# RESEARCH



# Unraveling the impact of the COVID-19 pandemic on the mortality trends in Belgium between 2020–2022

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# Abstract

**Background** Over the past four years, the COVID-19 pandemic has exerted a profound impact on public health, including on mortality trends. This study investigates mortality patterns in Belgium by examining all-cause mortality, excess mortality, and cause-specific mortality.

**Methods** We retrieved all-cause mortality data from January 1, 2009, to December 31, 2022, stratified by age group and sex. A linear mixed model, informed by all-cause mortality from 2009 to 2019, was used to predict non-pandemic all-cause mortality rates in 2020–2022 and estimate excess mortality. Further, we also analyzed trends in cause-specific and premature mortality.

**Results** Different all-cause mortality patterns could be observed between the younger (<45 years) and older age groups. The impact of the COVID-19 pandemic was particularly evident among older age groups. The highest excess mortality occurred in 2020, while a reversal in this trend was evident in 2022. We observed a notable effect of COVID-19 on cause-specific and premature mortality patterns over the three-year period.

**Conclusions** Despite a consistent decline in COVID-19 reported mortality over this three-year period, it remains imperative to meticulously monitor mortality trends in the years ahead.

Keywords Belgium, Cause-specific mortality, COVID-19, Excess mortality, Years of life lost

# Background

The COVID-19 pandemic has left an indelible mark on global health in the past three years. Beyond the direct toll of the virus that reportedly claimed almost seven million lives globally as of 8 November 2023 [1], the pandemic has triggered a cascade of secondary effects. As the virus traveled across continents, countries grappled with overwhelmed healthcare systems, shortages of

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medical resources, and the unprecedented challenges of mitigating the spread of the virus [2].

Several methods have been proposed to evaluate the impact of COVID-19 on mortality patterns. The most sensible way to directly describe this impact is by using the reported deaths attributable to COVID-19. Although often at risk for under-reporting, COVID-19 deaths are accurately reported in Belgium [3, 4]. An alternative measure to assess the severity of an infection is the infection fatality ratio (IFR), which describes the probability of an individual dying from pathogen-related disease complications once infected with a pathogen [5]. However, COVID-19 frequently leads to numerous mild or asymptomatic cases, which often remain unrecorded in official statistics. This adds an additional layer of complexity to accurately estimating the true number of infections.



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Additionally, the detection of COVID-19 infection depends on both testing capabilities and individuals' willingness to undergo testing. Accurately estimating this metric has been particularly challenging, especially in the first year of the pandemic [6, 7]. Therefore, an alternative metric is preferable before more reliable datasets become available.

Excess mortality, defined as the difference between observed mortality during a crisis compared to the expected mortality in non-pandemic times, has been proposed as an alternative to assess the impact of the COVID-19 pandemic [8]. The excess mortality can be expressed in different ways, e.g., absolute number of excess deaths, deaths per million, or as a P-score. While the basic concept of excess mortality is relatively simple, its estimation can pose a challenge since the calculation of excess mortality requires reliable sources and/or models to estimate the all-cause mortality under nonpandemic conditions and reliable reporting of all-cause mortality in the past, present, and future. For example, Msemburi et al. predicted the pandemic all-cause deaths in all countries, both the ones with and without reliable reporting of all-cause mortality, using an overdispersed Poisson count framework that applies Bayesian inference techniques [9]. Based on this method, they estimated 14.83 million excess deaths globally in 2020-2021, 2.74 times higher than the reported COVID-19 deaths, with considerable variation across the six continents (excluding Antartica for obvious reasons). This approach, however, like many other models estimating excess mortality, includes all causes of excess mortality, including other seasonal infections or heat waves, which may perturb the relationship between excess mortality and COVID-19 mortality.

The mortality trend attributed to a novel infectious agent is subject to dynamic changes over time, in line with the changes in the provided medical care and mitigation measures (non-pharmaceutical or pharmaceutical interventions). In Belgium, multiple studies have investigated the impact of the COVID-19 pandemic on mortality trends in the first wave of 2020. Clear excess mortality in this period could be observed compared to the previous years (2009–2019), with a notably higher mortality observed among older age groups and residents of nursing homes [3, 4, 10-12]. While the first year of the pandemic proved to be a critical period globally, it is also important to extend the assessment to subsequent periods. Therefore, we aim to assess the impact of COVID-19 on the mortality trend in Belgium over the first three years of the pandemic. The trends were analyzed across different sex and age groups using both excess mortality and cause-specific mortality. The latter method is particularly informative for assessing the long-term impact of the COVID-19 pandemic on other causes of death.

# Materials and methods Data

StatBel, the Belgian national statistical institute, publicly released data encompassing daily all-cause mortality, monthly cause-specific mortality, and annual population figures (https://statbel.fgov.be/en/open-data). We used the data from year 2009 to 2022, aggregated by sex and age group (0–24 years, 25–44 years, 45–64 years, 65–74 years, 75–84 years, 85+ years). These data were retrieved on November 7, 2023.

Taking into account the potential influence of heatwave on the mortality pattern, we obtained data on heatwave occurrences in 2009–2022 from the Royal Meteorological Institute of Belgium (https://www.meteo.be/nl/klima at/klimaat-van-belgie/klimatologisch-overzicht). During the initial two years of the COVID-19 pandemic, nonpharmaceutical interventions (NPIs) were crucial in mitigating the virus's impact. To assess the influence of NPIs on the cause-specific mortality, we also retrieved the stringency index from Our World in Data (https://ourwo rldindata.org/explorers/covid) which provides an average score based on nine metrics related to mitigation measures, with higher values indicating more stringent policies within a certain period [13].

# Statistical analysis

To minimize daily variations and the weekend effect, the daily all-cause mortality data were arranged continuously and then aggregated based on sex and age groups in weekly periods according to the International Standard ISO 8601 definition, i.e., Monday is the first day of the week and the first week of the year is the one that includes the first Thursday. In this way, the length of each week remains consistent. We excluded week 53 since this week is not consistently present in every year. To accommodate heterogeneity in the weekly mortality among age groups, we used a logarithmic transformation of the mortality rate per 100,000 individuals, Y<sub>ij</sub>, with week i = 1, ..., 52 in the reference years j = 2009, ..., 2019. Taking into account the relative changes in each demographic group, we used a cubic spline interpolation to calculate the population in week *i* and year *j* [14]. Using a modification of the general linear mixed model proposed by Verbeeck et al. [4], we modeled  $Y_{ij}$ , considering the effect of sex and age group k = 1, ..., l, with l denotes the number of age groups used in a specific model. The potential interaction between sex and age groups is also evaluated, as well as the effect of heatwave, which

indicates whether the corresponding week is a part of a heatwave period. The proposed model is given by:

$$\log Y_{ij} = (\beta_0 + b_{0j}) + \beta_1 \operatorname{female}_{ij} + \sum_{k=1}^{l} \beta_{2k} \operatorname{age}[k]_{ij} + \beta_3 \operatorname{heatwave}_{ij} + \sum_{k=1}^{l} \beta_{4k} \operatorname{female} \times \operatorname{age}[k]_{ij} + \sum_{m=1}^{n} \alpha_m \sin\left(\frac{2m\pi i}{52}\right) + \sum_{m=1}^{n} \gamma_m \cos\left(\frac{2m\pi i}{52}\right) + \varepsilon_{ij},$$
(1)

with  $\varepsilon_{ij} \sim N(0, \sigma^2)$ ,  $b_{0j} \sim N(0, \sigma_D^2)$ , and  $\varepsilon_{ij}$ ,  $b_{0j}$  mutually independent. This model captures the annual changes of the mortality rate for each age and sex group through the random intercept  $b_{0i}$ , as well as the cyclic mortality pattern within a year through n Fourier terms. Due to the possibility of a non-significant effect, we allowed the Fourier terms to be non-sequential during the model selection. For each model, we explored up to six Fourier terms (n = 3) which correspond to a yearly sine wave  $(\alpha_1)$ , a yearly cosine wave ( $\gamma_1$ ), a half-yearly sine wave ( $\alpha_2$ ), a half-yearly cosine wave ( $\gamma_2$ ), a quarterly sine wave ( $\alpha_3$ ), and a quarterly cosine wave ( $\gamma_3$ ). The most parsimonious model was selected based on sequential exclusion of nonsignificant terms and minimal Akaike information criterion (AIC) value. We then predicted the weekly all-cause mortality rate in 2020-2022 from the final model and compared the 95% prediction interval (transformed back to the original scale) with the observed all-cause mortality rate.

The cause-specific mortality was evaluated using a descriptive time-trend analysis stratified by sex and age groups. The monthly data were available starting from 2009 until 2021. StatBel compiled the causes of death based on the International Statistical Classification of Diseases and Related Health Problems version (https://www.who.int/classifications/classification-11 of-diseases) and reported these causes in 21 groups. To maintain the comprehensiveness of our analysis, we further divided these groups into seven broader groups, namely COVID-19, external causes (including road accidents and suicide), heart and vascular diseases, infection diseases, mental and behavioral disorder, neoplasms, and other causes (see Table S1). Similar to the all-cause mortality, the cause-specific mortality rate was calculated as the number of cause-specific deaths divided by the interpolated monthly population. We compared the cause-specific mortality trend in 2020 and 2021 with year 2009-2019.

To gain a deeper understanding of the impact of COVID-19 on cause-specific mortality patterns, we focused our analysis on data from years 2020 and 2021. For each group of causes, we modeled the logarithmic transformation of the monthly mortality rate,  $Y_{ij}$ , with month i = 1, ..., 12 and year j = 2020, 2021. Since the

data were aggregated in a monthly period, we decided to omit the effect of heatwave and added the median stringency index in the corresponding month. Taking into account the granularity of the cause-specific mortality data and to maintain the comparability among the causes, we adjusted the proposed model in (1) to accommodate possible interactions among all covariates:

$$\log Y_{ij} = (\beta_0 + b_{0j}) + \beta_1 \text{female}_{ij} + \sum_{k=1}^{l} \beta_{2k} \text{age}[k]_{ij} + \beta_3 \text{stringency}_{ij}$$
$$+ \sum_{k=1}^{l} \beta_{4k} \text{female} \times \text{age}[k]_{ij} + \beta_5 \text{female} \times \text{stringency}_{ij}$$
$$+ \sum_{k=1}^{l} \beta_{6k} \text{age}[k] \times \text{stringency}_{ij} + \sum_{k=1}^{l} \beta_{7k} \text{female} \times \text{age}[k] \times \text{stringency}_{ij}$$
$$+ \varepsilon_{ij}, \qquad (2)$$

with  $\varepsilon_{ij} \sim N(0, \sigma^2)$ ,  $b_{0j} \sim N(0, \sigma_D^2)$ , and  $\varepsilon_{ij}$ ,  $b_{0j}$  mutually independent. Similar to the all-cause mortality, the most parsimonious model was selected based on sequential exclusion of non-significant terms and minimal AIC value.

Finally, we also analyzed the premature mortality pattern using years of life lost (YLL). YLL is calculated by multiplying the number of deaths by the residual life expectancy at the age of death, allowing us to quantify the burden of each cause of death in terms of the potential years of life lost [15]. Since the cause-specific mortality data were already aggregated into specific age brackets, we used the median age of each group as a proxy for the age of death. This allowed us to estimate the residual life expectancy based on the Belgian life table, which is made publicly available by Statbel. We multiplied this residual life expectancy with the number of cause-specific deaths in each year.

## Results

## All-cause and excess mortality

The weekly observed all-cause mortality rate in 2009–2022 is shown in Fig. 1. We observed similar mortality patterns in year 2020–2022 compared to the reference years (i.e., 2009–2019) in younger age groups (0–24 and 25–44). Starting from age 65, we observed a seasonal pattern with higher mortality rates in weeks 10–15, 31–33, and 42 onward of year 2020. The mortality rates in these age groups showed a clear peak in all-cause mortality, especially for year 2020. Compared to the older age groups, age groups 0–24 and 25–44 had considerably lower weekly mortality.

Considering the distinct all-mortality patterns between the younger and older age groups, we also fitted the model proposed in (1) separately for the younger age groups (0-24 and 25-44 years) and the older age groups



Fig. 1 All-cause mortality rate in 2009–2022. The y-axis range varies across age groups for clarity of the visualisation

(45+). All fitted models and their corresponding AIC values are summarized in Table S2.

In the model that includes all age groups, we observed significant effects of sex, age groups, heatwave, and interaction between sex and age groups. This finding was consistent across all fitted models. Regarding the cyclical parameters, we found initially four significant Fourier terms (i.e., n = 2 for both parameters  $\alpha_m$  and  $\gamma_m$ ), corresponding to a yearly sine wave ( $\alpha_1$ ), a yearly cosine wave ( $\gamma_1$ ), a half-yearly sine wave ( $\alpha_2$ ), and a half-yearly cosine wave ( $\gamma_2$ ). We reduced the full model by excluding non-significant terms in each step until we reached a reduced model with only significant parameters (Reduced model 2). Our selection is further supported by the lowest AIC value of Reduced model 2.

When fitting the model separately, we identified significant effects of sex, age groups, and interaction between sex and age groups in the younger as well as the older age groups. A significant effect of heatwave on the mortality rate was found in the older age groups but not in the younger age groups.

In age groups 0–24 and 25–44 years, we also found a significant yearly sine wave  $\alpha_1$ . However, the seasonal pattern in these age groups were not so pronounced compared to the older age groups (Fig. 1). As shown in Table S2, a model with yearly sine wave had a higher AIC value compared to a model without any Fourier term (1363.9 and 1360.1, respectively). In view of this, we decided to use the simpler model for the following model comparison.

Similar to the model with all age groups, we identified four significant Fourier terms (yearly sine wave  $\alpha_1$ , yearly cosine wave  $\gamma_1$ , half-yearly sine wave  $\alpha_2$ , and halfyearly cosine wave  $\gamma_2$ ) for the age groups  $\geq 45$  years. The separate models yielded a substantially lower AIC value (-6657.8) compared to the model that included all age groups (-2084.7). Therefore, we opted to use the separate

 Table 1
 Final separate linear mixed model for the younger and older age groups

Age group <i>k</i>	Model notation
0-24, 25-44	$\begin{array}{rcl} \log Y_{ij} &= (\beta_0 + b_{0j}) + \beta_1 \text{female}_{ij} + \beta_{2,2} \text{age}[25 - 44]_{ij} + \beta_{3,2} \text{female } \times \text{age}[25 - 44]_{ij} \\ + \varepsilon_{ij} \\ \text{with } \varepsilon_{ij} &\sim N(0, \sigma^2), \ b_{0j} \sim N(0, \sigma_D^2), \ \text{and } \varepsilon_{ij}, \ b_{0j} \text{ mutually independent.} \end{array}$
45-64, 65-74, 75-84, 85+	$\begin{split} \log Y_{ij} &= (\beta_0 + b_{0j}) + \beta_1 \text{female}_{ij} + \beta_{2,2} \text{age}[65 - 74]_{ij} + \beta_{2,3} \text{age}[75 - 84]_{ij} \\ &+ \beta_{2,4} \text{age}[85_+]_{ij} + \beta_3 \text{heatwave}_{ij} + \beta_{4,2} \text{female} \times \text{age}[65 - 74]_{ij} \\ &+ \beta_{4,3} \text{female} \times \text{age}[75 - 84]_{ij} + \beta_{4,4} \text{female} \times \text{age}[85_+]_{ij} + \alpha_1 \sin\left(\frac{2\pi i}{52}\right) \\ &+ \alpha_2 \sin\left(\frac{4\pi i}{52}\right) + \gamma_1 \cos\left(\frac{2\pi i}{52}\right) + \gamma_2 \cos\left(\frac{4\pi i}{52}\right) + \varepsilon_{ij} \\ \text{with } \varepsilon_{ij} \sim N(0, \sigma^2), \ b_{0j} \sim N(0, \sigma_D^2), \ \text{and} \ \varepsilon_{ij}, \ b_{0j} \ \text{mutually independent.} \end{split}$



Fig. 2 Observed (coloured dots) and predicted (solid line) mortality rate in 2020–2022 based on the linear mixed model estimates in Table S3

models denoted in Table 1, as our final model to predict mortality rates for 2020–2022.

The parameter estimates of each model in Table 1 are presented in Table S3. We compared the observed mortality with the 95% prediction interval derived from these estimates as shown in Fig. 2. In general, we observed higher predicted mortality rates in males with wider prediction intervals. For age group 0-24 years, the observed mortality rate in 2020-2022 was lower relative to the predicted intervals. In age group 25-44 years, the observed mortality rate in 2020–2022 followed the predicted trend. We found higher mortality rates in 2020 starting from age 45 years old. Higher values of the observed mortality compared to the 95% predicted intervals in year 2020, particularly in age groups 65–74, 75–84, and 85+ years, indicated a higher excess mortality in these age groups. The mortality pattern changed in 2021-2022 where we found relatively lower observed mortality rates compared to the 95% predicted intervals, especially in age group 45-64 years.

# **Cause-specific mortality**

The monthly cause-specific mortality rates from 2009 to 2021 are shown in Fig. 3. To ensure clarity in visualization, we grouped the causes of death into three broader categories: COVID-19, external causes, and internal causes (which include heart and vascular diseases, infectious diseases, mental and behavioral disorders, neoplasms, and other causes). A figure with seven groups is available in Figure S1.

Overall, we observed varying trends in the causes of death across different age groups. External and internal causes contributed almost equally to mortality in younger age groups, while internal causes were clearly more dominant in the older age groups (Fig. 3). However, when the causes of death were further subdivided, mortality in younger age groups was predominantly attributed to external or other causes, particularly in males aged 25–44 years (Figure S1). From the age of 45 years onward, the primary causes shifted specifically towards neoplasms, heart and vascular diseases, or other causes. Interestingly, following the onset of the COVID-19 pandemic in 2020, there were notable declines in all causes of death except for COVID-19 across all sex and age categories compared to the period from 2009 to 2019, as the mortality rate in 2020 (Fig. 3, solid lines) and 2021 (Fig. 3, dashed lines) were relatively lower compared to the reference years (Fig. 3, dotted lines). Notably, COVID-19 emerged as the predominant cause of death during the COVID-19 waves in 2020, especially in the older age groups. The trend changed again in 2021 where deaths caused by COVID-19 became considerably lower than year 2020.

All fitted models for each cause of death and their corresponding AIC values are presented in Table S4. Based on the AIC value, we found that Reduced model 5 had



Fig. 3 Monthly cause-specific mortality rate. Dotted lines: cause-specific rates in year 2009–2019. Solid lines: cause-specific rates in year 2020. Dashed lines: cause-specific rates in year 2021. The y-axis range varies across age groups for clarity of visualisation

the lowest AIC value for most causes of death. This model is given by:

remained relatively stable (Fig. 4). When the pandemic started in 2020, the YLL attributed to COVID-19

$$\log Y_{ij} = (\beta_0 + b_{0j}) + \beta_1 \text{female}_{ij} + \beta_{2,2} \text{age}[25 - 44]_{ij} + \beta_{2,3} \text{age}[45 - 64]_{ij} + \beta_{2,4} \text{age}[65 - 74]_{ij} + \beta_{2,5} \text{age}[75 - 84]_{ij} + \beta_{2,6} \text{age}[85_+]_{ij} + \beta_3 \text{stringency}_{ij} + \beta_{4,2} \text{female} \times \text{age}[25 - 44]_{ij} + \beta_{4,3} \text{female} \times \text{age}[45 - 64]_{ij} + \beta_{4,4} \text{female} \times \text{age}[65 - 74]_{ij} + \beta_{4,5} \text{female} \times \text{age}[75 - 84]_{ii} + \beta_{4,6} \text{female} \times \text{age}[85_+]_{ii} + \varepsilon_{ii}$$
(3)

with  $\varepsilon_{ij} \sim N(0, \sigma^2)$ ,  $b_{0j} \sim N(0, \sigma_D^2)$ , and  $\varepsilon_{ij}$ ,  $b_{0j}$  mutually independent. It should be noted that for COVID-19 mortality, the model with only fixed effects (Reduced model 8) exhibited a lower AIC value compared to Reduced model 5. However, we aimed to maintain comparability across different causes of death. Additionally, the AIC values were relatively similar between Reduced models 5 and 8 (732.4 for Reduced model 5 and 725.1 for Reduced model 8). Therefore, we decided to use Reduced model 5 for all causes of death.

The full estimates from the linear mixed models based on (3) are provided in Table S5. Overall, we observed significant effects of age group and sex. However, the interaction between age group and sex was not statistically significant for COVID-19-related mortality. Among non-COVID-19 causes, the stringency index demonstrated a significant negative effect, i.e., decreasing the mortality rate, for external causes, mental and behavioral disorders, neoplasms, and other causes.

Between 2009 and 2019, some causes of deaths showed a considerable decline in YLL, while others

reached immediately a similar level as the major agespecific causes of deaths before the pandemic, especially in the oldest age groups. We found an interesting turning point in 2021, where the YLL attributed to COVID-19 was markedly decreased, while other causes experienced an increase in the YLL.

# Discussion

The mortality trends in Belgium changed considerably during the three years of the COVID-19 pandemic with distinct patterns between younger age groups (below 45 years) and older age groups (45 years and above). These distinct patterns could be observed in the excess mortality and cause-specific mortality.

In the younger age groups, we found similar all-cause mortality patterns in 2020–2022 compared to the prepandemic reference years. The observed mortality rate in some weeks in 2020–2022 is lower than the 95% prediction intervals, especially in age group 0–24 years. This is likely explained by the lower mortality due to external causes, as a result of the non-pharmaceutical COVID-19



Fig. 4 Cause-specific years of life lost. The y-axis range varies across age groups for clarity of visualisation

mitigation measures (including lockdown). Starting from age 65 years, we observed higher mortality rates in 2020-2022 and consequently higher excess mortality. These age-related trends of excess mortality have been reported in other settings. For example, in Israel, Peretz et al. reported fewer deaths than expected in age group 0-19 years between 2020–2021, while the older age groups had higher deaths than expected [16]. Similar results have been reported in other European or high income countries [11, 17]. The higher excess mortality in the older age categories might be directly related to the amount of COVID-19 infections in this group (although the transmission shifted to younger age groups in September 2020 in Belgium [18]) or caused by other factors such as the presence of comorbidities in older age groups or changes in other cause of deaths due to COVID-19 mitigation measures. On top of this, a decrease in emergency admissions for acute life-threatening conditions such as stroke or myocardial infarctions would eventually increase the mortality [19, 20].

We observed lower cause-specific mortality in 2020 and 2021 compared to the reference years, except for COVID-19. Similar results were reported in Korea [21] or Brazil [22] where the mortality in the recent years decreased for most causes of death. Our finding also showed an evident decline in mortality attributed to external causes, such as road accidents or suicides, especially in males aged 25–44 years. This decline may be associated with the implementation of COVID-19 mitigation measures that prohibited travel or recreational activities. Our stratified linear mixed model analysis further supports the positive

impact of NPIs in reducing mortality rates associated with external causes, mental and behavioral disorders, neoplasms, and other causes. In contrast to our results, Lee et al. found an increase in mortality due to external causes among individuals under 44 years, especially during periods of stricter interventions, with a major contribution from unintentional injuries, assaults, homicides, and drug overdoses [23]. This contrast may be attributable to underlying sociodemographic differences related to the sub-level of external causes; however, we did not conduct further investigation as the available data did not permit disaggregation of external causes.

In older age groups, a more pronounced reduction in cause-specific mortality was observed in chronic diseases such as neoplasms or heart and vascular diseases. This phenomenon could be directly linked to COVID-19 infections, where individuals with pre-existing conditions might succumb to the infection rather than the underlying disease. Additionally, delays in diagnosing these conditions may have occurred due to reduced ambulatory care for non-COVID-19 illnesses during the initial year of the pandemic, potentially leading to incomplete or inaccurate registration in healthcare databases [24–26].

Similar to the observed mortality rates, we identified distinct patterns in the predominant causes of premature mortality across different age groups, with variations between younger and older populations. The external and other causes remained the leading causes of premature mortality in the younger age groups, while neoplasms and cardiovascular diseases predominantly causes the premature deaths in older age groups [27]. It should be noted that Alzheimer's disease and other dementias were also important causes of premature mortality in older age groups that were almost on par with cerebrovascular diseases [28]. We classified Alzheimer's disease and other types of dementia under the category of "other causes", making this category a leading cause to premature mortality in our analysis.

In 2020, a substantial increase in YLL attributable to COVID-19 was expected. However, this increase was accompanied by a decrease in YLL from other causes. This combination suggests a compensatory reduction in mortality, also known as the harvesting effect, due to the COVID-19 pandemic [29]. In the following year, we observed a reversal in YLL trends. While the reversal of COVID-19 mortality might be primarily due to the vaccination campaign that effectively reduced severe cases and thus, deaths, we should consider the potential contribution of a reverse harvesting effect, which is characterized by an increase in mortality due to a surge in other causes of death, such as other infectious diseases, outside their typical peak seasons [30]. Although we do not yet have data to directly investigate this phenomenon, i.e., cause-specific mortality data in 2022 is not available yet for Belgium, Sciensano reported indeed an increase in respiratory syncytial virus (RSV) infection outside the winter season of 2022 [31] on top of five COVID-19 waves and two influenza epidemics that caused a peak of mortality in December 2022 [32].

The robustness of our study is underscored by the inclusion of multi-year data stratified according to both sex and age groups. The combination of excess mortality and cause-specific mortality provides a comprehensive assessment of the impact of COVID-19 on mortality. Some limitations, however, should be noted. The substantial increase in mortality among older age groups suggests the potential importance of further dividing the age group of 45-64 years into narrower age bands. However, the publicly available mortality data are aggregated in this age band. While it is possible to redistribute the number of deaths using other population data, we seek to minimize the risk of introducing additional bias and/ or uncertainty into our analysis. Furthermore, there was a potential for underestimating YLL when using the median age within each age group as a proxy for age at death. For more precise estimates, it is advisable to use the exact age of death when individual data are available. Lastly, week 53 was excluded in certain years, resulting in the omission of approximately 0.45% of all deaths between 2009 and 2022. Given this small proportion, we consider the impact of excluding these weeks on our estimates would be very minimal.

# Conclusions

The COVID-19 pandemic played a substantial role in shaping the mortality pattern in Belgium. The effects were particularly evident among males and older age groups. Despite a steady decline in reported COVID-19 mortality over this triennial period, a persisting concern lies in the field of excess mortality. It is imperative to vigilantly track the mortality trend in the forthcoming years.

# **Supplementary Information**

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-20415-x.

Supplementary Material 1.

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Not applicable.

#### Authors' contributions

YAN participated in data acquisition, analysis, visualization, and writing the original draft. JV contributed in data acquisition, interpretation of the results, and reviewing the manuscript. GM involved in study conception, design, preliminary analysis, and reviewing the manuscript. CF and TN were involved in interpretation of the results and critical revision of the manuscript. All authors approved the final version of the manuscript.

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#### Data availability

All data supporting the findings of this study are made publicly available by Statbel (https://statbel.fgov.be/en/open-data), the Royal Meteorological Institute of Belgium (https://www.meteo.be/nl/klimaat/klimaat-van-belgie/ klimatologisch-overzicht), and Our World in Data (https://ourworldindata.org/ explorers/covid).

#### Code availability

Not applicable.

#### Declarations

**Ethics approval and consent to participate** Not applicable.

## **Consent for publication**

Not applicable.

#### Competing interests

The authors declare no competing interests.

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