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.

Comparing SARS-CoV-2 with SARS-CoV and influenza pandemics

Eskild Petersen, Marion Koopmans, Unyeong Go, Davidson H Hamer, Nicola Petrosillo, Francesco Castelli, Merete Storgaard, Sulien Al Khalili, Lone Simonsen

The objective of this Personal View is to compare transmissibility, hospitalisation, and mortality rates for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) with those of other epidemic coronaviruses, such as severe acute respiratory syndrome coronavirus (SARS-CoV) and Middle East respiratory syndrome coronavirus (MERS-CoV), and pandemic influenza viruses. The basic reproductive rate (R_0) for SARS-CoV-2 is estimated to be 2·5 (range 1·8–3·6) compared with 2·0–3·0 for SARS-CoV and the 1918 influenza pandemic, 0·9 for MERS-CoV, and 1·5 for the 2009 influenza pandemic. SARS-CoV-2 causes mild or asymptomatic disease in most cases; however, severe to critical illness occurs in a small proportion of infected individuals, with the highest rate seen in people older than 70 years. The measured case fatality rate varies between countries, probably because of differences in testing strategies. Population-based mortality estimates vary widely across Europe, ranging from zero to high. Numbers from the first affected region in Italy, Lombardy, show an all age mortality rate of 154 per 100 000 population. Differences are most likely due to varying demographic structures, among other factors. However, this new virus has a focal dissemination; therefore, some areas have a higher disease burden and are affected more than others for reasons that are still not understood. Nevertheless, early introduction of strict physical distancing and hygiene measures have proven effective in sharply reducing R_0 and associated mortality and could in part explain the geographical differences.

Introduction

WHO declared the COVID-19 outbreak, caused by severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), a pandemic on March 11, 2020.[1] Initially, superspreading events, a cruise ship in Japan, mass gathering of a religious group in South Korea, skiing resorts in Italy and Austria, and a popular pilgrimage city (Iran) contributed to the rapid dissemination globally. Since then, the rate of global spread has accelerated, and widespread epidemics have occurred in numerous countries.

The SARS-CoV-2 virus is genetically closely related to severe acute respiratory syndrome coronavirus (SARS-CoV), the first pandemic threat of a novel and deadly coronavirus that emerged in late 2002 and caused an outbreak of severe acute respiratory syndrome (SARS). SARS-CoV was highly lethal but faded out after intense public health mitigation measures.[2] By contrast, the novel SARS-CoV-2 that emerged in December, 2019, rapidly caused a global pandemic. The SARS 2003 outbreak ceased in June, 2003, with a global total of 8098 reported cases and 774 deaths, and a case fatality rate of 9·7%, with most cases being acquired nosocomially.[2] In comparison, the Middle East respiratory syndrome coronavirus (MERS-CoV)—another deadly coronavirus, but which is currently not presenting a pandemic threat—emerged in 2012, and has caused 2494 reported cases and 858 deaths in 27 countries and has a very high case fatality rate of 34%.[3] Because MERS-CoV is widespread in dromedary camels, zoonotic cases continue to occur, unlike SARS-CoV, which emerged from wildlife and was eliminated from the intermediate host reservoir.

The new coronavirus SARS-CoV-2 is less deadly but far more transmissible than MERS-CoV or SARS-CoV. The virus emerged in December, 2019, and as of June 29, 2020, 6 months into the first pandemic wave, the global count is rapidly approaching 10 million known cases and has passed 500 000 deaths.[4] Because of its broad clinical spectrum and high transmissibility, eradicating SARS-CoV-2, as was done with SARS-CoV in 2003, does not seem a realistic goal in the short term.

In this Personal View we summarise key epidemiological characteristics of SARS-CoV-2 in comparison with other epidemic coronaviruses and pandemic influenza. We explore what makes SARS-CoV-2 different from pandemic influenza virus and the other epidemic severe coronaviruses such as SARS-CoV and MERS-CoV. We study the various characteristics of each virus, including the transmission and severity characteristics, case fatality rates (mortality in individuals with the disease), and the

Key messages

- The basic reproductive rate (R_0) of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is similar to, or higher than, the R_0 of SARS-CoV and pandemic influenza
- Mortality due to SARS-CoV-2 and SARS-CoV is strongly skewed towards people older than 70 years, dissimilar to the 1918 and 2009 influenza pandemics
- The proportion of symptomatic people requiring hospital admission is higher for SARS-CoV-2 infections than for the 2009 influenza pandemic
- The population risk of admission to the intensive care unit is five to six times higher in patients infected with SARS-CoV-2 than in those with the fairly mild 2009 influenza pandemic
- The case fatality rate is probably around 1% after adjusting for asymptomatic and mild illness; serological studies will aid in refining this estimate

Lancet Infect Dis 2020; 20: e238–44

Published Online July 3, 2020 https://doi.org/10.1016/S1473-3099(20)30484-9

European Society for Clinical Microbiology and Infectious Diseases, Basel, Switzerland (Prof E Petersen MD, Prof M Koopmans DVM, N Petrosillo MD, M Storgaard MD); **Department of Molecular Medicine, The University of Pavia, Pavia, Italy** (Prof E Petersen); **Department of Clinical Medicine, Aarhus University, Aarhus, Denmark** (Prof E Petersen); **Department of Viroscience, Erasmus University Medical Center, Rotterdam, Netherlands** (Prof M Koopmans); **International Tuberculosis Research Center, Seoul, South Korea** (U Go MD); **Department of Global Health, Boston University School of Public Health, Boston, MA, USA** (D H Hamer MD); **Department of Medicine, Boston University School of Medicine, Boston, MA, USA** (D H Hamer); **National Emerging Infectious Diseases Laboratories, Boston University, Boston, MA, USA** (D H Hamer); **Department of Clinical Research, National Institute for Infectious Diseases Lazzaro Spallanzani, Rome, Italy** (N Petrosillo); **Department of Infectious and Tropical Diseases, Spedali Civili and University of Brescia, Brescia, Italy** (Prof F Castelli MD); **Department of Infectious Diseases, Aarhus University Hospital, Aarhus, Denmark** (M Storgaard); **Directorate General for Disease Surveillance and Control, Ministry of Health, Muscat, Oman** (S Al Khalili MD); **Department of Science and Environment, Roskilde University, Roskilde, Denmark** (Prof L Simonsen PhD); **and Department of Global Health, George Washington University, Washington, DC, USA** (Prof L Simonsen)

Correspondence to:
Prof Eskild Petersen, European Society for Clinical Microbiology and Infectious Diseases, 4010 Basel, Switzerland
eskild.petersen@gmail.com

See Online for appendix

population-level mortality of the SARS-CoV-2 pandemic (table 1).

Transmissibility and the basic reproductive rate

Estimating the ability of a new pathogen to spread is a key measure in an emerging disease outbreak. A metric used to describe this spread is the basic reproductive rate (R_0). R_0 is defined as the average number of secondary transmissions from one infected person; when R_0 is greater than 1, the epidemic is growing. The R_0 estimates for SARS-CoV, SARS-CoV-2, MERS-CoV, and the influenza pandemics are summarised in the appendix (p 1).

The R_0 for the SARS outbreak in 2003 was estimated to be between 2·0 and 3·0 in the early months (until the end of April), before public health control measures were introduced.[2,5,6] Various control measures soon reduced the transmissibility to 1·1, with a wide IQR of 0·4–2·4.[6,7] For MERS-CoV, the R_0 (unmitigated) was estimated to be 0·69 (95% CI 0·50–0·92), consistent with MERS-CoV never having caused sustained epidemics.[8,37] For SARS-CoV-2, a recent China joint mission by WHO concluded that "transmission of SARS-CoV-2 is mostly driven by clusters in close contacts, particularly family clusters, and less so by community transmission".[9] Since the statement was released, this conclusion has been challenged, although superspreading events continue to occur in the pandemic. Studies have estimated the R_0 at 2·2 (95% CI 1·4–3·9)[10] and 2·7 (2·5–2·9);[11] therefore, an average R_0 of 2·5 seems a reasonable estimate (appendix p 1). By comparison, the initial R_0 estimate for the 2009 influenza A H1N1 pandemic was 1·7,[12] later estimated between 0·17 and 1·3 after mitigation was initiated.[13–15] R_0 for the 1918 influenza pandemic was estimated at around 2·0 in the first wave in July, 1918.[16]

The R_0 values have important implications for disease control. R_0 magnitude indicates the level of mitigation efforts needed to bring an epidemic under control.[6] Mitigation reduces the effective transmission coefficient, now called R_e. R_e needs to be reduced to less than 1 to ensure cessation of an epidemic, which can be done by rapid case identification, quarantine measures, and physical distancing to prevent secondary transmissions. For childhood diseases such as measles, the cessation of epidemic spread was achieved with an effective vaccine. However, a vaccine has never been a major tool for control of pandemics because they either occurred before the era of modern vaccines or, as in 2009, the vaccine became available only after the first waves had already occurred.

For SARS-CoV-2 with an R_0 value of approximately 2·5, transmission would need to be reduced by more than 60% to reach R_e of less than 1 ($1–1/R_0$). The transmissibility coefficient declines over time as control measures start having an effect, which was seen during the successful eradication of SARS-CoV in 2003.[8] By contrast with SARS-CoV and SARS-CoV-2, MERS-CoV has limited transmissibility even in the absence of mitigation, although the virus has caused several nosocomial outbreaks since 2012, mainly in hospitals in Saudi Arabia, Jordan, and South Korea.[17]

Incubation period of SARS-CoV-2 and viral excretion

All three coronaviruses have a longer incubation period (time from infection to symptom onset) than influenza viruses. One study estimated the mean incubation period of SARS-CoV-2 to be 5·8 days, ranging from 1·3 to 11·3 days.[18] Another study estimated the median incubation period to be 5·1 days and found that 97·5% of people showed symptoms within 11·5 days of infection.[19] A study from China estimated an incubation period of 5·2 days.[9]

A notable difference between SARS-CoV, SARS-CoV-2, and MERS-CoV are the kinetics of virus shedding. Whereas SARS-CoV and MERS-CoV have tropism for lower airways, with less virus present in the upper respiratory tract, this tropism is different in SARS-CoV-2. For SARS-CoV-2, the average viral load in a family cluster was $6·8\times10^5$ copies per upper respiratory tract swab during the first 5 days, and live virus isolates were

	SARS-CoV-2	SARS-CoV	Pandemic influenza 1918	Pandemic influenza 2009	Interpretation
Transmissibility, R_0	2·5	2·4	2·0	1·7	SARS-CoV-2 has the highest average R_0
Incubation period, days	4–12	2–7	Unknown	2	Longer incubation period; SARS-CoV epidemics form slower
Interval between symptom onset and maximum infectivity, days	0	5–7	2	2	SARS-CoV-2 is harder to contain than SARS-CoV
Proportion with mild illness	High	Low	High	High	Facilitates undetected transmission
Proportion of patients requiring hospitalisation	Few (20%)	Most (>70%)	Few	Few	Concern about capacity in the health sector
Proportion of patients requiring intensive care	1/16 000	Most (40%)	Unknown	1/104 000	Concern about capacity in the health sector
Proportion of deaths in people younger than 65 years out of all deaths	0·6–2·8%	Unknown	95%	80%	SARS-CoV-2 might cause as many deaths as the 1918 influenza pandemic, but fewer years of life lost and disability-adjusted life-years, as deaths are in the older population with underlying health conditions
Risk factors for severe illness	Age, comorbidity	Age, comorbidity	Age (<60 years)	Age (<60 years)	..

Data from the following references.[2,3,5–36] MERS-CoV=Middle East respiratory syndrome coronavirus. SARS-CoV=severe acute respiratory syndrome coronavirus. SARS-CoV-2=severe acute respiratory syndrome coronavirus 2.

Table 1: **Characteristics of SARS-CoV-2, SARS-CoV, and pandemic influenza**

obtained from swabs during the first week of illness.[20] In a study from Hong Kong,[38] high viral loads were found in the first samples obtained after admission to hospital. This finding was confirmed in a study from China,[39] which found a high viral load at the onset of symptoms that declined in the following 5–6 days. This quick decline in the viral load makes isolation and quarantine of patients with SARS-CoV-2 and their contacts much more challenging and less effective, as it has to be done as soon as possible after illness onset in order to reduce transmission. By contrast, for SARS-CoV viral loads peaked at 6–11 days after symptom onset,[21,22] allowing a full extra week to identify and isolate cases before transmission occurred. This difference would in part explain why SARS could be eradicated in 2003 compared with the trajectory seen in the SARS-CoV-2 pandemic.

There is increasing evidence of transmission from asymptomatic people, although what proportion of these individuals are presymptomatic remains unknown. It is clear that COVID-19 has a broad clinical picture which includes asymptomatic and mild illness.[23,40] A study from Iceland[24] found that 43% of PCR-positive cases had no symptoms, although some individuals showed symptoms later on (number of days remains unknown). Unofficial data from China suggest that 78% of cases were asymptomatic.[25]

Viral shedding might be occurring for prolonged periods. A study of viral load[26] in respiratory tract samples, faeces, and blood from 96 patients with COVID-19 found a viral load of 10^5–10^6 copies per mL up to 3 weeks after symptom onset. Viral shedding tended to be longer in stool samples; however, as of June 9, 2020, there is no documented evidence of faecal–oral transmission. Viral load is higher and persists for longer in the lower respiratory tract of patients who are severely ill with COVID-19.[26] For SARS, lower respiratory tract infection occurred without upper respiratory tract infection. As a consequence, transmission of SARS-CoV was infrequent during the first 5 days of illness,[2] and unlike transmission of influenza, transmission in household settings was rare.[41]

Case fatality and risk of severe illness

A key difference between SARS-CoV-2 and pandemic influenza is the age distribution of patients who are severely ill. The mortality rate in people infected with SARS-CoV-2 increases steeply with age, and fatal outcomes are almost exclusively seen in people older than 50 years (table 2). This age-related increase in severe morbidity and mortality was also observed for SARS-CoV (although with a far greater case fatality). In Hong Kong, the case fatality due to SARS-CoV was 0% for age group 0–24 years, 6% for those aged 25–44 years, 15% for those aged 45–64 years, and 52% for people who were 65 years and older.[2,27] For both SARS and COVID-19, children rarely had severe illness (table 2). Recently, a rare hyperinflammatory syndrome has been reported in children with COVID-19.[45] In one study looking at close household contacts of people with COVID-19,[28] children and adults both had a secondary attack rate of 15%, but whether children transmit the virus as effectively as adults is still unknown.

Clinical case fatality, for which the case definition was fever and respiratory symptoms (including pneumonia), was around 5% in Hubei province and only around 1% in the rest of China and South Korea.[43] In the USA, case fatality rates among patients with COVID-19 were less than 1% for people aged 20–54 years, 1–5% in those aged 55–64 years, 3–11% in those aged 65–84 years, and 10–27% in people aged 85 years and older. Early in the outbreak there have been few deaths in children and young adults younger than 20 years.[46] Although most patients (90%) with COVID-19 have mild clinical illness, there is considerable demand for intensive care because of the subset of patients who develop acute respiratory distress syndrome. This requirement for respiratory support is higher for SARS-CoV-2 cases than for the influenza pandemic in 2009 (table 1). In a study[29] of patients who were admitted to hospital in New York, NY, USA, 14% required intensive care (median age 68 years).

A Danish study of the 2009 influenza A H1N1 pandemic[47] found that the proportion of patients with pandemic influenza never exceeded 4·5% of the total national intensive care unit (ICU) bed capacity, and the ICU admission rate was estimated to be approximately one patient per 5500 patients infected with influenza A H1N1.[48] Such figures are lacking for the COVID-19 pandemic, but it is evident that ICU capacity in this pandemic is a crucial element. In Lombardy, Italy, an estimated 2·3% of COVID-19 cases needed an ICU bed.[44] Comparing these rates is difficult because most people in the 2009 pandemic were younger than 60 years, whereas SARS-CoV-2 affects mainly older individuals. We compared key variables and features of the 1918 and 2009 influenza pandemics with SARS-CoV-2, SARS-CoV, and MERS-CoV in table 3.

	Morbidity, % of positive tests			Fatality rates, %		
	China	South Korea	Italy (Lombardy)	China	South Korea	Italy (all regions)
0–9 years	0·9	1·0	0·4	0·0	0·0	0·0
10–19 years	1·2	5·2	0·8	0·2	0·0	0·0
20–29 years	8·1	28·0	2·7	0·2	0·0	0·0
30–39 years	17	10·3	5·1	0·2	0·1	0·0
40–49 years	19·2	14·0	9·4	0·4	0·1	0·1
50–59 years	22·4	19·3	16·6	1·3	0·4	0·6
60–69 years	19·2	12·4	17·5	17·5	1·6	2·7
70–79 years	8·8	6·5	23·2	8·0	5·4	9·6
≥80 years	3·2	3·3	19·7	14·8	10·2	16·6

Data for China,[42] South Korea,[43] and Italy.[44] Average age of death in Italy is 81 years, and mortality in Italy in people older than 90 years was 19%.[44]

Table 2: **COVID-19 age-specific case morbidity and fatality rates**

	Number of deaths (adjusted to year 2000 population)	Mean age at death (years)	Years of life lost (adjusted to year 2000 population)
2009 influenza pandemic	7500–44 100*; 8500–17 600†	37·4	334 000–1 973 000; 328 900–680 300
1968 influenza pandemic	86 000‡	62·2	1 693 000
1957 influenza pandemic	150 600‡	64·6	2 698 000
1918 influenza pandemic	1 272 300‡	27·2	63 718 000
1979–2001 average influenza A H3N2 season	47 800	75·7	594 000
2003 SARS-CoV	774	Unknown	Unknown
2012 MERS-CoV	858	>65·0	Unknown
2019 SARS-CoV-2	302 059§	Unknown	Unknown

MERS-CoV=Middle East respiratory syndrome coronavirus. SARS-CoV=severe acute respiratory syndrome coronavirus. SARS-CoV-2=severe acute respiratory syndrome coronavirus 2. *Range based on estimates of excess pneumonia and influenza deaths (lower range number) and all-cause deaths (upper range number); estimated from projections of mortality surveillance from 122 cities. †Probabilistic estimates from the Centers for Disease Control and Prevention using 2009 pandemic survey data.[36] ‡Estimates based on the excess mortality approach applied to final national vital statistics and adjusted to year 2000 population-age structure. §As per the May 17, 2020, WHO situation report.[4]

Table 3: **Mortality from influenza and coronaviruses[30,31]**

	Number of known cases	Known cases per 100 000 population	Deaths	Deaths per 100 000 population	Tests per 100 000 population
USA	1 382 362	421	83 819	26	3623
South Korea	11 037	21	262	0·5	1458
Spain	230 183	490	27 459	58	6498
Italy (Lombardy)	84 119	841	5374	54	9398
Germany	173 772	209	7881	9	3759
UK	236 715	353	33 998	51	3670
South Africa	13 524	23	247	0·4	742

Data taken from the WHO situation report on May 17, 2020.[4] Population data from Eurostat.

Table 4: **Cumulated prevalence, mortality, and diagnostic tests per country**

For the **COVID-19 Eurostat data** see https://www.worldometers.info/coronavirus/

Population-based mortality

The mortality impact of seasonal and pandemic influenza has long been estimated as the excess mortality above baseline. Excess mortality is ideally estimated from a mortality time series updated once per week, during, or at the end of a pandemic.[30,31] A study on excess mortality in the 2009 influenza pandemic used data from 33 countries,[31] and found that the global burden was approximately 300 000 deaths. The mean excess mortality for seasonal influenza was 0·1–6·4 per 100 000 people younger than 65 years, 2·9–44·0 per 100 000 people aged 65–74 years, and 17·9–223·5 per 100 000 people aged 75 years and older.[31] It is too early to study excess mortality for COVID-19 in South Korea and Italy, but such studies from China would be helpful. As of June 8, 2020, in Lombardy (Italy), the mortality rate for COVID-19 has reached 159 per 100 000 population.[32] Notably, these data are not from the end of the outbreak and numbers are expected to increase further, as some patients spent 4 weeks in intensive care and thus have not yet resolved the infection.

The timely European Morbidity and Mortality (EuroMOMO) surveillance system updated once per week is a great resource for accessing excess mortality studies relating to the COVID-19 pandemic in European countries.[49] The website shows *Z* score elevations in a time series of deaths due to any cause, allowing comparison with elevations caused by seasonal influenza. The EuroMOMO data show high COVID-19 associated excess mortality in a number of countries including Italy, Spain, the UK, and Sweden, whereas other countries such as Germany, Norway, and Greece have found no, or low, excess mortality (appendix p 2). Case fatality rates are shown in table 4.[49] In the USA, the Centers for Disease Control and Prevention also reports substantial elevation in national respiratory deaths.[50] For comparison, the influenza pandemic excess mortality has ranged from extreme (1918) to mild (2009) over the past 100 years (table 3). A study modelling global excess mortality for the moderate 1957 influenza A H2N2 pandemic[30] found a respiratory excess mortality rate of 0·02%. For the deadly 1918 influenza pandemic estimates show that about 1–2% of the global population died.[51] However, excess mortality for the 2009 pandemic was not much greater than that of a severe seasonal influenza, at about 0·04% deaths in the global population[30,31]

Because the mean age at death varied greatly in past pandemics, one excess mortality study also looked at excess years of life lost.[30] Using years of life lost as a metric, this study found that the three influenza pandemics in 1957, 1968, and 2009 had a similar size effect. Although it is too early to draw conclusions, the effect of COVID-19 might be higher in terms of excess mortality, possibly with numbers somewhere in between the 1957 and 1918 influenza pandemics. However, in terms of excess years of life lost, because of the mean age (~80 years) of COVID-19 fatalities, the COVID-19 pandemic would score lower, perhaps similarly to the 1957 and 1968 influenza pandemics. More time and data are needed before the COVID-19 pandemic can be accurately compared with past pandemics.

Incidence of SARS-CoV-2 infections

Because of the broad clinical spectrum, it has become evident that to find out the true attack rate of SARS-CoV-2 serological studies are needed. Meanwhile we can look at reported cases, deaths, and the number of tests per 100 000 population, understanding that more testing and a broader clinical case definition mean a higher rate of cases. Currently, each country is in a different phase of the pandemic, which will lead to a bias in early country comparisons.

Official figures are available for the USA, South Korea, the UK, Spain, Germany, and South Africa (table 4, appendix pp 3–4). As of Feb 16, 2020, Hubei, the earliest affected province in China, had 67 466 confirmed cases of COVID-19 and 2902 deaths reported.[9] These figures correspond to 0·11% of the population being affected and a mortality rate of 4·8 per 100 000 population, which

is low compared with certain countries in Europe,[52] possibly because people with mild symptoms were not tested.[23–25] Serological surveys will shed light on these discrepancies. For comparison, seasonal influenza attack rates are in the range of 10–20% every winter.[53]

SARS-CoV-2 spread compared with SARS-CoV

It is still unclear what characteristics the newly emerging coronavirus, SARS-CoV-2, possesses—which its relative SARS-CoV did not possess in 2003—allowing it to succeed in causing a global pandemic. Even at the height of the 2003 SARS-CoV epidemic, 140 new infections were reported per week,[2] compared with more than 100 000 infections with SARS-CoV-2. In 2003, SARS began to spread globally after a patient travelled from mainland China to Hong Kong. International flight traffic from China has increased at least ten times since 2003, and a massive high-speed train network connects a large part of eastern China and Wuhan where the COVID-19 outbreak began in 2019. Aside from this dissemination advantage, patients with COVID-19 begin viral shedding a few days before symptom onset, which is very different from SARS-CoV and makes quarantine measures much less efficient.

SARS-CoV-2 and warmer weather

A recent study[54] modelled possible scenarios for COVID-19 up to 2024, on the basis of epidemiology of the seasonal coronaviruses OC43 and HKU1. The study assumed a winter-time R_0 of 2·2 and a summertime R_0 of 1·3, and predicted winter cycles of COVID-19 after the pandemic phase. By comparison, the A H1N1 influenza pandemic started in Mexico in February, 2009, and by June a total of 73 countries had reported more than 26 000 laboratory-confirmed cases.[55] In July, 1918, there was a peak of H1N1 influenza infections seen in Copenhagen before the second wave hit in November.[16,56] These previous pandemics have shown that influenza transmission does occur over the summer and seasonality is difficult to predict.

Temperature and humidity makes a difference for viral survival in the environment. A study using enveloped virus Phi6 as a surrogate virus[57] found that infectivity was sensitive to temperature and decreased by two orders of magnitude between 19°C and 25°C. Some data on the effect of temperature are available for SARS-CoV only. A study of SARS-CoV found a two-log reduction in virus titre after 7 h at 38°C and 95% humidity.[58] At 4°C, SARS-CoV persisted for up to 28 days, and the lowest level of inactivation occurred at 20% relative humidity. Inactivation was faster at 20°C than at 4°C at all humidity levels. These experimental data suggest that SARS-CoV-2 might be less able to survive in the summer.

SARS-CoV-2 and the effect of containment measures

A mortality study[59] in 17 cities in the USA during the 1918 influenza pandemic found that the cities which implemented mitigation strategies early on had a delayed, flatter epidemic curve, with a 50% lower peak mortality, and a 20% lower overall mortality. Thus, mitigating policies are of paramount importance to ensure that the burden on the health-care system remains manageable. The examples of China and South Korea, and early signs of bending the curve seen in Europe, show that influencing the spread of SARS-CoV-2 is possible. However, the socioeconomical costs are enormous and will be long lasting.

Radical containment measures have been used to curb the pandemic in some affected countries. The approach taken in South Korea was especially effective, done by rapidly applying extensive testing, quarantine, and contact tracing of individuals from a large church group in the early stages of the outbreak. Also, schools were closed, and all international arrivals were quarantined for 2 weeks.[43] China, South Korea, and Singapore show that mitigation using a combination of contact tracing and rigorous social distancing measures is possible.[60] However, new outbreaks have started to occur in each of these countries and renewed control measures have been implemented

Countries such as Denmark, Italy, Spain, and Germany have relied mostly on social distancing and hygiene measures, in population lockdowns of various magnitudes of intensity. Such draconic measures were used when the epidemics were progressing too fast and capacity for effective case identification, contact tracing, and containment became impossible. The consensus is that rigorous mitigation measures are needed early to slow down SARS-CoV-2 transmission.[61] Drastic measures of quarantine and mobility restrictions put in place by China, Europe, and the USA are no different than those used for plague in the 14th century. The COVID-19 pandemic so far has shown that such measures could possibly halt the pandemic if individuals follow the specific country guidelines.

Conclusion

The first WHO "disease X" scenario has become a reality.[33] The SARS-CoV-2 pandemic has already caused severe morbidity and mortality in older adults, much higher than in the pandemic influenza. Although children are clearly less affected, their role in the transmission of the virus still needs to be studied.

At this early stage in the pandemic there are no effective treatments such as antivirals or passive immunisation schemes. Development of a safe and effective vaccine will take time. Thus, only supportive treatment in hospitals is currently available, and efforts to slow and limit the spread of the virus continue. The goal is to reduce the impact of the virus, prevent overwhelming the health-care system, and protect the people at highest risk of severe outcomes, while waiting for an effective vaccine and treatments.

Historical evidence from influenza pandemics which occurred in the past century shows us that pandemics

tend to come in waves over the first 2–5 years as the population immunity builds-up (naturally or through vaccination), and then the number of infected cases tends to decrease. This observation is the most likely trajectory for the SARS-CoV-2 virus. However, the near future will require a transition to a new normal, in which a combination of physical distancing, enhanced testing, quarantine, and contact tracing will be needed for a long time. While clinical research and testing of antivirals and vaccine candidates is ongoing, scientists will learn from regions and countries that were first affected. Also, epidemiological and phylogenetic studies can yield much information about risk factors (other than age) such as disease transmission, the role of children in transmission, and a better estimate of case fatality.

It is highly likely that after SARS-CoV-2 there will be another pandemic. It might be another coronavirus, an influenza virus, a paramyxovirus, or a completely new disease. We believe that learning from this experience is crucial so that we can meet a future pandemic threat with far better preparation in terms of testing, adequate stocks of personal protective equipment, and critical care capability. International pandemic planning is needed to ensure collaboration between countries, including better surveillance of emerging infections especially zoonoses. Controlling an outbreak has everything to do with mitigating casualties such as economic losses, joblessness, loneliness, and even loss of human dignity at the end of life.

Contributors

EP and SAK drafted the Personal View. MK contributed to the description of influenza virus, MERS-CoV, SARS-CoV, and SARS-CoV-2. UG, DHH, NP, FC, and MS helped with the data. UG provided expertise on South Korea, DHH provided expertise on the USA, and NP and FC provided expertise on Italy. MS contributed with data from Denmark and LS contributed with the historical analysis of previous influenza pandemics.

Declaration of interests

MK received funding from the Versatile Emerging Infectious Disease Observatory Horizon 2020 project (grant 874735). DHH is supported by a cooperative agreement (U50 C1000359) between the US Centers for Disease Control and Prevention and the International Society of Travel Medicine. LS is supported by The Carlsberg Foundation (grant C20–0046). All other authors declare no competing interests.

Editorial note: the *Lancet* Group takes a neutral position with respect to territorial claims in published maps and institutional affiliations.

References

1 WHO. WHO characterizes COVID-19 as a pandemic. March 11, 2020. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen (accessed May 14, 2020).

2 WHO. Consensus document on the epidemiology of severe acute respiratory syndrome (SARS). 2003. https://www.who.int/csr/sars/WHOconsensus.pdf?ua=1 (accessed May 14, 2020).

3 Alfaraj SH, Al-Tawfiq JA, Assiri AY, Alzahrani NA, Alanazi AA, Memish ZA. Clinical predictors of mortality of Middle East respiratory syndrome coronavirus (MERS-CoV) infection: a cohort study. *Travel Med Infect Dis* 2019; **29:** 48–50.

4 WHO. Coronavirus disease (COVID-19). Situation Report– 161. June 29, 2020. https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200629-covid-19-sitrep-161.pdf?sfvrsn=74fde64e_2 (accessed June 30, 2020).

5 Bell DM. Public health interventions and SARS spread, 2003. *Emerg Infect Dis* 2004; **10:** 1900–06.

6 Chowell G, Castillo-Chavez C, Fenimore PW, Kribs-Zaleta CM, Arriola L, Hyman JM. Model parameters and outbreak control for SARS. *Emerg Infect Dis* 2004; **10:** 1258–63.

7 Lipsitch M, Cohen T, Cooper B, et al. Transmission dynamics and control of severe acute respiratory syndrome. *Science* 2003; **300:** 1966–70.

8 Breban R, Riou J, Fontanet A. Interhuman transmissibility of Middle East respiratory syndrome coronavirus: estimation of pandemic risk. *Lancet* 2013; **382:** 694–99.

9 WHO. Report of the WHO–China joint mission on coronavirus disease 2019 (COVID-19). Feb 16–24, 2020. https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf (accessed April 23, 2020).

10 Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. *N Engl J Med* 2020; **382:** 1199–207.

11 Wu JT, Leung K, Leung GM. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. *Lancet* 2020; **395:** 689–97.

12 Balcan D, Hu H, Goncalves B, et al. Seasonal transmission potential and activity peaks of the new influenza A(H1N1): a Monte Carlo likelihood analysis based on human mobility. *BMC Med* 2009; **7:** 45.

13 Girard MP, Tam JS, Assossou OM, Kieny MP. The 2009 A (H1N1) influenza virus pandemic: a review. *Vaccine* 2010; **28:** 4895–902.

14 Cowling BJ, Lau MS, Ho LM, et al. The effective reproduction number of pandemic influenza: prospective estimation. *Epidemiology* 2010; **21:** 842–46.

15 Kwok KO, Davoudi B, Riley S, Pourbohloul B. Early real-time estimation of the basic reproduction number of emerging or reemerging infectious diseases in a community with heterogeneous contact pattern: using data from Hong Kong 2009 H1N1 pandemic influenza as an illustrative example. *PLoS One* 2015; **10:** e0137959.

16 Andreasen V, Viboud C, Simonsen L. Epidemiologic characterization of the 1918 influenza pandemic summer wave in Copenhagen: implications for pandemic control strategies. *J Infect Dis* 2008; **197:** 270–78.

17 Killerby ME, Biggs HM, Midgley CM, Gerber SI, Watson JT. Middle East respiratory syndrome coronavirus transmission. *Emerg Infect Dis* 2020; **26:** 191–98.

18 Backer JA, Klinkenberg D, Wallinga J. Incubation period of 2019 novel coronavirus (2019-nCoV) infections among travellers from Wuhan, China, 20–28 January 2020. *Euro Surveill* 2020; **25:** 2000062.

19 Lauer SA, Grantz KH, Bi Q, et al. The incubation period of coronavirus disease 2019 (COVID-19) from publicly reported confirmed cases: estimation and application. *Ann Intern Med* 2020; **172:** 577–82.

20 Wolfel R, Corman VM, Guggemos W, et al. Virological assessment of hospitalized patients with COVID-2019. *Nature* 2020; **581:** 465–69.

21 Cheng PK, Wong DA, Tong LK, et al. Viral shedding patterns of coronavirus in patients with probable severe acute respiratory syndrome. *Lancet* 2004; **363:** 1699–700.

22 Pan Y, Zhang D, Yang P, Poon LLM, Wang Q. Viral load of SARS-CoV-2 in clinical samples. *Lancet Infect Dis* 2020; **20:** 411–12.

23 Chan JF, Yuan S, Kok KH, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. *Lancet* 2020; **395:** 514–23.

24 Gudbjartsson DF, Helgason A, Jonsson H, et al. Spread of SARS-CoV-2 in the Icelandic population. *N Engl J Med* 2020; **382:** 2302–15.

25 Day M. Covid-19: four fifths of cases are asymptomatic, China figures indicate. *BMJ* 2020; **369:** m1375.

26 Zheng S, Fan J, Yu F, et al. Viral load dynamics and disease severity in patients infected with SARS-CoV-2 in Zhejiang province, China, January–March 2020: retrospective cohort study. *BMJ* 2020; **369:** m1443.

27 Peiris JSM, Guan Y, Yuen KY. Severe acute respiratory syndrome. *Nat Med* 2004; **10** (suppl)**:** S88–97.

28 Bi Q, Wu Y, Mei S, et al. Epidemiology and transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: a retrospective cohort study. *Lancet Infect Dis* 2020; published online April 27. https://doi.org/10.1016/S1473-3099(20)30287-5.

29 Richardson S, Hirsch JS, Narasimhan M, et al. Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City area. *JAMA* 2020; **323:** 2052.

30 Viboud C, Miller M, Olson D, Osterholm M, Simonsen L. Preliminary estimates of mortality and years of life lost associated with the 2009 A/H1N1 pandemic in the US and comparison with past influenza seasons. *PLoS Curr* 2010; **2:** RRN1153.

31 Simonsen L, Spreeuwenberg P, Lustig R, et al. Global mortality estimates for the 2009 influenza pandemic from the GLaMOR project: a modeling study. *PLoS Med* 2013; **10:** e1001558.

32 Lombardia News Online. Covid-19 situazione regione Lombardia. 2020 (in Italian). https://lombardianotizie.online/covid-19/ (accessed May 18, 2020).

33 WHO. Prioritizing diseases for research and development in emergency contexts. 2018. https://www.who.int/activities/prioritizing-diseases-for-research-and-development-in-emergency-contexts (accessed April 21, 2020).

34 Munster VJ, Koopmans M, van Doremalen N, van Riel D, de Wit E. A novel coronavirus emerging in China—key questions for impact assessment. *N Engl J Med* 2020; **382:** 692–94.

35 Olson DR, Simonsen L, Edelson PJ, Morse SS. Epidemiological evidence of an early wave of the 1918 influenza pandemic in New York City. *Proc Natl Acad Sci USA* 2005; **102:** 11059–63.

36 Centers for Disease Control and Prevention. CDC estimates of 2009 H1N1 influenza cases, hospitalizations and deaths in the united states. 2011. https://www.cdc.gov/h1n1flu/estimates_2009_h1n1.htm (accessed May 14, 2020).

37 Cauchemez S, Fraser C, Van Kerkhove MD, et al. Middle East respiratory syndrome coronavirus: quantification of the extent of the epidemic, surveillance biases, and transmissibility. *Lancet Infect Dis* 2014; **14:** 50–56.

38 To KK-W, Tsang OT-Y, Yip CC-Y, et al. Consistent detection of 2019 novel coronavirus in saliva. *Clin Infect Dis* 2020; published online Feb 12. DOI:10.1093/cid/ciaa149.

39 Wang FS, Zhang C. What to do next to control the 2019-nCoV epidemic? *Lancet* 2020; **395:** 391–93.

40 Li G, Li W, He X, Cao Y. Asymptomatic and presymptomatic infectors: hidden sources of COVID-19 disease. *Clin Infect Dis* 2020; published online April 9. https://doi.org/10.1093/cid/ciaa418.

41 Goh DLM, Lee BW, Chia KS, et al. Secondary household transmission of SARS, Singapore. *Emerg Infect Dis* 2004; **10:** 232–34.

42 Epidemiology Working Group for NCIP Epidemic Response, Chinese Center for Disease Control and Prevention. The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) in China. *Zhonghua Liu Xing Bing Xue Za Zhi* 2020; **41:** 145–51 (in Chinese).

43 Korea Centers for Disease Control and Prevention. Updates on COVID-19 in Republic of Korea (as of 17 March). 2020. https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030 (accessed April 23, 2020).

44 Ministro della Salute. Covid-19: the cases in Italy at 6 pm on March 15th. March 15, 2020 (in Italian). http://www.salute.gov.it/portale/news/p3_2_1_1_1.lingua=italiano&menu=notizie&p=dalministero&id=4240 (accessed April 26, 2020).

45 Riphagen S, Gomez X, Gonzalez-Martinez C, Wilkinson N, Theocharis P. Hyperinflammatory shock in children during COVID-19 pandemic. *Lancet* 2020; **395:** 1607–08.

46 CDC COVID-19 Response Team. Severe outcomes among patients with coronavirus disease 2019 (COVID-19)—United States, February 12–March 16, 2020. *MMWR Morb Mortal Wkly Rep* 2020; **69:** 343–46.

47 Gubbels S, Perner A, Valentiner-Branth P, Molbak K. National surveillance of pandemic influenza A(H1N1) infection-related admissions to intensive care units during the 2009–10 winter peak in Denmark: two complementary approaches. *Euro Surveill* 2010; **15:** 19743.

48 Petersen E, Keld DB, Ellermann-Eriksen S, et al. Failure of combination oral oseltamivir and inhaled zanamivir antiviral treatment in ventilator- and ECMO-treated critically ill patients with pandemic influenza A (H1N1)v. *Scand J Infect Dis* 2011; **43:** 495–503.

49 EuroMOMO. Graphs and maps. 2020. https://euromomo.eu/graphs-and-maps/ (accessed May 16, 2020).

50 Centers for Disease Control and Prevention. NCHS mortality surveillance data. 2020. https://www.cdc.gov/coronavirus/2019-ncov/covid-data/covidview/04172020/nchs-mortality-report.html (accessed May 16, 2020).

51 Murray CJL, Lopez AD, Chin B, Feehan D, Hill KH. Estimation of potential global pandemic influenza mortality on the basis of vital registry data from the 1918–20 pandemic: a quantitative analysis. *Lancet* 2006; **368:** 2211–18.

52 WHO. Coronavirus disease 2019 (COVID-19). March 15, 2020. https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200315-sitrep-55-covid-19.pdf?sfvrsn=33daa5cb_8 (accessed April 21, 2020).

53 Somes MP, Turner RM, Dwyer LJ, Newall AT. Estimating the annual attack rate of seasonal influenza among unvaccinated individuals: a systematic review and meta-analysis. *Vaccine* 2018; **36:** 3199–207.

54 Kissler SM, Tedijanto C, Goldstein E, Grad YH, Lipsitch M. Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. *Science* 2020; **368:** 860–68.

55 Fineberg HV. Pandemic preparedness and response—lessons from the H1N1 influenza of 2009. *N Engl J Med* 2014; **370:** 1335–42.

56 Miller MA, Viboud C, Balinska M, Simonsen L. The signature features of influenza pandemics—implications for policy. *N Engl J Med* 2009; **360:** 2595–98.

57 Prussin AJ, Schwake DO, Lin K, Gallagher DL, Buttling L, Marr LC. Survival of the enveloped virus Phi6 in droplets as a function of relative humidity, absolute humidity, and temperature. *Appl Environ Microbiol* 2018; **84:** e00551–18.

58 Chan KH, Peiris JS, Lam SY, Poon LL, Yuen KY, Seto WH. The effects of temperature and relative humidity on the viability of the SARS coronavirus. *Adv Virol* 2011; **2011:** 734690.

59 Hatchett RJ, Mecher CE, Lipsitch M. Public health interventions and epidemic intensity during the 1918 influenza pandemic. *Proc Natl Acad Sci USA* 2007; **104:** 7582–87.

60 Lee VJ, Chiew CJ, Khong WX. Interrupting transmission of COVID-19: lessons from containment efforts in Singapore. *J Trav Med* 2020; **27:** taaa039.

61 WHO. WHO director-general's opening remarks at the media briefing on COVID-19 – 16 March 2020. 2020. https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---16-march-2020 (accessed May 14, 2020).