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Towards closing socio-economic status disparities in COVID-19 premature mortality: a nationwide and trend analysis in Chile

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Abstract

Background: Socio-economic status (SES) disparities in coronavirus disease 2019 (COVID-19) mortality have been reported but complete information and time trends are scarce. In this study, we analysed the years of life lost (YLL) due to COVID-19 premature mortality during the pandemic in Chile and its evolution according to SES and sex compared with a counterfactual scenario [cerebrovascular accidents (stroke)].

Method: We used Chile's national mortality databases from 2020 to 2022. YLL and age-standardized YLL and mortality rates by sex and by epidemic waves were determined. The 346 communes were stratified into SES groups according to their poverty index quintile. Negative binomial regression models were used to test trends.

Results: In >2 years of the pandemic, the COVID-19 YLL was 975 937, corresponding to 61 174 deaths. The YLL rate per 100 000 inhabitants was 1027 for males and 594 for females. There was a heterogeneous distribution of YLL rates and the regional level. Communes in the most advantaged SES quintile (Q5) had the highest YLL during the first wave compared with those in the lowest SES quintile (Q1) ($P < 0.001$) but the opposite was true during the second wave. COVID-19 YLL trends declined and differences between Q1 and Q2 vs Q5 converged from the second to the fourth waves (0.33 and 0.15, $P_{trend} < 0.001$ and $P_{trend} = 0.024$). YLL declined but differences persisted in stroke (–0.002, $P_{trend} = 0.979$).

Conclusions: COVID-19 deaths resulted in a higher impact on premature death in Chile, especially in men, with a heterogeneous geographic distribution along the territory. SES and sex disparities in COVID-19 premature mortality had narrowed by the end of the pandemic.

Keywords: Years of life lost, COVID-19, Premature mortality, Ompact, Socio-economic status disparities

Key Messages

- We analysed the years of life lost (YLL) due to coronavirus disease 2019 (COVID-19) premature mortality and its evolution according to socio-economic status (SES) and sex during the pandemic in Chile.
- COVID-19 mortality during the pandemic in Chile resulted in 975000 YLL due to premature mortality, with a heterogeneous geographical distribution. Sex and SES disparities gradually narrowed until the end of the pandemic compared with those in a counterfactual scenario [cerebrovascular accidents (stroke)].
- This study provided valuable information on identifying vulnerable groups to target response plans against possible new communicable epidemics and raised new hypotheses about closing disparities, thus contributing to public policy precision.

Introduction

The coronavirus disease 2019 (COVID-19) pandemic was responsible for ≥6.5 million deaths worldwide as of October 2022,[1] resulting in a devastating impact due to premature mortality. The 1.23 million COVID-19-related deaths during 2020 in 81 countries triggered 20.5 million years of life lost (YLL), which was two to nine times higher than the average YLL associated with seasonal influenza.[2] Socio-economic status (SES) disparities in all-cause premature mortality are well documented in many countries, especially for non-communicable diseases (NCDs).[3] Previous evidence has shown that this could be the same for COVID-19 mortality,[4–7] as people living in disadvantaged areas are overexposed to severe acute syndrome coronavirus 2 (SARS-CoV-2), are at higher risk of comorbidities associated with COVID-19 mortality and have less access to healthcare.

Chile is a Latin American country that has had rapid economic development during past decades but this has been disproportionately distributed along the territory. Consequently, substantial health inequalities and disparities, including NCDs,

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persist.[8] The country has a mixed healthcare system, public and private, and the population health coverage and financial protection in both still lag behind the average of Organization for Economic Cooperation and Development countries.[9]

Unlike prevention programmes for NCDs, the policy response to the pandemic was relatively unified in Chile, integrating private and public health systems with important and internationally recognized milestones, such as restrictive and mandatory healthcare measures, higher rates of mass testing[10] and successful vaccination rollout and coverage rates.[11,12] From the first COVID-19 case on 3 March 2020 until 31 October 2022, the country faced four waves of COVID-19, recording >4.7 million infected patients and 61 178 related deaths.[13] COVID-19-related deaths have since decreased substantially, remaining stable in recent months despite emerging new cases. A few previous studies reported SES disparities in COVID-19 mortality but only in specific geographical areas or during only the first year of the pandemic.[14,15] Thus, to the best of our knowledge, there has not been a complete evaluation of the impact of COVID-19 on premature mortality and SES disparities, and its evolution.

In this study, we aimed to quantify the YLL attributable to COVID-19 at national and subnational levels for the entire pandemic in Chile, as deaths at younger ages have a major impact on population health, and to analyse YLL evolution according to SES and sex across epidemic waves compared with the evolution of selected NCDs to find disparities and whether they have changed over time.

Methods

This study used national mortality databases from the Department of Health Statistics and Information (DEIS, by its acronym in Spanish) of the Chilean Ministry of Health, free and anonymously available (www.deis.cl). Consequently, this study did not require ethics approval or other administrative permissions.

DEIS systemically records age-disaggregated causes of death based on the International Classification of Diseases, 10th Revision guidelines (ICD-10). These are high-quality mortality databases because DEIS verifies information from death certificates and standardizes their records according to World Health Organization (WHO) recommendations,[16] with previously demonstrated high reliability.[17] Mortality databases also involve demographic information such as age, sex, date of death, place of residence and place of death.

We included ICD-10 codes U07.1 ('COVID-19, virus identified') and U07.2 ('COVID-19, virus not identified') corresponding to fatalities associated with COVID-19. As laboratory capacity was scarce in the initial stages of the pandemic in Chile, U07.2 was the most-used epidemiological criterion. Data on age, sex, date of death and place of residence were also included in the analysis.

Chile is territorially divided into three administrative levels: 16 regions, subdivided into 56 provinces and 346 communes. Regional and commune levels were considered for the subnational-level analysis.

COVID-19 pandemic study period and waves

The pandemic study period was from 3 March 2020 to 31 October 2022. It was divided into four epidemic waves as follows: the first wave was from 3 March to 10 October 2020; the second was from 1 November 2020 to 30 September 2021; the third was from 1 October 2021 to 30 April 2022; and the fourth wave was from 31 April to 31 October 2022. The criterion was based on the lowest points of the graphical behaviour of the epidemic curve in Chile, as reported by the Chilean Ministry of Health.[13]

YLL calculation

YLL is an accurate metric broadly used to analyse the impact of premature mortality as it reveals actual years lost due to dying earlier than expected.[18] Absolute YLL was calculated based on Global Burden of Diseases (GBD) methodology,[18] which is the difference between the age at death of each individual and the standard life expectancy (SLE). At the population level, the absolute number of YLL for a particular sex and SES group was multiplied by the SLE at the age of death for the same group. We used the GBD SLE tables 2013–16 and 1990 for total YLL estimation and by sex stratification, respectively.[18] For SES stratification, life expectancy tables were based on recently published SES data for Chile.[19]

The age-standardized YLL and mortality rates per 100 000 inhabitants were calculated using the direct standardization method and the WHO reference population to make reliable comparisons and complement YLL interpretation. Population projections based on the 2017 Chilean Census of the National Institute of Statistics were used for rate denominators.

COVID-19 YLL trends by communal SES and sex

The 346 communes of Chile were stratified into four SES groups according to their poverty index quintile distribution; thus, Quintile 1 (Q1) had the highest poverty level and Quintile 5 (Q5) had the lowest. The poverty index was extracted from poverty estimates published for free access by the Ministry of Social Development of Chile, updated to 2020.

To build a counterfactual scenario for SES and sex disparities in COVID-19 premature mortality, YLL for cerebrovascular accidents (stroke, ICD-10 I64) was calculated as these are non-chronic events related to SES inequalities before the pandemic.[19,20] Moreover, the Chilean health system did not suffer significant lags in caring for these patients during the pandemic.

Statistical analysis

Absolute YLL and age-standardized YLL and mortality rates were described considering the entire pandemic by sex at national and regional levels. The age-standardized YLL rate was only at the national level by sex and epidemic waves due to low mortality records in some strata.

YLL and stroke trends were estimated using the multivariate negative binomial regression models as follows:

$$\ln(E[V|t]) = \beta 0 + \beta 1t + \ln\ (Pt)\ \ (\text{model}\ \ 1)$$

$$\ln(E[V|t,x]) = \beta 0 + \beta 1t + \beta 2x + \ln(Pt)\ \ (\text{model}\ \ 2)$$

$$\ln(E[V|t,x]) = \beta 0 + \beta 1t + \beta 2x + \gamma tx + \ln(Pt)\ \ (\text{model}\ \ 3)$$

where $(E[V|t])$ is the expected value of the YLL or stroke rate for COVID-19 epidemic wave t ($t = 1, 2, 3$ and 4); $(E[V|t, x])$ is the expected value of the YLL or stroke rate for epidemic wave t and at the explanatory variable x (sex or quintile distribution of SES), which were introduced into models as categorical variables (Q5 and female were the reference groups). The offset term ln(Pt) is the population aged 0–79 years at

wave t for each age–sex group described previously. Negative binomial models were preferred over Poisson models due to overdispersion and were expected to vary in different subsets of the data.

In the three models, coefficient β0 is the model intercept. In Model 1, coefficient β1 estimates the overall YLL in each epidemic wave; thus, the last wave was introduced as a categorical variable and the first was introduced as a reference group. In Model 2, coefficient β2 tests the difference in explanatory variable x. Positive and negative coefficients mean that the YLL or stroke rate is higher or lower in one group compared with the reference group. Coefficient γtx in Model 3 is the interaction term between epidemic waves and x, testing whether the trends have parallel or different slopes. Thus, a significant coefficient means that slope trends converge or diverge, and non-significance implies that they are parallel (coefficients β and γ are vectors to the SES variable). For Models 2 and 3, the epidemic wave was introduced as a discrete variable.

YLL and stroke rates were modelled as the calculated YLL for each year of age on a discrete scale; consequently, age standardization was unnecessary. To test transversal differences of YLL by sex and SES at each epidemic wave, YLL estimated by using models were compared using the Student's t-test, assuming an asymptotic normal distribution. Significance was set at $P < 0.05$ to test trends and group comparisons. YLL estimate trends with 95% CIs were analysed and graphed using R Studio version 4.1.0 and Tableau Desktop version 2022.2.0 (Universidad del Desarrollo license).

Results

From 3 March 2020 to 31 October 2022, 793 778 fatalities were recorded in the Chilean nationwide database and there were 61 174 COVID-19-related deaths for all years of age, corresponding to 975 937 YLL attributable to COVID-19. The age-standardized mortality and YLL rates were 68.9 and 1247.1 per 100 000 inhabitants, respectively. Regarding sex distribution, the age-standardized mortality and YLL rates were nearly double in males compared with females (e.g. 1331.4 in males and 874.1 in females). The highest age-standardized mortality and YLL rates were observed during the first and second COVID-19 epidemic waves, which occurred in 2020. For instance, the age-standardized YLL rate was 1211 per 100 000 inhabitants in the first COVID-19 wave, 968.5 in the second wave, and 232.3 and 173.3 per 100 000 inhabitants in the third and fourth waves, respectively (Table 1).

Subnational premature mortality and mortality related to COVID-19

Figure 1 shows the geographical distribution of age-standardized YLL rates at the regional level and stratified by sex. For the study period and both sexes, all regions of Chile have lost years of life due to COVID-19 premature mortality. However, the highest YLL rates were in three regions of the northern zone of Chile (Arica, Tarapacá and Antofagasta), the Metropolitan Region (which is in the central area of the country) and a region of the southern zone of Chile (Magallanes), were similar according to sex distribution (Figure 1).

In Supplementary Table S1 (available as Supplementary data at *IJE* online), the number of COVID-19-related deaths, age-standardized mortality rate, absolute YLL and age-standardized YLL rate are reported at the subnational level and by sex. The subnational patterns of COVID-19 mortality rates were consistent with YLL patterns.

YLL trends by communal SES and sex

The YLL attributable to COVID-19 and stroke increased from the first to the second epidemic wave, subsequently declining to the fourth. The estimated coefficient slope of increment was 0.43 ($P < 0.001$) for COVID-19 and 0.14 for stroke ($P = 0.0158$). The decline from the second to the fourth wave was –1.47 ($P < 0.001$) and –0.41 ($P < 0.001$) for COVID-19 and stroke, respectively (Figure 2 and Supplementary Table S2, available as Supplementary data at *IJE* online).

Model 2 in Table 2 showed differences in YLL estimates in COVID-19 and stroke according to the communal SES quintile distribution. After adjusting for epidemic waves, COVID-19 YLL estimates were higher in communes with a higher level of poverty (Q1: 0.27, $P < 0.001$, Q2: 0.14, $P < 0.001$, Q3: 0.15, $P < 0.001$) than in those with the lowest level of poverty (Q5). Similarly, there were differences in YLL estimates for stroke, but with higher coefficients (Q1: 0.85, Q2: 0.48, Q3: 0.27 vs Q5, $P < 0.001$). There were no differences between Q4 and Q5 for COVID-19 and stroke.

During the first epidemic wave, communes with the lowest poverty quintile (Q5) had the highest COVID-19 YLL estimates and communes with the highest poverty level (Q1) had the lowest COVID-19 YLL ($P < 0.001$); this pattern was the opposite in the second epidemic wave ($P < 0.001$). Meanwhile, there

Table 1. Mortality and premature mortality attributable to COVID-19 from 3 March 2020 to 31 October 2022 in Chile by sex and epidemic wave

	Chile[b]				Male[c]				Female[c]			
	Number of deaths	Mortality rate[a]	Absolute YLL	YLL rate[a]	Number of deaths	Mortality rate[a]	Absolute YLL	YLL rate[a]	Number of deaths	Mortality rate[a]	Absolute YLL	YLL rate[a]
Total	61 174	68.9	975 937	1247.1	33 865	89.8	476 060	1331.9	27 309	52.6	362 412	874.4
Epidemic wave[d]												
Wave 1	19 260	67.6	309 359	1211.0	10 948	90.3	154 665	1324.8	8313	49.8	110 409	813.7
Wave 2	29 077	50.7	493 309	968.5	16 149	65.7	243 014	1037.0	12 931	38.9	183 679	681.4
Wave 3	9248	14.7	125 827	232.3	4882	18.9	57 237	237.5	4366	11.8	49 392	171.2
Wave 4	3589	11.2	47 442	173.3	1890	14.3	21 144	173.4	1699	8.9	18 932	131.9

YLL, years of life lost.
[a] Age-standardized rate per 100 000 inhabitants.
[b] Estimated using the Global Burden of Disease (GBD) Standardized Life Expectancy (SLE) tables.
[c] Estimated using GBD 1990 SLE tables.
[d] Estimated using GBD 2013–16 and 1990 SLE tables.

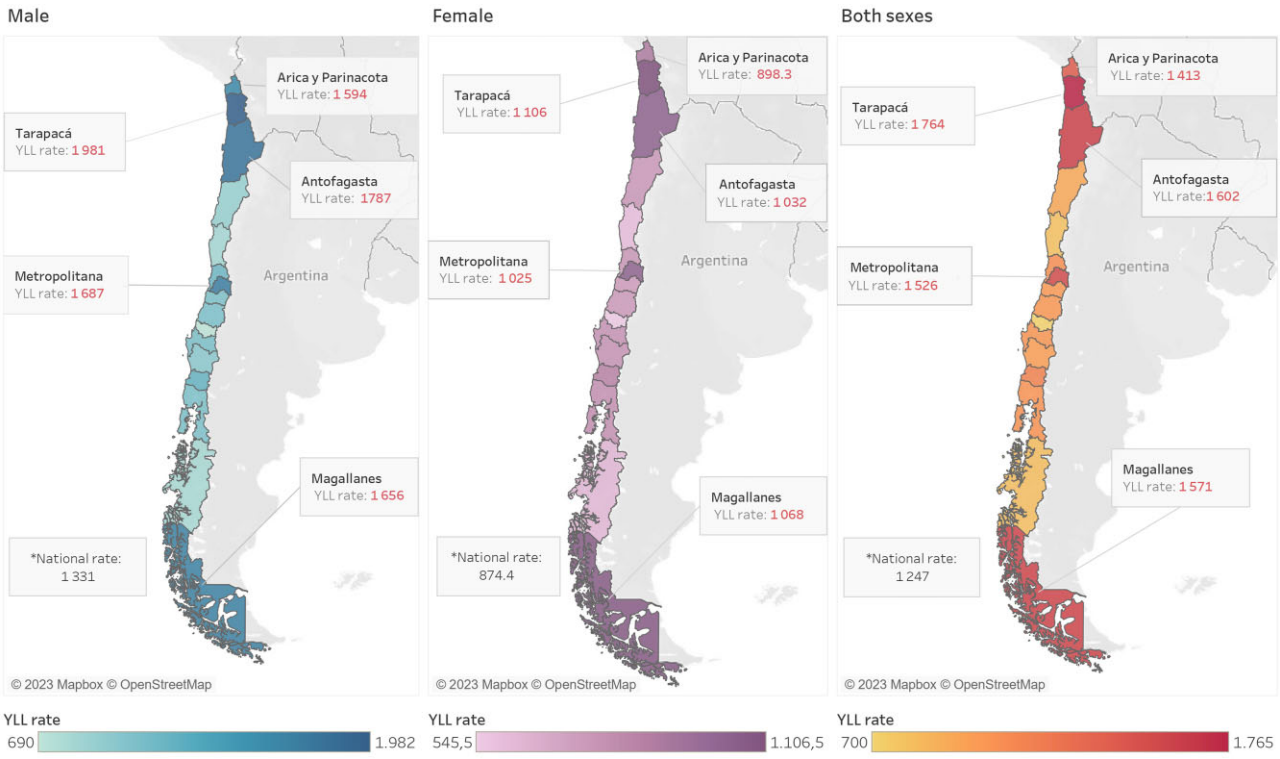

Figure 1. COVID-19 age–sex standardized years of life lost (YLL) rates from 3 March 2020 to 31 October 2022 at the subnational level (regions) and by sex in Chile

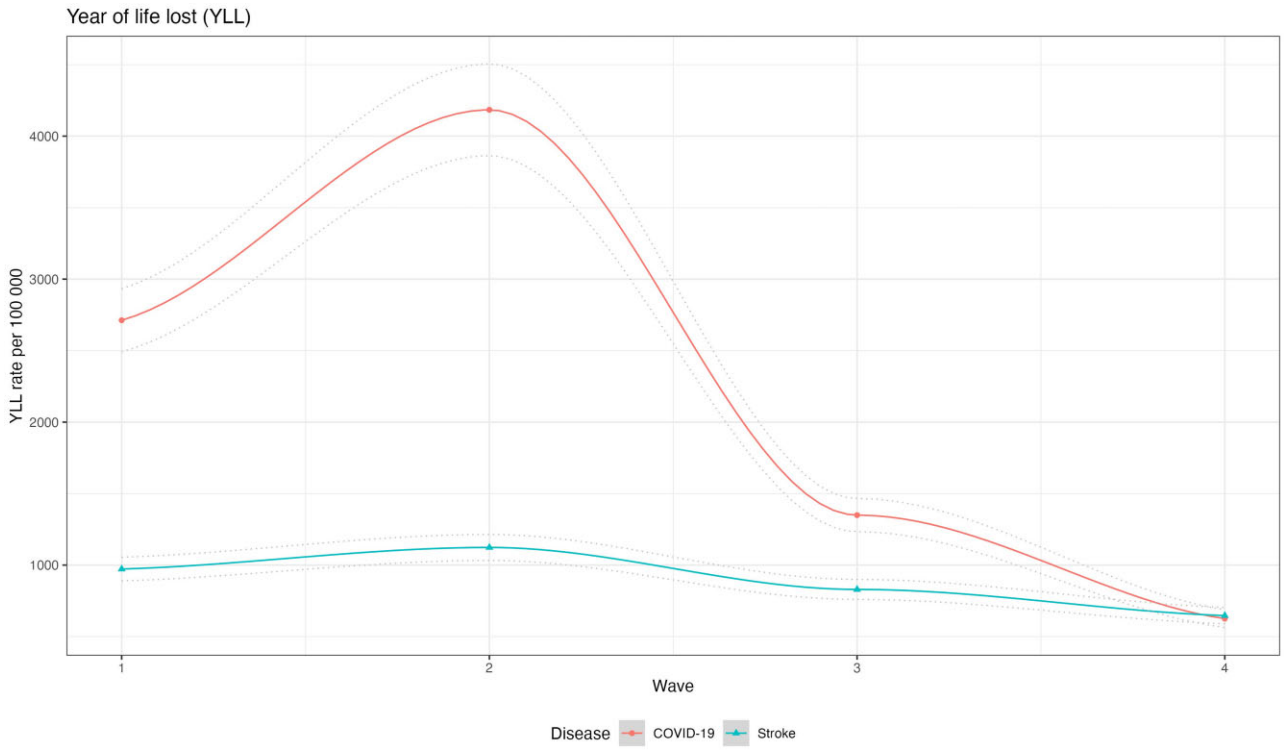

Figure 2. Years of life lost (YLL) rate trends across epidemic waves for COVID-19 and stroke

were no differences between Q2 and Q3 ($P = 0.291$) and Q4 and Q5 ($P = 0.140$) (Figure 4).

Figure 3 and Model 3 in Table 2 show the YLL estimate trends for COVID-19 and stroke according to communal SES groups. Comparing YLL trends of Q1 to Q5 poverty distribution, slope trends converge across epidemic waves for COVID-19 (coefficients interaction term 0.33, $P_{trend} < 0.001$), but were parallel for stroke (coefficient interaction terms 0.0005, $P_{trend} = 0.979$ in Model 3). Similar results were found for Q2 vs Q5 (coefficient interaction terms 0.15,

Table 2. Negative binomial regression model for YLL trends estimates by sex and communal SES

	Model 2				Model 3			
	COVID-19		Stroke		COVID-19		Stroke	
	Coefficient	*P*	Coefficient	*P*	Coefficient	*P**	Coefficient	*P**
Sex								
Epidemic waves	–0.57	<0.001	–0.15	<0.001	–0.62	<0.001	–0.15	<0.001
Male (female reference)	0.32	<0.001	0.26	<0.001	0.56	<0.001	0.28	0.005
Male*wave interaction term	–	–	–	–	0.10	0.012	–0.01	0.827
Communal SES								
Epidemic waves	–0.57	<0.001	–0.15	<0.001	–0.68	<0.001	–0.16	0.0001
SES (Q5 reference)								
Q1	0.27	0.001	0.85	<0.001	–0.52	0.007	0.84	<0.001
Q2	0.14	0.052	0.48	<0.001	–0.21	0.216	0.45	0.009
Q3	0.15	0.043	0.27	<0.001	–0.03	0.844	0.19	0.251
Q4	–0.09	0.224	0.10	0.121	–0.40	0.017	0.09	0.596
Q5*wave interaction term								
Q1*wave	–	–	–	–	0.33	<0.001	–0.002	0.979
Q2*wave	–	–	–	–	0.15	0.024	0.001	0.884
Q3*wave	–	–	–	–	0.08	0.255	0.028	0.652
Q4*wave	–	–	–	–	0.13	0.038	0.004	0.948

Q1–Q5, socio-economic Quintiles 1–5; SES, socio-economic status; YLL, years of life lost.
* *P* trend for the interaction terms.

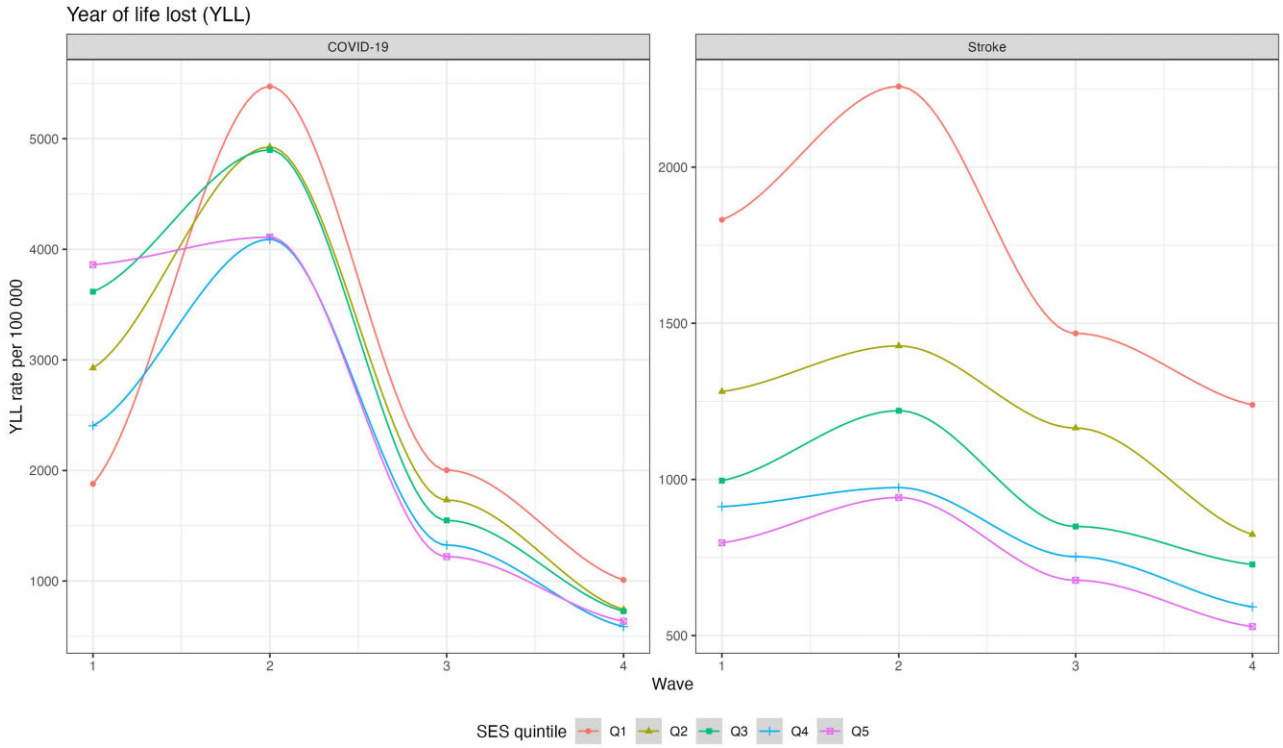

Figure 3. Years of life lost (YLL) rate trends across epidemic waves and by communal socio-economic status (SES) quintile distribution for COVID-19 and stroke

P_{trend}= 0.024) and Q4 vs Q5 (coefficient interaction terms 0.13, P_{trend}= 0.038). YLL slope trends were parallel for stroke (Model 3 in Table 3 and Figure 3). Supplementary Figure S1 (available as Supplementary data at *IJE* online) displays each quintile SES distribution with its 95% CI.

Independently of epidemic waves, there were differences in YLL according to sex for COVID-19 and stroke. For both conditions, the estimated YLL was higher in males than in females (coefficient 0.32, $P < 0.001$ for COVID-19; coefficient 0.56 in stroke, $P < 0.001$ for stoke) (Table 2, Model 2). Compared with those in females, YLL trends in males declined and converged across the epidemic waves in COVID-19 (coefficient interaction term 0.10, P_{trend}= 0.012); however, this pattern was parallel in YLL for stroke (coefficient interaction term –0.01, P_{trend}= 0.827; Model 3 in Table 2 and Figure 4).

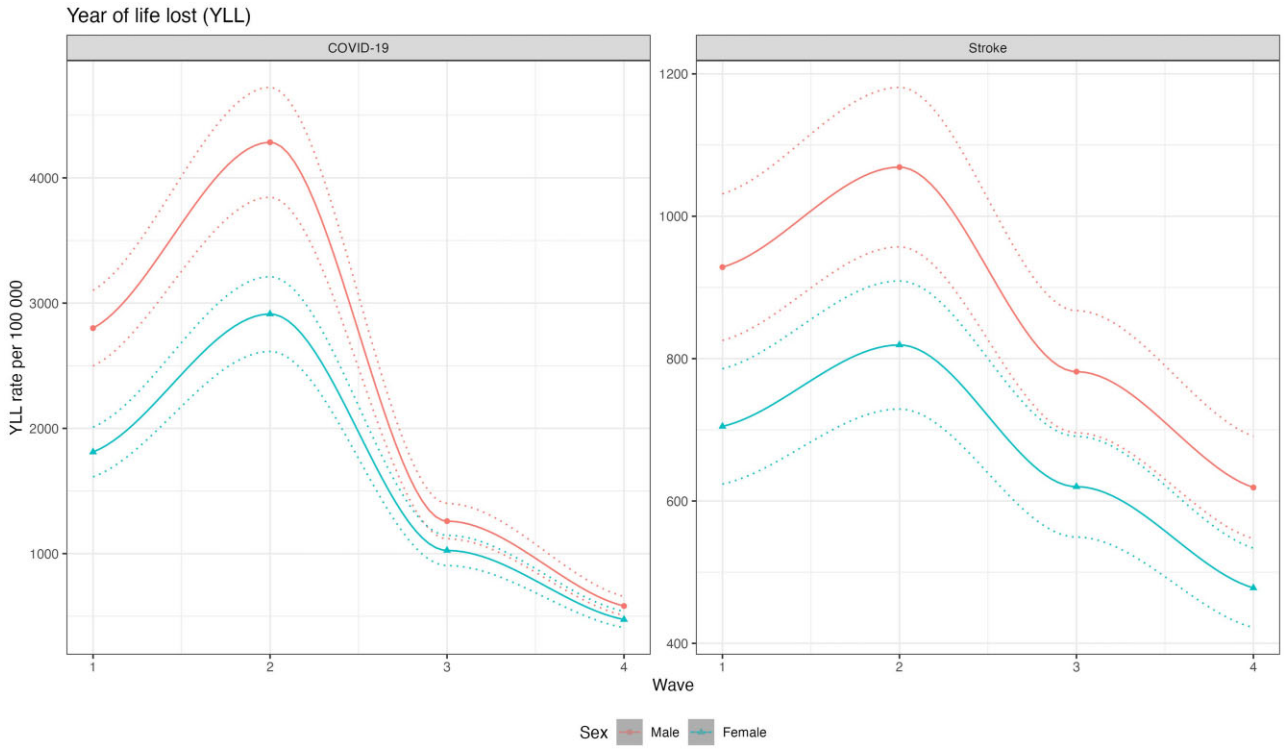

Figure 4. Years of life lost (YLL) rate trends across epidemic waves and by sex for COVID-19 and stroke

Discussion

Our results revealed a substantial impact of COVID-19 mortality during almost 3 years of the pandemic in Chile. The 61 174 COVID-19-related deaths resulted in 975 000 YLL due to premature mortality, i.e. 15.9 years lost per person who died of COVID-19, and males were most affected. These findings were similar to other reports, with similar sex distribution.[21,22] For example, during the first year of the pandemic, 16 YLL per person were reported in 81 countries and 21 YLL per person were reported in 2 years of the pandemic in Malaysia.[23]

There were subnational geospatial variations in YLL. The northern and extreme south and the most populated regions (Metropolitan Region) were most affected, highlighting the importance of timely access to health services, early diagnosis and treatment in extreme areas. Geographical disparities may be explained by the fact that these regions are the main border points in Chile and the first COVID-19 detected case was in the Metropolitan Region. Social and individual isolation was mandated in Chile to reduce mobility and limit SARS-CoV-2 transmission, accompanied by various fines and sanctions to ensure compliance. Unlike in other countries, deconfinement was gradual according to the epidemiologic situation of smaller geographic areas. Thus, outbreaks in most affluent areas in the first wave could be controlled in the subsequent waves. Social and environmental factors that influence subnational variations were reported in some studies.[6,24] In Brazil, a subnational difference was found in YLL in different states due to racial differences.[24] Additionally, a multi-city international study showed that low temperatures in the south of Chile and low absolute humidity in the northern regions increased the incidence of the disease.[25]

After the study period, new cases continued to emerge, but mortality dropped sharply. Although SES disparity was marked at the initial stage of the pandemic, interestingly, it gradually narrowed until the end of the pandemic. Similarly, results were recently reported in Barcelona but only in the incidence of COVID-19 cases.[26] In contrast, disparities in COVID-19 YLL by area deprivation were exacerbated from 2020 to 2021 despite high vaccine coverage in Scotland.[27] Although multiple factors can explain these findings, i.e. the natural history of diseases or confounding factors, having used a counterfactual comparison allow us to hypothesize that the centralized management of the pandemic in Chile may explain this gap closure, which includes equal access to testing and healthcare, with particular attention on rapid access to vaccines and high vaccination coverage rates. Moreover, the Chilean Ministry of Health established a national and centralized public and private management plan for intensive healthcare beds to provide respiratory assistance, independently of the patient's health insurance status and set healthcare price.[26]

The main strength of this study is that we used high-quality national mortality databases for our analysis because the DEIS standardizes them. This study included the entire COVID-19 pandemic in Chile, including subnational analysis, in order to have a more complete and comprehensive understanding of the impact of the COVID-19 pandemic. A counterfactual scenario was used to compare the evolution of COVID-19 with other severe conditions that require hospitalizations, although, ideally, it would have been other immuno-preventable diseases. However, stroke events were not interrupted during the pandemic and had decentralized management that was different from the COVID-19 management implemented in Chile, postulating complex and centralized interventions for closing gaps in communicable diseases. Nevertheless, it would be interesting to investigate how much can be attributed to vaccination.

We performed a robust YLL estimation, providing evidence for later COVID-19 disability adjusted life years (DALY) calculations.[26] Although YLL and DALY are broadly used to quantify the burden of NCDs, their comorbidity correction for acute illnesses in infectious diseases is still controversial.[28–30] Dying from infectious diseases, as occurs in COVID-19, is exacerbated by multimorbidity conditions, associated with less life expectancy and SES. Thus, correcting YLL for comorbidities could be counterproductive in detecting SES disparities.[28] This approach would not lead to other burden disease comparisons,[31,32] e.g. influenza.[33]

One limitation is that our study used an SES ecological indicator instead of an individual indicator due to data unavailability. Moreover, our study did not include confounders and other explanatory variables in trend analysis. However, this is an explanatory study and further research would examine this later. Although trends were compared with the counterfactual scenario of stroke, there is some relationship between stroke trends used as the control group and COVID-19 deaths. However, it is challenging to find any disease that has any relationship with COVID-19, even in treatment or impacted by non-pharmaceutical interventions. Finally, our geographical distribution results were estimated under the assumption of non-spatial correlation due to the unified care system for COVID-19 in Chile. Therefore, later studies should consider autoregressive parameters to quantify this spatial autocorrelation.

In conclusion, this study quantified the impact of COVID-19 mortality in Chile and identified important sex, geospatial and SES disparities for >2 years of the pandemic.

Ethics approval

We use open data sets; consequently, this study did not require ethical approval or administrative permissions. The study and analysis were performed in accordance with the Declaration of Helsinki.

Data availability

The data for this article will be shared on reasonable request to the corresponding author.

Supplementary data

Supplementary data are available at *IJE* online.

Author contributions

L.M., C.U. and M.S. designed the study. L.M. and A.S. analysed the results, and C.U. and L.M. wrote the manuscripts with the participation of the other authors. C.U., M.S. and P. M. interpreted the results and reviewed the manuscript.

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Conflict of interest

None declared.

References

1. The Johns Hopkins University of Medicine. *Coronavirus Resource Center*. https://coronavirus.jhu.edu/map.html (18 October 2022, date last accessed).
2. Pifarré I Arolas H, Acosta E, López-Casasnovas G *et al.* Years of life lost to COVID-19 in 81 countries. *Sci Rep* 2021;**11**:3504–506.
3. Wong MD, Shapiro MF, Boscardin WJ, Ettner SL. Contribution of major diseases to disparities in mortality. *N Engl J Med* 2002; **347**:1585–92.
4. Hoebel J, Michalski N, Diercke M *et al.* Emerging socio-economic disparities in COVID-19-related deaths during the second pandemic wave in Germany. *Int J Infect Dis* 2021;**113**:344–46.
5. Dukhovnov D, Barbieri M. County-level socio-economic disparities in COVID-19 mortality in the USA. *Int J Epidemiol* 2022;**51**:418–28.
6. Wang L, Calzavara A, Baral S *et al.* Differential patterns by area-level social determinants of health in COVID-19 related mortality and non-COVID-19 mortality: a population-based study of 11.8 million people in Ontario, Canada. *Clin Infect Dis* 2023;**76**:1110–20.
7. Khanijahani A, Iezadi S, Gholipour K, Azami-Aghdash S, Naghibi D. A systematic review of racial/ethnic and socioeconomic disparities in COVID-19. *Int J Equity Health* 2021;**20**:248.
8. López R, Miller SJ. Chile: the unbearable burden of inequality. *World Dev* 2008;**36**:2679–95.
9. *Health at a Glance 2021: OECD Indicators*. https://www.oecd.org/chile/health-at-a-glance-Chile-EN.pdf (18 October 2022, date las accessed).
10. Our World in Data. COVID-19 testing. https://ourworldindata.org/coronavirus-testing#how-many-tests-are-performed-each-day (24 November 2022, date last accessed).
11. Aguilera X, Mundt AP, Araos R, Weitzel T. The story behind Chile's rapid rollout of COVID-19 vaccination. *Travel Med Infect Dis* 2021;**42**:102092.
12. Our World in Data. *Coronavirus (COVID-19) Vaccinations*. https://ourworldindata.org/covid-vaccinations (18 September 2022, date last accessed).
13. Gobierno de Chile. *Cifras Oficiales COVID-19*. https://www.gob.cl/coronavirus/cifrasoficiales/ (18 October 2022, date last accessed).
14. Mena GE, Martinez PP, Mahmud AS, Marquet PA, Buckee CO, Santillana M. Socioeconomic status determines COVID-19 incidence and related mortality in Santiago, Chile. *Science* 2021; **372**:eabg5298.
15. Mena G, Aburto JM. Unequal impact of the COVID-19 pandemic in 2020 on life expectancy across urban areas in Chile: a cross-sectional demographic study. *BMJ Open* 2022;**12**:e059201.
16. World Health Organization. Certificación médica de causa de defunción: instrucciones para los médicos sobre el empleo del modelo internacional del certificado médico de causa de defunción. 1980. https://iris.paho.org/handle/10665.2/48059 (18 October 2022, date last accessed).
17. Antini C, Rajs D, Muñoz-Quezada MT, Mondaca BAL, Heiss G. Reliability of cause of death coding: an international comparison. *Cad Saude Publica* 2015;**31**:1473–82.
18. Martinez R, Soliz P, Caixeta R, Ordunez P. Reflection on modern methods: years of life lost due to premature mortality—a versatile and comprehensive measure for monitoring non-communicable disease mortality. *Int J Epidemiol* 2019;**48**:1367–76.
19. Alonso F, Nazzal C, Cerecera F, Ojeda JI. Reducing health inequalities: comparison of survival after acute myocardial infarction according to health provider in Chile. *Int J Health Serv* 2019; **49**:127–41.
20. Lavados PM, Díaz V, Jadue L, Olavarría VV, Cárcamo DA, Delgado I. Socioeconomic and cardiovascular variables explaining regional variations in stroke mortality in Chile: an ecological study. *NED* 2011;**37**:45–51.
21. Williams G, Spencer A, Farragher T, Gittins M, Verma A. Years of life lost to COVID-19 in 20 countries. *J Glob Health* 2022;**12**:05007.
22. Ugarte MP, Achilleos S, Quattrocchi A *et al.*; C-MOR Consortium. Premature mortality attributable to COVID-19:

potential years of life lost in 17 countries around the world, January–August 2020. *BMC Public Health* 2022;**22**:54.
23. Tan L, Ganapathy SS, Chan YM *et al.* Estimating the COVID-19 mortality burden over two full years of the pandemic in Malaysia. *Lancet Reg Health West Pac* 2022;**22**:100456.
24. Castro APBd, Moreira MF, Bermejo PHdS, Rodrigues W, Prata DN. Mortality and years of potential life lost due to COVID-19 in Brazil. *Int J Environ Res Public Health* 2021;**18**:7626.
25. Nottmeyer L, Armstrong B, Lowe R *et al.* The association of COVID-19 incidence with temperature, humidity, and UV radiation—a global multi-city analysis. *Sci Total Environ* 2023;**854**:158636.
26. Martinez-Beneito MA, Marí-Dell'Olmo M, Sánchez-Valdivia N *et al.* Socioeconomic inequalities in COVID-19 incidence during the first six waves in Barcelona. *Int J Epidemiol* 2023;dyad105.
27. Wyper GMA, Fletcher E, Grant I *et al.* Widening of inequalities in COVID-19 years of life lost from 2020 to 2021: a Scottish Burden of Disease Study. *J Epidemiol Community Health* 2022;**76**:746–49.
28. Wyper GMA, Devleesschauwer B, Mathers CD, McDonald SA, Speybroeck N. Years of life lost methods must remain fully equitable and accountable. *Eur J Epidemiol* 2022;**37**:215–16.
29. Ferenci T. Different approaches to quantify years of life lost from COVID-19. *Eur J Epidemiol* 2021;**36**:589–97.
30. Mangen MJJ, Plass D, Havelaar AH, BCoDE Consortium *et al.* The pathogen- and incidence-based DALY approach: an appropriated methodology for estimating the burden of infectious diseases. *PLoS ONE* 2013;**8**:e79740.
31. Emadi M, Delavari S, Bayati M. Global socioeconomic inequality in the burden of communicable and non-communicable diseases and injuries: an analysis on global burden of disease study 2019. *BMC Public Health* 2021;**21**:1771.
32. Cassini A, Colzani E, Pini A *et al.*; on behalf of the BCoDE Consortium. Impact of infectious diseases on population health using incidence-based disability-adjusted life years (DALYs): results from the Burden of Communicable Diseases in Europe study, European Union and European Economic Area countries, 2009 to 2013. *Eurosurveillance* 2018;**23**:17.
33. Viboud C, Miller M, Olson DR, Osterholm M, Simonsen L. Preliminary estimates of mortality and years of life lost associated with the 2009 A/H1N1 pandemic in the US and comparison with past influenza seasons. *PLoS Curr* 2010;**2**:RRN1153.