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# Prevalence and epidemiological trends in mortality due to COVID-19 in Saudi Arabia

D.A. Alissa [a, b], W. Aburas [c], R. Almasuood [a], H.Y. Almudaiheem [a], Z. Al Aseri [d, e], F. Alrabiah [f], H. Ezzat [g, h, i], A.A. Moulana [j], M.M. Alawi [k], E. Al-mutairy [f], T. Alaama [a, b], M.S. Alamri [a], M.S. Bamousa [a, l], A.A. Alshehri [m], M.H. Alosaimi [a, n], A. Alali [o], R. Nori [p], E.B. Devol [q], G. Mohamed [q], A.H. Al-jedai [a, b, *]

[a] Therapeutic Affairs Deputyship, Ministry of Health, Riyadh, Saudi Arabia
[b] Colleges of Medicine and Pharmacy, Al-Faisal University, Riyadh, Saudi Arabia
[c] University of Hail, College of Pharmacy, Hail, Saudi Arabia
[d] Department of Emergency Medicine and Critical Care, King Saud University, Riyadh, Saudi Arabia
[e] Adult Critical Care, Ministry of Health, Riyadh, Saudi Arabia
[f] Department of Medicine, King Faisal Specialist Hospital and Research Center, Riyadh, Saudi Arabia
[g] Hematology Programs, Ministry of Health, Saudi Arabia
[h] John Hopkins Aramco Healthcare, Dharan, Saudi Arabia
[i] University of British Columbia, Canada
[j] Forensic Medicine Center, Makkah Al Mukarramah, Saudi Arabia
[k] Infection Control & Environmental Health Unit, Department of Medical Microbiology & Parasitology, Faculty of Medicine, King Abdulaziz University Hospital, Jeddah, Saudi Arabia
[l] Forensic Medicine General Directorate, Ministry of Health, Riyadh, Saudi Arabia
[m] Forensic Medicine Center, Ministry of Health, Riyadh, Saudi Arabia
[n] Mortality Affairs, Ministry of Health, Riyadh, Saudi Arabia
[o] Internal Medicine and Infectious Diseases, King Saud Medical City, Riyadh, Saudi Arabia
[p] Internal Medicine Department, Prince Mohammed Bin Abdulaziz Hospital, Riyadh, Saudi Arabia
[q] Department of Biostatistics, Epidemiology & Scientific Computing, King Faisal Specialist Hospital and Research Center, Riyadh, Saudi Arabia

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ABSTRACT

*Objectives:* This article describes the prevalence and epidemiological trends of COVID-19 mortality in the largest registry in the Kingdom of Saudi Arabia (KSA).
*Study design:* A prospective epidemiological cohort study using data from all healthcare facilities in KSA collected between March 23, 2020, and April 30, 2022. Data on the number of daily deaths directly related to COVID-19 were gathered, analyzed, and reported.
*Method:* Data analysis was carried out using national and regional crude case fatality rate and death per 100,000 population. Descriptive statistics using numbers and proportions were used to describe age, gender, nationality, and comorbidities. The mortality trend was plotted and compared with international figures. In addition, the most common comorbidities associated with mortality and the proportion of patients who received COVID-19 vaccine were reported.
*Results:* The total reported number of deaths between March 23, 2020, and April 30, 2022, was 9085. Crude case fatality rate was 1.21%, and death per 100,000 population was 25.38, which compared favorably to figures reported by several developed countries. The highest percentages of deaths were among individuals aged between 60 and 69 years, males (71%), and individuals with diabetes (60%). Only 2.8% of mortalities occur in patients who received COVID-19 vaccine. Diabetes, hypertension, and heart failure had the highest attributable risk of mortality among patients who died due to COVID-19.
*Conclusion:* Case fatality rate and death per 100,000 population in KSA are among the lowest in the world due to multiple factors. Several comorbidities have been identified, namely, diabetes, hypertension, obesity, and cardiac arrhythmias.


* Corresponding author. Ministry of Health, Riyadh, Saudi Arabia.
*E-mail address:* ahaljedai@moh.gov.sa (A.H. Al-jedai).

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## Introduction

COVID-19, an infectious respiratory illness caused by acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has devastating implications on health, economy, and daily life. The first case of COVID-19 emerged in Wuhan, China, in late December of 2019. Cases continued to mount worldwide, with the first confirmed case announced in the Kingdom of Saudi Arabia (KSA) in early March 2020.[1] COVID-19 was declared a pandemic by the World Health Organization (WHO) in March 2020. By mid-April 2022, approximately 500 million COVID-19–confirmed cases were reported worldwide, with 6,190,349 related deaths.[2,3]

In 2018, 2019, 2020, and 2021 death rates reported in KSA were 3.470, 3.513, 3.557, and 3.600, respectively. Circulatory system–related deaths were the highest contributor with 14.2%, followed by 4.3% for respiratory system diseases, 3.3% for certain infectious and parasitic diseases, and 2.2% for endocrine (nutritional and metabolic disorders).[4] The annual seasonal influenza epidemic contributed to death globally, accounting for approximately 290,000 to 650,000 respiratory deaths globally. High-risk populations, such as elderly patients and individuals with immunosuppressive conditions, chronic cardiac, pulmonary, and metabolic diseases, are more prone to death due to seasonal influenza.[5] Influenza and COVID-19 tend to overlap histologically, and both exhibit similar responses to severe virus-induced lung injury.[6]

To properly evaluate the impact of COVID-19 on society, excess deaths have been recognized as an essential and meaningful measure. It was reported as the third leading cause of death in the United States, right after heart diseases and cancer.[7] It has been suggested that the mortality rate because of COVID-19 could be underestimated or overestimated depending on reporting mechanism and definition of COVID-19 direct cause of mortality.[8] Healthcare systems were unprepared for the pandemic, where some countries suffered from overcrowded hospitals.[9,10] As a result, undercounting COVID-19 cases and their related deaths on a global level has been suggested by several investigators. This discrepancy may have been due to various factors, including but not limited to low laboratory capacity and inaccurate sampling techniques.[11,12] On the other hand, overestimation could result from counting deaths as COVID-19 related when in fact they are not. This could be because of testing patients who do not have the typical phenotype of viral illness caused by SARS-CoV-2 and who died of a different immediate cause of death, for example, motor vehicle accident or advanced cancer.[13] Disease severity may be attributed to multiple factors, pre-existing comorbidities, age, air pollution, temperature, and humidity.[14–17]

Excess mortality estimates the degree to which currently measured mortality exceeds baseline levels estimated using historical data. Rapid mortality surveillance, 'a system that generates daily or weekly counts of total mortality by age, sex, date of death, place of death' was proposed to inform decision-makers about the trajectory and magnitude of the pandemic, with excess mortality being the main focal point.[18]

The WHO defined death due to COVID-19 as 'A death resulting from a clinically compatible illness, in a probable or confirmed COVID-19 case, unless there is a clear alternative cause of death that cannot be related to COVID disease (e.g., trauma),' the death caused by COVID-19 may not be credited to another disease and should be counted freely of prior conditions that are associated with triggering a severe course of COVID-19.[19]

Saudi Arabia is divided into 13 regions covered by 20 health directorates. Each directorate has its autonomy in managing its health affairs according to policies and guidelines set by the Ministry of Health (MOH).[4] Epidemiological trends of any pandemic are essential to deciding whether to escalate or deescalate the precautionary measures and policies and allocate healthcare resources. Death per region has played a role in the lockdown for each area, and the identified risk factors are significant in prioritizing therapy and vaccination strategies. All COVID-19–related statistics including the number of SARS-CoV-2 polymerase chain reaction (PCR) tests, hospitalizations, intensive care unit (ICU) admissions, infected patients, and number of deaths are published and updated around the clock through a government website.[1] Our study aims to report the prevalence and epidemiological trends of mortality due to COVID-19 disease and report the most common comorbidities associated with mortality in KSA.

## Methods

This study was performed following the Declaration of Helsinki and was approved by the central institutional review board of the Saudi MOH (log No: 20-168M). All methods were carried out under relevant guidelines and regulations of KSA. The institutional review board did not require informed consent, as this was not an interventional study, and the exemption was granted. Daily death data for the 20 health directorates were studied and obtained from the MOH and non-MOH public and private hospitals from March 23, 2020, through April 30, 2022. The analysis included all direct causes of death due to COVID-19. According to the WHO definition, the Saudi MOH registers COVID-19 as a possible cause of death under three categories. First direct death, in which death resulted from a clinical illness compatible with COVID-19 infection for confirmed or suspected cases. Second, indirect death resulted from another disease (e.g. diabetes, cardiovascular diseases, emphysema, etc.), and the patient's condition worsened due to a confirmed or suspected COVID-19. The last scenario is death unrelated to COVID-19, which is any death in a confirmed or suspected case with COVID-19, but COVID-19 was not a direct or indirect cause of death[1] (Fig. 1).

Since the beginning of the pandemic and to address any possible underestimation of reported COVID-19 mortality cases, the MOH has mandated that all healthcare facilities report all deaths to a mortality committee after filling a standardized form that contained all needed information to assess and evaluate the cause of death, including SARS-CoV-2 PCR test. The MOH established the COVID-19 mortality scientific committee to determine the causes of deaths during the COVID-19 pandemic, report COVID-19 mortalities, and evaluate the quality of care provided to patients with COVID-19. The committee met daily to assess and evaluate each case and decide whether mortality is direct, indirect, or unrelated to COVID-19. Any mortality case with confirmed or suspected COVID-19 was reported to the COVID-19 mortality scientific committee using the approved electronic form within 3 h from the time of death. These precautionary approaches are intended to enhance the accuracy of the number of reported cases and reduce the possibility of underestimation. The information in the form included demographics, symptoms, comorbidities, co-infections, vital signs, and laboratory values, all reported investigations, medications, ventilation setting and requirements, and complications during hospital stay (supplement 1). Analysis of all reports was sent to the statistics department, whereas only direct COVID-19–related mortalities were announced. By the end of 2020, the government of KSA approved the first COVID-19 vaccine Pfizer-BioNTech (Comirnaty), followed by the approval of the second vaccine in February 2021, Oxford-AstraZeneca (Vaxzevria), then Moderna (Spikevax). Vaccination was made available at many centers across KSA for Saudi and non-Saudi citizens at no cost.[20]

This report describes the prevalence of COVID-19 death in KSA, including mortality trends, COVID-19 vaccination, risk factors of

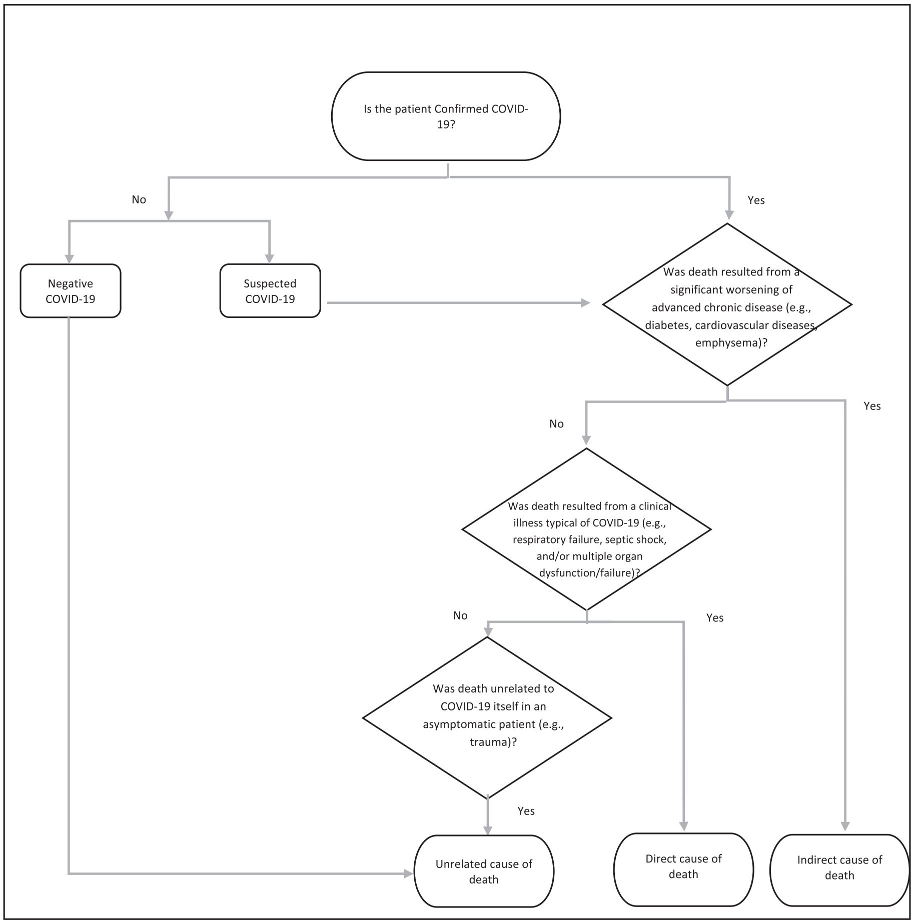



**Fig. 1.** Cause of death flowchart evaluation by Saudi MOH for COVID-19.

death, and population estimates for the prevalence of the various comorbidities. In addition, we report the association between comorbidities and death from COVID-19.

*Statistical analysis*

National and regional crude case fatality rate (cCFR) is defined as the number of mortality cases divided by the number of confirmed COVID-19 cases and the number of mortality cases per 100,000 population.[18] Descriptive statistics using numbers and percentages were used to describe the categorical variables such as nationality, age, gender, comorbidities, and geographical location of case fatalities. The median and interquartile (first quartile to third quartile; interquartile range [IQR]) for the time from the last COVID-19 vaccine till the time of death. Weekly mortality trends were reported as the number of deaths per period. The mortality trend was plotted per week and compared with international figures. Relative and absolute measures of association between comorbidities and death were calculated using odds ratios (ORs), attributable risk, and attributable risk percent. Population estimates for the prevalence of the various comorbidities were used to calculate population attributable risk estimates for comorbidities. Measures of association were derived from data for which each observation is classified along two dimensions, exposure and outcome, and each dimension is binary. The exposure is comorbidity (yes or no), and the outcome is death from COVID-19 (yes or no). Emphasis was placed on cause-specific death and death from COVID-19 vs death from another cause as the outcome of interest.

Comorbidities were analyzed individually and in combinations (e.g. diabetes and obesity together). Furthermore, the unexposed group was regarded in two different ways. First, we considered the unexposed to be those with no comorbidity and then investigated the extent to which the comorbidity (or combination of comorbidities) was associated with COVID-19 death vs no comorbidity. The second way to consider the unexposed was those without the comorbidity but possibly with various comorbidities. The former type of unexposed definition would reflect the isolated association of the comorbidity, whereas the latter would reflect the association of the comorbidity vs the set of other comorbidities seen in the population. To calculate the attributable risk and attributable risk percent associated with comorbidities, the risk of death from COVID-19 for the exposed and unexposed was calculated as follows[21]:

$$\text{Risk}_{\text{exposed}} = \frac{\text{Number of SARS} - \text{CoV2 with the comorbidity dying}}{\text{Total number of SARS} - \text{CoV2 with the comorbidity}}$$

and

$$\text{Risk}_{\text{unexposed}} = \frac{\text{Number of SARS} - \text{CoV2 without the comorbidity dying}}{\text{Number of SARS} - \text{CoV2 without the comorbidity}}.$$

Given these risk values, then the attributable risk and the attributable risk percent are as follows:

$$\text{Attributable risk} = \text{Risk}_{\text{exposed}} - \text{Risk}_{\text{unexposed}}$$

and

$$\text{Attributable risk percent} = \frac{\text{Risk}_{\text{exposed}} - \text{Risk}_{\text{unexposed}}}{\text{Risk}_{\text{exposed}}} \times 100.$$

Finally, the number needed to harm, defined as the number of subjects infected with SARS-CoV-2 who need to be exposed to comorbidity for one subject to die from COVID-19, was calculated as follows:

$$\text{NNH} = \frac{1}{\text{Attributable risk}}.$$

Measures of association were calculated together with 95% confidence intervals (CIs). Analyses were carried out using SAS/JMP, Version 15.0. SAS Institute Inc., Cary, NC, 1989–2021.

## Results

Between March 23, 2020, and April 30, 2022, among the 10,110 subjects studied, 1025 had died from causes unrelated to COVID-19, and 9085 had died from causes directly related to COVID-19 from a total of 754,011 infected patients by COVID-19. The first reported death was on March 23 in Madinah province. Compared with cCFR in Brazil, China, Germany, Italy, South Korea, and the United States, KSA's cCFR was 1.21%. Among the 20 health directorates in KSA, Qurayyat Province accounted for the highest cCFR (4.70%), whereas Madinah reported a cCFR of 0.61% (Table 1). The national number of deaths per 100,000 population was 25.38, with Makkah province reporting the highest (48/100,000) and Tabuk reporting the lowest (12.18/100,000). The highest number of reported deaths was reported in the most populated provinces (Riyadh, Jeddah, Makkah, Jizan, Asir, and Hassa). The youngest reported death was a 42-day-old boy on August 18, 2020, who developed Multisystem Inflammatory Syndrome in Children, and the oldest was a male of 113 years. Males accounted for 71% of total deaths, and the highest percentage of deaths per age group was between the age of 60–69 years. The most common comorbidities associated with death were diabetes (60%), followed by hypertension (52%), obesity (12%), and heart failure (11%; Table 2). The highest number of reported mortalities was reached on week 15, then plateaued on week 16 and declined thereafter. Another peek was observed in week 63 with the second wave (Fig. 2).

There was a total of 225 patients (2.8%) who received COVID-19 vaccine; of those, 213 (94.6%) got only one dose of the vaccine, 10 (4.4%) received two doses, and only two (0.8%) got the total three doses. This is in contrast to the proportion of the vaccinated individuals (25,082,132) in the community, which corresponds to 73.5% of the total population. The median time from the last vaccine until the day of death was 44.5 (IQR: 26.5–78) days. Those who got only one dose of the vaccine had a median time till death of 45 (IQR: 28–76) days, whereas patients who received two doses of vaccine had a median time of 113 (IQR: 20–177) days.

Across the whole cohort, there were 271 distinct comorbidity profiles. Diabetes (OR: 1.7, 95% CI 1.33–2.15) and hypertension (OR: 1.75, 95% CI 1.24–2.47) were the most common comorbidities associated with COVID-19 mortality. Diabetes, hypertension, arrhythmias (OR: 2.55, 95% CI 0.34–18.83), and obesity (OR: 3.79, 95% CI 2.01–7.13) were the top single comorbidity that was associated with COVID-19 mortality. Multiple coexisting comorbidities were compared with those without any comorbidity with regard to the risk of death, which showed that diabetes in combination with

**Table 2**
Demographics and baseline characteristics of deceased patients.

| Demographics | Number of patients | Percentage |
|---|---|---|
| Male gender | 6454 | 71% |
| Saudi nationality | 4569 | 50% |
| Age $\geq$ 70 years | 2487 | 27% |
| Medically free | 1096 | 12% |
| **Comorbidities** | | |
| Diabetic | 5482 | 60% |
| Hypertension | 4681 | 52% |
| Obesity | 1058 | 12% |
| Heart failure | 1002 | 11% |
| Renal impairment | 776 | 9% |
| Respiratory disorders | 849 | 9% |
| Neurological disorder | 439 | 5% |
| Arrhythmias | 324 | 4% |
| Thromboembolic disorders | 286 | 3% |
| Thyroid dysfunction | 305 | 3% |
| Liver impairment | 82 | 1% |

**Table 1**
National crude case fatality rate and number of deaths per 100,000 population by April 30, 2022.

| Health directorates | Population | Total cases | Total deceased | Number of deceased per 100,000 population | % Total deceased of cases |
|---|---|---|---|---|---|
| Riyadh | 8,872,712 | 200,904 | 1590 | 17.92 | 0.79 |
| Jeddah | 5,031,820 | 86,766 | 1577 | 31.34 | 1.82 |
| Makkah | 2,512,462 | 44,006 | 1206 | 48.00 | 2.74 |
| Jizan | 1,670,569 | 30,465 | 691 | 41.36 | 2.27 |
| Asir | 1,940,123 | 44,094 | 681 | 35.10 | 1.54 |
| Eastern | 3,485,383 | 96,807 | 633 | 18.16 | 0.65 |
| Al Hassa | 1,305,172 | 45,631 | 613 | 46.97 | 1.34 |
| Taif | 1,387,686 | 25,872 | 429 | 30.91 | 1.66 |
| Madinah | 2,291,092 | 51,644 | 317 | 13.84 | 0.61 |
| Qasim | 1,520,434 | 28,074 | 304 | 19.99 | 1.08 |
| Ha'il | 746,046 | 15,611 | 230 | 30.83 | 1.47 |
| Hafr Albatin | 476,443 | 7587 | 141 | 29.59 | 1.86 |
| Tabuk | 968,414 | 11,949 | 118 | 12.18 | 0.99 |
| Najran | 621,040 | 13,135 | 116 | 18.68 | 0.88 |
| Northern | 390,656 | 6758 | 110 | 28.16 | 1.63 |
| Al Baha | 506,866 | 9152 | 102 | 20.12 | 1.11 |
| Jouf | 362,580 | 2906 | 81 | 22.34 | 2.79 |
| Bisha | 414,197 | 5745 | 59 | 14.24 | 1.03 |
| Qunfotha | 329,289 | 4306 | 45 | 13.67 | 1.05 |
| Qurayat | 180,430 | 894 | 42 | 23.28 | 4.70 |

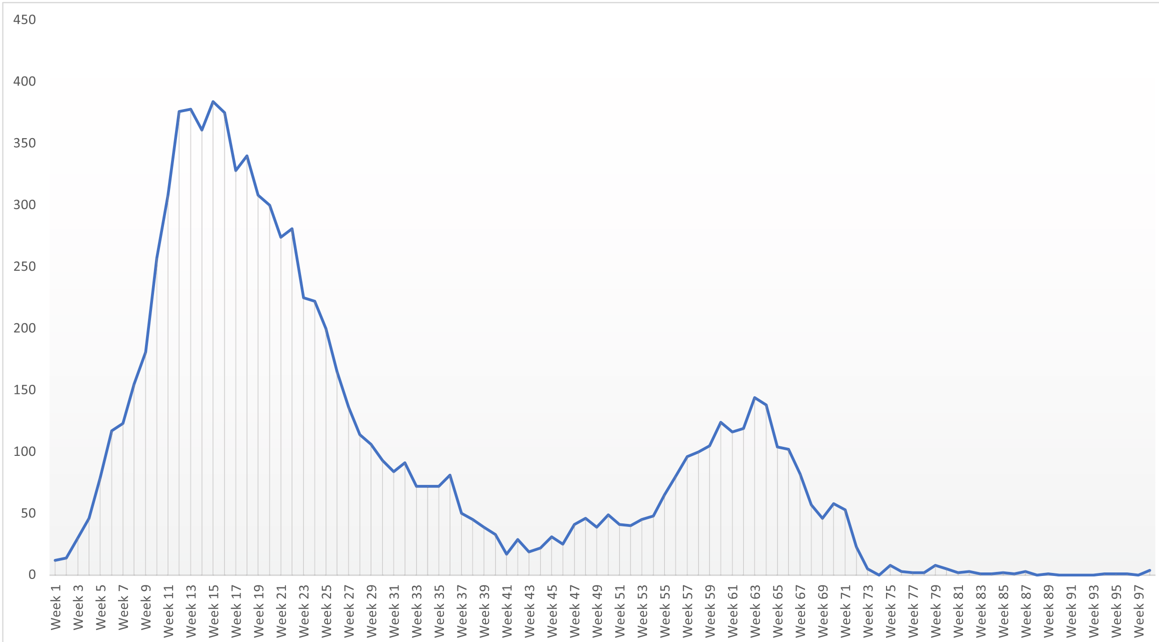



**Fig. 2.** Death per week trend by April 30, 2022.

hypertension and obesity (OR: 1.66, 95% CI 1.37–2.01) ranked as the highest multiple comorbidities associated with COVID-19 mortality, followed by the combination of diabetes with hypertension and heart failure (OR: 1.57, 95% CI 1.29–1.89), then diabetes and heart failure combined (OR: 1.42, 95% CI 1.14–1.76; Fig. 3). Table 3 shows the attributable risk of death and the number needed to harm as absolute measures of the risk of death for each comorbidity.

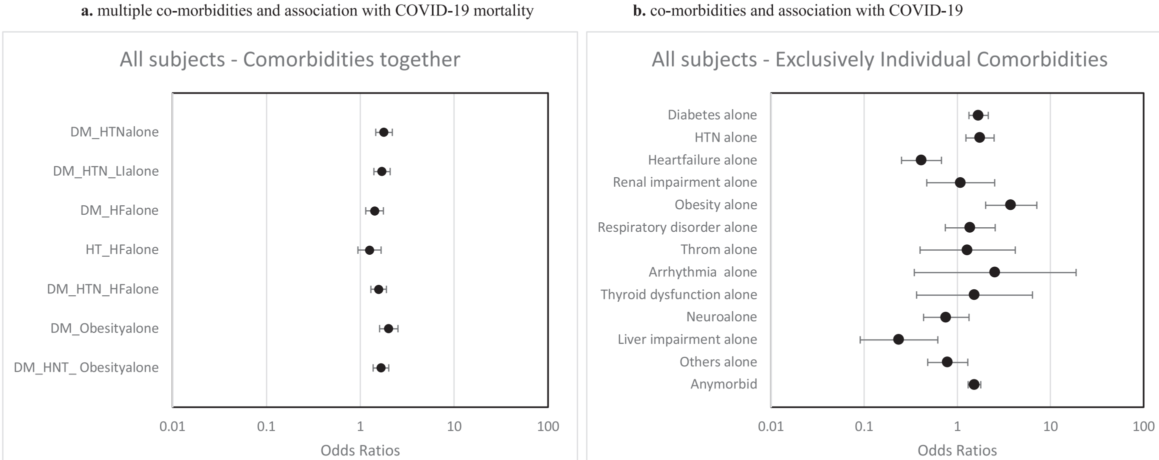
## Discussion

This is the largest registry on the prevalence and epidemiological trends of COVID-19 mortality in KSA. Several countries have published the prevalence of mortalities related to COVID-19. The cCFR among European countries was the highest in Italy (2.8%).[22] Italy defines death related to COVID-19 in a broader term due to the lack of clear criteria for COVID-19 deaths. Death is recorded as related to COVID-19 in individuals who tested positive by real-time PCR for SARS-CoV-2 regardless of pre-existing conditions that might have contributed to their death.[13] In China, the case fatality rate reached 0.6% of confirmed cases, whereas in the United Kingdom, 0.8% of deaths were recorded as related to COVID-19.[22] In the United States, 81,863,725 COVID-19 cases were reported, with an estimated fatality rate of 1.2%.[22] The Centers for Disease Control and Prevention (CDC) reported a list of medical conditions that contributes to a severe COVID-19 outcome. Severity was defined as the need for hospitalization, ICU admission, intubation or mechanical ventilation, and death.[23]

The KSA has lower cCFR and deaths per 100,000 compared with many developed countries. This could be due to several factors, including multiple strategies of early preventive measures by the

**a.** multiple co-morbidities and association with COVID-19 mortality

**b.** co-morbidities and association with COVID-19




diabetes (DM), hypertension (HT), heart failure (HF), renal impairment (RI), obesity (Ob), respiratory disorder (RD), thromboembolic disorder (TE), arrhythmia (Arr), thyroid dysfunction (TD), neurological disorder (ND), liver impairment (LI), some other comorbidity(ies) (Oth)

**Fig. 3.** Forest plots represented by odds ratios and confidence intervals.

**Table 3**
Comorbidities absolute measures of association with mortality.

| Comorbidity | Exposed risk | Unexposed risk | Attributable risk | Attributable risk percent | NNH |
|---|---|---|---|---|---|
| Diabetes | 0.96 | 0.84 | 0.11 | 11.94 | 8.76 |
| Hypertension | 0.96 | 0.86 | 0.10 | 10.34 | 10.09 |
| Heart failure | 0.97 | 0.90 | 0.06 | 6.69 | 15.49 |
| Renal impairment | 0.96 | 0.90 | 0.05 | 5.41 | 19.37 |
| Obesity | 0.98 | 0.90 | 0.09 | 8.68 | 11.71 |
| Respiratory disorder | 0.96 | 0.90 | 0.05 | 5.68 | 18.41 |
| Thromboembolic disorders | 0.96 | 0.91 | 0.05 | 5.26 | 19.90 |
| Arrhythmias | 0.96 | 0.91 | 0.06 | 5.94 | 17.48 |
| Neurological disorder | 0.93 | 0.91 | 0.02 | 2.21 | 48.72 |
| Liver impairment | 0.86 | 0.91 | −0.05 | −5.76 | −20.24 |
| Other | 0.80 | 0.85 | −0.05 | −6.00 | −21.30 |

NNH, number needed to harm.

government and early lockdown before the first COVID-19 mortality was reported. In addition, ICU bed expansion from 6360 beds to 10,401 beds (increased by 164%) during the pandemic period played a significant role in accommodating more critical patients. In addition, early outpatient intervention through the creation of ‘fever clinics’ in primary healthcare centers around the Kingdom. These clinics aimed to treat patients with early symptoms to prevent hospital admissions and decongest emergency departments in hospitals. Finally, MOH developed multiple protocols for COVID-19 that are continuously updated, which helped standardize the care across the Kingdom. More than 32 protocols covered different aspects of COVID-19-disease, including but not limited to COVID-19 treatment protocol, radiology preparedness, COVID-19 in pregnancy, ICU admission criteria, mechanical ventilation, and high flow nasal cannula and helmet use in COVID-19.

The number of cases in Italy had reached 16,798,998 in mid-2022.[22] In China, the prevalence of COVID-19 between men and women was also nearly the same (51.4% vs 48.6%). However, the fatality rate among men was significantly higher than women (relative risk (RR): 1.67, 95% CI 1.47−1.89; *P*-value: <0.001).[24,25] In the United Kingdom, mortality was also higher in men than women (OR: 1.47, 95% CI 1.26−1.73).[26] This is similar to our findings, as males accounted for more than two-thirds of mortalities. Different social and occupational factors could explain this among both genders.[27]

An increase in age was strongly associated with an increased risk of severe COVID-19 outcomes. One study reported case mortality and in-hospital mortality increased per age year by 3.4% and 7.4%, respectively (effect size case mortality: 1.074, 95% CI 1.061−1.087; effect size in-hospital mortality: 1.057, 95% CI 1.038−1.054).[28] Another study showed that age ≥50 years was an independent factor in ICU admission and in-hospital mortality.[29] According to the CDC, individuals aged ≥65 years accounted for 74.6% of the total COVID-19 deaths.[30] In the United Kingdom, age had the strongest impact on the COVID-19 associated mortality, people aged ≥50 years accounted for 98% of the total COVID-19 deaths, whereas 84% of the deaths were observed in people aged ≥70 years.[31] In Italy, the fatality rate was exceptionally high in the old population. A steep age-dependent fatality rate was seen in Bergamo province, 1.89% in the 70s, 4.84% in the 80s, and 11.06% in the age group above 90 years.[13] Our study showed that most mortalities occurred in patients aged 60−69 years.

Minorities ethnic groups have been especially affected by COVID-19, with an increase in fatality rate in the United States and the United Kingdom than in most populations.[32,33] Disparities in race, ethnicity, age, socio-economic status, and geographical location have been the key hallmarks of the previous US waves of COVID-19.

Individuals with pre-existing conditions are at an exceptionally high risk of death due to COVID-19.[14,34] In the United States, the most common comorbidities associated with COVID-19 mortality are influenza and pneumonia (48.9%), hypertension (18.6%), diabetes (15.4%), Alzheimer's disease, and other dementias (11.1%), and sepsis (9.8%).[30] After adjusting for sex, age, ethnicity, and race, it was found that having ≥3 underlying health conditions was associated with a greater risk of ICU admission (RR: 1.30, 95% CI 1.09−1.54) and death (RR: 1.81, 95% CI 1.44−2.28).[29] Diabetes has also been noted to increase the risk of death in both China and UK patients (RR: 4.43, 95% CI 3.49−5.61). $HbA_{1c} \geq 58$ mmol/mol had the greatest hazard ratio (HR): 1.95, 95% CI 1.83−2.07.[24,33] Our study suggests that diabetes is one of the important comorbidities associated with COVID-19 mortality. Knowing that diabetes prevalence in KSA is about 20%, this is particularly concerning. China and the United Kingdom have also established an association of increased risk of severe COVID-19 outcomes with respiratory disease (excluding asthma in both. RR: 3.43, 95% CI 2.42−4.87, HR 1.63, 1.55−1.71).[24,33] Severe asthma was associated with the risk of death in Chinese patients (asthma with oral corticosteroid use had the most significant HR: 1.13, 95% CI 1.01−1.26).[33] This is similar to our findings, as respiratory diseases were three times more likely to result in death due to COVID-19.

Vaccination was not available when our study began. Although this study was limited to reporting prevalence and did not explore vaccination in detail, another study conducted in KSA focused solely on vaccination launching and trends reported that one million doses were administered in about 3 months after the COVID-19 vaccine's introduction. The government made considerable efforts to make it widely available, and by May 2021, a total of 587 vaccine centers had been established, and more than 10 million doses had been administered.[20] Vaccines have been proven to be highly effective in reducing COVID-19 mortality ($P < 0.001$).[35] Our study showed that only 2.8% of patients who died due to COVID-19 received at least one dose of vaccine.

In our study, other pre-existing conditions that increased the risk of death in a patient with COVID-19 included cardiovascular diseases, renal impairment, obesity, thromboembolic disorders, thyroid dysfunction, and neurological disorders. A study from China found cardiovascular disease (RR: 6.75, 95% CI 5.40−8.43) and hypertension (RR: 4.48, 95% CI 3.69−5.45) among the most common comorbidities associated with COVID-19 mortality.[24] Another study in the United Kingdom showed that obesity was associated with an increased risk of death (BMI >40 $kg/m^2$; HR: 1.92, 95% CI 1.72−2.13). Chronic heart disease (HR: 1.17, 95% CI 1.12−1.22), liver disease (HR: 1.75, 95% CI 1.51−2.03), stroke/dementia (HR: 2.16, 95% CI 2.06−2.27), other neurological diseases (HR: 2.58, 95% CI 2.38−2.79), reduced kidney function (estimated glomerular filtration rate <30 had the greatest HR, HR: 2.52, 95% CI 2.33−2.72), autoimmune diseases (rheumatoid arthritis, lupus, or psoriasis, HR: 1.19, 95% CI 1.11−1.27), and other immunosuppressive conditions (HR: 1.70, 95% CI 1.34–2.16), were also associated with increased risk of death.[33]

It is important to note that we reported the association of different comorbidities, which does not necessarily mean correlation or causality. Furthermore, two critical assumptions are necessary for the validity of the measures of association in this study. First, it must be assumed that the presence or absence of comorbidity is independent of the likelihood of getting infected by the COVID-19 virus. Second, the distribution of the comorbidities among the study subjects who died from unrelated causes matches the distribution of the comorbidities in the population of interest.

Although the study illustrated the impact of different comorbidities on the rate of COVID-19–related mortality, some limitations must be acknowledged. First, confounding factors that may contribute to the disease severity, such as air pollution, humidity, and temperature were not investigated. However, each mortality case in this study was subjected to a scientific committee evaluation that determined the probability of a COVID-19–related event. In addition, because vaccinations were introduced 9 months after the study began, the vaccination effect on COVID-19 mortality may not have been accurate. It is important to know that we did not perform a quantitative comparison between KSA and G20 countries based on well-recognized epidemiological models, as this was not the aim of the study. Direct comparison based on semiquantitative comparison should be interpreted with caution.

### *Conclusion*

CFR and death per 100,000 population in KSA are among the lowest worldwide due to multiple factors. Several comorbidities have been identified, namely, diabetes, hypertension, obesity, and cardiac arrhythmias. Therefore, understanding COVID-19 mortality epidemiological trends and associated factors will help prepare healthcare systems for inevitable pandemics, hence reducing the healthcare burden and expediting recovery. Data from this study could assist in public health decision-making and preparedness efforts.

## Author statements

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### *Ethical approval*

This study was performed in accordance with the Declaration of Helsinki and was approved by the central institutional review board of the Saudi Ministry of Health (log No: 20-168M). The institutional review board did not require informed consent as this was not an interventional study, and the exemption was granted.

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### *Competing interests*

The authors of this article have no conflicts of interest or any direct or indirect financial interests.

### *Consent for publication*

Approval for publication was granted by the central institutional review board of the Saudi Ministry of Health.

### *Availability of data and materials*

All data and materials are available on request.

### *Author contributions*

D.A.A. was the primary investigator and contributed to writing the proposal, figures, study design, data collection, data analysis, data interpretation, and writing the article. W.A. and R.A. contributed to literature search and writing the article. H.Y.A., Z.A., F.A., H.E., A.A.M., M.M.A., E.A., T.A., M.S.A., M.S.B., A.A.A., M.H.A., A.A., and R.N. contributed to reviewing article, reviewing cases, and methodology. E.B.D. and G.M. contributed to data analysis. A.H.A. contributed to study design, data interpretation, and writing the article.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2022.07.014.

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