Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

International Journal of Infectious Diseases 104 (2021) 102–107

Contents lists available at ScienceDirect

International Journal of Infectious Diseases

journal homepage: www.elsevier.com/locate/ijid

Effects of COVID-19 on mortality: A 5-year population-based study in Oman

Adil Al Wahaibi*, Amal Al-Maani, Fatma Alyaquobi, Khalid Al Harthy, Amina Al-Jardani, Bader Al Rawahi, Seif Al-Abri

Ministry of Health, Muscat, Oman

ARTICLE INFO

Article history:
Received 1 November 2020
Received in revised form 17 December 2020
Accepted 18 December 2020

Keywords:
COVID-19
Pandemic
Retrospective studies
Non-communicable diseases
Communicable diseases
Oman

ABSTRACT

Background: Mortality surveillance provides a crucial method for monitoring disease activity. Coronavirus disease 2019 (COVID-19) can cause excess mortality both directly and indirectly by increasing deaths from other diseases. The aim of this study was to investigate the effects of COVID-19 on mortality in Oman.

Methods: A cross-sectional retrospective analysis of mortality data from 1 January 2015 to 16 August 2020 was undertaken. Baseline mortality estimated using the Farrington flexible model and excess mortality were calculated for the pandemic period (16 March–16 August 2020) according to cause of death, place of death and age group.

Results: During the pandemic period, there was a 15% [95% confidence interval (CI) 14–17] increase in all-cause mortality from baseline. When classifying by cause, there was a 9% (95% CI 5–12) increase in deaths due to respiratory diseases, a 2% (95% CI 1–4) increase in deaths due to infectious diseases and a 9% (95% CI 8–11) increase in unclassified deaths. In terms of place of death, 12% (95% CI 11–14) of excess mortality occurred in hospitals and 7% (95% CI 5–8) occurred in homes during the pandemic period. Patients aged >60 years recorded a 15% (95% CI 13–16) increase in all-cause mortality during this period.

Conclusion: The COVID-19 pandemic has resulted in a 15% increase in all-cause mortality in Oman, mainly as a result of deaths from COVID-19. However, unclassified deaths, deaths due to respiratory diseases and deaths due to infectious diseases have also increased, enforcing the need for a holistic approach and appropriate coordination of health services during such health crises.

Introduction

Coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), first emerged in December 2019 in Wuhan, China, and spread rapidly across the world. In Oman, the first imported case was diagnosed on 24 February 2020 (Wahaibi et al., 2020). Until mid-August 2020, there was ongoing community transmission, with a total of 79,701 confirmed cases of SARS-CoV-2 infection and 488 deaths in Oman. The estimated number of infected individuals based on a national sero-survey for the same time period was 507,256, which indicates a case fatality rate (fraction of deaths among infected cases) of 0.1% (Oman News Agency, 2020).

Mortality surveillance provides crucial information for health-care systems about population-level disease progression, and guides the development of public health interventions and assessments of their impact. Concerns have been raised about the increasing number of deaths from COVID-19 and its impact on the healthcare system, and indirect effects of COVID-19 on the increasing numbers of deaths have also been documented. This includes increasing deaths from non-communicable diseases (NCDs) (World Health Organization, 2020a), deaths related to increased healthcare-associated infections (antimicrobial-resistant pathogens and candidiasis), and other categories of deaths unrelated to SARS-CoV-2 infection (Lansbury et al., 2020; Weinberger et al., 2020).

The limited availability of viral testing and the imperfect sensitivity of the tests may have resulted in not counting some deaths from COVID-19, and counting other deaths more than once due to persistent positivity on polymerase chain reaction for up to 12 weeks because of virus shedding (Kucirka et al., 2020; Yang et al., 2020).

* Corresponding author at: Ministry of Health, PO Box 393, Post Code 100, Muscat, Oman.
E-mail address: adilwahaibi@gmail.com (A. Al Wahaibi).

https://doi.org/10.1016/j.ijid.2020.12.054

One of the most important methods of mortality surveillance is the monitoring of cause of death as reported by healthcare facilities using a death certificate and/or the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10) coding system. Estimated excess mortality due to an emerging infectious agent is a commonly used method for assessing the increased number of deaths beyond what would be expected if the pathogen had not circulated (Weinberger et al., 2020). The aim of this study was to investigate the effects of COVID-19 on mortality in Oman using a 5-year population mortality data analysis from 2015 to 2020.

Methods

Data source

This was a retrospective cross-sectional analysis of daily mortality data, extracted from the Al-Shifa system which is a comprehensive electronic healthcare information management system that was developed by the Ministry of Health (MoH), Oman. It is installed in more than 200 MoH healthcare facilities in Oman of different sizes and capacities. Other health recording systems (private and non-MoH) in Oman were not included in this study. All mortality data in the Al-Shifa system were acquired from 1 January 2015 to 16 August 2020 for nationals and non-nationals. The variables included were: date of death, age at death, nationality, ICD-10 code for direct cause of death, and place of death (home or hospital). To calculate the crude mortality rate (CMR), annual population data were taken from the National Centre for Statistics and Information, Oman for 2016–2020.

Studied causes of death

ICD-10 codes indicating the direct cause of death were divided into characters and numbers in the dataset. The entire dataset was classified as 'all-cause mortality', and specific characters, represented as letters, were divided and classified as per ICD-10 code (World Health Organization, 2020b). Only certain ICD-10 codes were used in this study depending on the number of deaths: 'A', infectious diseases; 'I', cardiovascular diseases; and 'J', respiratory diseases. The code 'U' in the data was used for deaths from COVID-19. The codes 'S', 'T', 'V' and 'Y' were all listed as injury and poisoning.

Statistical analysis

Baseline characteristics of the data were described using percentages for categorical data, and medians and interquartile ranges (IQR) for continuous variables. Data were categorized by pandemic periods, and compared using Pearson's Chi-squared test of independence for categorical data and the Wilcoxon rank-sum test for continuous data. The trend in the daily number of deaths divided by cause of death was plotted in ggplot package in R software (Wickham, 2016), and the trend was estimated using a generalized additive model. Death was represented as CMR per 100,000 population.

The Farrington flexible model was used to estimate the expected daily deaths classified by cause of death, place of death and age group for the pandemic period (16 March–16 August 2020) to compare deaths from COVID-19 and non-COVID-19 deaths. This model used historical data from 1 January 2015 to 16 August 2020 to calculate the expected daily deaths for the pandemic period (16 March–16 August 2020). The model uses a generalized linear model with Poisson distribution controlling for seasonality (Höhle and Mazick, 2010). Excess mortality was calculated as the difference between observed number of deaths and the expected number of deaths in the period of study. The proportion of excess mortality was calculated as the sum of all excess deaths divided by the sum of all expected deaths in that time period (Woolf et al., 2020). To calculate excess mortality by cause of death, place of death and age group, the model was run with data divided for these subgroups. For place of death and age group, injuries and poisoning were excluded because of the increasing numbers of deaths out-of-

Table 1
Demographic characteristics of deaths recorded in Ministry of Health institutes from 1 January 2015 to 16 August 2020.

		Before pandemic period: 1 January 2015–15 March 2020 (n = 29,218)	Pandemic period: 16 March–16 August 2020 (n = 3484)	Total cases (n = 32,702)	P-value
Age (years)	Median (IQR)	61.5 (32.0–75.9)	65.5 (42.4–78.3)	62.0 (33.3–76.2)	<0.001
Sex	Female	11,461 (39.2)	1345 (38.6)	12,806 (39.2)	0.489
	Male	17,757 (60.8)	2139 (61.4)	19,896 (60.8)	
Nationality	Non-Omani	4624 (15.8)	531 (15.2)	5155 (15.8)	0.384
	Omani	24,594 (84.2)	2953 (84.8)	27,547 (84.2)	
Brought in dead	No	25,518 (87.3)	3143 (90.2)	28,661 (87.6)	<0.001
	Yes	3700 (12.7)	341 (9.8)	4041 (12.4)	
Disease (ICD-10 code)	COVID-19 (U)	–	376 (10.8)	376 (1.1)	<0.001
	Cardiovascular diseases (I)	5593 (19.1)	471 (13.5)	6064 (18.5)	
	Congenital malformations (Q)	919 (3.1)	69 (2.0)	988 (3.0)	
	Contact with health services (Z)	532 (1.8)	69 (2.0)	601 (1.8)	
	Diseases of the ear and mastoid process (H)	5 (0.0)	1 (0.0)	6 (0.0)	
	Endocrine and metabolic (E)	394 (1.3)	40 (1.1)	434 (1.3)	
	Gastrointestinal diseases (K)	713 (2.4)	57 (1.6)	770 (2.4)	
	Genitourinary diseases (N)	684 (2.3)	63 (1.8)	747 (2.3)	
	Infectious diseases (A and B)	3387 (11.6)	290 (8.3)	3677 (11.2)	
	Injury and poisoning (S, T, V and Y)	1406 (4.8)	70 (2.0)	1476 (4.5)	
	Mental and behavioural (F)	33 (0.1)	1 (0.0)	34 (0.1)	
	Musculoskeletal diseases (M)	87 (0.3)	9 (0.3)	96 (0.3)	
	Neoplasms and haematological (C and D)	2077 (7.1)	181 (5.2)	2258 (6.9)	
	Nervous system (G)	381 (1.3)	14 (0.4)	395 (1.2)	
	Pregnancy and childbirth (O and P)	1677 (5.7)	128 (3.7)	1805 (5.5)	
	Respiratory diseases (J)	2433 (8.3)	255 (7.3)	2688 (8.2)	
	Skin diseases (L)	124 (0.4)	11 (0.3)	135 (0.4)	
	Unclassified	8773 (30.0)	1379 (39.6)	10,152 (31.0)	

IQR, interquartile range; COVID-19, coronavirus disease 2019; ICD-10, 10th revision of the International Statistical Classification of Diseases and Related Health Problems.

hospital and in middle-aged people in these categories. All statistical analyses were performed using R Version 4.0 (R Foundation for Statistical Computing, Vienna, Austria) (R Core Team, 2020) and the surveillance library (Meyer et al., 2017).

This study was approved by the Directorate General for Disease Surveillance and Control. There was no need for consent as the study was anonymous and used data produced for public health purposes.

Results

In total, 32,702 deaths were registered in the Al-Shifa electronic system from 1 January 2015 to 16 August 2020, and 3484 deaths were recorded during the pandemic period. The median age at death was 62.4 (IQR 33.3–76.2) years. Males accounted for 60.8% of deaths, 84.2% were Omani and 87.6% died in hospital. Table 1 shows the most common causes of death: cardiovascular disease, 18.5%; infectious diseases, 11.2%; and unclassified, 31.0% (only 40% were coded as 'unclassified' in the pandemic period). In total, 367 deaths were coded as COVID-19 deaths in the data from the pandemic period, representing 10.8% of total deaths, and there was a 121-case deficit from the nationally announced number of COVID-19-related deaths for the same period (n = 488).

Figure 1 shows daily CMR per 100,000 population in Oman from 1 January 2015 to 16 August 2020. There was a sharp increase in all-cause mortality from March 2020, reaching 0.55 per 100,000 population. Classifying the CMR into different causes revealed that the increase was mainly due to an increase in the number of unclassified deaths and the addition of deaths due to COVID-19.

The proportions of excess deaths (from baseline) by cause of death, place of death and age group are presented in Table 2. There was a 15% [95% confidence interval (CI) 14–17] increase in all-cause mortality from baseline for the pandemic period (16 March–16 August 2020). Classifying by cause, there was a 9% (95% CI 5–12) increase in deaths due to respiratory diseases, a 2% (95% CI 1–4) increase in deaths due to infectious diseases, and a 9% (95% CI 8–11) increase in unclassified deaths compared with baseline. For place of death, there was a 12% (95% CI 11–14) increase in hospital deaths and a 7% (95% CI 5–8) increase in deaths at home for all-cause mortality for the pandemic period. Table 2 also shows that there was a 15% (95% CI 13–16) increase in deaths in patients aged >60 years in the pandemic period.

Figures 2–4 show the trends in weekly excess mortality according to cause of death, place of death and age group. For all-cause mortality, the weekly excess started in June and peaked in late July, before decreasing towards the beginning of August 2020. However, the number of unclassified deaths started to increase in July and stayed high during August 2020 (Figure 2). Figure 3 shows that excess hospital deaths accounted for more cases of all-cause mortality than excess home deaths, whereas home deaths accounted for more unclassified deaths. In addition, Figure 3 shows that excess mortality from infectious diseases and respiratory diseases only occurred in hospitals. Figure 4 shows that the trend in weekly excess all-cause mortality was above baseline by early June 2020 in patients aged 15–60 years and >60 years. However, by July 2020, the trend in patients aged 15–60 years declined, and excess all-cause mortality was dominated by patients aged >60 years.

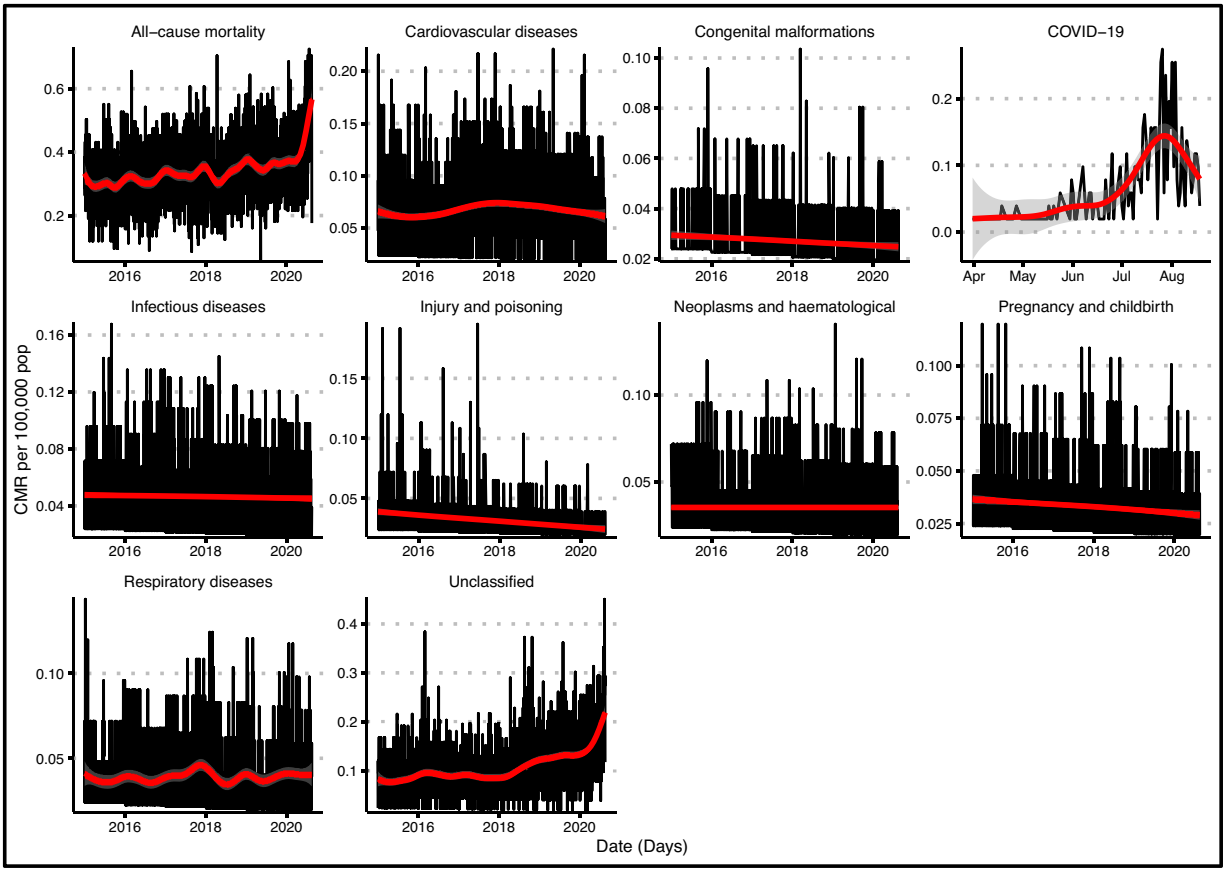

Figure 1. Time trend of deaths registered by Ministry of Health institutes by International Statistical Classification of Diseases and Related Health Problems (ICD)-10 coded cause of death, 1 January 2015–16 August 2020. CMR, crude mortality rate; COVID-19, coronavirus disease 2019.

Table 2
Excess mortality in the pandemic period according to place of death and age group calculated using the Farrington flexible model.

ICD-10 cause of death	Subgroup	Expected deaths	Excess deaths[a]	Proportion[b] of excess deaths (95% CI)[c]
All-cause	–	3005	462	15 (14–17)
Cardiovascular disease	–	718	0	0
Infectious disease	–	414	9	2 (1–4)
Injury	–	156	0	0
Respiratory disease	–	297	25	9 (5–12)
Unclassified	–	1383	127	9 (8–11)
	Place of death			
All-cause	Home	1331	87	7 (5–8)
All-cause	Hospital	1978	239	12 (11–14)
Cardiovascular disease	Home	219	1	0
Cardiovascular disease	Hospital	643	0	0
Infectious disease	Hospital	427	6	1 (1–3)
Respiratory disease	Hospital	294	28	9 (7–13)
Unclassified	Home	1198	77	6 (5–8)
Unclassified	Hospital	250	34	14 (10–18)
	Age group (years)			
All-cause	<15	627	0	0
All-cause	1–60	1124	95	8 (7–10)
All-cause	>60	1827	270	15 (13–16)

ICD-10, 10th revision of the International Statistical Classification of Diseases and Related Health Problems; CI, confidence interval.
[a] Excess deaths is the difference between observed and expected deaths (calculated using the Farrington flexible model; only the positive excesses were used in this analysis, assuming the negative excess to be zero excess).
[b] Proportion of excess deaths in subgroups may not add up because they were the product of dividing excess deaths by total expected deaths for each group.
[c] Calculated using CIs for binomial probabilities.

Figure 2. Excess mortality in the pandemic period (16 March–16 August 2020) by International Statistical Classification of Diseases and Related Health Problems (ICD-10)-coded cause of death.

Discussion

There was a 15% increase in all-cause mortality in the pandemic period (16 March–16 August 2020) compared with baseline. This was mainly due to excess unclassified deaths and, to a lesser extent, deaths due to respiratory diseases and infectious diseases. Excess hospital deaths accounted for more cases of all-cause mortality than excess home deaths in the pandemic period. Deaths in ages >15 years (specially in ages >60-year-old) were also higher in the pandemic period compared to the baseline.

Excess mortality during the COVID-19 pandemic have been studied by many authors. Wu et al. (2020) found 35% excess deaths in the UK. In addition, excess mortality was seven-fold higher than baseline in New York City, USA at the peak of the pandemic (Weinberger et al., 2020), and Woolf et al. (2020) reported 20% excess mortality in all US cities. In their comparison of excess all-cause mortality per 100,000 population in 18 countries, Bilinski and Emanuel (2020) classified countries as high (>25), moderate (5–25) or low (<5) excess mortality. Based on this, Oman, with 11.36 excess mortality per 100,000 population, is classified as having moderate excess mortality.

Similar to the present findings, a pooled estimate of excess all-cause mortality in Europe was published for the pandemic period until 3 May 2020, and showed that mortality among patients aged

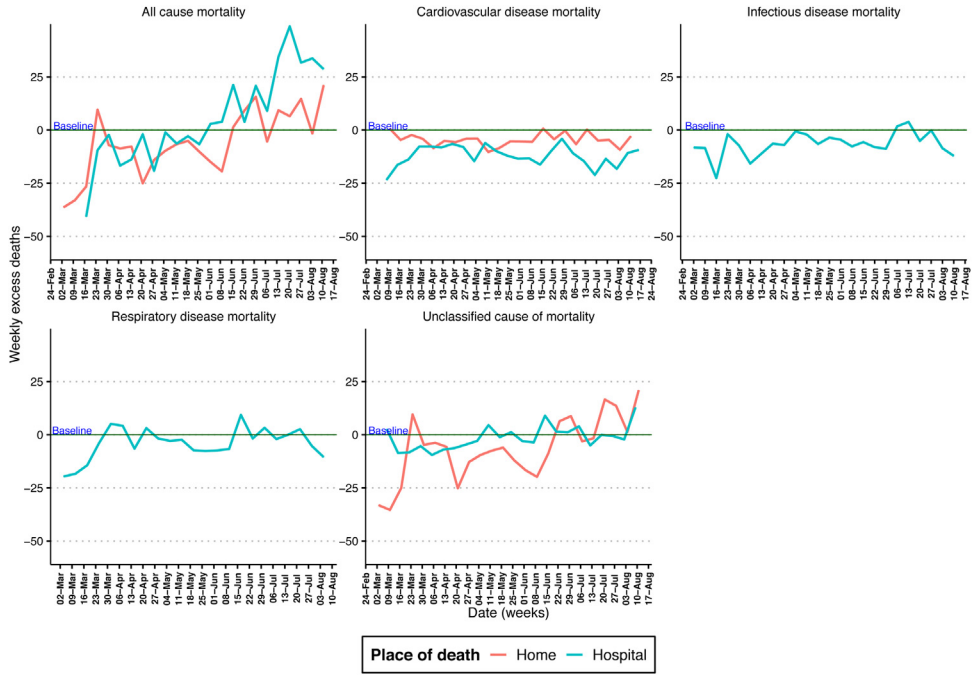

Figure 3. Excess mortality in the pandemic period (16 March–16 August 2020) by International Statistical Classification of Diseases and Related Health Problems (ICD-10) coded cause of death and place of death.

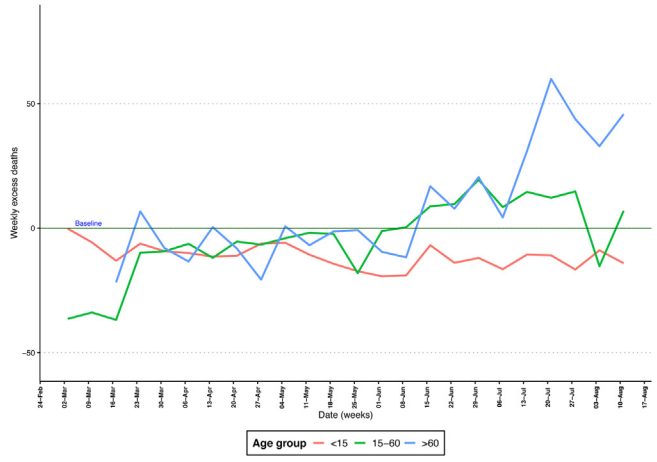

Figure 4. Excess all-cause mortality in the pandemic period (16 March–16 August 2020) by age group.

>65 years was higher in this period compared with the 4-year baseline, with no excess mortality in younger age groups (Vestergaard et al., 2020). Similar age group susceptibility of excess all-cause mortality was also noted in the UK (Sinnathamby et al., 2020). Excess mortality in this age group reflects the increased susceptibility of this group for the severe course of the disease (Onder et al., 2020; Wang et al., 2020).

This study revealed that excess mortality in hospitals and at home were almost similar. However, excess mortality due to infectious diseases and respiratory diseases during the pandemic period occurred only in hospitals. Early in the pandemic, hospitals were overwhelmed by critically ill patients with COVID-19 and reported 90% mortality rates, compared with 30–40% in recent studies that reflect typical outcomes for patients with acute respiratory distress syndrome not associated with SARS-CoV-2 infection (Grasselli et al., 2020). In addition, infection with SARS-CoV-2 may be the direct cause of death or may exacerbate underlying chronic conditions or secondary bacterial infections, as is the case for influenza (Simonsen and Viboud, 2012). Furthermore, excess mortality in hospitals may be attributed to increased healthcare-associated infections (antimicrobial-resistant pathogens and candidiasis) (Lansbury et al., 2020).

In this study, 10.8% of excess mortality was attributed directly to COVID-19, leaving 5% of the total excess mortality (estimated as 15%) due to other causes, mainly unclassified (40% of deaths were coded as 'unclassified' during the pandemic period, see Table 1). These excess 'unclassified' deaths might be explained by the increasing excess home deaths in the 'unclassified' category (Figure 3). Overall, this excess mortality in Oman might be explained by many factors. As a consequence of the pandemic, the overwhelmed health services have significantly decreased elective services which mainly target diagnosis of new diseases, care of patients with NCDs and public health screening programmes, causing disruption of services dealing with NCDs. The World Health Organization showed that 75% of 122 surveyed countries experienced disruption in NCD services during the pandemic (WHO, 2020a). In addition, the public's increased fear of COVID-19 or being diagnosed with COVID-19 has significantly affected their medical-seeking behaviour. Such attitudes were noted particularly in slums and in communities of low socio-economic status in Bangladesh, Kenya, Nigeria and Pakistan (Ahmed et al., 2020).

The fact that the data used in this study originated entirely from national MoH institutes could be considered a limitation. However, the large sample size for the 5-year period from the same source enabled a reasonable baseline calculation to investigate the presence of any deviation from baseline. Therefore, it is believed that the number of deaths may be higher, but the excess proportion was more or less acceptable.

Another limitation of this study was the dependency on physicians' judgement to identify the direct cause of death and its ICD-10 code. This might explain the high proportion of unclassified deaths in the data, and the discrepancy between ICD-10-coded COVID-19 deaths and nationally announced COVID-19-related deaths (based on a positive laboratory test) for the same period. Nevertheless, some of the tertiary hospitals in Oman have

dedicated ICD-10 coders who revise all causes of deaths and recode them to ensure maximum accuracy.

Excess mortality in the pandemic period, both from COVID and from non-COVID causes, was due to the shift of the entire health system towards dealing with the pandemic and disregarding other causes of death such as NCDs. Collectively, these diseases are more evident in unfavoured socio-economic communities, which have suffered disproportionately in terms of the economic impact of the pandemic (Horton, 2020). This merits a holistic approach to the management of this pandemic and appropriate coordination of health services during such health crises.

Conclusion

The COVID-19 pandemic in Oman resulted in 15% excess all-cause deaths (11.36 deaths per 100,000 population), mainly among patients aged >60 years. Although the majority of the excess deaths were classified as COVID-19-related deaths, increased numbers of unclassified deaths, deaths due to infectious diseases and deaths due to respiratory diseases re-enforces the importance of a holistic approach in managing the syndemic effects of COVID-19. This would involve maintenance of care for patients with chronic diseases and prevention of healthcare-associated infections in hospitals during pandemics.

Conflict of interests

None declared.

Funding

None.

Ethical approval

The study was approved by the Directorate General for Disease Surveillance and Control. There was no need for consent as the study was anonymous and used data produced for public health purposes.

Authors' contributions

Adil Al Wahaibi conducted the statistical analysis and wrote the draft manuscript and discussion. Amal Al Maani wrote the introduction, helped with the discussion, and reviewed and edited the manuscript. Badar Al Rawahi, Khalid Said Al Harthy, Fatma Alyaquobi and Amina Al-Jardani reviewed and edited the manuscript, Seif Al-Abri supervised the study and participated in all stages of manuscript preparation.

Acknowledgements

The authors wish to thank Lesley Carson for editorial assistance in finalizing the manuscript. The authors would also like to acknowledge the Directorate General for information technology of the MoH of the Sultanate of Oman for their effort in extracting and providing data.

References

Ahmed SAS, Ajisola M, Azeem K, Bakibinga P, Chen Y-F, Choudhury NN, et al. Impact of the societal response to COVID-19 on access to healthcare for non-COVID-19 health issues in slum communities of Bangladesh, Kenya, Nigeria and Pakistan: results of pre-COVID and COVID-19 lockdown stakeholder engagements. BMJ Glob Health 2020;5:e003042.

Bilinski A, Emanuel EJ. COVID-19 and excess all-cause mortality in the US and 18 comparison countries. JAMA 2020;e2020717.

Grasselli G, Greco M, Zanella A, Albano G, Antonelli M, Bellani G, et al. Risk factors associated with mortality among patients with COVID-19 in intensive care units in Lombardy, Italy. JAMA Intern Med 2020;180:1345–55.

Höhle M, Mazick A. Aberration detection in R illustrated by Danish mortality monitoring. In: Kass-Hout T, Zhang X, editors. Biosurveillance: a Health Protection priority. Boca Raton, FL: Chapman and Hall/CRC; 2010. p. 1–20.

Horton R. COVID-19 is not a pandemic. Lancet 2020;396:874.

Kucirka L, Lauer S, Laeyendecker O, Boon D, Lessler J. Variation in false negative rate of RT-PCR based SARS-CoV-2 tests by time since exposure. Ann Intern Med 2020;173:262–7.

Lansbury L, Lim B, Baskaran V, Lim WS. Co-infections in people with COVID-19: a systematic review and meta-analysis. J Infect 2020;81:266–75.

Meyer S, Held L, Höhle M. Spatio-temporal analysis of epidemic phenomena using the R package surveillance. J Stat Soft 2017;77:1–55.

Oman News Agency. Results Summary of COVID-19 National Sero-Survey First Phase. Muscat: Oman News Agency; 2020 Available at: https://omannews.gov.om/NewsDescription/ArtMID/392/ArticleID/20053/Results-Summary-of-COVID-19-National-Sero-Survey-First-Phase [Accessed 30 October 2020].

Onder G, Rezza G, Brusaferro S. Case-fatality rate and characteristics of patients dying in relation to COVID-19 in Italy. JAMA 2020;323:1775–6.

R Core Team. R: a Language and Environment for Statistical Computing. Vienna: R Foundation for Statistical Computing; 2020.

Simonsen L, Viboud C. The Art of Modeling the Mortality Impact of Winter-Seasonal Pathogens. Oxford: Oxford University Press; 2012.

Sinnathamby MA, Whitaker H, Coughlan L, Lopez Bernal J, Ramsay M, Andrews N. All-cause excess mortality observed by age group and regions in the first wave of the COVID-19 pandemic in England. Euro Surveill 2020;25:2001239.

Vestergaard LS, Nielsen J, Richter L, Schmid D, Bustos N, Braeye T, et al. Excess all-cause mortality during the COVID-19 pandemic in Europe–preliminary pooled estimates from the EuroMOMO network, March to April 2020. Euro Surveill 2020;25:2001214.

Wahaibi AA, Manji AA, Maani AA, Rawahi BA, Harthy KA, Alyaquobi F, et al. COVID-19 epidemic monitoring after non-pharmaceutical interventions: the use of time-varying reproduction number in a country with a large migrant population. Int J Infect Dis 2020;99:466–72.

Wang R, Pan M, Zhang X, Han M, Fan X, Zhao F, et al. Epidemiological and clinical features of 125 hospitalized patients with COVID-19 in Fuyang, Anhui, China. Int J Infect Dis 2020;95:421–8.

Weinberger DM, Chen J, Cohen T, Crawford FW, Mostashari F, Olson D, et al. Estimation of excess deaths associated with the COVID-19 pandemic in the United States, March to May 2020. JAMA Intern Med 2020;180:1336–44, doi: http://dx.doi.org/10.1001/jamainternmed.2020.3391.

Wickham H. ggplot2: Elegant Graphics for Data Analysis. New York: Springer-Verlag; 2016.

Woolf SH, Chapman DA, Sabo RT, Weinberger DM, Hill L, Taylor DD. Excess deaths from COVID-19 and other causes, March–July 2020. JAMA 2020;324:1562–4.

World Health Organization. Information Note: COVID-19 and NCDs. Geneva: WHO; 2020 Available at: https://www.who.int/docs/default-source/inaugural-who-partners-forum/covid-19-and-ncds—final—corr7.pdf [Accessed 31 October 2020].

World Health Organization. ICD-10 Online Versions. Geneva: WHO; 2020 Available at: http://www.who.int/classifications/icd/icdonlineversions/en/ [Accessed 13 October 2020].

Wu J, Mafham M, Mamas M, Rashid M, Kontopantelis E, Deanfield J, et al. Place and underlying cause of death during the COVID19 pandemic: retrospective cohort study of 3.5 million deaths in England and Wales, 2014 to 2020. MedRxiv 2020;, doi:http://dx.doi.org/10.1101/2020.08.12.20173302.

Yang Y, Yang M, Shen C, Wang F, Yuan J, Li J, et al. Evaluating the accuracy of different respiratory specimens in the laboratory diagnosis and monitoring the viral shedding of 2019-nCoV infections. MedRxiv 2020;, doi:http://dx.doi.org/10.1101/2020.02.11.20021493.