

Original article

Socio-demographic inequalities and excess non-COVID-19 mortality during the COVID-19 pandemic: a data-driven analysis of 1 069 174 death certificates in Mexico

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Abstract

Background: In 2020, Mexico experienced one of the highest rates of excess mortality globally. However, the extent of non-COVID deaths on excess mortality, its regional distribution and the association between socio-demographic inequalities have not been characterized.

Methods: We conducted a retrospective municipal and individual-level study using 1 069 174 death certificates to analyse COVID-19 and non-COVID-19 deaths classified by ICD-10 codes. Excess mortality was estimated as the increase in cause-specific mortality in 2020 compared with the average of 2015–2019, disaggregated by primary cause of

death, death setting (in-hospital and out-of-hospital) and geographical location. Correlates of individual and municipal non-COVID-19 mortality were assessed using mixed effects logistic regression and negative binomial regression models, respectively.

Results: We identified a 51% higher mortality rate (276.11 deaths per 100 000 inhabitants) compared with the 2015–2019 average period, largely attributable to COVID-19. Non-COVID-19 causes comprised one-fifth of excess deaths, with acute myocardial infarction and type 2 diabetes as the two leading non-COVID-19 causes of excess mortality. COVID-19 deaths occurred primarily in-hospital, whereas excess non-COVID-19 deaths occurred in out-of-hospital settings. Municipal-level predictors of non-COVID-19 excess mortality included levels of social security coverage, higher rates of COVID-19 hospitalization and social marginalization. At the individual level, lower educational attainment, blue-collar employment and lack of medical care assistance prior to death were associated with non-COVID-19 deaths.

Conclusion: Non-COVID-19 causes of death, largely chronic cardiometabolic conditions, comprised up to one-fifth of excess deaths in Mexico during 2020. Non-COVID-19 excess deaths occurred disproportionately out-of-hospital and were associated with both individual- and municipal-level socio-demographic inequalities.

Key words: Excess mortality, inequalities, social lag, COVID-19, Mexico

Key Messages

- Mexico experienced one of the highest rates of excess mortality in Latin America following the onset of the COVID-19 pandemic but the extent to which non-COVID-19 deaths contributed to excess mortality has not yet been characterized.
- We conducted a retrospective, municipal and individual-level study using data from 1 069 174 death certificates to estimate mortality related to COVID-19 and to non-COVID-19 causes using ICD-10 codes in 2020 compared with 2015–2019.
- There was a 51% higher mortality rate in 2020 compared with the 2015–2019 average, largely attributable to COVID-19 deaths (76.1% of cases), which occurred primarily in-hospital; conversely, one-fifth of excess deaths in Mexico in 2020 were attributable to non-COVID-19 causes, largely cardiometabolic conditions, which occurred primarily out-of-hospital.
- Southern regions and marginalized communities in Mexico carried a disproportionate burden of excess mortality; municipal-level correlates of these excess deaths included lower healthcare coverage, whereas individual-level factors that correlated with non-COVID-19 mortality included lower educational attainment, blue-collar employment and lack of medical care assistance prior to death.
- Excess mortality in Mexico in 2020 was attributed to both COVID-19 and non-COVID-19 causes, likely reflecting a complex interplay between a fragmented and under-resourced health system, strained hospital capacity and socio-demographic inequalities further unmasked by the pandemic.

Introduction

Over 6 million deaths attributable to COVID-19 have been reported globally since the onset of the pandemic in early 2020.¹ Beyond this devastating death toll, there is increasing recognition of the widespread disruption of the pandemic on healthcare services, with a far-reaching impact on the care of non-COVID-19 conditions.² Excess mortality has been proposed as a key indicator that captures both deaths caused by

COVID-19 and indirect deaths attributed to the pandemic more broadly due to interruption in routine care of chronic conditions.^{3,4} Notably, many low- and middle-income countries (LMICs), particularly in Latin America, were vulnerable to the direct and indirect effects of the COVID-19 pandemic due to chronic underinvestment in public health-care.⁵ Though several reports have estimated that rates of excess mortality were disproportionately higher in LMICs

following the onset of the COVID-19 pandemic, there is limited insight regarding non-COVID-19 deaths and their contribution to the reported rates of excess mortality in Latin America.⁶

Mexico is of particular interest given that it ranks as one of the countries with the highest rates of excess mortality in the Latin American region following onset of the COVID-19 pandemic.⁷ A confluence of health and socio-demographic inequalities that pre-dated the COVID-19 pandemic, a high burden of chronic cardiometabolic conditions and a fragmented healthcare system all contributed to a high and disproportionate burden of excess mortality among marginalized communities.^{5,8} A descriptive assessment performed in Mexico showed that chronic cardiometabolic conditions, which are highly prevalent among communities of low socio-economic status, were the main causes of death independently of registered COVID-19 deaths in Mexico during 2020.⁹ However, whether hospital saturation had ripple effects on out-of-hospital excess mortality, particularly for highly prevalent chronic health conditions across different vulnerable regions, has not yet been characterized. Hence, there is a need to comprehensively assess the extent to which individual- and municipal-wide-level socio-demographic inequalities impacted excess mortality to further guide health policies to strengthen existing systems and mitigate ongoing health disparities.

In this study, we sought to: (i) estimate the age-adjusted rates of cause-specific excess mortality due to COVID-19 and non-COVID-19 deaths in 2020 compared with the 2015–2019 period, stratified by in-hospital and out-of-hospital setting; (ii) evaluate the geographical distribution of cause-specific excess mortality in Mexico in 2020; and (iii) characterize the association between municipal- and individual-level socio-demographic inequality measures and non-COVID-19-related excess mortality.

Methods

Study design and data sources

Based on the work by Lima *et al.*, we conducted a retrospective municipal- and individual-level study using national mortality records from 2015–2019 compared with 2020.⁶ Death certificate records of individuals living in Mexico were collected by the National Institute of Statistics and Geography (INEGI). Briefly, INEGI generates annual mortality statistics from death certificates and vital socio-demographic characteristics issued by the Ministry of Health, which includes the primary cause of death in accordance with the tenth version of the International Statistical Classification of Diseases and Related Health Problems (ICD-10).¹⁰ Complete methodology of the death certification

process, validation and collected variables are available in the [Supplementary material](#) (available as [Supplementary data](#) at *IJE* online).

Variables and definitions

Outcome variables

Cause-specific excess mortality was centred on two primary outcomes: deaths due to COVID-19 and deaths related to non-COVID-19 causes. Overall excess mortality was the sum of excess mortality due to non-COVID-19 causes and all registered COVID-19 deaths.

COVID-19 deaths. Deaths attributable to COVID-19 were defined based on the following ICD-10 codes: U071 (identified SARS-CoV-2), U072 (suspected SARS-CoV-2) and deaths after April 2020 classified as J00–J99 (respiratory deaths). This aggregation of COVID-19 deaths considers inadequate registration of COVID-19 cases across 2020 as there are an unknown number of deaths that could have been classified with unspecified respiratory diseases in the early stages of the pandemic due to limited SARS-CoV-2 testing capacity in Mexico.¹¹

Non-COVID-19 cause-specific mortality. All other causes of death were classified as non-COVID-19-related deaths and were coded using the 2020 Mexican list of mortality, which includes 436 specific causes of death.¹² To simplify result presentation, we only display the first 10 cause-specific deaths in the main results, with the full list provided in the [Supplementary material](#) (available as [Supplementary data](#) at *IJE* online).

Excess mortality estimation

According to the approach proposed by Karlinsky and Kobak, we estimated excess mortality as the difference between average deaths during the 2015–2019 period compared with deaths registered during 2020.¹³ We used average deaths for two reasons: (i) the use of average deaths is a simple approach shown to be a reliable assessment based on sensitivity analyses estimations; and (ii) given that we are estimating 436 specific causes of death, predictive methods based on generalized linear models may overestimate the standard error for low-frequency causes.⁹ Excess deaths were standardized to age-adjusted rates per 100 000 population with age structures by state, municipalities, and regions per 5-year increments using population projections provided by the National Population Council (CONAPO). Percent increase in 2020 compared with 2015–2019 was also used as a proxy of excess mortality.

Stratification by setting of death

We hypothesized that the COVID-19 pandemic posed a significant burden on in-hospital care, which may have influenced increases in excess mortality, particularly for non-COVID-19-related deaths. To evaluate this hypothesis, we stratified excess mortality according to whether the death occurred out-of-hospital or in-hospital, as registered on death certificates. Out-of-hospital deaths were defined accordingly if the death was not registered in a hospital setting or if they were coded as occurring at the deceased person's home or elsewhere (i.e. in the streets in some instances). Deaths with an unspecified setting were excluded across all the analysis.

Marginalization index

To quantify the impact of municipal socio-demographic inequalities on excess mortality, we used the 2020 municipal social lag index (SLI) estimated by the National Council for Evaluation of Social Development Policy (CONEVAL).¹⁴ Since we intended to evaluate social inequalities independently from urbanization and centralized health services, we used residuals of linearly regressed mean urban population density and hospital beds per 100 000 inhabitants using data extracted from CONEVAL to fit an adjusted municipal SLI (aSLI). We then categorized municipalities into four aSLI categories (Low-aSLI, Moderate-aSLI, High-aSLI and Very-High aSLI) based on the Dalenius & Hodges method (Supplementary material, available as Supplementary data at *IJE* online).

Municipal-level correlates of excess mortality

We included the percentage of the population without healthcare coverage and the hospital occupancy due to COVID-19 inpatients as municipal-level factors related to excess mortality. Healthcare coverage was obtained from 2020 CONEVAL estimations. To estimate a surrogate of hospital occupancy, we used the number of hospitalizations with confirmed COVID-19 from the National Epidemiological Surveillance System (SINAVE) data set collected by the General Directorate of Epidemiology (DGE) of the Mexican Ministry of Health, which includes reports of daily updated suspected COVID-19 cases.¹⁵ Complete methodology, the protocol of testing and the variables included are available in the Supplementary material (available as Supplementary data at *IJE* online).

Statistical analysis

To visualize differences in deaths over time in 2020 compared with the 2015–2019 period, we first plotted excess mortality per 100 000 inhabitants by month of occurrence, stratified by COVID-19 and non-COVID-19 causes. We

then disaggregated excess mortality rates due to COVID-19 or non-COVID-19 causes by state and municipality. Next, to visualize whether the proportion of age-adjusted excess mortality in each municipality increased due to COVID-19 or non-COVID-19 causes, we used choropleth maps classified using the quantile method with the *biscale* R package. We further visualized the relationship between excess mortality and aSLI using the same method. The median value for the estimated age-adjusted excess mortality and the aSLI were considered as the cut-off threshold.

Municipal-level factors associated with excess mortality

Next, we evaluated the impact of municipal characteristics on increased risk of age-adjusted excess mortality using negative binomial regression models to obtain incidence rate ratios (IRRs) (Supplementary material, available as Supplementary data at *IJE* online). Models were adjusted for municipal male-to-female death ratio, education percentage, access to medical assistance and urbanization (to adjust for residual covariance). We also calculated the ratio of out-of-hospital to in-hospital deaths, which was also adjusted for the above outlined covariates.¹⁶ IRRs were plotted using the *jtools* R Package.

Individual-level factors related to non-COVID-19 mortality

To identify individual-level factors associated with the probability of death attributable to non-COVID-19 causes as compared with COVID-19, we fitted hierarchical random-effects logistic regression models, which included individual- and municipal-level variables (Supplementary material, available as Supplementary data at *IJE* online). Individual-level variables included sex, education, self-reported indigenous identity, work occupation, access to medical assistance prior to death and social security coverage. We perform a municipal-level adjustment that included living in municipalities with low hospital bed occupancy (<1 bed per 100 000 inhabitants) and municipal aSLI categories. For this model, we used the municipality of death occurrence as a random intercept to account for inter-municipal variability in death registration in the model and to establish a hierarchical relationship between individual- and municipal-level variables. All analyses were performed using R software (Version 4.1.2).

Results

Overall and cause-specific excess mortality in Mexico during 2020

We identified 1 069 174 deaths in Mexico during 2020 compared with 686 567 average deaths in 2015–2019. We

estimated an age-adjusted mortality rate of 833.5 deaths per 100 000 inhabitants for 2020, with an estimated age-adjusted excess mortality of 282.41 deaths per 100 000 inhabitants; this represents a 51% increase in mortality compared with the average age-adjusted mortality rates in 2015–2019 (551.09 per 100 000 inhabitants). Peak excess mortality during 2020 was observed during the May-to-June period. Approximately 76.1% of excess deaths were attributable to confirmed or suspected COVID-19, whereas 23.9% were attributable to non-COVID-19 causes. The main contributors of excess mortality were suspected or confirmed COVID-19 deaths (199.26 per 100 000 inhabitants). The five leading causes of non-COVID-19 excess mortality were acute myocardial infarction (46.7 deaths per 100 000 inhabitants), type 2 diabetes (34.84 deaths per 100 000 inhabitants), violent assaults (3.45 deaths per 100 000 inhabitants), hypertensive heart disease (3.13 deaths per 100 000 inhabitants) and essential arterial hypertension (2.9 deaths per 100 000 inhabitants). All excess deaths were recorded after April 2020, with a steep increase after this period for COVID-19, acute myocardial infarction and type 2 diabetes-related deaths (Figure 1).

Excess mortality according to in-hospital vs out-of-hospital death

When stratified by the setting of death, we estimated an in-hospital excess mortality rate of 112.47 deaths per 100 000 inhabitants and an out-of-hospital excess mortality rate of 162.54 deaths per 100 000 inhabitants; this represents an increase of 45.4% and 55.5% of in-hospital and out-of-hospital deaths, respectively, compared with the average of 2015–2019. When stratified by the specific cause of death, we observed that excess in-hospital mortality rates were primarily attributable to COVID-19 deaths, whereas there was a decrease for in-hospital non-COVID-19-related deaths after March 2020. An estimated 80.96% of all out-of-hospital excess mortality was attributable to non-COVID-19 causes, whereas only 19.03% were attributable to COVID-19 deaths. Excess deaths attributable to COVID-19 occurred predominantly in the in-hospital setting, whereas most non-COVID-19 deaths occurred largely out-of-hospital (Supplementary Table S1, available as Supplementary data at *IJE* online). Among the 10 leading causes of excess mortality, acute myocardial infarction and type 2 diabetes decreased in-hospital but increased out-of-hospital after April 2020 (Figure 2).

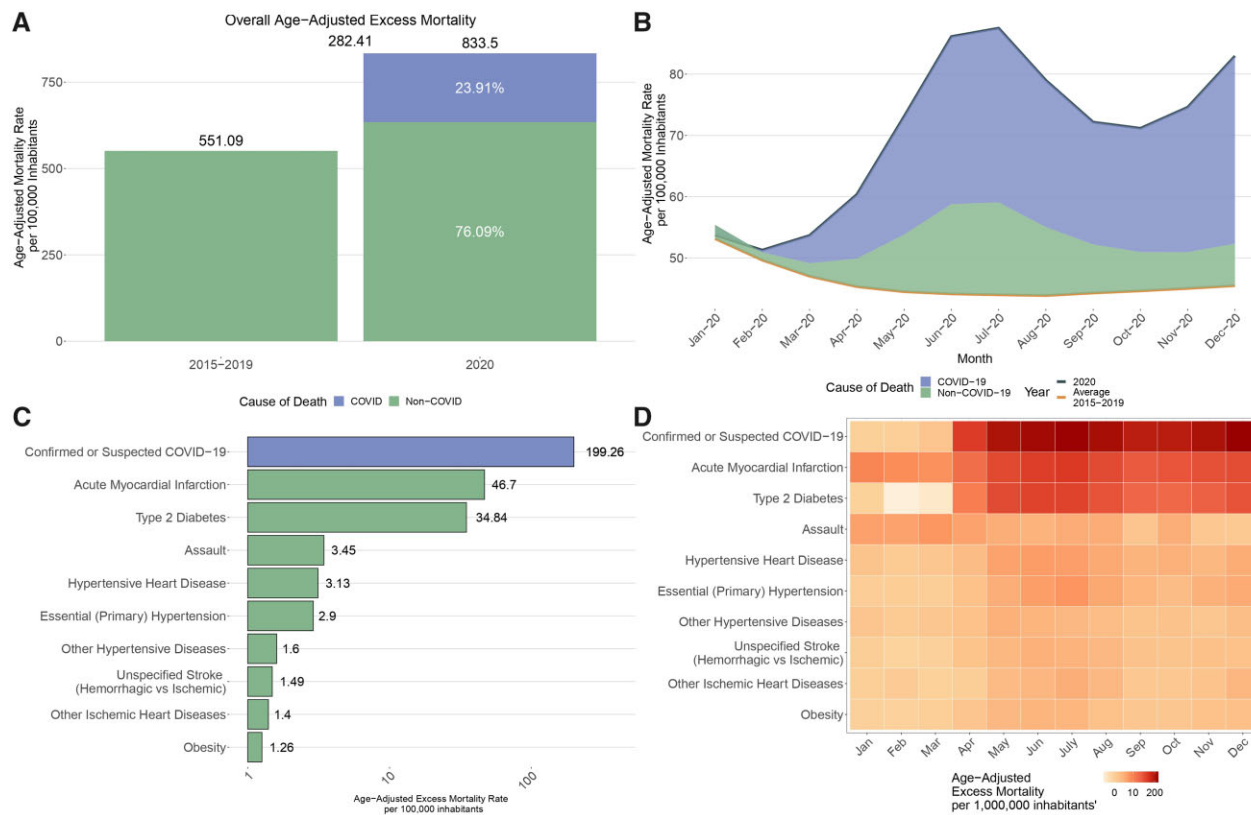


Figure 1 Age-adjusted mortality rates and excess mortality in Mexico in 2020. (a) Age-adjusted mortality rates in 2020 compared by the average period of 2015–2019. (b) Distribution of excess mortality in Mexico stratified by deaths associated with COVID-19 and non-COVID-19 for the year 2020. (c) Ten main causes of age-adjusted excess mortality in Mexico. (d) Stratification of the 10 main causes of age-adjusted excess mortality by month of occurrence in Mexico

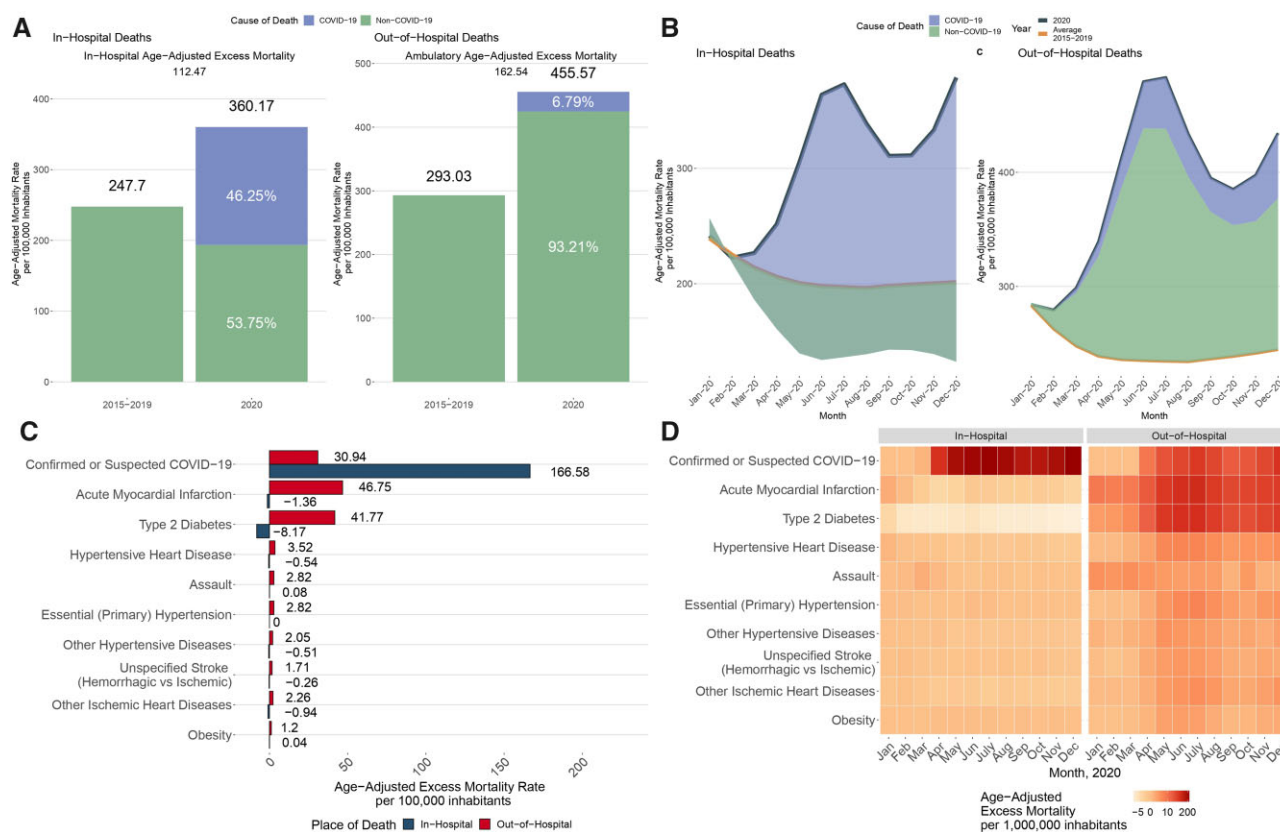


Figure 2 In-hospital and out-of-hospital age-adjusted mortality rates and excess mortality in Mexico in 2020. (a) Stratification of in-hospital and out-of-hospital age-adjusted mortality rates in 2020 compared with the average period of 2015–2019. (b) Distribution of excess mortality in Mexico stratified by death setting and by deaths associated with COVID-19 and non-COVID-19 for the year 2020. (c) Ten main causes of age-adjusted excess mortality stratified by place of occurrence in Mexico. (d) Stratification of the 10 main causes of age-adjusted excess mortality by month and place of occurrence of death in Mexico

Regional state- and municipal-level heterogeneity in COVID-19 and non-COVID-19 excess mortality

When COVID-19 and non-COVID-19 excess mortality was stratified at the state level, Mexico City, Baja California and Chihuahua displayed the highest COVID-19 age-adjusted excess mortality rate, whereas Chihuahua, Mexico City and Chiapas had the highest non-COVID-19 excess mortality rates. There was an unequal distribution of non-COVID-19 age-adjusted excess mortality at the state level, with the southern states of Chiapas, Oaxaca and Michoacan having the highest rates of non-COVID-19-related excess mortality (Supplementary Figure S1, available as Supplementary data at *IJE* online). Further stratification revealed a geographical aggregation of non-COVID-19 deaths caused by acute myocardial infarction, type 2 diabetes, essential arterial hypertension and unspecified strokes clustered in the southern states of Mexico (Supplementary Figure S2, available as Supplementary data at *IJE* online). We also evaluated age-adjusted excess mortality at the municipal level to obtain a more detailed overview of these geographical differences. Excess mortality had a heterogenous geographical distribution and

correlated with the SLI in municipalities in Mexico with higher excess mortality due to both COVID-19 and non-COVID-19 causes (Supplementary Figure S3, available as Supplementary data at *IJE* online). At the state level, the highest decrease in non-COVID-19 in-hospital deaths was seen in Oaxaca, Yucatan and Veracruz, whereas the highest proportion of non-COVID-19 out-of-hospital deaths were observed in Tlaxcala, Yucatan and Colima (Supplementary Figure S4, available as Supplementary data at *IJE* online).

Municipal-level impact of socio-demographic inequalities in excess mortality

We observed marked geographic variability in age-adjusted excess mortality across municipalities with higher aSLI (Figure 3a). After excluding COVID-19-related deaths, only the southern municipalities displayed the highest combination of excess mortality and aSLI (Supplementary Figure 5, available as Supplementary data at *IJE* online). Stratifying by aSLI categories, age-adjusted mortality rates and excess mortality showed a stepwise

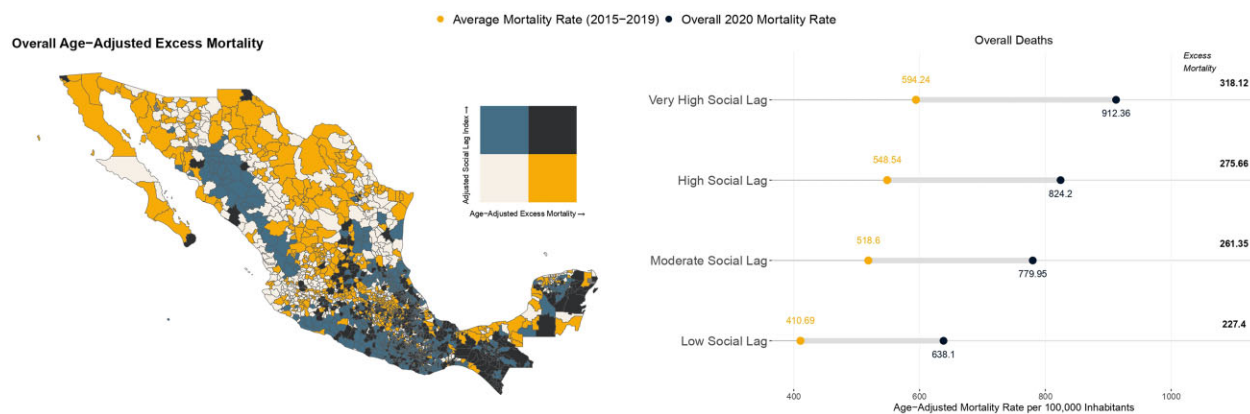


Figure 3 Geographical distribution and age-adjusted excess mortality by adjusted social lag categories in Mexico in 2020. (a) Choropleth map of Mexico to visualize the geographical distribution of age-adjusted excess mortality and adjusted social lag index by municipality of occurrence in 2020. (b) Age-adjusted average mortality rate (2015–2019), overall mortality rate in 2020 and excess mortality stratified by adjusted social lag categories in Mexico

increase with each higher marginalization level (Figure 3b). Municipalities with very high aSLI displayed both the higher age-adjusted mortality (912.36 per 100 000 inhabitants) and excess mortality (318.12 per 100 000 inhabitants) rates in Mexico.

Municipal-level correlates of excess mortality

To evaluate the hypothesis that excess mortality was correlated with social inequalities in healthcare access and hospital occupancy due to COVID-19 at the municipal level, we fitted negative binomial regression models for age-adjusted excess mortality rates. As observed in the geographic distribution of age-adjusted excess mortality (Supplementary Figure S5, available as Supplementary data at *IJE* online), municipalities at high and very high social lag had the highest risk for non-COVID-19 age-adjusted excess mortality in 2020. Municipalities with a higher percentage of the population without social security coverage (IRR 1.03, 95% CI 1.02–1.04), higher COVID-19 hospital occupancy (IRR 1.03, 95% CI 1.01–1.06) and higher social lag categories were at higher risk of excess mortality after adjusting for covariates (Figure 4). We observed an interaction effect for higher risk of non-COVID-19 age-adjusted excess mortality in municipalities with very high social lag and higher COVID-19 hospital occupancy (IRR 1.08, 95% CI 1.03–1.12, Supplementary Figure S6, available as Supplementary data at *IJE* online).

Individual-factor correlates of non-COVID-19 deaths

Finally, we explored the role of socio-demographic conditions and healthcare-related inequalities for the risk of

non-COVID-19 deaths using random-effects logistic regression models. We observed that women, people who had lower educational attainment and those who worked as craftsmen, farmers, labourers or were unemployed had an increased odds for death attributable to non-COVID-19 compared with COVID-19 causes. Regarding healthcare-related factors, people without medical assistance before death, people who reported public or unspecified social security coverage or people who lived in municipalities with low availability of hospital beds had an increased odds of death from non-COVID-19 compared with COVID-19 causes. Finally, people living in municipalities with high and very high social lag had the highest odds of non-COVID-19 compared with COVID-19 death (Figure 4).

Discussion

In this study of 1 069 174 deaths recorded in Mexico between 2015 and 2020, we report that 51% of deaths in 2020 were in excess compared with the average reported between 2015 and 2019. Although cause-specific excess mortality during 2020 was largely attributable to COVID-19 (76.1% of cases), non-COVID-19 causes comprised up to one-fifth of excess deaths in Mexico during 2020. Moreover, we report a differential impact on excess mortality related to the setting in which the deaths occurred; whereas COVID-19 deaths occurred primarily in-hospital, non-COVID-19 deaths sharply decreased in this setting and had a concurrent increase in the out-of-hospital setting. These findings contribute to the growing literature on the far-reaching impact of the COVID-19 pandemic on the health system and suggest both an excess in non-COVID-19 mortality as well as a displacement of these deaths to the out-of-hospital setting in Mexico.

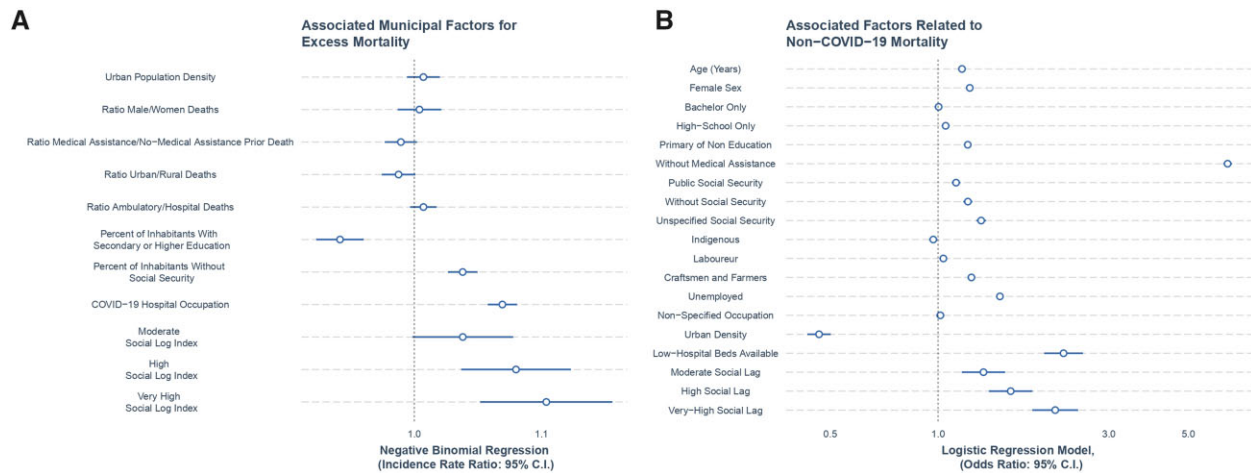


Figure 4 Regression models to evaluate factors for excess mortality and death from non-COVID-19 causes. (a) Negative binomial regression model to evaluate municipal-level factors related to excess mortality. (b) Logistic regression model to assess individual-related factors linked to the probability of death from non-COVID-19 causes

We also observed that excess mortality exhibited marked geographical heterogeneity, which was associated with higher social lag; states in the southern region of Mexico had the highest social marginalization and similarly high rates of non-COVID-19 excess mortality. We showed that lower prevalence of population without social security coverage and higher rates of COVID-19 hospitalization, combined with social marginalization, were municipal-level correlates of non-COVID-19 excess mortality. Finally, at the individual level, lower educational attainment, blue-collar employment (labourers, craftsmen and farmers), unemployment and lack of medical assistance before death were significant correlates of non-COVID-19 compared with COVID-19 mortality during 2020. These findings suggest that excess mortality from non-COVID-19-related causes, which occurred disproportionately out-of-hospital and among populations with social disadvantage, may reflect a complex interplay between a fragmented health system, strained hospital capacity, interruptions in chronic disease care and socio-demographic inequalities further unmasked by the pandemic.⁵ This situation is applicable to Mexico, but also to countries with similar socio-demographic profiles in the region or with high rates of SARS-CoV-2 infections.

Previous reports have documented the high burden of excess mortality caused by the COVID-19 pandemic in Mexico, with excess mortality rates being estimated from 26.1 to 36.0 deaths per 100 000 inhabitants;^{6,13,17–19} moreover, Karlinsky *et al.* projected that Mexico's actual toll of deaths could be twice the number of deaths registered during 2020.¹⁴ These reports positioned Mexico as one of the leading countries in terms of excess mortality in Latin America and worldwide.^{6,13} However, there is limited information regarding cause-specific contributors to

global excess mortality rates in Mexico. Besides contributing to the literature on COVID-19 excess mortality in Mexico, our findings also expand this literature by showing that excess deaths were also related to cardiometabolic chronic health conditions, including type 2 diabetes, cardiovascular disease, arterial hypertension and obesity, which had a steep increase in the out-of-hospital setting.^{9,20} Excess non-COVID-19 deaths could be attributable to hospital reconversion policies and healthcare restructuring designed to improve care for COVID-19 cases, which may have reduced access to care for people with chronic health conditions who required continuous medical assistance during the COVID-19 pandemic. Other high-income countries have documented the association between hospital occupancy and excess mortality during periods of peak COVID-19 infections.^{21–23} Explanations related to this phenomenon rely on data on restricted access to healthcare services in places that experienced hospital overload due to COVID-19, reduced out-of-hospital attention due to severely restricted healthcare services and personnel availability, lower insurance coverage and a lower number of healthcare personnel per capita.^{24–26} Other reported non-related healthcare contributors were social stigma for being treated in hospitals due to potentially acquiring COVID-19 infection and reduced physical activity due to pandemic restrictions on mobility, which could have exacerbated complications due to chronic health conditions.²⁷ Overall, excess non-COVID-19 mortality could be interpreted as an indirect proxy of the negative effects attributable to healthcare policies that prioritized in-hospital COVID-19 attention over the care of other chronic health conditions.

Notably, increased rates of COVID-19 hospitalizations and mortality in Mexico were observed in municipalities

with high marginalization independently of urbanization, likely attributed to increased stress on their healthcare systems.^{28,29} This phenomenon may explain the disproportionate burden of non-COVID-19 deaths among marginalized municipalities in Mexico. Our results support the hypothesis that populations with social disadvantage experienced the highest impact of excess mortality attributable to hospital saturation, with this impact having an unequal distribution within Mexico. In the European region, countries with high excess mortality, such as Bulgaria, Russia and Serbia, were impacted by diverse social barriers, such as difficulties in fully adhering to social isolation policies.^{30,31} Two recent reports in England showed that communities with a high density of care homes, with a high proportion of residents on income support, overcrowding conditions and ethnic minorities were at higher risk of excess mortality and years of life lost due to the COVID-19 pandemic.^{32,33} In Latin American countries, socio-economic inequalities widened due to difficulty adhering to lockdown mandates given low stipend support, a high proportion of their population working in the informal economy and lack of access to healthcare, even among healthcare personnel.^{3,30,34} Nevertheless, this evidence and the comparison between countries should be interpreted with caution given the variation in COVID-19 dynamics, within-country gradients of socio-demographic inequalities and different epidemiological profiles of high-risk comorbidities.

Our results highlight the impact of healthcare-related and individual-level social inequalities in exacerbating overall and cause-specific excess mortality in Mexico. We show that the main contributor to higher non-COVID-19 excess mortality rates at the municipal level was a lower percentage of the population with access to social security health coverage; in Mexico, social security providers condition the type of healthcare access by individuals, which likely also influences received quality of care and healthcare access. Furthermore, the interaction between a lower percentage of the population with access to social security health coverage and social marginalization confirmed the hazardous interplay between social and healthcare inequalities.³⁵ At the individual level, we showed that certain socially vulnerable occupations experienced unequal risks for non-COVID-19 mortality. The role of individual and socio-demographic determinants in the risk for adverse COVID-19 outcomes has been previously reported.^{36,37} Nevertheless, our findings demonstrate that socio-demographic inequalities impacted individuals with preventable chronic conditions, regardless of public healthcare policies aimed at mitigating the impact of the COVID-19 pandemic in healthcare infrastructure and provision. Overall, our results represent an urgent call to action for

local authorities to perform a healthcare restructuring, particularly in marginalized municipalities and with special attention to vulnerable populations to prioritize full coverage of hospital bed capacity, well-trained healthcare personnel and availability of primary care services that cover the management of chronic health conditions. These policies could prevent associated complications in the context of future COVID-19 waves or other circumstances that increase stress and reduce access to healthcare in Mexico and other LMICs.

Our study has some strengths and limitations. Among the strengths, we highlight the use of 1 069 174 nationwide mortality registries to compare all-cause and cause-specific excess mortality during the COVID-19 pandemic in Mexico in 2020. This approach allowed us to estimate with higher confidence state- and municipal-level excess mortality rates that helped us to study the regional impact of the COVID-19 pandemic and identify vulnerable zones in Mexico that were especially affected during 2020 compared with previous years. Additionally, the use of socio-demographic variables at different levels gave us insights to evaluate municipal- and individual-level correlates of excess non-COVID-19 mortality. Nevertheless, limitations to be acknowledged include the lack of specific clinical information and co-morbidity assessment for correlates known to be key determinants of higher risk of death from COVID-19 and non-COVID-19 causes, particularly regarding management of chronic cardiometabolic conditions. Second, we could not ascertain the number of non-COVID-19 deaths that occurred due to exacerbation of underlying chronic conditions by current or previous SARS-CoV-2 infection, which could increase the risk of long-term complications, including cardiovascular diseases.³ Third, our COVID-19 death construct included cases that could have been misclassified as atypical pneumonia or severe acute respiratory infections of unknown aetiology, registered after the onset of the COVID-19 pandemic; this was done to reduce the risk of under-reporting or misclassified COVID-19 deaths, but could have led to overestimation of COVID-19 deaths. Fourth, we used a surveillance data set to assess COVID-19 hospitalization as a proxy for hospital occupancy; however, identification of COVID-19-related hospitalizations may have varied according to weekly SARS-CoV-2 testing capacity and adequate reporting. Therefore, the use of this proxy could be biased in municipalities with higher marginalization and reduced access to testing. Finally, our municipal-level factors should be interpreted as structural conditions that displayed an association with higher excess mortality rates and therefore we should avoid an ecological fallacy in determining personal actions in clinical and healthcare management during the COVID-19 pandemic.

In conclusion, we show a high burden of excess mortality in Mexico in 2020, largely attributable to in-hospital COVID-19 and out-of-hospital non-COVID-19 deaths. We observed regional heterogeneity of non-COVID-19 excess mortality, with a disproportionate burden on marginalized municipalities in southern Mexico. High hospital occupancy due to COVID-19 and a higher percentage of the population without social security coverage were municipal-wide-level correlates of excess mortality, whereas individual-level lower educational attainment, vulnerable working occupations, lack of medical assistance before death and public or underspecified healthcare access were factors related to higher non-COVID-19 mortality likelihood. Our findings underscore the impact of socio-demographic inequalities on excess mortality related to non-COVID-19 causes in Mexico during 2020 compared with the 2015–2019 period. These results should prompt an urgent call to action to improve healthcare coverage and access, particularly in primary care settings and among populations with social disadvantage. Such policies could reduce health disparities in Mexico in circumstances that increase the stress of healthcare systems, including the ongoing COVID-19 pandemic and beyond.

Ethics approval

This project was registered and approved by the Ethics and Research Committee at Instituto Nacional de Geriátria, project number DI-PI-006/2020.

Data availability

All code, data sets and materials are available for reproducibility of results at https://github.com/oyaxbell/excess_non_covid/.

Supplementary data

Supplementary data are available at *IJE* online.

Author contributions

Research idea and study design: N.E.A.V., C.A.F.M., O.Y.B.C.; data acquisition: N.E.A.V., C.A.F.M.; data analysis/interpretation: N.E.A.V., C.A.F.M., J.M.A., L.F.C., J.P.A., A.G.D., A.V.V.; statistical analysis: N.E.A.V., C.A.F.M., O.Y.B.C.; manuscript drafting: N.E.A.V., O.Y.B.C., C.A.F.M., J.M.A., L.F.C., J.P.A., A.G.D., A.V.V., J.A.S., S.B., L.M.G.R.; supervision or mentorship: N.E.A.V., O.Y.B.C. Each author contributed important intellectual content during manuscript drafting or revision and accepted accountability for the overall work by ensuring that questions pertaining to the accuracy or integrity of any portion of the work are appropriately investigated and resolved.

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Conflict of interest

None declared.

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