.1111/cts.13077](https://doi.org/10.1111/cts.13077)

15. Skirrow H, Barnett S, Bell S, et al. Women’s views on accepting COVID-19 vaccination during and after pregnancy, and for their babies: A multi-methods study in the UK. *BMC Pregnancy and Childbirth*. 2022;22(1). doi:[10.1186/s12884-021-04321-3](https://doi.org/10.1186/s12884-021-04321-3)

16. Stoler J, Enders AM, Klofstad CA, Uscinski JE. The limits of medical trust in mitigating COVID-19 vaccine hesitancy among black americans. *Journal of General Internal Medicine*. 2021;36(11):3629-3631. doi:[10.1007/s11606-021-06743-3](https://doi.org/10.1007/s11606-021-06743-3)

17. Khubchandani J, Sharma S, Price JH, Wiblishauser MJ, Sharma M, Webb FJ. COVID-19 vaccination hesitancy in the united states: A rapid national assessment. *Journal of Community Health*. 2021;46(2):270-277. doi:[10.1007/s10900-020-00958-x](https://doi.org/10.1007/s10900-020-00958-x)

18. Guay M, Maquiling A, Chen R, et al. Measuring inequalities in COVID-19 vaccination uptake and intent: Results from the canadian community health survey 2021. *BMC Public Health*. 2022;22(1). doi:[10.1186/s12889-022-14090-z](https://doi.org/10.1186/s12889-022-14090-z)

19. Muhajarine N, Adeyinka DA, McCutcheon J, Green KL, Fahlman M, Kallio N. COVID-19 vaccine hesitancy and refusal and associated factors in an adult population in saskatchewan, canada: Evidence from predictive modelling. Gesser-Edelsburg A, ed. *PLOS ONE*. 2021;16(11):e0259513. doi:[10.1371/journal.pone.0259513](https://doi.org/10.1371/journal.pone.0259513)

20. Hussain B, Latif A, Timmons S, Nkhoma K, Nellums LB. Overcoming COVID-19 vaccine hesitancy among ethnic minorities: A systematic review of UK studies. *Vaccine*. 2022;40(25):3413-3432. doi:[10.1016/j.vaccine.2022.04.030](https://doi.org/10.1016/j.vaccine.2022.04.030)

21. Mosby I, Swidrovich J. Medical experimentation and the roots of COVID-19 vaccine hesitancy among indigenous peoples in canada. *Canadian Medical Association Journal*. 2021;193(11):E381-E383. doi:[10.1503/cmaj.210112](https://doi.org/10.1503/cmaj.210112)

22. Bogart LM, Ojikutu BO, Tyagi K, et al. COVID-19 related medical mistrust, health impacts, and potential vaccine hesitancy among black americans living with HIV. *JAIDS Journal of Acquired Immune Deficiency Syndromes*. 2021;86(2):200-207. doi:[10.1097/qai.0000000000002570](https://doi.org/10.1097/qai.0000000000002570)

23. Freeman D, Loe BS, Chadwick A, et al. COVID-19 vaccine hesitancy in the UK: The oxford coronavirus explanations, attitudes, and narratives survey (oceans) II. *Psychological Medicine*. 2020;52(14):3127-3141. doi:[10.1017/s0033291720005188](https://doi.org/10.1017/s0033291720005188)

24. Malik AA, McFadden SM, Elharake J, Omer SB. Determinants of COVID-19 vaccine acceptance in the US. *EClinicalMedicine*. 2020;26:100495. doi:[10.1016/j.eclinm.2020.100495](https://doi.org/10.1016/j.eclinm.2020.100495)

25. Nguyen KH, Nguyen K, Corlin L, Allen JD, Chung M. Changes in COVID-19 vaccination receipt and intention to vaccinate by socioeconomic characteristics and geographic area, united states, january 6 march 29, 2021. *Annals of Medicine*. 2021;53(1):1419-1428. doi:[10.1080/07853890.2021.1957998](https://doi.org/10.1080/07853890.2021.1957998)

26. Mollalo A, Tatar M. Spatial modeling of COVID-19 vaccine hesitancy in the united states. *International Journal of Environmental Research and Public Health*. 2021;18(18):9488. doi:[10.3390/ijerph18189488](https://doi.org/10.3390/ijerph18189488)

27. Yang TC, Matthews SA, Sun F. Multiscale dimensions of spatial process: COVID-19 fully vaccinated rates in u.s. counties. *American Journal of Preventive Medicine*. 2022;63(6):954-961. doi:[10.1016/j.amepre.2022.06.006](https://doi.org/10.1016/j.amepre.2022.06.006)

28. Tiu A, Susswein Z, Merritt A, Bansal S. Characterizing the spatiotemporal heterogeneity of the COVID-19 vaccination landscape. *American Journal of Epidemiology*. 2022;191(10):1792-1802. doi:[10.1093/aje/kwac080](https://doi.org/10.1093/aje/kwac080)

29. Bhuiyan MAN, Davis TC, Arnold CL, et al. Using the social vulnerability index to assess COVID-19 vaccine uptake in louisiana. *GeoJournal*. Published online December 2022. doi:[10.1007/s10708-022-10802-5](https://doi.org/10.1007/s10708-022-10802-5)

30. Wood AJ, MacKintosh AM, Stead M, Kao RR. Predicting future spatial patterns in COVID-19 booster vaccine uptake. Published online September 2022. doi:[10.1101/2022.08.30.22279415](https://doi.org/10.1101/2022.08.30.22279415)

31. Choi KH, Denice PA, Ramaj S. Vaccine and COVID-19 trajectories. *Socius: Sociological Research for a Dynamic World*. 2021;7:237802312110529. doi:[10.1177/23780231211052946](https://doi.org/10.1177/23780231211052946)

32. McKinnon B, Quach C, Dubé Ève, Nguyen CT, Zinszer K. Social inequalities in COVID-19 vaccine acceptance and uptake for children and adolescents in montreal, canada. *Vaccine*. 2021;39(49):7140-7145. doi:[10.1016/j.vaccine.2021.10.077](https://doi.org/10.1016/j.vaccine.2021.10.077)

33. Tsasis P, Evans JM, Owen S. Reframing the challenges to integrated care: A complex-adaptive systems perspective. *International Journal of Integrated Care*. 2012;12(5). doi:[10.5334/ijic.843](https://doi.org/10.5334/ijic.843)

34. Muratov S, Lee J, Holbrook A, et al. Regional variation in healthcare spending and mortality among senior high-cost healthcare users in ontario, canada: A retrospective matched cohort study. *BMC Geriatrics*. 2018;18(1). doi:[10.1186/s12877-018-0952-7](https://doi.org/10.1186/s12877-018-0952-7)

35. Dong L, Sahu R, Black R. Governance in the transformational journey toward integrated healthcare: The case of ontario. *Journal of Information Technology Teaching Cases*. Published online December 2022:204388692211473. doi:[10.1177/20438869221147313](https://doi.org/10.1177/20438869221147313)

36. Auditor General of Ontario O of the, ed. Annual Report 2015. In: *Section 3.08: LHINs - Local Health Integration Networks*. Queen’s Printer for Ontario; 2015. Accessed May 12, 2023. <https://www.auditor.on.ca/en/content/annualreports/arreports/en15/3.08en15.pdf>

37. Auditor General of Ontario O of the, ed. Annual Report 2016. In: *Section 3.03: Electronic Health Records’ Implementation Status*. Queen’s Printer for Ontario; 2016. Accessed May 12, 2023. <https://www.auditor.on.ca/en/content/annualreports/arreports/en16/v1_303en16.pdf>

38. Sethuram C, McCutcheon T, Liddy C. An environmental scan of ontario health teams: A descriptive study. *BMC Health Services Research*. 2023;23(1). doi:[10.1186/s12913-023-09102-6](https://doi.org/10.1186/s12913-023-09102-6)

39. Nguyen KH, Anneser E, Toppo A, Allen JD, Parott JS, Corlin L. Disparities in national and state estimates of COVID-19 vaccination receipt and intent to vaccinate by race/ethnicity, income, and age group among adults  18 years, united states. *Vaccine*. 2022;40(1):107-113. doi:[10.1016/j.vaccine.2021.11.040](https://doi.org/10.1016/j.vaccine.2021.11.040)

40. Shih SF, Wagner AL, Masters NB, Prosser LA, Lu Y, Zikmund-Fisher BJ. Vaccine hesitancy and rejection of a vaccine for the novel coronavirus in the united states. *Frontiers in Immunology*. 2021;12. doi:[10.3389/fimmu.2021.558270](https://doi.org/10.3389/fimmu.2021.558270)

41. Cénat JM, Noorishad PG, Farahi SMMM, et al. Prevalence and factors related to COVID-19 vaccine hesitancy and unwillingness in canada: A systematic review and meta-analysis. *Journal of Medical Virology*. 2022;95(1). doi:[10.1002/jmv.28156](https://doi.org/10.1002/jmv.28156)

42. Deming WE, Stephan FF. On a least squares adjustment of a sampled frequency table when the expected marginal totals are known. *The Annals of Mathematical Statistics*. 1940;11(4):427-444. doi:[10.1214/aoms/1177731829](https://doi.org/10.1214/aoms/1177731829)

43. Lumley T. *Complex Surveys*. John Wiley & Sons; 2011.

44. Wickham H, Averick M, Bryan J, et al. Welcome to the tidyverse. *Journal of Open Source Software*. 2019;4(43):1686. doi:[10.21105/joss.01686](https://doi.org/10.21105/joss.01686)

45. Allaire J. *Quarto: R Interface to ’Quarto’ Markdown Publishing System*.; 2022. <https://CRAN.R-project.org/package=quarto>

46. Arel-Bundock V. modelsummary: Data and model summaries in R. *Journal of Statistical Software*. 2022;103(1):1-23. doi:[10.18637/jss.v103.i01](https://doi.org/10.18637/jss.v103.i01)

47. Sjoberg DD, Whiting K, Curry M, Lavery JA, Larmarange J. Reproducible summary tables with the gtsummary package. *The R Journal*. 2021;13:570-580. doi:[10.32614/RJ-2021-053](https://doi.org/10.32614/RJ-2021-053)

48. Carter MA, Biro S, Maier A, Shingler C, Guan TH. COVID-19 vaccine uptake in southeastern ontario, canada: Monitoring and addressing health inequities. *Journal of Public Health Management and Practice*. 2022;28(6):615-623. doi:[10.1097/phh.0000000000001565](https://doi.org/10.1097/phh.0000000000001565)

49. Basta NE, Sohel N, Sulis G, et al. Factors associated with willingness to receive a COVID-19 vaccine among 23, 819 adults aged 50 years or older: An analysis of the canadian longitudinal study on aging. *American Journal of Epidemiology*. 2022;191(6):987-998. doi:[10.1093/aje/kwac029](https://doi.org/10.1093/aje/kwac029)

50. Cénat JM, Noorishad PG, Bakombo SM, et al. A systematic review on vaccine hesitancy in black communities in canada: Critical issues and research failures. *Vaccines*. 2022;10(11):1937. doi:[10.3390/vaccines10111937](https://doi.org/10.3390/vaccines10111937)

51. Cénat JM, Farahi SMMM, Bakombo SM, et al. Vaccine mistrust among black individuals in canada: The major role of health literacy, conspiracy theories, and racial discrimination in the healthcare system. *Journal of Medical Virology*. 2023;95(4). doi:[10.1002/jmv.28738](https://doi.org/10.1002/jmv.28738)

52. Njoku A, Joseph M, Felix R. Changing the narrative: Structural barriers and racial and ethnic inequities in COVID-19 vaccination. *International Journal of Environmental Research and Public Health*. 2021;18(18):9904. doi:[10.3390/ijerph18189904](https://doi.org/10.3390/ijerph18189904)

53. Iveniuk J, Leon S. *Uneven Recovery: Measuring Covid-19 Vaccine Equity in Ontario*. Wellesley Institute; 2021. Accessed May 12, 2023. <https://www.wellesleyinstitute.com/wp-content/uploads/2021/04/An-uneven-recovery-Measuring-COVID-19-vaccine-equity-in-Ontario.pdf>

54. Gill M, Datta D, Gregory P, Austin Z. COVID-19 vaccination in high-risk communities: Case study of brampton, ontario. *Canadian Pharmacists Journal / Revue des Pharmaciens du Canada*. 2022;155(6):345-351. doi:[10.1177/17151635221123042](https://doi.org/10.1177/17151635221123042)

55. Hawkins D. Differential occupational risk for COVID-19 and other infection exposure according to race and ethnicity. *American Journal of Industrial Medicine*. 2020;63(9):817-820. doi:[10.1002/ajim.23145](https://doi.org/10.1002/ajim.23145)

56. Côté D, Durant S, MacEachen E, et al. A rapid scoping review of COVID-19 and vulnerable workers: Intersecting occupational and public health issues. *American Journal of Industrial Medicine*. 2021;64(7):551-566. doi:[10.1002/ajim.23256](https://doi.org/10.1002/ajim.23256)

57. Mishra S, Stall NM, Ma H, et al. *A Vaccination Strategy for Ontario COVID-19 Hotspots and Essential Workers*. Ontario COVID-19 Science Advisory Table; 2021. doi:[10.47326/ocsat.2021.02.26.1.0](https://doi.org/10.47326/ocsat.2021.02.26.1.0)

58. Nguyen KH, Yankey D, Coy KC, et al. COVID-19 vaccination coverage, intent, knowledge, attitudes, and beliefs among essential workers, united states. *Emerging Infectious Diseases*. 2021;27(11):2908-2913. doi:[10.3201/eid2711.211557](https://doi.org/10.3201/eid2711.211557)

59. Shah TI, Clark AF, Seabrook JA, Sibbald S, Gilliland JA. Geographic accessibility to primary care providers: Comparing rural and urban areas in southwestern ontario. *The Canadian Geographer / Le Géographe canadien*. 2019;64(1):65-78. doi:[10.1111/cag.12557](https://doi.org/10.1111/cag.12557)

60. Crighton EJ, Ragetlie R, Luo J, To T, Gershon A. A spatial analysis of COPD prevalence, incidence, mortality and health service use in ontario. *Health Rep*. 2015;26(3):10-18.

61. Timony P, Houle SKD, Gauthier A, Waite NM. Geographic distribution of ontario pharmacists: A focus on rural and northern communities. *Canadian Pharmacists Journal / Revue des Pharmaciens du Canada*. 2022;155(5):267-276. doi:[10.1177/17151635221115411](https://doi.org/10.1177/17151635221115411)

62. *Annual Business Plan 2022/23*. Ontario Health; <https://www.ontariohealth.ca/sites/ontariohealth/files/2022-05/OHBusinessPlan22_23.pdf>; 2022.

63. Smylie J, McConkey S, Rachlis B, et al. Uncovering SARS-COV-2 vaccine uptake and COVID-19 impacts among first nations, inuit and métis peoples living in toronto and london, ontario. *Canadian Medical Association Journal*. 2022;194(29):E1018-E1026. doi:[10.1503/cmaj.212147](https://doi.org/10.1503/cmaj.212147)

64. Eissa A, Lofters A, Akor N, Prescod C, Nnorom O. Increasing SARS-CoV-2 vaccination rates among black people in canada. *Canadian Medical Association Journal*. 2021;193(31):E1220-E1221. doi:[10.1503/cmaj.210949](https://doi.org/10.1503/cmaj.210949)

65. DeRoo SS, Pudalov NJ, Fu LY. Planning for a COVID-19 vaccination program. *JAMA*. 2020;323(24):2458. doi:[10.1001/jama.2020.8711](https://doi.org/10.1001/jama.2020.8711)

66. Stephenson M, Olson SM, Self WH, et al. Ascertainment of vaccination status by self-report versus source documentation: Impact on measuring COVID-19 vaccine effectiveness. *Influenza and Other Respiratory Viruses*. 2022;16(6):1101-1111. doi:[10.1111/irv.13023](https://doi.org/10.1111/irv.13023)

67. Ontario COVID-19 Data Tool. Accessed February 27, 2023. <https://www.publichealthontario.ca/en/data-and-analysis/infectious-disease/covid-19-data-surveillance/covid-19-data-tool?tab=vaccine>