

Epidemiology

COVID-19 and the flu: data simulations and computational modelling to guide public health strategies

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Abstract

Background: Pandemics threaten lives and economies. This article addresses the global threat of the anticipated overlap of COVID-19 with seasonal *influenza*.

Objectives: Scientific evidence based on simulation methodology is presented to reveal the impact of a dual outbreak, with scenarios intended for propagation analysis. This article aims at researchers, clinicians of family medicine, general practice and policy-makers worldwide. The implications for the clinical practice of primary health care are discussed. Current research is an effort to explore new directions in epidemiology and health services delivery.

Methods: Projections consisted of machine learning, dynamic modelling algorithms and whole simulations. Input data consisted of global indicators of infectious diseases. Four simulations were run for '20% versus 60% flu-vaccinated populations' and '10 versus 20 personal contacts'. Outputs consisted of numerical values and mathematical graphs. Outputs consisted of numbers for 'never infected', 'vaccinated', 'infected/recovered', 'symptomatic/asymptomatic' and 'deceased' individuals. Peaks, percentages, R_0 , durations are reported.

Results: The best-case scenario was one with a higher flu-vaccination rate and fewer contacts. The reverse generated the worst outcomes, likely to disrupt the provision of vital community services. Both measures were proven effective; however, results demonstrated that 'increasing flu-vaccination rates' is a more powerful strategy than 'limiting social contacts'.

Conclusions: Results support two affordable preventive measures: (i) to globally increase *influenza*-vaccination rates, (ii) to limit the number of personal contacts during outbreaks. The authors endorse changing practices and research incentives towards multidisciplinary collaborations. The urgency of the situation is a call for international health policy to promote interdisciplinary modern technologies in public health engineering.

Key words: Artificial learning, coronavirus, *influenza*, SARS-CoV-2, social distancing, vaccination.

Key Messages

- Prevention for the global threat of a COVID-19 and *influenza* double pandemic.
- Multidisciplinary research methodology with epidemiological simulation modelling.
- Limiting the number of personal contacts, increasing global flu-vaccination rates.
- Innovation policy for research in primary care, family medicine and general practice.
- Quantitative comparative analysis, public health forecasting and projection models.
- The critical importance of interdisciplinary collaborations for future research.

Introduction

Health authorities warn that the collision of the flu season with the COVID-19 pandemic can be more deadly than before. World Health Organization (WHO) forewarns that averting flu pandemic may be harder as surveillance switches to COVID-19 (1,2). This original research article expands on the current COVID-19 situation with simulation analyses to generate two effective public health (PH) directives in disease control. Scientific evidence supporting ‘flu-vaccination’ and ‘limiting the number of contacts’ is based on simulation methodology.

Media discussions primarily focus on enhancing critical care capacities and increasing the number of ventilators. Strengthening competencies in primary health care (PHC), confronting emerging challenges in community health centres and small district hospitals can provide a critical first line of defence in managing the pandemic. Authorities draw attention to the importance of creating a framework of partnerships with family physicians (FPs), GPs, providers in outpatient clinics and nursing homes (3). A survey study in the USA evaluated the first 3 months of the pandemic and reported that 6% of 558 PHC physicians closed their practices and 35% furloughed staff (4). PHC practice losses were initially inevitable (5).

The British Medical Association (BMA) warns that GPs will not be able to cope with future waves unless urgent measures are put in place to support FPs. Fact remains that the damage is escalating (6,7). WHO draws attention to the significance of PHC in the COVID-19 response in differentiating patients with similar symptoms, making early diagnoses, helping vulnerable people cope with anxiety, reducing the demand for hospital services. The appropriate approach is to identify and manage potential cases, avert the risks of transmission, maintain delivery of essential health services (HSs), adhere to and enhance existing surveillance practice, strengthen risk communication and community engagement. Actions should aim to modify and improve infrastructure, human resources, supplies, medicines and personal protective equipment. WHO suggests an algorithm for triage and referral. Post-clinical assessment of suspected cases include transportation to the hospital, environmental cleaning, follow-up of contacts and notification. Establishment of alternate first-contact strategies, home visits, community follow-up and the use of e-health are among other considerations in PHC (8).

Influenza virus and SARS-CoV-2 have similar disease presentations, especially in the beginning. Pre-symptomatic transmission is a major driver in both. The fractions of severe and critical infection seem to be higher for COVID-19. Antivirals and vaccines are available in the treatment and prevention of *influenza*. For COVID-19, there are currently a number of therapeutics in clinical trial, and vaccines in development with encouraging results (1,9,10). Global severity assessments use indicators of transmissibility, seriousness of disease and impact. Key epidemiologic parameters defining communicable diseases are the number of annually infected individuals

worldwide, incubation period (IP), basic reproduction number (R_0), case fatality rate (CFR), in addition to reports of confirmed cases, patients cured and deaths. Statisticians and mathematical modellers use these numbers to estimate outcomes and measure the importance of a health event (1).

Seasonal-influenza

Flu is an acute contagious respiratory viral infection, not be confused with bacterial *Haemophilus influenza* disease (1). Pandemic flu is a rare global outbreak that is different from seasonal-flu (11). Yearly vaccinations against *influenza* are recommended by WHO for high risk groups, and by the Centers for Disease Control and Prevention (CDC) for individuals ≥ 6 months (1,11). *Influenza* vaccine effectiveness (VE) depends on how well the season’s flu viruses in the circulation are matched to the flu vaccine viruses of that year. Given that the two are well matched, flu-vaccination is expected to reduce the risk of flu illness by 40–60% in the overall population. Additional factors include health status and age (11). Vaccination remains the best preventative intervention. The *influenza* vaccine is not effective against SARS-CoV-2, but recommended during the COVID-19 pandemic, especially for priority groups (1,12). IP for seasonal-flu is typically around 2 days, range 1–4 (11,13). R_0 mean estimated for seasonal-*influenza* strains is 1.3, range 0.9–2.1. This value represents the people infected by one individual (11,14–18). CFR is the estimate of the portion of a population that dies during a specified period. A crude indicator with certain limitations, CFR measures how virulent and lethal a novel infection is. Only ascertained cases are included, yet CFR remains the best tool in the initial phases (19–22). CFR for *influenza* has been reported as 0.05–0.1%, based on CDC data (11,23). WHO notes that mortality for seasonal-*influenza* is usually well below 0.1% (1).

COVID-19

The global outbreak still remains a major PH challenge (1,24). According to US-based Worldometer, there are 61 325 450 reported cases, 42 405 725 recovered cases, 1 438 037 deaths in the pandemic, as of 27 November 2020. IP is typically reported as 4–14 days, median 4–5, range 2–24. It is most likely that IP will be narrowed down as more data becomes available (1,9,11,25,26). WHO estimated R_0 to be 1.4–2.5 in January and 2.0–2.5 in March 2020. For an outbreak to gradually disappear, R needs to be less than 1 ($R < 1$) (1,11). Mortality appears higher for COVID-19 than for seasonal-*influenza*, CFR was reported as 3.4% with no known immunity to the disease (11,23). WHO Director-General stated in March that about 3.4% of reported COVID-19 cases died globally. Seasonal-flu generally kills far $< 1\%$ of those infected (1). Although no COVID-19 vaccine has completed clinical trials, multiple attempts are in progress (27,28).

Medical data projections using mathematical modelling (MM) and machine learning (ML) were used in the current research. Dynamic simulation tools have not yet been used to their full

potential in Family Medicine (FM), GP, PHC planning and effective policy decision-making. Mainstreaming MM, simulations and leading-edge technologies in health care (HC) forecasting are promoted. For heightened accuracy and aggregation of diverse data sets, authors advocate changing practices and research incentives towards multidisciplinary collaborations (29). Artificial intelligence (AI) refers to machines programmed to think, learn and solve problems like a human mind (30). A subset of AI, ML provides systems the ability to automatically learn and improve from experience without being explicitly programmed (31). Modelling is a representation. MM is a set of equations based on experimental data and phenomenon. Computational modelling (CM) solves sets of equations such as coding, programming at different levels, simulations, analyses, predictions and visualizations, including graphs. MM and CM simulate prescience to provide insight, cultivate the strategic planner’s prediction. AI algorithms do this through deep machine learning (DML) and save several months-to-years for humankind. Compartmental models, for the distribution of different sectors in the population, simplify MM of infectious diseases. Susceptible-Exposed-Infected-Recovered (SEIR) model whole simulations are considered predictive for person-to-person transmissions.

Objectives

Current research (i) simulates the effect of the *influenza* vaccine during the COVID-19 pandemic, (ii) presents a case study with likely scenarios to be considered in PH policy decision-making and (iii)

provides a mathematical model to be used with real-time numerical data of PH significance.

Methods

Input data consisted of global indicators for infectious diseases. The process consisted of AI, DML algorithms, whole simulations run for a COVID-19 and seasonal-*influenza* overlap, with/without adequate flu-vaccination, with higher/fewer number of personal contacts. Outputs of the study consisted of simulation graphs and numerical values.

Factual information was studied and interpreted in order to submit approximations for MM, based on best available data. Indicators of transmissibility, seriousness, impact of disease used in the simulations were, ‘number of globally infected individuals per year, IP, R_0 , CFR’ with values of ‘~1000000000, 1–4 days, 1.3, %0.05–0.1’ for *influenza*, and ‘yet unknown, 4–14 days, 2.0–2.5, 3.4%’ for SARS-CoV-2. The time interval under analysis was 3 months.

Input data, determined/attained

The simulation time step width was determined as 1 day, on the x-axis (Figs. 1 and 2). Population sample size was taken as 100 000, auto-populated by the algorithm. Number of people contacted by each individual was taken as 10 or 20. The probability of transmission from one infected asymptomatic individual is 3.26%/day/

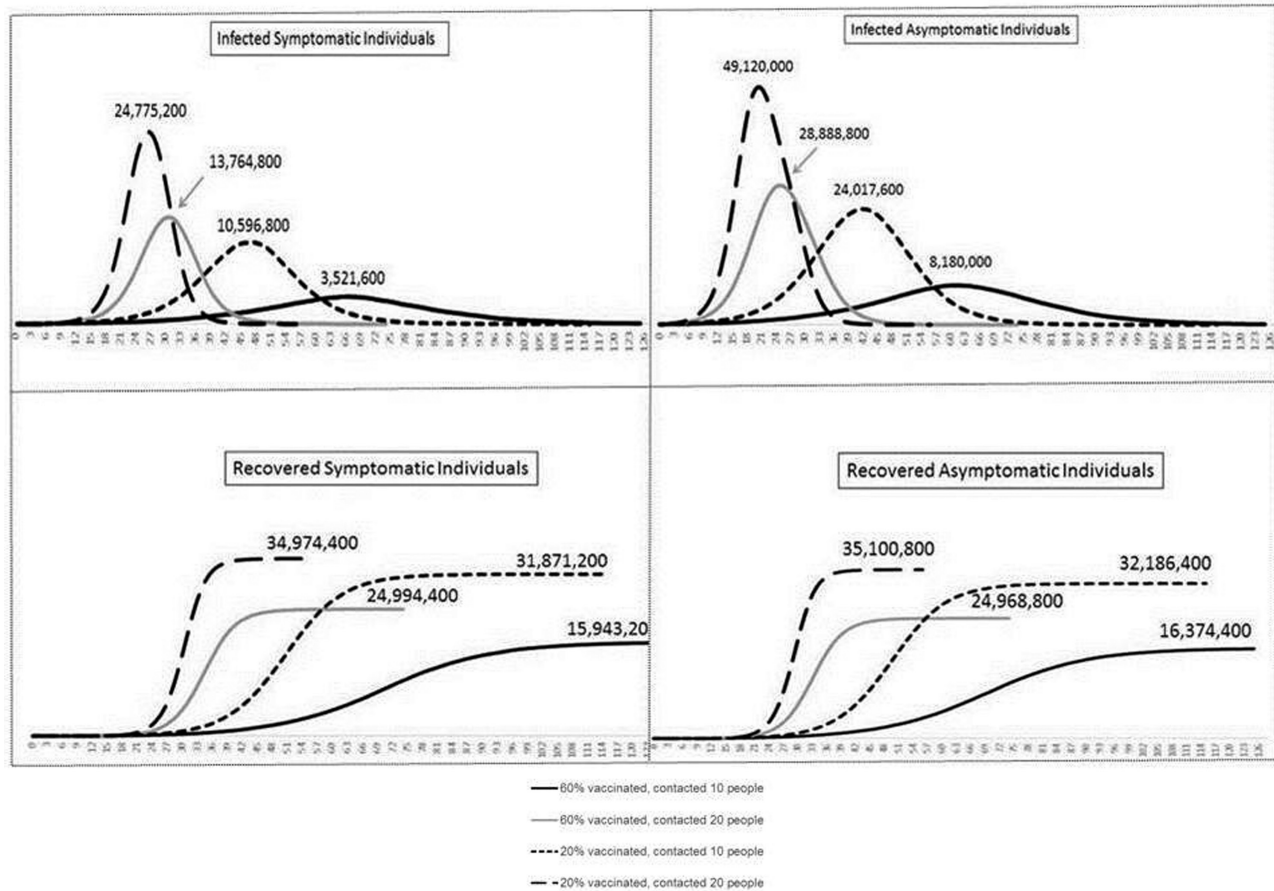


Figure 1. Timeline graphics for infected/recovered symptomatic/asymptomatic individuals, ‘days’ on horizontal x-axis, ‘# of individuals’ on vertical y-axis.

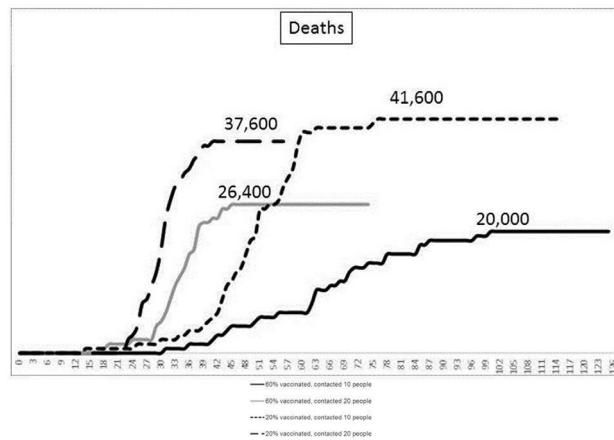


Figure 2. Timeline graphic for deaths, ‘days’ on horizontal x-axis, ‘# of individuals’ on vertical y-axis.

contact. The probability of asymptomatic infection is 5.0%/day/contact, based on WHO data simulations. Flu-vaccinated population was taken as 60% versus 20%, with %60 VE. Symptomatic cases over all positive individuals was 50%. Sample size determined was 1.0%, representing the number of people initially infected. VE was taken as 70–90%. One environmental parameter was applied, in the effort to construct dynamic social-network models representing person-to-person interactions.

Four simulations were run. Scenarios 1, 2, 3, 4 correspond to ‘60% vaccinated, 10 contacts’, ‘60% vaccinated, 20 contacts’, ‘20% vaccinated, 10 contacts’ and ‘20% vaccinated, 20 contacts’ in the appropriate order.

DML algorithm was applied to information from WHO and CDC resources. Data was artificially produced applying a mathematical operation, with 95% confidence. In the SEIR compartmental model whole simulations, the number of individuals represented by SEIR may vary over time, even if the total population size remains constant. In a specific population, the size of which is calculated by DML, these functions provide decision-makers with information about the expected trajectory of an epidemic, future infectious disease risks, or the likely impact of control measures. For COVID-19 and seasonal-flu, the sector exposed was merged with the infected, as for the possible asymptomatic nature of COVID-19.

Python programming language was used for data manipulation, Tensorflow AI library for dataset population, Numpy library of Python for scientific computing to manipulate data and to reflect disease distribution. Python-plotting Matplotlib was mainly used for visualizations. In some cases, HyperText Markup Language HTML coding methodology was also used to create user-friendly graphics.

Results

Simulation counts, durations and peak values are presented (Table 1). ‘Infected symptomatic’, ‘infected asymptomatic’, ‘recovered symptomatic’, ‘recovered asymptomatic’ and ‘deceased’ individuals are illustrated in timeline graphics (Figs. 1 and 2).

In the first scenario, 60% of the population was vaccinated for seasonal-flu; each person contacted 10 individuals. Peak numbers for ‘never infected’, ‘vaccinated’, ‘infected symptomatic’, ‘infected asymptomatic’, ‘recovered symptomatic’, ‘recovered asymptomatic’ and ‘deceased’ individuals were 51 120 000; 28 800 000; 3 521 600; 8 180 800; 15 943 200; 16 374 400 and 20 000 in consecutive order,

respectively. In the same order, 19.40%; 36.00%; 0.00%; 0.00%; 19.93%; 20.47% and 0.03% were affected. Peak was reached in 60 days. This best-case scenario has a longer course, and all indicators show lowest numbers. Best results were obtained with a higher rate of vaccination and a lower number of social contacts.

In the second scenario, 60% of the population was vaccinated for seasonal-flu; each person contacted 20 other individuals. Peak numbers for ‘never infected’, ‘vaccinated’, ‘infected symptomatic’, ‘infected asymptomatic’, ‘recovered symptomatic’, ‘recovered asymptomatic’ and ‘deceased’ individuals 51 120 000; 28 800 000; 13 764 800; 28 888 800; 24 994 400; 24 968 800 and 26 400 in consecutive order, respectively. In the same order, 1.50%; 36.00%; 0.00%; 0.00%; 31.24%; 31.21% and 0.03% were affected. Peak was reached in 30 days. Reducing the number of contacts decreased the number of cases.

In the third scenario, 20% of the population was vaccinated for seasonal-flu; each person contacted 10 other individuals. Peak numbers for ‘infected symptomatic’, ‘infected asymptomatic’, ‘recovered symptomatic’, ‘recovered asymptomatic’ and ‘deceased’ individuals were 70 400 000; 9 600 000; 10 596 800; 24 017 600; 31 871 200; 32 186 400 and 41 600 in consecutive order, respectively. In the same order, 7.80%; 12.00%; 0.00%; 0.00%; 39.84%; 40.23% and 0.05% were affected. Peak was reached in 45 days. The reduction in the number of deaths was noteworthy in scenario 2 in comparison to scenario 3. The decline associated with a ‘higher vaccination rate’ was more noticeable than that associated with the ‘number of contacts’.

In the fourth scenario, 20% of the population was vaccinated for seasonal-flu; each person contacted 20 other individuals. Peak numbers for ‘never infected’, ‘vaccinated’, ‘infected symptomatic’, ‘infected asymptomatic’, ‘recovered symptomatic’, ‘recovered asymptomatic’ and ‘deceased’ individuals were 70 400 000; 9 600 000; 24 775 200; 49 120 000; 34 974 400; 35 100 800 and 37 600 in consecutive order. In the same order, 0.40%; 12.00%; 0.00%; 0.00%; 43.72%; 43.88% and 0.05% were affected. Peak was reached in 23 days. Scenario 4, with a lower flu-vaccination rate and higher number of personal contacts, is the worst-case scenario. The course is comparatively brief. Indicator numbers demonstrate worst outcomes.

In scenarios 1–4, the numbers for ‘infected symptomatic’ individuals were 3 521 600; 13 764 800; 10 596 800; 24 775 200; ‘infected asymptomatic’ individuals were 8 180 800; 28 888 800; 24 017 600; 49 120 000; ‘recovered symptomatic’ individuals were 15 943 200; 24 994 400; 31 871 200; 34 974 400; ‘recovered asymptomatic’ individuals were 16 374 400; 24 968 800; 32 186 400; 35 100 800, all in consecutive order.

Scenario 1 has the longest course and the lowest number of affected individuals. Scenario 4 generates the highest numbers, for the shortest duration of time. Results are consistent with observations in practice.

The number of ‘deaths’ in scenarios 1–4 are 20 000; 26 400; 41 600; 37 600 in consecutive order. Vaccination is highly effective in reducing deaths.

Discussion

The COVID-19 pandemic is an extraordinary time in human history. General practice had to rapidly change its working patterns in order to cope with the COVID-19 crisis. Medical practitioners are urged to expand professional connectivity with colleagues. As professionals

Table 1. Simulation counts, durations, peak values

	Never infected	Vaccinated	Infected SYM	Infected ASX	Recovered SYM	Recovered ASX	Deaths	
Scenario 1, 60% vaccinated, contacted 10 people								R_0 : 1.6 Peak was reached in 60 days.
Number of individuals	15 555 200	28 800 000	—	—	15 943 200	16 374 400	20 000	
Peak	51 120 000	28 800 000	3 521 600	8 180 800	15 943 200	16 374 400	20 000	
Days (duration)			6–167 (162)	0–162 (162)	14–167 (154)	13–162 (150)	31–100 (70)	
% affected	19.40%	36.00%	0.00	0.00	19.93%	20.47%	0.03%	
Scenario 2, 60% vaccinated, contacted 20 people								R_0 : 3.2 Peak was reached in 30 days.
Number of individuals	1 210 400	28 800 000	—	—	24 994 400	24 968 800	26 400	
Peak	51 120 000	28 800 000	13 764 800	28 888 800	24 994 400	24 968 800	26 400	
Days (duration)			6–167 (162)	0–74 (74)	14–67 (54)	13–69 (57)	18–45 (28)	
% affected	1.50%	36.00%	0.00	0.00	31.24%	31.21%	0.03%	
Scenario 3, 20% vaccinated, contacted 10 people								R_0 : 2.2 Peak was reached in 45 days.
Number of individuals	6 217 600	9 600 000	—	—	31 871 200	32 186 400	41 600	
Peak	70 400 000	9 600 000	10 596 800	24 017 600	31 871 200	32 186 400	41 600	
Days (duration)			6–115 (110)	0–113 (113)	14–115 (102)	13–111 (99)	14–76 (63)	
% affected	7.80%	12.00%	0.00	0.00	39.84%	40.23%	0.05%	
Scenario 4, 20% vaccinated, contacted 20 people								R_0 : 4.4 Peak was reached in 23 days.
Number of individuals	287 200	9 600 000	—	—	34 974 400	35 100 800	37 600	
Peak	70 400 000	9 600 000	24 775 200	49 120 000	34 974 400	35 100 800	37 600	
Days (duration)			6–56 (51)	0–56 (56)	14–56 (43)	13–56 (44)	23–41 (18)	
% affected	0.40%	12.00%	0.00	0.00	43.72%	43.88%	0.05%	

SYM, symptomatic; ASX: asymptomatic.

in the forefront, FPs should be adequately informed (3). Measures must be taken to support and protect primary care. BMA proposes constructing the biggest flu program ever delivered (6).

Novel research combines techniques in automated ML, MM, simulations with practices in FM, GP, PH, medicine, engineering, data science, and promotes interdisciplinary research. Data sharing is crucial, provided that critical information is shared in a safe, accurate, confidential, transparent and timely manner. It is important to reinforce collaborative skills and work towards a common goal. A number-driven epidemiological approach, which integrated ML with simulation modelling (SM), was used in this article to advocate for applicable, affordable, effective prevention. Epidemiological projections of big data, with insights from ML-AI-SM, will carve out a better future in PH research.

Findings and recommendations presented here are consistent with the suggestions in practice, to increase flu vaccine rates.

Scenario 1, with a higher flu-vaccination rate and relatively fewer personal contacts, generates best outcomes. This best-case scenario has a longer course and lowest indicator values. Increasing

vaccination rates and lowering the number of contacts are two measures proven effective. Scenario 4, with a lower flu-vaccination rate and higher number of personal contacts, has the shortest duration and the highest indicator values. This worst-case scenario, which could possibly disrupt the supply of essential services in the community, raises concerns in terms of the PH consequences. A comparison between scenarios 2 and 3 reveals that limiting an individual's number of personal contacts is effective strategy for lowering the number of cases; however, a higher flu-vaccination rate is more powerful in lowering deaths. Results declare that flu-vaccination is an especially effective strategy in diminishing preventable double-disease burdens. Deaths are lower in scenario 4, when singly compared to deaths in scenario 3. This finding is open to interpretation. The duration of the outbreak is shorter, which might explain fewer losses.

A linear rise is observed in the number of days it took to reach the four peak values. Scenarios 4–2–3–1 correspond to 23–30–45–60 days, respectively. This linear correlation suggests a direct relationship, in support of two inexpensive effective solutions in disease control. 'Getting the flu shot' and 'having fewer contacts'

help prevent the spread. Simulation results simplify health communication (Table 1, Figs. 1 and 2). Delaying the incident of the ‘index case’, the onset of an outbreak within a certain community provides some advantages. Shared experiences from earlier medical practices contribute to improving survival rates. Likewise, a relative late start provides advantages in reducing burnout and preventing overloads. Results confirm that adequate *influenza*-vaccination is critical in reducing risks during the COVID-19 pandemic. Steep rises and sudden spikes are highly unfavourable in epidemic control. Providers of primary–secondary–tertiary HC and pre-hospital emergency medical services face excessive pressure to meet the demands. The multifaceted problem causes adversities in HS delivery, causes sufferings at the individual level and impacts economic growth.

The provision of PHC has a whole-of-society approach to health and well-being. The main objective is to offer comprehensive care for individuals, families and communities (1). There are wide-spread concerns, that it is unsafe to attend regular appointments at clinics and hospitals during the COVID-19 pandemic. Health care workers (HCWs) minimized in-person contact with patients, prioritized urgent visits and delayed elective care. Missed vaccines are likely to lead to further outbreaks of life threatening diseases. WHO Director-General comments that the best defence is preparedness, which includes investing in PHC (1,32). Ambulatory care in-person visits declined, telemedicine gained momentum and private practices struggled to deliver care (33). HSs spending decreased as resources are poured into combating the virus. Inpatient service delivery was challenged by COVID-19 patients in need of hospitalization and ICU care (11,23). Even advanced HCSs were stretched beyond capacity in the earlier phases. A projections model, based on WHO and governmental statistics, forecasted that the enactment and sustainability of social distancing measures will determine the level of demand (34). ‘Two deadly viruses together’ will be hard to control unless PH control measures are emphasized, implemented, enforced and maintained. Otherwise, medical–social–economic adversities will be more devastating than before. Evidence suggests flu-vaccination and fewer personal contacts are two promising efforts to avert significant losses.

The emergence of SARS-CoV-2 gave rise to prioritization of digital HC transformation. HCSs will unavoidably be reshaped. Multinational Deloitte-DTTL’s April–June documents highlight issues such as a transition towards prevention and communicable diseases, transformed skill sets of HCWs, technological sovereignty integrated into health policy, incentives for innovation, heightened agility, resilience and intersectoral partnerships with increased roles delegated to digitalization, data-tracking, monitoring systems, technology stocks, prevention science and e-health. Health comes first. As the saying goes, an ounce of prevention is worth a pound of cure.

Conclusions

Pandemics threaten lives and economies. Several rounds of COVID-19 are likely to come in waves, in future years. Numbers will fluctuate, impacting populations, burdening the delivery of HSs, with adverse consequences around the globe. Uncertainty prevails. At this juncture, urgent consideration is due, to be prepared ahead of peak volumes and staggering events. This PH data SM research was designed to equip scientists and technocrats with useful tools for the modern world. Improved techniques in projection methodology are a recommended route to take in developing processes with the advantages of forecasting and quantitative comparative analyses. Interdisciplinary collaboration is vital.

Declaration

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Data availability

Available upon request.

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