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Reimagining universal health coverage and other global health targets in the post COVID-19 era

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Reimagining universal health coverage and other global health targets in the post COVID-19 era

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Table of contents

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Editorial: Reimagining universal health coverage and other global health targets in the post-COVID-19 era

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Editorial on the Research Topic
Reimagining universal health coverage and other global health targets in the post-COVID-19 era

This special issue, "Reimagining Universal Health Coverage and other global health targets in the post-COVID-19 era," presents a collection of articles on Universal Health Coverage (UHC) and other health-related United Nations' Sustainable Development Goals (SDGs). Achieving UHC was one of the world's nations' goals when they adopted the SDGs in 2015. UHC is firmly based on the 1948 WHO Constitution, which declares health a fundamental human right and commits to ensuring the highest attainable level of health for all (1). UHC means all individuals and communities have access to the necessary healthcare services without experiencing financial hardship. It encompasses the entire gamut of critical, high-quality health services, including health promotion, prevention, treatment, rehabilitation, and palliative care across the lifespan (1). Over 18 million additional health workers are required by 2030 to achieve the SDGs and UHC targets for the health workforce.

The special issue has a rich collection of 7 original research articles, 3 policy briefs, and 2 perspectives submitted globally from North America, Asia, Europe, and the Middle East, which included analyses of African and Caribbean regions. A study by Bergmann and Wagner addressed the impact of COVID-19 on informal caregiving across Europe from 26 countries based on the eighth wave of the Survey of Health, Aging, and Retirement in Europe (SHARE). The study has highlighted that the perception of unmet care needs was significantly associated with country differences regarding the duration of the stay-at-home orders and further called for a reduction of burden and symptoms of anxiety or depression for caregivers and care recipients.

Another study by Qazi et al., using Gray Incidence Analysis Model (Gray Relational Analysis), evaluated the health systems at the country level. They reported that the healthcare system of advanced countries, i.e., the UK, USA, France, Denmark, etc. (almost the whole of western Europe/Schengen area/OECD), has a very poor response to the shock of the COVID-19 pandemic, which is in contrast to the myth that these countries have the best healthcare systems in the world. However, 30 countries are categorized as countries having much better health systems, most of which are member countries of the Southern Africa Development Community. Another interesting study from Italy by Blasi et al., to renovate the current healthcare system and guarantee equal access to health services, have proposed a multidisciplinary Think Tank and proposed a manifesto with six drivers for change: vision, governance, competence, intelligence, humanity, and relationship. Further, each driver was linked to action to actively move toward a new healthcare system based on trust between science, citizens, and institutions.

Some of the articles have emphasized the role of health systems strengthening and, in this context, Cuschieri et al. have highlighted the Cypriot resilience plan in response to the lessons learned from the pandemic put forward by the Government of the Republic of Cyprus with 6% of the total budget (74.1 million euros) to be allocated on strengthening the capacity of the Global Health Security and supporting public health protection. They further called for the Cypriot government and other states with a similar population or geographical distribution to consider the transformation for public health emergency preparedness and transition to a working syndemic model. Similarly, a Mexican study by Ramos Herrera et al., have highlighted the timely installation and work of the University of Guadalajara- health situation room helped the state of Jalisco in Mexico to maintain one of the lowest incidence and mortality rates in the country.

Globally, the COVID-19 pandemic had several impacts on various dimensions, including the global economy. An in-depth analysis by Tang et al. on the impact of the UHC Healthcare system on stock returns during COVID-19 found that the sudden onset of an epidemic disease results in unevenly distributed medical system resources, consequently diminishing the impact of UHC on abnormal returns. Further, the study concluded that abnormal cumulate returns emerge at the early stages of the pandemic, signifying that the strategy of investment as a sudden reaction to the outbreak is normally at the beginning of the pandemic and that a well-organized UHC system is a key factor in avoiding the risk of damage to stock markets as a result of a sudden outbreak. Da Silva and Da Silva have analyzed the relationship between the country's gross domestic product and COVID-19 mortality globally and have reported various scenarios. Their statistical analysis did not reveal any relationship between GDP per capita and the COVID-19 mortality rate. With a base GDP-per capita level of US$1200, a significant statistical relationship (at 5%level) between GDP per capita and COVID-19 mortality rate can no longer be found ($p = 0.0588$).

An epidemiological study of COVID-19 in Saudi Arabia using the data from the Ministry of Health, as reported by Salam et al., has highlighted that though COVID-19 transmission since March 2020 is considered to be widespread, creating an excess burden on the public health system, the disciplined life in compliance with law and order paved the way for effective program implementation and epidemic control. In terms of the dynamics between urbanization and infectious disease spread, a Chinese national study by Yu et al., have concluded that urban education, employment and entrepreneurship, housing, medical and health care, and other basic public services brought by urbanization can help reduce the risk of the spread of infectious diseases. However, the increasing density of buildings caused by land urbanization increases the risk of spreading infectious diseases. Another study in China by Si et al. investigated the links between the COVID-19 vaccination and public attitudes toward protective countermeasures have found that gender, age, education level, occupation risk, individual health risk perception, public health risk perception, social responsibility, peer effect, and government supervision are the main drivers for participants to be vaccinated. The results further show that vaccination lessened participants' frequency of hand washing by 1.75 times and their compliance frequency intensity of observing physical distancing by 1.24 times. However, the rate of mask-wearing did not reduce significantly, implying that China's main countermeasure of effective mask-wearing effectively controls COVID-19.

UHC demands a multifaceted strategy. Primary health care and life course approaches are crucial. A primary healthcare strategy focuses on organizing and developing health systems so individuals can obtain services for their health and wellbeing based on their needs and preferences as early as possible and in their everyday settings. Two aspects should be considered when tracking progress toward UHC: (1) The proportion of a population that has access to basic, high-quality health care (SDG 3.8.1) and (2) The proportion of the population that spends a significant portion of their family income on health (SDG 3.8.2). In this regard, Frank et al. have highlighted that Canada ranks highest in the world on the UHC Service Coverage Index, at 89 on a scale of 0 to 100, surpassing comparator countries such as Australia, New Zealand, Norway, the UK, Netherlands, Sweden, and other G-7 nations including the USA, France, Germany. However, they emphasized that UHC systems could easily fall prey to powerful and wealthy forces worldwide, seeking to make healthcare just another profitable business commodity citing the example of "Cambie Trial" (Cambie Surgeries Corporation vs. British Columbia). In this context, Montagu shared the European experience in involving the private sector in achieving UHC, where it can be effectively provided with or without large-scale private sector provision in hospital, specialty, and primary care services, and moreover,

it can be provided with high levels of patient satisfaction. The study further claimed that the European examples provide critical insight for governments of low-and-middle-income countries that large-scale privately provided medical services are neither necessary for achieving UHC nor a barrier to it. A recent article by Lal et al. highlighted that Health systems designed for UHC had been shown to support communities more equitably through primary health care (2).

In conclusion, the nations and states that progress toward achieving UHC will certainly make progress toward other health-related targets and goals. Good health allows children to learn and adults to earn, helps people escape from poverty and provides the basis for sustainable economic development. Therefore, this special issue provides original research, reviews, and evidence-based policy recommendations from various geographical regions in achieving the target of UHC amid the COVID-19 pandemic. The COVID-19 pandemic highlighted the critical significance of the health and care workforce and the importance of increasing spending in this sector to reap the economic benefits at the national level.

Author contributions

VC wrote the first draft. BN-K, TS, and HA revised and provided critical inputs. All authors discussed the results, and recommendations and contributed their inputs to the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The Provision of Private Healthcare Services in European Countries: Recent Data and Lessons for Universal Health Coverage in Other Settings

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Universal Health Coverage (UHC) exists in all of the countries of Europe, despite variation on the ownership structure of health delivery systems. As countries around the world seek to advance UHC and manage the private sector within their health systems, the European experiences can offer useful insights. We found four different models for the provision of healthcare, with the private sector predominant in some countries, and of minimal importance in others. The European experiences indicate that UHC can be effectively provided with, or without, large-scale private sector provision in hospital, specialty, and primary care services, and that moreover it can be provided with high levels of patient satisfaction. These findings offer regulatory models for countries in other regions to review as they advance UHC.

Keywords: private sector, Universal Health Coverage, health policy, health system governance, health seeking behavior

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BACKGROUND

There is a global movement to make healthcare accessible for those in need, assuring Universal Health Coverage in all countries by 2030. While pursuing this, many Low- and Middle-Income Countries (LMICs) continue to struggle with how and how much to integrate private providers into the formal government regulated and funded health system. This is a very immediate question in countries, such as Nigeria, India, and Myanmar where well over 50% of all services provided are private and quality assurance is a challenge, but also relevant to countries, such as Ethiopia or Vietnam where private care is below 25% and policy makers must wonder if higher levels would accelerate investments in coverage and care availability (1–3).

Ministerial level platforms like the Joint Learning Network use case studies to provide examples for health officials on key policies related to financing and governance which can advance Universal Health Coverage (4, 5). Case studies on health reforms have been used to demonstrate important lessons on regulatory changes and the system and health outcomes that result (6). Researchers hope to understand how the divisions in public-private service ownership affect critical health system indicators, such as efficiency, morbidity, mortality, and equity. This descriptive paper seeks to establish a categorization of systems and provide a foundational first step for future research in both OECD and LMIC settings. Healthcare services in Europe are effective, appreciated by their citizens,

and delivered with many different models and degrees of private involvement (7, 8). In the push for UHC, Europe can provide insights into differing experiences with private provision in the context of nationally managed systems. This study provides an up-to-date review of private provision across different sectors in countries across Europe. The experiences are relevant to many settings.

Financing Context

Provision of healthcare functions independently of financing and there is more competition, more variance, and more change within the ownership, incentives, and regulation of care provision than is the case with financing. Nevertheless, financing sets the context for ownership, together with policy and regulatory guidance, directly or indirectly determining what ownership mix can develop.

Universal Health Coverage (UHC) exists in all of the European countries we studied. Unlike LMICs, healthcare financing in Europe is almost universally government managed, either directly through taxation revenue (as in the UK) or semi-directly through mandated, managed, and government subsidized Social Health Insurance (as in Germany). Across Europe, government and social health insurance provide a healthcare safety net for nearly all citizens as shown by data from the OECD health system survey (**Figure 1**, blue bars). While the form of insurance varies between countries, and supplemental private insurance (orange bars) is common in some (Belgium, Holland, Slovenia) but not others (France, Norway), the most important implication for service provision, is that where they exist, private providers in most countries are paid either by national health insurance systems or by tightly regulated social health insurance schemes that coordinate purchasing (4–6). Out of pocket payments for healthcare are consistently low across all European countries surveyed, totaling <0.5% of spending on preventative care and <20% of Total Health Expenditure in 2018 (9, 10). The lesson for other countries is that government purchasing and regulation are neither a guarantee of, nor a barrier to a large private market for healthcare provision.

METHODS

Scope and Focus

We restricted our analysis to European countries which are members of the OECD. We excluded EU members which were not also OECD members, and OECD countries outside of Europe. Turkey is an OECD country and partially on the European continent, however 97% of the landmass is in Asia and we made a decision to exclude it from this analysis for that reason. In this paper, for the sake of simplicity, we refer to the selected countries as "Europe."

Data Sources

We reviewed all publications on the included countries' health systems from the OECD and WHO European websites. For each country we also searched for journal publications in English through PubMed and Google Scholar, and where data was contradictory or lacking we conducted subject specific Google Scholar searches by country (e.g., "dentist Luxembourg") for additional sources from white papers. Where all of these sources failed, we contacted experts within WHO and personal connections within academic institutions in the countries with information gaps for supplemental sources in other languages.

When calculating the scale of the private sector role within each country we relied heavily on the Health System in Transition (HSiT) national reports from the European Observatory on Health Systems and Policies. These ranged in date-produced from 2003 (Iceland) to 2019 (Latvia) (11, 12). If country-specific reports use pre-2008 data, regardless of when they were published, we set them aside, and instead used data from the 2008/9 OECD health system survey (8). When journal publications or national reports had credible national data which was more recent than either the 2008/9 Survey or the national HSiT report, we used that source. The year of data used for each country is shown in a **Supplementary Material**.

We applied the healthcare service categories used by the OECD to look separately at inpatient services, specialist services, primary care, and pharmacies (8, 13). We use hospitals as a proxy for inpatient services, this reflecting the majority of providers and care delivered in hospitals across all countries surveyed (14). Outpatient Specialist services and dentistry are treated together. Primary Care could be either general practitioners (UK) or primary care centers (Sweden). And pharmacies here refer only to community pharmacies and so exclude hospital-based pharmacies.

Patient and Public Involvement

This study used publicly available data to look at health-systems behaviors. No patients were involved, and no direct data collection was undertaken which would have prompted public involvement.

RESULTS AND DISCUSSION

We evaluated each country on hospital ownership data and then reviewed for consistency against other aspects of care provision. From this we grouped the health systems in Europe into four types (**Figure 2**), based on how reliant the overall system is on private provision. This grouping was informed by analyses of the interaction between regulatory and purchasing agencies of government and privately owned providers of care across health service domains (15–17). Health systems are highly path-dependent (18, 19) and the four types, or Groups, reflect the continued influence of the financing and ownership models which created current structures. In Germany, the influence of the Bismarkian model of social insurance and privately contracted delivery remains evident (20). In the UK, the influence of Beveridge's vision for the National Health System continues to resonate in current days (21). Nevertheless, as Kutzin argued convincingly a decade ago already, the distinctions between European health systems are becoming less important as financing models align, driven by aging populations and growing expectations for care so that

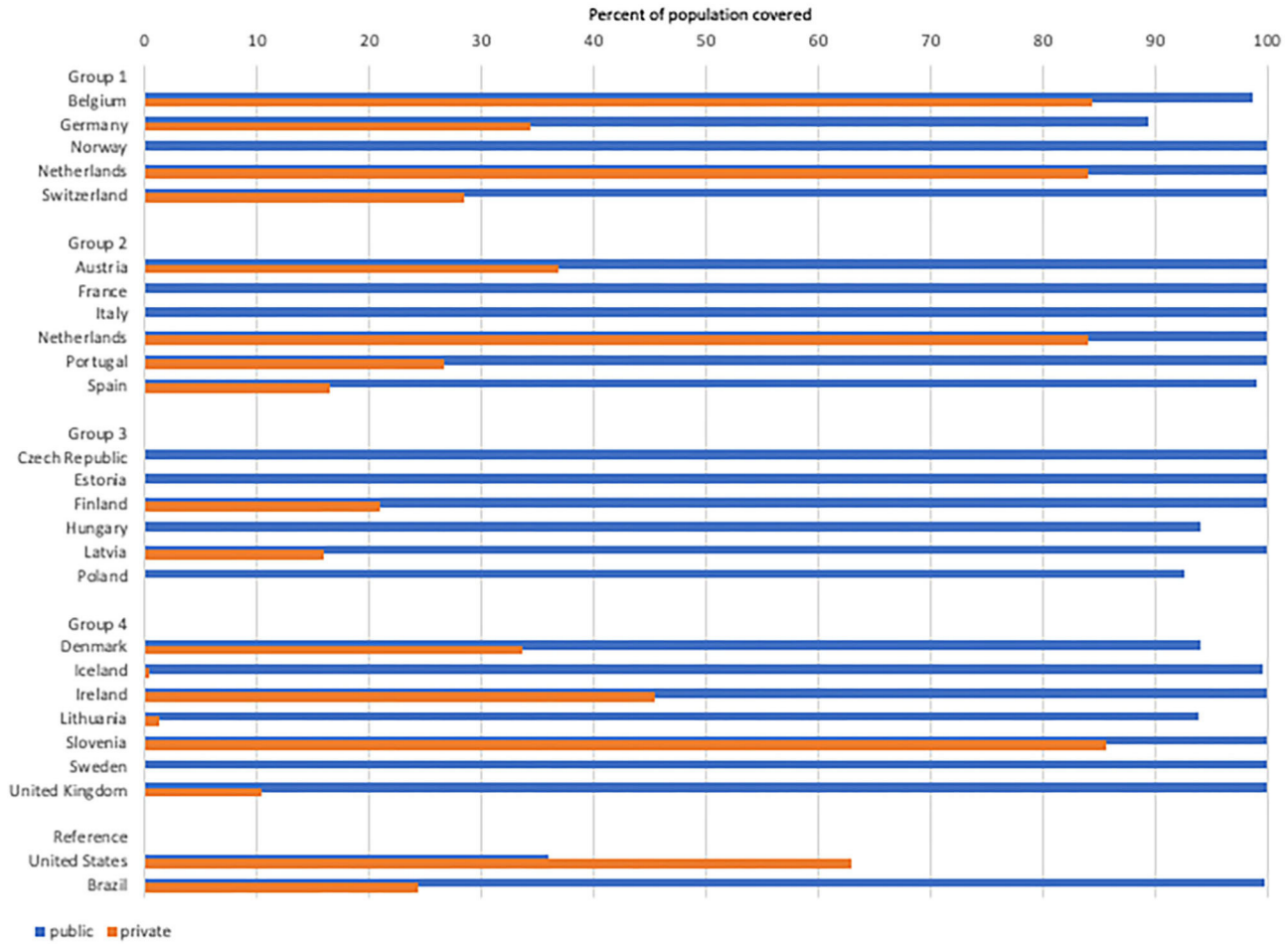

FIGURE 1 | Public and private insurance coverage. Blue bars show population covered by public insurance. Orange bars show population with private insurance*. *Private insurance is supplemental to public in all countries except the US, where private coverage is often a substitute for public insurance. Countries showing zero private insurance coverage did not report any to the OECD in 2018. (Source: https://stats.oecd.org/).

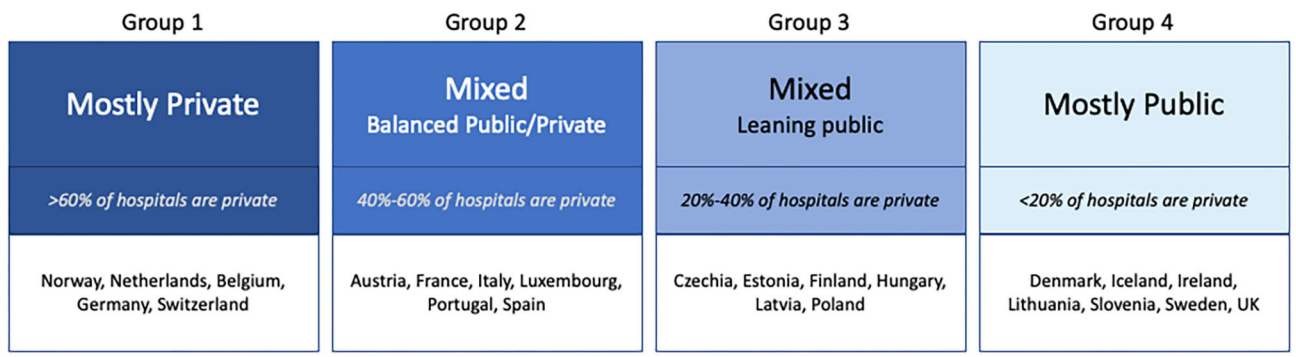

FIGURE 2 | Hospital ownership models within European health systems. Data not available for: Greece and Slovakia.

government funding fills more and more gaps in traditional social health insurance, while competition is increasingly common in national health insurance systems to manage costs (22–24).

Hospitals

Hospitals are in transition across Europe as outpatient services shift outside of medical facilities and most countries push for increased efficiency as measured by shorter average

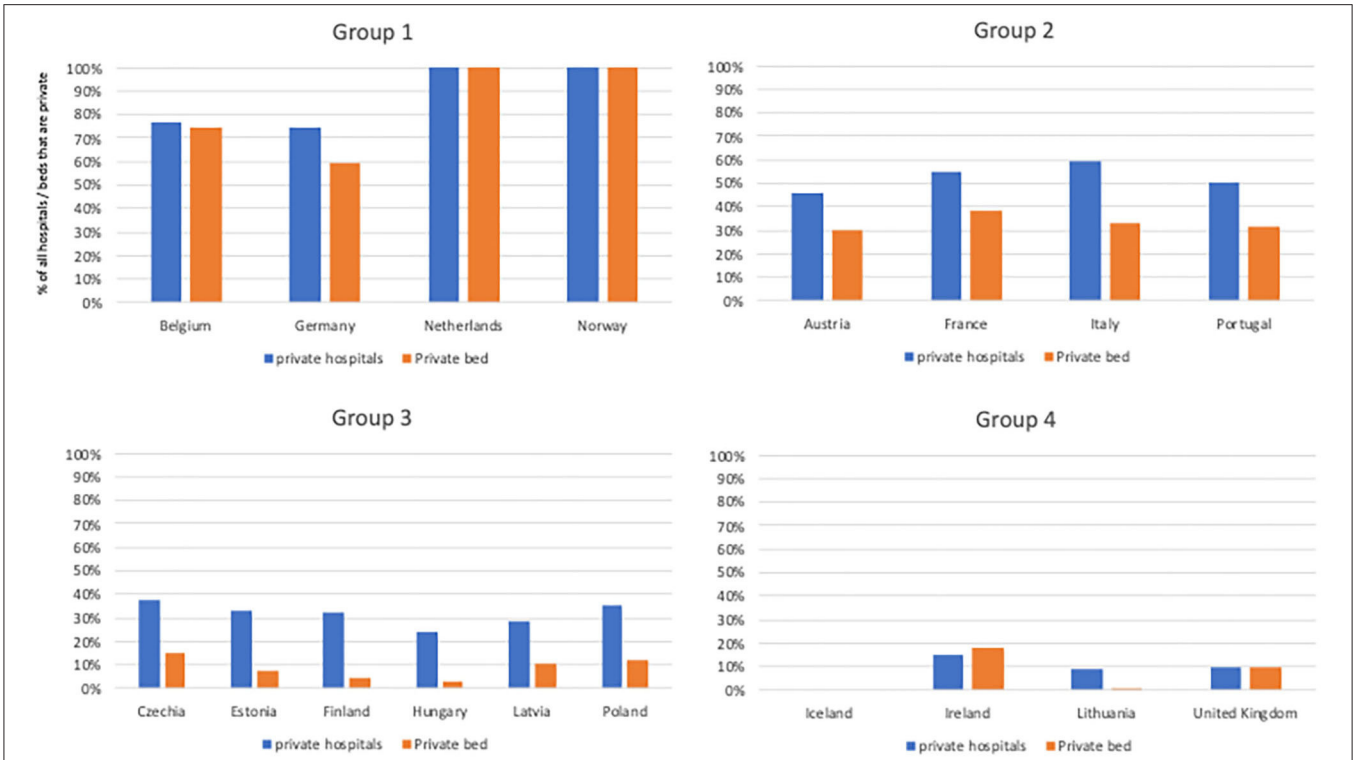

FIGURE 3 | Percent of all hospitals that are private and percent of all hospital beds that are private. Where private beds are much smaller than hospitals, hospitals focus on outpatient care. Data not available for: Denmark, Greece, Luxembourg, Slovenia, Slovakia, Spain, Sweden, and Switzerland.

stays and higher bed usage rates (14, 15). Our findings from countries with more recent data showed little change from the ownership status summarized in a 2008/2009 survey among OECD countries (8). Across all European countries the role, and importance, of private hospitals within the larger health system fall into four distinct categories (**Figure 2**).

The behavior of private hospitals differs between the four groups, as can be seen in how private hospitals contribute to available inpatient bed within each group (**Figure 3**). In some countries private hospitals provide inpatient beds and services in proportion to their importance within the overall system; in other countries private hospitals have very few beds, focusing instead on outpatient care only. In Group 1, the private hospitals beds roughly match the private hospital numbers: this is where most inpatient care of all kinds is offered. Where public and private hospitals exist in parallel, as in Germany, the differences in services offered, bed numbers, bed-stay duration, and patient experiences between public and private hospitals are minimal: to the consumer and the social health insurance payer, public and private facilities are functionally equivalent. These countries' health systems are based on Bismarck's model of care and financing.

In Group 2, this equivalence exists for some services, or in some regions, but is not universal. In these countries private facilities increasingly have taken on profit-making outpatient services, often surgeries that have few co-morbidities and predictable management but also including delivery services and (among non-profits) some cancer management. The result of this can be seen in the average facility size: private hospitals in Group 2 have fewer beds than government facilities, and higher bed turnover reflecting their emphasis on outpatient and clearly defined, lower risk, care (26). These countries' health systems are heavily influenced by the Bismarckian model.

In Group 3 this same leaning away from comprehensive inpatient services and toward a narrower set of short-stay areas of care continues. Facilities are smaller and more specialized; non-profits are less predominant within the overall mix of facilities. While private hospitals exist, they offer fewer inpatient stay opportunities and take on fewer inpatient, chronic, or emergency services. Health systems in Group 3 countries have, largely, derived from the Semashko model which influenced much of Eastern European social services during the 20th century (**Box 1**) (27).

BOX 1 | Countries in Transition: Group 3 Hospitals (25).

A decade ago, the countries in Group 3 would have been called "economies in transition" from planned economies, organized around government provision of social services, including health, to market economies. It may be, then, that Group 3 will shift, or has already shifted, in ways not reflected in our data from 4 or 5 years ago, toward or away from Group 2.

TABLE 1 | Principal mode of specialist and primary care provision.

	Primary care	Specialist care
GROUP 1		
Belgium	Private Solo Practice	Private Solo Practice
Germany	Private Solo Practice	Private Solo Practice
Netherlands	Private Group Practice	Private Group Practice
Norway	Private Solo Practice	Private Solo Practice
Switzerland	Private Solo Practice	Private Solo Practice
GROUP 2		
Austria	Private Solo Practice	Private Solo Practice
France	Private Solo Practice	Private Solo Practice
Italy	Public Center	Public Hospital
Luxembourg	Private Solo Practice	Private Solo Practice
Portugal	Public Center	Public Hospital
Spain	Public Center	Public centers
GROUP 3		
Czechia	Private Solo Practice	Public Hospital
Finland	Public Center	Public Hospital
Hungary	Private Solo Practice	Public Center
Poland	Public Center	Public Center
GROUP 4		
Denmark	Private Group Practice	Private Solo Practice
Iceland	Public Center	Private Group Practice
Ireland	Private Solo Practice	Public Hospital
Sweden	Public Center	Public Hospital
United Kingdom	Private Group Practice	Public Hospital

Comparable data not available for: Estonia, Greece, Latvia, Lithuania, Slovenia, and Slovakia.

TABLE 2 | Citizen satisfaction with the health care system, 2016.

Group 1	**AVG**	**89.4%**
Belgium		91%
Germany		88%
Netherlands		86%
Norway		89%
Switzerland		93%
Group 2	**AVG**	**73.7%**
Austria		88%
France		78%
Italy		56%
Luxembourg		86%
Portugal		63%
Spain		71%
Group 3	**AVG**	**60.5%**
Czechia		72%
Finland		77%
Hungary		50%
Poland		43%
Group 4	**AVG**	**73.2%**
Denmark		85%
Iceland		67%
Ireland		60%
Sweden		78%
United Kingdom		76%

Source: Gallup World Poll, cited in OECD "Government at a Glance" (50) statlink: http://dx.doi.org/10.1787/888933533834.

The Group 4 countries are all countries with a strong national emphasis on social services. This group also includes many of Europe's small and isolated countries. For these, centralized management of a limited number of facilities is practical and competition unlikely to be an effective complement to government purchasing. In all Group 4 countries private hospitals either don't exist at all (Iceland), or exist as a small minority of facilities, principally serving only private patients for services not covered by national insurance (eg: cosmetic surgery) or outpatient services for patients who are willing to pay to avoid the wait times for government care. Health systems based upon Beveridge.

The differing role of private hospitals can be seen in the different ratio of beds-per-hospital shown in **Figure 3**, using the most recent data from each country. Ireland appears to be an anomaly; the only country where the private sector has more beds/facility than the public, although as elsewhere these beds are primarily for short-term services (28, 29). The very low percentage of private beds in all Group 3 countries indicates that in all of these countries private hospitals exist, but largely to provide outpatient surgeries and consultations.

Dentists

Nearly all dentists in Europe work privately either in solo or group practices. In France 91% of the country's dentists are self-employed private practitioners (26). In Czechia the rate is 95%, in Austria 80%. Other than a few within hospitals, nearly 100% of dentists are private practitioners in Iceland, Italy, Lithuania, Luxembourg, Netherlands, Portugal, Greece, Germany, Spain, and the UK (10, 11, 30–37). The exceptions are few. In Finland private practitioners represent just more than half of all dentists and provide approximately one half of all dental care (38, 39). While there is some concern within the dental profession regarding how the growth in third-party payments will affect practices, most dental services across Europe continue to be funded by a mix of direct patient payment and government subsidy (40). Dental services for children up to 18 are government funded in all European countries (41). In Italy and Greece, dental services are nominally free within the government sector, but long wait times leads many patients to seek care from private offices (41). In the UK, dental care has been included in National Health Service (NHS) funding since 1948, however as in other countries, since 1951 adults have a co-payment required for non-acute services (41).

Specialist Services

Data on specialist services (**Table 1**) comes from the OECD health systems survey (8). It found that in more than half of surveyed European countries specialists operate in private practice, either as solo practitioners

(9/22 countries) or in groups (3/22). The countries where government specialist services dominate are all either in Group 2 (Italy, Spain, Portugal), Group 3 (Czechia, Finland, Hungary, Poland), or Group 4 (Ireland, Sweden, UK).

Primary Care

The 2008/9 OECD health systems survey found that primary care services were predominantly provided in private settings in 15 of the 22 European countries, including almost all countries with social health insurance systems and five countries with national health systems: Denmark, Ireland, Norway, France, and the United Kingdom. In Finland, Iceland, Italy, Poland, Portugal, Spain, and Sweden primary care is mostly public (**Table 1**).

In Sweden, primary care is provided by health centers, comprised of a multidisciplinary workforce including general practitioners, nurses, specialist nurses with expertise in diabetes or other chronic illnesses, and often occupational therapists and psychologists. In 2019, 56.2% of Sweden's 496 primary care centers are public. The remaining 43.8% are private, operating under contracts with a region (42).

Pharmacy

Outside of hospitals, community pharmacies across Europe are all privately owned and operated. There remain country variations in ownership restrictions, with Spain, France, and other countries restricting ownership by corporate chains and franchise arrangements as a way to protect and encourage local ownership (43). Eighty-five percent of the 145,143 pharmacies in Europe are private. Of these private pharmacies, one in three are affiliated with a franchise or other shared brand and one in eight are part of a chain (44, 45). The retail pharmaceutical component of the health system is sometimes inefficient, inequitable, unevenly distributed, and expensive. But it mostly works, and despite some shortcomings pharmacies function much like groceries, bakeries, or other commodity retailers. As a result most countries in Europe regulate pharmacies as a traditional, privately owned, market (46). The case study of Estonia, which liberalized its pharmacy market between 1993 and 1995 after gaining independence from the USSR, showed private ownership resulted in greater use, lower cost to the consumer, and greater client satisfaction (47). However, by 2014 regulation was needed to correct for market failures. Specifically, rural communities unserved by pharmacies were able to apply to the State which then mandated pharmacy chains meet certain size criteria to open a pharmacy in those regions (48).

In Sweden, a similar transition occurred. Until 2009 all pharmacies were government owned as part of the National Corporation of Swedish Pharmacies. From 2009, half of the government pharmacies were sold, and new private pharmacies were permitted. The total number of pharmacies increased by 20% in the following year and by 2011 there were 13 pharmacy operators in the country (49). The trend toward greater free-market structuring of pharmacies, and adaptive regulation to correct for market failings, has occurred across most countries of Europe, albeit at differing rates.

Satisfaction

Gallup Poll data from 2016 shows high levels of satisfaction with national health services in Group 1 countries with high levels of private hospitals, private primary care, and private specialist services; but equally high satisfaction numbers in some countries within Groups 2 and 4 (**Table 2**) (50). Past studies have concluded that what European patients value most is choice and low out-of-pocket costs, and these are determined more by financing policies than service ownership arrangements (51).

CONCLUSIONS

The delivery of healthcare in Europe, from hospitals to primary care to specialty services to pharmacies, demonstrates that while there have been and remain significant variations in how the private sector is engaged to provide healthcare within the larger health system, the variety can be taken to show that there are many ways to effectively deliver care. The private sector is neither necessary for the provision of national health care, nor is private sector service an impediment to a strong and effective national healthcare system. That can be said about hospitals, where the distinctions between ownership models are most stark and most clearly determined by national policy differences and changes. It can also be said for the provision of primary and specialty care, where the degree of private provision has historic roots, but both public and private models appear to deliver effective equity, access, and care (20).

At the same time, there is a near-universal accord within European health systems that the provision of community pharmacy and dental services are best served by private markets. These services and products are the most standard between providers, and hence the easiest for both purchasers and citizens to compare based on cost and accessibility. Among all healthcare goods and services, these behave the most like traditional market-based products and economists argue that private provision is the most efficient delivery option for this reason, something the European experience appears to confirm (52).

Case studies are critical for the many LMIC countries current expanding national and social health insurance, increasing investments, and revising regulatory systems to advance toward Universal Health Coverage in alignment with the Sustainable Development Goals. The European examples provide a critical insight for these governments: large scale privately provided medical services are neither necessary for achieving UHC nor a barrier to it. For any country now pursuing UHC, historical experiences and path dependency may dictate whether the private sector is an important provider of care. This was the case across the countries studied here. The varied models, and

success, of Europe show that any extant delivery mix can be managed. Well-planned national policies and financing can assure effective universal coverage regardless of any inherited delivery structure.

This study offers a foundation on which further analysis should be conducted. We hope future efforts will assess the applicability of the system categories developed for Europe to countries in Asia, Africa, and Latin America.

AUTHOR CONTRIBUTIONS

DM was solely responsible for the analysis and writing.

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GENERAL COMMENTARY
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Commentary: COVID-19 Mortality: A Matter of Vulnerability Among Nations Facing Limited Margins of Adaptation

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INTRODUCTION

De Larochelambert et al. (1) claimed to find a correlation between GDP/Capita and COVID-19 mortality, and that they also found such correlation of mortality with many other variables (partly in correlation with GDP/Capita). Economic development and associated growth in GDP tend to increase comorbidities, they argued, and therefore the most severe forms of COVID-19.

Researchers from developed countries should think less schematically of Africa (and other developing countries) and be more open-minded and scientifically careful. On the one hand, developing countries also have significant comorbidity rates, on the other hand, their health statistics may be unreliable.

Indeed, Africans, in particular, are not free of comorbidities. Research has shown a hypertension prevalence rate higher than that of the population of European origin (2). Similarly, obesity affects up to 30% of the urban adult population. According to the WHO, across 36 African countries, 23.8% of the women are overweight, with the rate exceeding 40% in Gabon, Ghana and Lesotho, and reaching a maximum of 50.6% in Swaziland (3). The WHO estimates the prevalence of diabetes at ∼5% of the African population (4).

The low COVID-19 mortality rate in emerging countries is usually attributed to other possible factors than that of the prevalence of comorbidities: endemic diseases reduce life expectancy and so the average age of the population is very low (5). As a result, a large part of the population never reaches the peak age of susceptibility to COVID-19. Furthermore, lower population density and the fact that few seniors live in care homes may also be factors in the low mortality rate (6). At the moment, unpublished studies are focusing on the possibility of cross-protective immunity with other coronaviruses common in Africa (HCoV-OC43, HCoV-HKU-1, HCoV-NL63, HCoV-229).

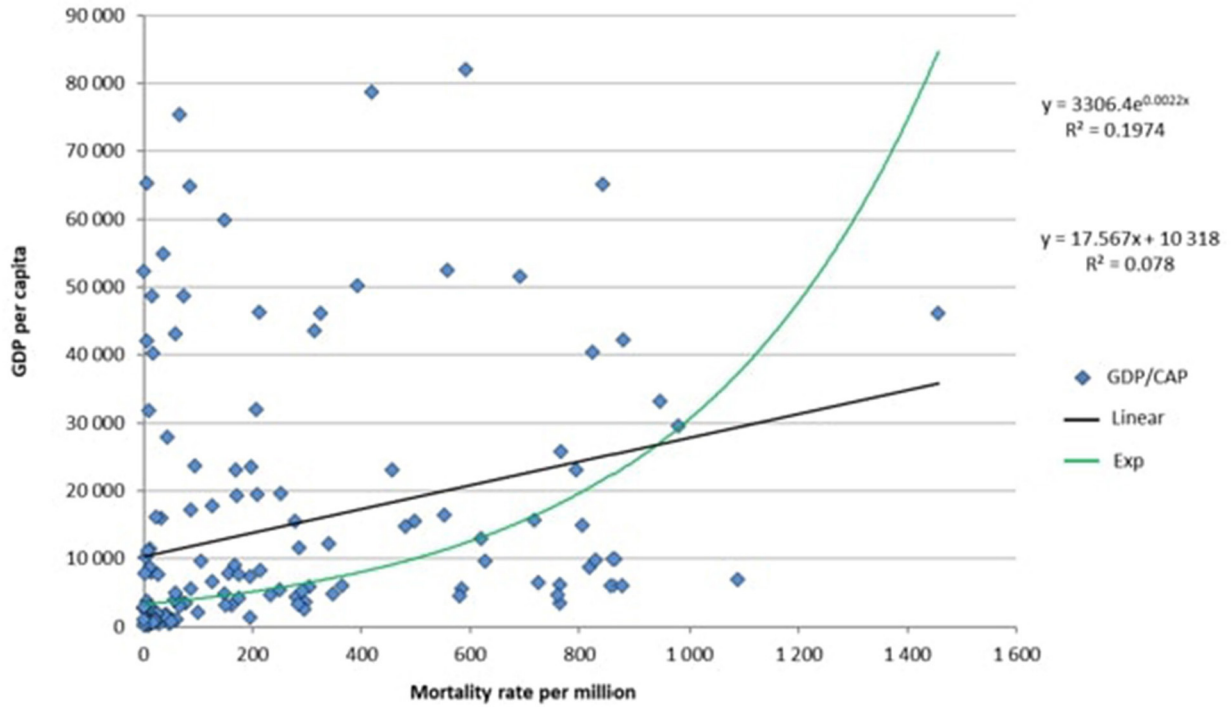

FIGURE 1 | Relationship between GDP per capita and mortality rate per one million inhabitants, for 150 countries with populations of over one million.

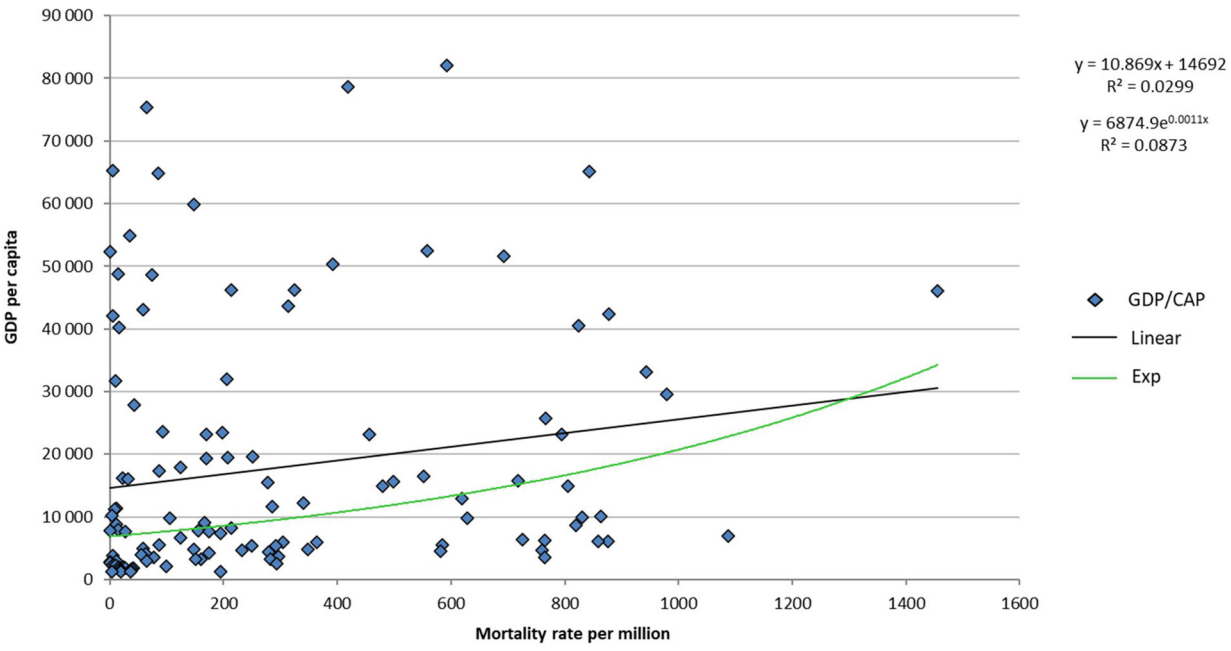

FIGURE 2 | Relationship between GDP per capita and mortality rate per million inhabitants for 120 countries with more than one million inhabitant and a GDP per capita greater than $1,200.

IS THERE A RELATIONSHIP BETWEEN A COUNTRY'S GROSS DOMESTIC PRODUCT (GDP) AND ITS COVID-19 MORTALITY RATE?

If comorbidities are not at the root of the difference in COVID-19 mortality rates, is there really a relationship between GDP per capita and the COVID-19 mortality rate? Like De Larochelambert et al., we have found a significant statistical relationship between these two variables. Our **Figure 1** shows the theoretical straight line and curve that could represent this relationship (In our analysis we found that $p = 0.0005$.) The figure concerns 150 countries having populations of over one million (data for countries with smaller populations are subject to statistical fluctuation). For each country, we crossed GDP per capita from 2019 (7) with its COVID-19 mortality rate for one million inhabitants as of December 11, 2020 (8).

But this statistical result is strongly impacted by a bias stemming from a confounding variable: the reliability rate of each country's public health data records. In all likelihood, there is a strong statistical relationship between the degree of reliability of the data and the GDP per capita (the lower a country's GDP per capita, the less able it will be to produce reliable public health statistics). That explains the major clustering of data points close to the origin (zero) of the coordinate axes. The cluster is made up of very-low-GDP countries that are not able to ensure the accuracy of their public health data, nor provide their inhabitants with easy access to PCR testing, especially in cases where the country is in turmoil. This clustering near zero is a major factor in statistical significance and deprives the statistical analysis of all credibility. It is also important to consider that each country has its own method of counting deaths by COVID-19, which includes one or more or all possible places where deaths occur (in a hospital, seniors' residence, at home).

To make their data more reliable, the authors excluded countries that reported fewer than 10 deaths by covid-19. But this restriction seems insufficient. In our calculation, we included only countries having a GDP per capita of greater than US$1200. The last country to make this cut-off was Benin, which had a COVID-19 mortality rate of four for every one million inhabitants. On this basis, the following countries were excluded: Lesotho, Tanzania, South Sudan, Nepal, Equatorial Guinea, Guinea, Yemen, Mali, Tajikistan, Ethiopia, Rwanda, Uganda, Burkina Faso, Haiti, Gambia, Chad, Guinea-Bissau, Togo, Liberia, Niger, Democratic Republic of Congo, Madagascar, Sierra Leone, Afghanistan, Mozambique, Central African Republic, Sudan, Malawi, Burundi, Somalia.

When restricted to these 120 countries, the statistical analysis did not reveal any relationship between GDP per capita and COVID-19 mortality rate. With a base GDP-per capita level of US$1200 dollars, a significant statistical relationship (at 5%level) between GDP per capita and COVID-19 mortality rate can no longer be found ($p = 0.0588$) (**Figure 2**). Note that for the 107 countries with a GDP per capita greater than $2,000, the alpha statistical risk is amplified ($p = 0.29$).

DISCUSSION

While the choice we made, certainly involves a loss of information, the loss is offset by the greater reliability of the retained data.

The statistical relationship identified by the authors omits consideration of a major confounding variable that is strongly linked to GDP when the latter is low: the reliability rate of each country's public health data records. The conclusion regarding the relationship between GDP and the COVID-19 mortality rate is biased and unclear with respect to its application.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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ORIGINAL RESEARCH
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The Impact of COVID-19 on Informal Caregiving and Care Receiving Across Europe During the First Phase of the Pandemic

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Purpose: We analyzed the effects of COVID-19 as well as its accompanying epidemiological control measures on health-related outcomes (physical and mental health) and unmet care needs of both caregivers and care recipients across Europe and Israel by taking into account country differences.

Methods: We applied comparisons of adjusted predictions, controlling for a large set of relevant respondent characteristics, to investigate changes in the physical and mental health of caregivers and care recipients due to COVID-19. Furthermore, multilevel regression models were used to analyze the effect of individual and contextual indicators on the probability of reporting difficulties in receiving care. For the analyses, we used data from 26 countries with 51,983 respondents over 50 years based on the eighth wave of the Survey of Health, Aging and Retirement in Europe (SHARE), which had to be suspended in March 2020, and the SHARE Corona Survey fielded from June to August 2020.

Results: During the first phase of the pandemic in spring/summer 2020, the frequency of providing personal care to parents increased in almost all European countries, while care to children, in turn, decreased. Parental caregivers who increased the frequency of providing personal care reported significantly more mental health strains, that is, feeling sad/depressed and anxious/nervous more often since the outbreak of the pandemic. With respect to receiving care, about one out of five care recipients had difficulty in obtaining adequate care from outside the household during the pandemic. The perception of unmet care needs was significantly associated with country differences regarding the duration of the stay-at-home orders. In contrast, the number of confirmed deaths did not have a significant effect on perceiving difficulties related to receiving care.

Conclusions: Our findings show the extent of the burden to which caregivers and care recipients were exposed with respect to the unintended consequences of COVID-19-related epidemiological control measures. There is a great need within this population for interventions, which effectively reduce the burden as well as the symptoms of anxiety or depression for caregivers as well as care recipients. This should be recognized by (health) policymakers and social organizations.

Keywords: SHARE, COVID-19, informal care, physical and mental health, epidemiological control measures, stay at home orders

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INTRODUCTION

The first phase of the COVID-19 pandemic, which hit European countries at the beginning of 2020, has especially affected those in need of care and those providing the care needed. While media attention has mainly focused on the problematic and often dramatic situation in nursing homes, a major part of care in Europe is provided to people living at home (1–3). This home care is often provided by cohabitating family members and by family members from outside the household (mainly female children) or by paid service providers (4–6). In the context of the COVID-19 pandemic, physical distancing and other epidemiological control measures (e.g., stay-at-home orders, travel restrictions, etc.) instituted in almost all European countries have restricted individuals' access to both formal and informal support resources (7–10). Particularly, older people and individuals with chronic medical conditions have been advised to stay at home as much as possible, raising concerns about the provision of personal care. In addition to these accompanying or *indirect* effects of the pandemic, there are *direct* effects of the virus itself on physical health that might influence the provision of personal care. Thus, it is obvious that caregivers who provide personal care to family members outside their own household are at higher risk of getting infected by COVID-19 themselves, as they regularly travel to and meet with care recipients, accompany them to the doctors and hospitals, and also often do grocery shopping for them. Fearing an infection as well as fearing infecting someone close might therefore also have an impact on the frequency and amount of informal care provision and the use of it (11). Taken together, these direct and indirect effects of the pandemic can be assumed to (a) increase the intensity and burden for caregivers and (b) lead to a worsening of the situation for those who rely on personal care, as less care will be provided, and the remaining amount does not meet the needs of care recipients anymore. In this respect, it is crucial to examine how private care networks have been affected by the pandemic and to what degree personal care could be provided to those who need it most. Furthermore, our knowledge of the possible negative effects of the pandemic on the physical and mental health of care recipients as well as on the caregiving family members is still limited. In particular, we lack reliable and internationally comparable evidence that can increase our knowledge about country differences regarding the challenges caregivers and care recipients are facing during the COVID-19 pandemic as well as with regard to the handling of the pandemic by national governments.

With respect to informal caregiving, we know that personal care is usually done by one main caregiver, who might be supported by other family members and/or by additional formal care providers, the so-called support or care network [e.g., (12, 13)]. During the pandemic, these additional family caregivers often reduced their contacts either voluntarily or forcedly to avoid transmission of the virus and/or to reduce their own risk of infection (14). This has led to smaller care networks and hence to more responsibilities for the main caregiver. Further, many informal caregivers usually receive support from formal care providers, who have often had to close, reduce, or rearrange services since the outbreak of the pandemic (15). In Germany, for example, the provision of ambulant care has been affected by staff shortages (16). In addition, day care and night care centers have had to close (14), and rehabilitation centers and hospitals have sent their patients home in order to free capacity for expected COVID-19 patients (17). Also, many live-in migrant care workers have returned to their home countries during the pandemic and have been unable to cross European borders afterwards, as many work without an official work contract (18, 19). As a consequence, many (single-country) studies have reported a substantial increase in carers helping people outside their own household and in the average time spent on caring (9, 13, 20, 21). Concerning the situation of caregivers, Eggert et al. (14) provided evidence that one out of three caregivers in Germany reported a worsening of the care situation after the outbreak of COVID-19. Evidence from several countries shows that large proportions of caregivers have experienced an increased burden and stress-related symptoms, like trouble sleeping, since the outbreak of the pandemic [e.g., (9, 13, 22, 23)]. Furthermore, informal caregivers frequently reported worsened physical and mental health, such as being depressed or anxious as well as feeling more socially isolated and lonely [e.g., (9, 24, 25)]. Based on these considerations, we formulated the following hypotheses:

H1: COVID-19 and its accompanying control measures lead to an increase in the frequency of providing informal family care to those who rely most strongly on personal care.

H2: COVID-19 and its accompanying control measures lead to a worsening of physical and mental health for informal caregivers.

H3: Caregivers who have increased the frequency of providing personal care suffer more from physical and mental health strains than caregivers who have not increased the frequency of providing personal care.

Compared to caregivers, evidence concerning how the pandemic and its accompanying epidemiological control measures have affected care recipients is rather scarce. For example, we currently still lack comprehensive knowledge about whether care receivers had more unmet (health) care needs during the first phase of the pandemic and what the consequences are thereof. As older care receivers often have the greatest risk to their health from being infected with COVID-19, they typically are in higher need of health care. In addition, it has been long known that meeting older people's care needs is crucial for maintaining their mental and physical well-being (26). Compared with older adults receiving adequate care, those reporting unmet needs face greater challenges. Since the outbreak of the pandemic, it can be assumed that such challenges have greatly increased. While evidence was mixed in the beginning regarding physical and mental health [(20, 27), cf. (28)], more and more studies have recently reported higher rates of depression and greater loneliness since the onset of the pandemic with respect to older adults (29–31), as well as higher levels of stress, anxiety, and depression among people with health problems or dementia (32–34). In this respect, other studies emphasized reduced opportunities for social interaction and made use of examples in which caregivers reported that their relatives with dementia were frustrated as it was difficult

for them to understand why they should not go out or had to reduce contacts (25). This coincides with observations that caregivers in many countries reported a worsening of the care situation (9, 32). Therefore, it is likely that such a worsening will also be noticed by care recipients. In this respect, Comas-Herrera et al. (35) presented indications that the quality of social care services to older adults decreased during the early stages of the pandemic. This can partly be attributed to government distancing guidelines and travel restrictions, which also affected care recipients who rely on the provision of care by people from outside their own household. A study of older adults in the UK during the early stages of lockdown found that public health measures disrupted individuals' access to medical care, including accessing medications and the cancellation or delay of doctors' appointments and surgeries (36). Another British study found that around 40% of outpatient and 60% of inpatient care was canceled by the National Health Service in spring 2020 and that 20% of patients canceled their doctor's visits by themselves (37). In contrast, there is also evidence that the majority of caregivers, particularly when providing personal care to people with more advanced health conditions like dementia, maintained their services (23). Thus, it can be assumed as well that care recipients with severe chronic conditions will be prioritized by the health care system as a vulnerable and high-risk group. Finally, epidemiological control measures affected informal caregivers and care recipients alike, but the intensity and the duration of these measures (as well as its perception and adherence) differed across countries and hence might have exhibited effects in varying degrees (38–40). Therefore, it is crucial to relate country-specific conditions to both changes in caregiving behavior and the unmet care needs of care recipients.

H4: Care recipients suffer more from physical and mental health strains due to COVID-19 and its accompanying control measures compared to non-care recipients.

H5: Indicating difficulties in receiving care is positively associated with problems in getting access to medical treatments.

H6: Contextual (country) characteristics affect respondents' perception of difficulties in receiving care.

Against this background, we focus on how both family caregivers and care recipients in Europe experienced and dealt with the situation during the first phase of the COVID-19 pandemic in spring 2020. In this respect, we contribute to the existing literature in several ways: First, we focus on personal caregiving and care receipt to and from outside the household because these two groups are most directly and severely affected by the pandemic. We hence exclude more common forms of help and support (e.g., obtaining necessities like food or help with household repairs) to analyze the direct and indirect effects of COVID-19 for care recipients who rely on personal care and caregivers who provide care to those in need. By this, we are able to derive a comprehensive picture of the impact of the pandemic on informal care rather than one-sidedly focusing on either caregiving or care receiving. Second, our results are based on a large, high-quality survey derived from full probability samples, which included 26 European countries plus Israel. This country-comparative perspective enables us to better understand the effects and consequences of a global pandemic like COVID-19 and hence is superior to studies from single countries. Third, by extending survey data collected after the first phase of the pandemic with panel information collected before the outbreak of the pandemic, we are able to use the full wealth of information on the situation of people 50+ who have been the hardest hit by COVID-19. In particular, we know details of their economic situation and their health conditions that can feed our analyses. This provides us with crucial context information on respondents'/household situations before the outbreak of the pandemic and enables us to thoroughly investigate how COVID-19 has changed the situation of informal caregivers and care recipients and what the consequences are thereof regarding unmet care needs in particular. Finally, our results increase our understanding with regard to what support is needed most by both informal carers and care recipients due to the direct and indirect effects of COVID-19. This is important for finding common responses to the short-, mid-, and long-term consequences of the pandemic by policymakers and social organizations.

The remainder of this paper is organized as follows: In the Materials and Methods section, we describe the data and measures used for the analyses as well as our analysis strategy. Afterwards, we first explore changes in caregiving during the first phase of the pandemic (Caregiving During the Pandemic section) and then focus on care receiving and the problems care recipients faced in receiving the care they needed in spring/summer 2020 (Care Receiving During the Pandemic section). Finally, in the Discussion section, we discuss our findings and their implications.

MATERIALS AND METHODS

Data Source

The following analyses use Wave 8 (release 0) data from the Survey of Health, Aging and Retirement in Europe [SHARE; (41)], which was suspended in March 2020 (42), and the SHARE Corona Survey fielded from June to August 2020 (43), that is, some weeks after the peak of the first COVID-19 phase in most countries. SHARE is a multidisciplinary panel study providing information on health, socioeconomic status, and social and family networks of respondents aged 50 and over. From 2004, data were collected every 2 years in person (Computer-Assisted Personal Interview; CAPI). By its eighth wave, SHARE included 27 European countries plus Israel. While all waves so far have been conducted face-to-face, the SHARE Corona Survey was done by telephone (Computer-Assisted Telephone Interview; CATI) and covered the most important life domains for the target population and asked specific questions about infections and life during the lockdown (44). For most countries, the SHARE Corona Survey was based on the complete national SHARE panel sample, including both panel members who have not been interviewed before the suspension of fieldwork and panel members who have already been interviewed face to face in Wave 8. Only in two countries (the Netherlands and Sweden) needed to have a stratified subsample to be selected due to funding issues. Our analyses were based on data from 51,983 respondents over 50 years in the SHARE Corona Survey (we excluded Austria

from our analyses, because fieldwork there only started at the beginning of August when most other countries had nearly finished the SHARE Corona Survey). The preliminary average response rate based on eligible respondents participating in Wave 8 was 79%, ranging from 58% (Luxembourg) to 96% (Romania). There were 18,398 respondents who exclusively answered the SHARE Corona survey through telephone interview after the outbreak of the pandemic but could not be successfully approached in person before the suspension of the Wave 8 fieldwork. These data have been carefully augmented with information from previous waves where appropriate (45–52). The SHARE data are unanimous based on full probability samples (53, 54), providing internationally comparable data that can add important insights to recent studies, which are frequently restricted to the national level. Both the methodological rigor and the cross-country harmonization of SHARE are prerequisites to properly investigate the direct and indirect effects of a global pandemic like COVID-19 and hence support evidence-based policymaking. By further including country-specific data not only on the pandemic itself but also on accompanying epidemiological control measures (39), our results offer a unique perspective that allows to compare how the high-risk group of older respondents coped with the crisis, how the national governments and health care systems responded to the pandemic, and which lessons should be drawn from the variability between countries for the future.

Measures

Caregiving and Care Receiving

In our analyses, we focused on informal (i.e., non-professional, unpaid) caregiving and care receiving, excluding more common forms of help or support [for the latter see, e.g., (55)]. Caregiving was measured by the following question: "Since the outbreak of Corona, did you provide personal care to others outside your home?" followed by a request to indicate the frequency and the recipient of the caregiving activities (if applicable): "How often did you provide personal care to the following people from outside your home compared to before the outbreak of Corona; less often, about the same, or more often?" The list of recipients included one's own children; one's own parents; other relatives; and other non-relatives like neighbors, friends, or colleagues. Care receiving was asked the following way: "Did you regularly receive home care before the outbreak of Corona?" In contrast to caregiving, there were no follow-up questions on the frequency or on the provider of personal care. Instead, we used the respondents' answers on possible difficulties in receiving personal care for our analyses: "Since the outbreak of Corona, did you face more difficulties in getting the amount of home care that you need?" It has to be noted that the use of the term "home care" in the generic version of the SHARE Corona questionnaire potentially complicated distinguishing the receipt of informal and formal care. However, a careful inspection of the different translations did not reveal any systematic differences across countries. Furthermore, our analyses regarding the associations of care receiving were not substantially affected by this issue.

COVID-19-Related Health Outcomes

To explore the direct and indirect effects of the pandemic, we included several indicators that measured changes in respondents' physical and mental health since the outbreak of the COVID-19 crisis. In this respect, we used respondents' self-rated health ("If you compare your health with that before the outbreak of Corona, would you say your health has improved, worsened, or stayed about the same?") as well as indications of depression ("In the last month, have you been sad or depressed?"), anxiety ("In the last month, have you felt nervous, anxious, or on edge?"), sleeping problems ("Have you had trouble sleeping recently?"), and loneliness ("How much of the time do you feel lonely? Often, some of the time, or hardly ever or never?"). We then generated dichotomized variables that indicate a worsening of respondents' self-rated physical and mental health in case respondents confirmed that their health strains have increased since the outbreak of the pandemic ("Has that been more so, less so or about the same as before the outbreak of Corona?"). In addition, we included a measure that indicates whether the respondent was directly affected by COVID-19, using a set of questions on (a) having experienced symptoms, (b) having been tested for COVID-19, and (c) having been hospitalized. For analyzing the associations with care receiving, we further included two dichotomized variables measuring problems regarding a continuation of medical treatments since the outbreak of the pandemic: first, whether a medical treatment was canceled by the respondents themselves because of being afraid of getting infected and second, whether a planned medical treatment was postponed or denied by the doctor or medical facility.

Covariates that could potentially confound the relationship with caregiving and care receiving were selected according to existing knowledge regarding their predictors [e.g., (56–58)] and included the following.

Socio-Demographics

We used the respondents' sex (0: male, 1: female) and their age at interview. Further, we coded the level of education attained based on the Internal Standard Classification of Education 1997 (ISCED-97). Respondents were then grouped into three categories [e.g., (59)]: primary education (ISCED-97 score: 0–2), secondary education (ISCED-97 score: 3), and post-secondary education (ISCED-97 score: 4–6).

Living Conditions

We used information on the respondents' type of living area (0: rural area, 1: urban area like a large town or big city), household composition (0: living with a partner, 1: living alone), and whether s/he is living in a nursing home. Furthermore, we measured each respondent's economic status by a question that asked the degree to which respondents can make ends meet (0: with great/some difficulty, 1: fairly easily/easily) and included a measure related to whether the respondent was employed (including self-employment) at the beginning of the outbreak of COVID-19.

Physical Health Before the Pandemic

To control for respondents' physical health before the pandemic, we used indicators from the previous SHARE waves that have been conducted before the outbreak of COVID-19. In this respect, we used the reversed 5-point scale on respondents' self-rated health (0: poor, 1: fair, 2: good, 3: very good, and 4: excellent). Furthermore, we used three disability measures to assess (a) difficulties in basic activities of daily living [ADL; (60)], such as dressing, walking, bathing/showering, or using the toilet (0: no limitations, 1: ≥1 limitation); (b) difficulties in instrumental activities of daily living [IADL; (61)], such as using a map, preparing a meal, shopping for groceries, or making telephone calls (0: no limitations, 1: ≥1 limitation); and (c) long-standing activity limitations based on the Global Activity Limitation Index [GALI; (62)] that refers to general health problems in activities people usually do (0: not limited, 1: somewhat/severely limited).

Governmental Policy Measures

To assess differences in national policy responses to the pandemic, we used the Oxford COVID-19 Government Response Tracker [OxCGRT; (39)] that considers different policy measures (e.g., school and workplace closures, stay-at-home orders, or restrictions on internal movement) and also provides chronological data for each country regarding the cumulative number of infections and confirmed deaths due to COVID-19. Based on these data, we built two indicators that we applied in our multivariate analyses: first, we used the cumulative number of confirmed deaths due to COVID-19 in each country to measure the current severity of the pandemic with respect to older, at-risk respondents. Second, we calculated the duration of stay-at-home orders in days to measure the length and stringency of a specific restriction, which is expected to directly influence the possibilities of caregiving and care receiving. In both cases, we matched the Oxford data to the SHARE Corona Survey data via the specific interview date of all respondents (63). By this, we were able to match precisely the country-specific context information on the pandemic to the respondents' answers on the day of the interview.

Analytic Strategy

We restricted our analyses to caregiving to and care receiving from someone outside one's own household because, other than personal care within the same household, we expect that care activities outside one's own household were more severely affected by the pandemic and accompanying epidemiological control measures, such as stay-at-home orders. To address our research questions, we first descriptively explored country differences regarding the prevalence of providing and receiving personal care since the outbreak of the COVID-19 crisis. Afterwards, we investigated differences in relevant health-related outcomes between caregivers and care recipients on the one hand and respondents who did not provide care to or receive care from someone outside their own household on the other. Here, we were particularly interested in differences with regard to a worsening of physical and mental health as well as the degree of affectedness by COVID-19. In this respect, we used comparisons of adjusted predictions, controlling for a large set of individual respondent characteristics. In particular, we controlled for the respondents' sex, age, level of education, household composition (i.e., living alone or with a partner), area of living (rural vs. urban), subjective economic status, and whether the respondent was (self-) employed before the pandemic. Furthermore, we controlled for respondents' self-rated health and limitations in ADL and IADL as well as in activities people usually do (GALI) due to long-standing health problems before the pandemic. Finally, country dummies were included to control for regional differences. With this approach, we were able to compare two hypothetical populations (e.g., non-caregivers and caregivers) that have identical values on all independent variables included in the model. The logic is similar to that of a matching study: Because the only difference between the two populations is the provision/receipt of care, caregiving/care receiving can be attributed with much more confidence as the cause of differences in the probabilities of reporting physical and mental health strains [see (64)].

In a second step, we used multilevel regression models with country as the level-two identifier to address the underlying hierarchical structure of the data and to analyze the effect of individual and context indicators, which are expected to play an important role during the pandemic, on the probability of reporting difficulties in receiving personal care. The multilevel approach enables analyzing variables from different levels simultaneously by properly taking into account the statistical dependencies between the observations to adjust standard errors, which are likely to be biased if the hierarchical structure of the data is ignored [e.g., (65–67)]. The dependent variable, difficulties in receiving personal care, was treated as binary in the multilevel model, with the customary logit function defined as $\text{logit}(x) = \ln[x / (1 - x)]$. The predicted value for P_{ij} in the general logistic multilevel model was extended to include an explanatory variable X at the individual level, and a country-level variable Z can be written as follows:

$$\text{logit}\left(P_{ij}\right) = \gamma_{00} + \gamma_{10}\text{X}_{ij} + \gamma_{01}\text{Z}_{j} + \text{u}_{0j},$$

where the random intercept γ_{00} is shared by all countries, while the residual term u_{0j} is specific to country j and assumed to follow a normal distribution with variance $\sigma^2_{u_0}$. To quantify the extent to which reporting difficulties in receiving care varies between countries, the intraclass correlation coefficient (ICC) was calculated as follows in the intercept-only model without explanatory variables:

$$\text{ICC} = \frac{\sigma^2_{u_0}}{\sigma^2_{u_0} + \sigma^2_{e}},$$

where $\sigma^2_{u_0}$ is defined as the country variance at level two, and the individual variance at level one, σ^2_e, was fixed to $\pi^2 / 3 \approx 3.29$ in logistic multilevel regressions [e.g., (67, 68)]. The ICC ranges between 0 and 1. An ICC of 0 indicates that no variance is attributable to country differences, whereas a value of 1 means that all variance is attributable at the country level. Higher values hence indicate a stronger influence of country differences on

the respondents perceiving difficulties in receiving care. Because variance components in multilevel logistic regressions cannot be directly compared across models with and without explanatory variables due to the fixed level-one variance, we followed the approach by Hox (67) and calculated a scale correction factor for each model with explanatory variables. With this correction, we were able to assess the amount of variance explained separately at the different levels. As explanatory variables, we included the measures described above, that is, socio-demographics (sex, age, and level of education), living conditions (area type, household composition, living in a nursing home, and subjective economic status), physical health before the pandemic (self-rated health and health limitations), COVID-19-related health outcomes (worsened health, direct affectedness, and mental health strains), and access to medical treatments at the individual level as well as COVID-19-related context effects (confirmed deaths and duration of stay-at-home orders) at the country level. To control for potential sample selection effects regarding the augmentation of respondents' background information, we included a dichotomous variable indicating which respondents could only be interviewed by telephone due to the suspension of regular fieldwork in Wave 8. All variables were standardized with regard to the overall sample mean. Analyses were performed using Stata 14 SE (69) based on robust standard errors and with calibrated weights for the SHARE Corona Survey sample as provided by SHARE. For the multilevel logistic regression model, we use Stata's *melogit* command, which is based on a maximum likelihood estimation procedure using adaptive quadrature with seven integration points.

RESULTS

Caregiving During the Pandemic

We started our analyses with reporting the overall prevalence of caregiving across Europe during the first phase of the pandemic. On average, 4% of all respondents ($n = 1{,}710$) indicated that they have provided personal care (excluding general help and support) to someone outside their own household since the outbreak of the pandemic. **Figure 1** shows rather large differences between countries. While Slovenia brought up the rear with only 1.4%, in Cyprus, respondents provided care about six times more often (8.9%). In addition, it was noticeable that due to the small sample size, standard errors were quite large in some countries. Further, there was no clear pattern visible with respect to region, and apart from Germany and Sweden, only countries from Southeastern Europe exhibited a prevalence of providing personal care significantly above the average.

What cannot been seen in **Figure 1** is whether the frequency of providing personal care changed due to COVID-19 and whether this differed with respect to the care relationship. In the following, we therefore differentiated between different recipients who received personal care from someone outside their own household when investigating changes in providing care (see **Figure 2**). Most striking in this respect was the huge increase in children providing care to their parents since the outbreak of the pandemic, which is visible in the upper left graph of **Figure 2**. This increase was consistent across different regions in Europe, which distinguishes between Northern European States (Sweden, Denmark, and Finland), Western European States (Belgium, France, Germany, Luxembourg, the Netherlands, and Switzerland), Southern European States (Croatia, Cyprus, Greece, Israel, Italy, Malta, Portugal, Slovenia, and Spain), Eastern European States (Bulgaria, Czech Republic, Hungary, Romania, Poland, and Slovakia), and the Baltic States (Estonia, Latvia, and Lithuania): Between 42% (Baltic States) and 59% (Eastern Europe) of all parental caregivers declared that they had increased the provision of personal care to their parents since the outbreak of the pandemic, that is, on average, more than every second parental caregiver reported an increase. In contrast, only between 7 and 11% indicated that they had decreased the personal care given to their parents. The rest, on average about 40%, had neither increased nor decreased their caregiving activities to parents since the outbreak of the pandemic. The picture considerably changed when looking at parents who provided personal care to their children (see upper right graph of **Figure 2**). Here, about one third of all caregivers providing personal care to their children reported a decrease, while only about 12% reported an increase. Thus, with the exception of the Eastern European States, decreases in the provision of care from parents to their children clearly outweighed the increases. Finally, with respect to other relatives and other non-kin, our findings were more balanced (see lower two graphs of **Figure 2**). In both cases, the overall share of caregivers who had decreased their respective caregiving activities was larger than the share who indicated an increase (38 vs. 24% with respect to other relatives and 32 vs. 30% with respect to other non-kin). This was mainly due to the countries in Southern Europe, where decreases most clearly outweighed increases in providing personal care.

Based on these findings, we were interested in two things: (a) whether caregiving in general was associated with higher physical and mental health strains compared to non-caregivers and (b) whether the strongly increased personal care activities of children to their parents in particular were associated with higher physical and mental health strains compared to respondents who had not increased their parental caregiving activities. To answer these questions, we first compared all caregivers with all non-caregivers in our sample (columns 2 and 3 in **Table 1**), while controlling for a broad range of relevant individual characteristics including health conditions that are well-known to differ between caregivers and non-caregivers [e.g., (57, 58)] and otherwise might have biased our results. **Table 1** thus presents adjusted predictions that are controlled for the covariates presented in the Measures section. With this approach, we were able to compare two hypothetical populations (e.g., non-caregivers and caregivers) that have identical values on all independent variables included in the model.

When comparing the entries of column 2 (labeled "Non-caregivers") with those of column 3 ("Caregivers"), we can see that caregivers, on average, indicated more mental health strains compared to non-caregivers. Since the outbreak of the pandemic, caregivers have felt depressed or sad significantly more often (+3 percentage points) and in particular anxious or nervous more often (+5 percentage points) than non-caregivers. In addition, they slightly more often struggled with sleeping

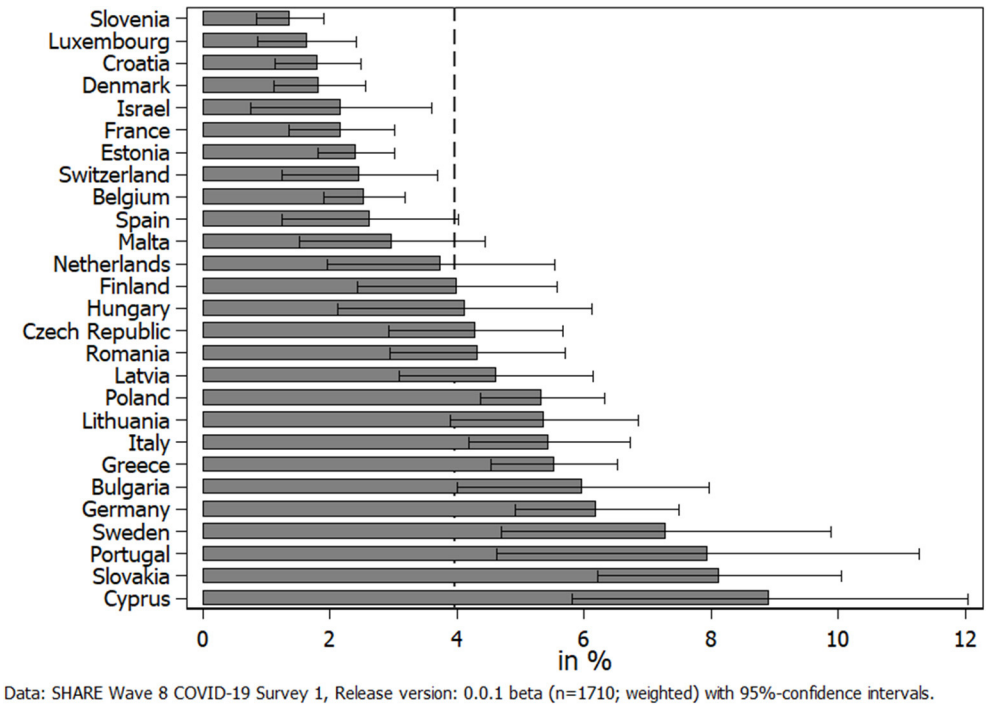


FIGURE 1 | Percent of respondents providing personal care to others outside their own household since the outbreak of the pandemic.

problems (not significant) but did not feel lonely more often. Further, general physical health seemed to be unaffected since the outbreak of the pandemic. Thus, the share of caregivers who indicated a worsening in general health was very similar to the share of non-caregivers. In this respect, it has to be stated that the overall prevalence of respondents indicating a worsening in health was low (about 7–8%, respectively). Finally, with regard to the direct effects of COVID-19 on health, it can be seen that only slightly (not significantly) more caregivers reported that they had been personally affected by the virus compared to non-caregivers. However, any further developments should be followed closely because an increase in the affectedness of caregivers might have strong implications for those who rely on the provision of personal care and at the same time are among the highest risk group (6).

When exploring whether parental caregivers who increased their provision of personal care differed from parental caregivers who did not increase (i.e., either decrease or maintain) the frequency of providing personal care to their parents, we see similar patterns: while general physical health and direct affectedness by COVID-19 again did not differ much, parental caregivers who increased the frequency of providing personal care reported many more mental health strains. The differences were most pronounced with respect to feeling sad/depressed and anxious/nervous more often since the outbreak of the pandemic: more than twice as many parental caregivers who reported an increase of their care activities indicated that they had felt sad or depressed more often since the outbreak of the pandemic, compared to those parental caregivers with the same amount or a decrease in their caregiving activities (+15 percentage points or nearly one out of three). With respect to feeling anxious or nervous more often, the difference was also substantial. Here, about 36% of parental caregivers with an increase in personal care indicated that they had felt anxious or nervous more often, compared to only 21% of parental caregivers who did not increase their caregiving activities. With regard to sleeping problems and feeling lonely more often, the differences were much smaller and not significant.

To investigate country differences, we calculated the country-specific average marginal effects of caregiving in general on the adjusted predictions of feeling anxious or nervous more often since the outbreak of the pandemic. **Figure 3** shows that caregivers in Southern European countries had a significantly higher probability of reporting anxiety more often compared to non-caregivers, with Spain, Portugal, and Malta as the countries with the highest probabilities. The same is true for the Baltic States, in which caregivers from Estonia reported anxiety most often. Eastern European countries were also slightly above a significant level, and no effect could be found in Northern and Western European countries. This illustrated that there indeed were country differences with regard to effects of the pandemic on caregivers' mental health, which should be taken into account.

Care Receiving During the Pandemic

When turning to care recipients, we first looked at the prevalence of care receiving across countries participating in SHARE (see **Figure 4**). Overall, about 5% of all respondents in our sample received home care (n = 3,315; Israel was excluded from this

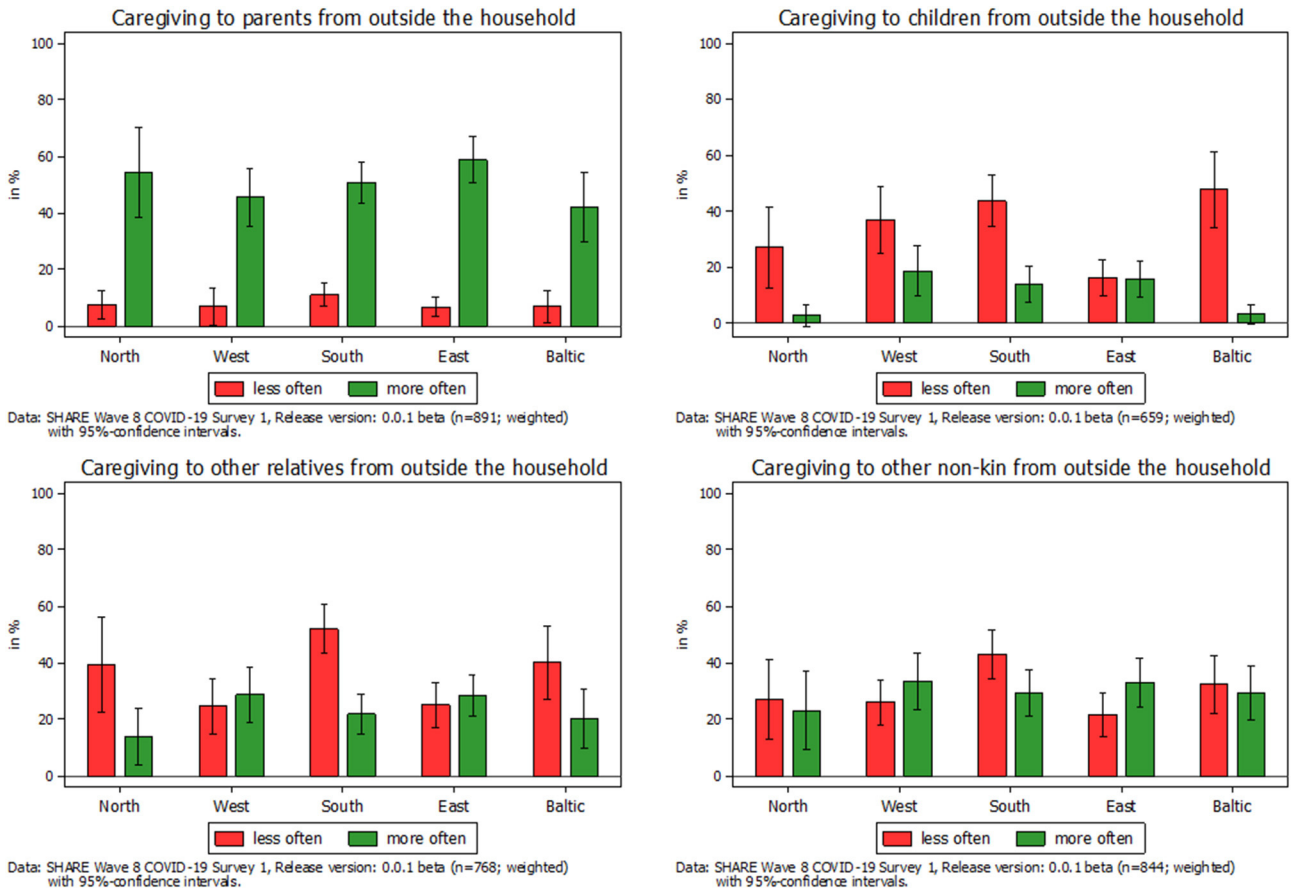


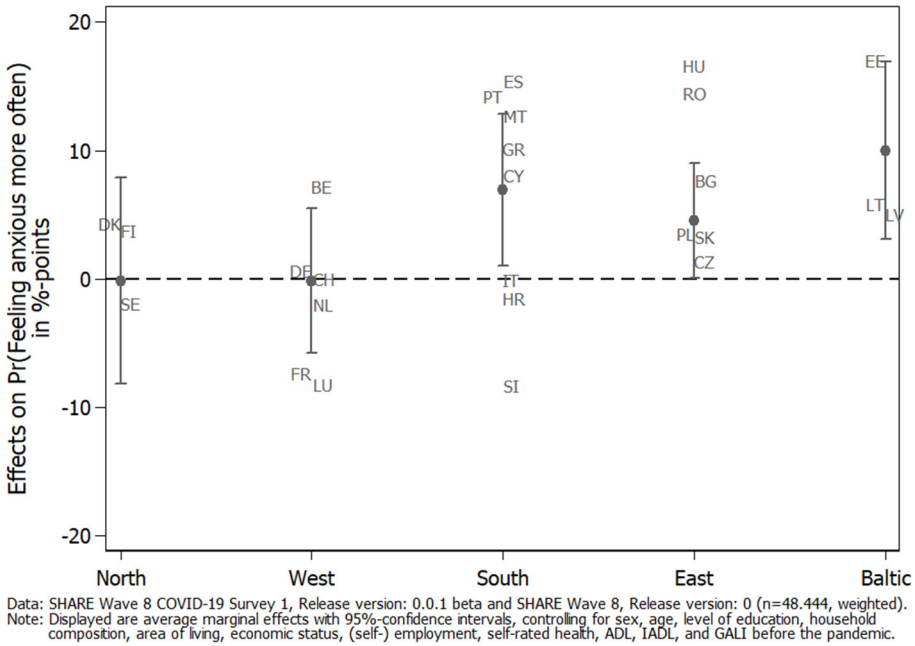
FIGURE 2 | Change in frequency of caregiving to someone outside their own household by type of care relation.

TABLE 1 | Adjusted predictions of health-related outcomes by caregiving and changes in parental caregiving.

	Non-caregivers (%)	Caregivers (%)	Parental caregivers, personal care → / ↓ (%)	Parental caregivers, personal care ↑ (%)
Worsened health	8	7	6	6
Affected by COVID-19	7	9	13	13
Felt sad/depressed more often	16	19**	13	27***
Felt anxious/nervous more often	21	26**	21	36***
Had trouble sleeping more often	8	10	10	12
Felt lonely more often	12	13	11	12
N	49,969	1,710	439	452

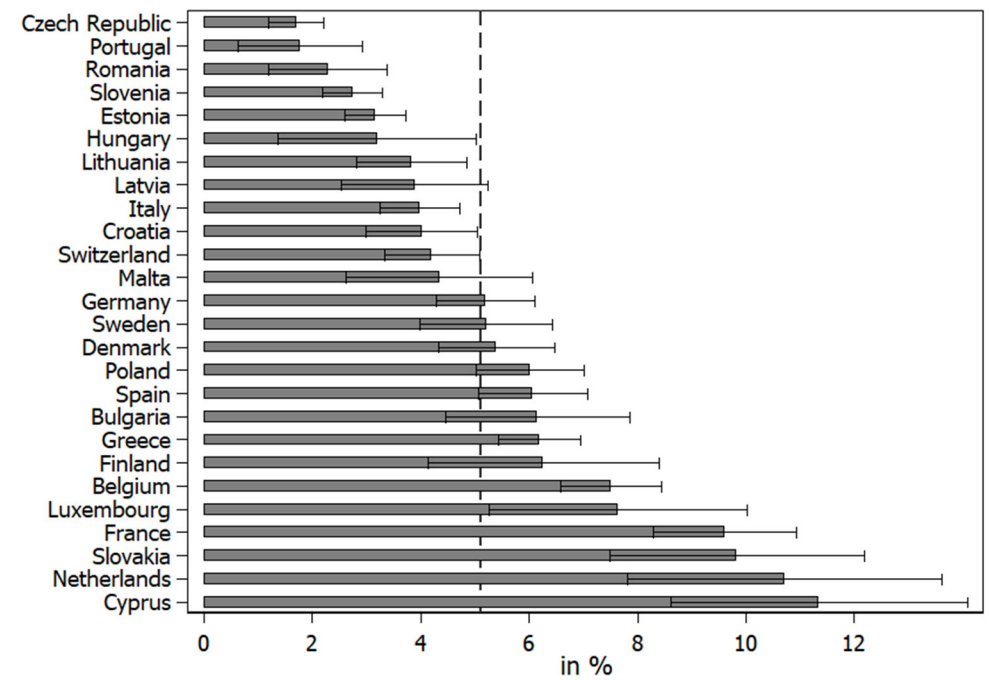
*Data: SHARE Wave 8 COVID-19 Survey 1, release version: 0.0.1 beta and SHARE Wave 8, release version: 0 (weighted). Entries are adjusted predictions, controlling for sex; age; level of education; household composition; area of living; economic status; (self-) employment; self-rated health; ADL, IADL, and GALI before the pandemic; and respondent's country. Significance level: *p < 0.05, **p < 0.01, ***p < 0.001 [significances based on average marginal effects (AMEs) refer to respective previous column].*

overview due to a potential mix-up between formal and informal home care activities). **Figure 4** again shows large differences between countries. The Czech Republic had the lowest number of care recipients (about 2%), while again Cyprus was the frontrunner with more than 11%. When geographically grouping countries, it was noticeable that Western European countries exhibited a larger share of care recipients. While it can be argued that the age distribution in the national samples affected the countries' ordering, this explanation could be ruled out. Thus, the Czech Republic and Portugal both had rather old samples (69 and 70 years, respectively) but at the same time showed the lowest percentage of care recipients. In addition, Slovakia



Data: SHARE Wave 8 COVID-19 Survey 1, Release version: 0.0.1 beta and SHARE Wave 8, Release version: 0 (n=48.444, weighted).
Note: Displayed are average marginal effects with 95%-confidence intervals, controlling for sex, age, level of education, household composition, area of living, economic status, (self-) employment, self-rated health, ADL, IADL, and GALI before the pandemic.

FIGURE 3 | Average marginal effects (AMEs) of caregiving on the adjusted prediction of feeling anxious/nervous more often since the outbreak of the pandemic by geographical regions.



Data: SHARE Wave 8 COVID-19 Survey 1, Release version: 0.0.1 beta (n=3315; weighted) with 95%-confidence intervals.

FIGURE 4 | Percent of respondents receiving home care by others from outside their own household since the outbreak of the pandemic.

and Cyprus had much younger samples (between 65 and 66 years), but both exhibited a much higher share of respondents receiving care.

Next, we investigated how the utilization of (home) care was perceived by those receiving care to answer the question if COVID-19 negatively affected the receipt of personal care

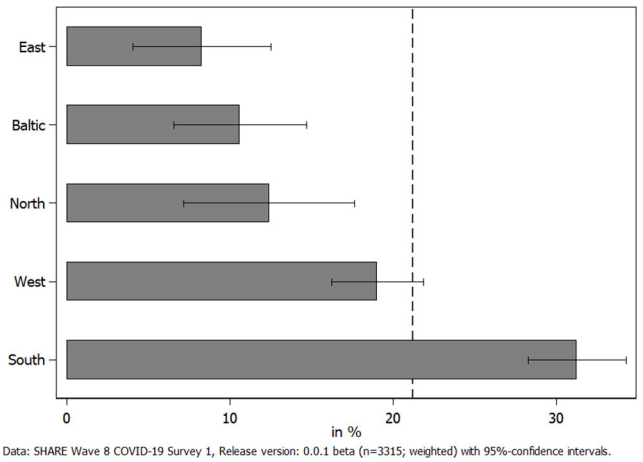


FIGURE 5 | Percent of care recipients facing difficulties in receiving home care since the outbreak of the pandemic.

in Europe. In this respect, **Figure 5** shows the share of care recipients who reported that they faced difficulties in receiving care by geographical regions. We did not differentiate between countries here, as the sample size for receiving home care in some countries was very low and might have jeopardized results. Overall, about 21% of all care recipients reported difficulties in receiving care. This share was by far the highest in Southern European countries: More than every third care recipient in these countries reported difficulties in receiving care since the outbreak of the pandemic, while it was <1out of 10 in Eastern Europe.

Based on these findings, we were further interested in whether care receiving in general during the pandemic as well as the perception of difficulties therein were associated with physical and mental health problems or with restrictions in the health care system (i.e., accessing medical treatments). To answer this question, we first compared all care recipients with all non-care recipients in our sample, while again controlling for relevant individual characteristics including health conditions and country dummies. **Table 2** reveals that care receiving actually was associated with worsened health: compared to non-care recipients, care recipients indicated a significantly worsened general physical health (+2 percentage points). In addition, significantly more care recipients (+3 percentage points) reported that they personally had been affected by the virus (i.e., having had symptoms, having been tested, or having been hospitalized). The same was true for most of the indicators regarding mental health strains: care recipients significantly more often reported that they felt sad/depressed, anxious/nervous, and lonely (about +2 percentage points, respectively). With regard to sleeping problems, there was no significant difference. The same was the case for respondents' access to appropriate medical treatment: treatments and appointments had not been canceled more often by care recipients themselves or by medical facilities than with respect to non-care recipients.

When turning to differences between care recipients with and without perceived problems in receiving care, the picture was somewhat different: now, general health no longer differed significantly between the two comparison groups, that is, worsened physical health was not significantly correlated with indicating difficulties in receiving care, although the absolute difference was even slightly larger than before (+3 percentage points). Mental health strains, at least partly, were still related to perceiving difficulties in care receiving: those care recipients who reported difficulties in receiving care felt anxious or nervous significantly more often (+5 percentage points) compared to care recipients who did not. Further, care recipients who reported difficulties in receiving care more often felt sad/depressed and lonely and had sleeping problems more frequently compared to care recipients who did not have such difficulties. However, none of these indicators reached a significant level. In contrast, care recipients who indicated difficulties in receiving care significantly more often reported that they canceled a medical treatment by themselves (+6 percentage points). Finally, there was no significant difference between care recipients who indicated or did not indicate difficulties in receiving care with regard to medical treatments being postponed or denied by a doctor or medical facility.

To explore whether these latter differences varied across countries, we calculated country-specific average marginal effects of the difficulties in receiving care (see **Figure 6**), both for reporting medical treatments that had been canceled by the care recipients themselves (left graph) and those that have been postponed or denied by medical facilities instead (right graph). In this respect, the left part of **Figure 6** shows that the significant difference of canceling medical treatments by care recipients themselves, which has been reported in **Table 2**, was mainly driven by Southern European (and to a lesser degree by Western European) countries that had been hit rather hard by the first phase of the pandemic. Additionally, the share of care recipients who had a medical appointment canceled by their doctor or medical facility was highest in Western European countries (see right part of **Figure 6**). This confirmed, for example, the situation in Switzerland or Belgium, where care professionals have been advised to prioritize their care and to assess whether the care is essential or can be postponed (15). Although the standard errors for these effects were rather high, our findings illustrate that the COVID-19 pandemic had different direct and indirect consequences for care recipients across Europe, dependent on the interaction between the severity of the pandemic and the (technical and personal) equipment of the national health care system.

In the last step, we analyzed the determinants of perceiving difficulties in receiving care. For this, we used a multilevel logistic regression model to account for country differences that might influence respondents' answers. First, our analysis revealed that indicating difficulties in receiving care differed significantly between countries. This was reflected in the ICC of the intercept-only model, which was $0.888/(3.290 + 0.888) = 21.3\%$, that is, about one fifth of the total variance in perceiving difficulties in receiving care was attributable to differences between countries. The intercept-only model also gives us a benchmark value of the deviance (i.e., the degree of misfit of the model), which can be used to compare models with additional explanatory

TABLE 2 | Adjusted predictions of health-related outcomes by care receiving and difficulties in receiving care.

	Non-care recipients (%)	Care recipients (%)	Care recipients without difficulties in receiving care (%)	Care-recipients with difficulties in receiving care (%)
Physical and mental health				
Worsened health	8	10*	18	21
Affected by COVID-19	7	10**	8	8
Felt sad/depressed more often	16	18*	23	26
Felt anxious/nervous more often	21	24*	24	29*
Had trouble sleeping more often	8	9	11	12
Felt lonely more often	12	13*	20	24
Access to medical treatments				
Medical treatment canceled by respondent	12	12	13	20**
Medical treatment postponed/denied	28	27	29	32
N	48,364	3,315	2,588	707

*Data: SHARE Wave 8 COVID-19 Survey 1, release version: 0.0.1 beta and SHARE Wave 8, release version: 0 (weighted). Entries are adjusted predictions, controlling for sex; age; level of education; household composition; area of living; economic status; self-rated health; ADL, IADL, and GALI before the pandemic; and respondent's country. Significance level: *p < 0.05, **p < 0.01, ***p < 0.001 [significances based on average marginal effects (AMEs) refer to respective previous column].*

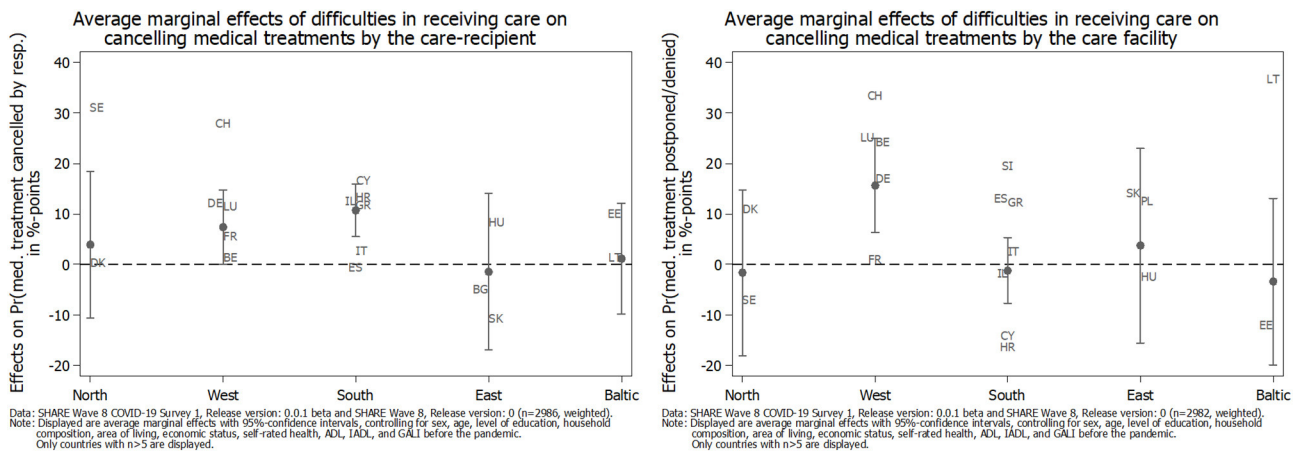


FIGURE 6 | Average marginal effects (AMEs) of difficulties in receiving care on the adjusted prediction of canceling medical treatments since the outbreak of the pandemic by geographical regions.

variables. From **Table 3**, it can be concluded that the deviance went down when including explanatory variables at the different levels, thus indicating an improved model fit. A formal chi-square test to evaluate the difference of the deviances indicated significant improvements of the model fit when including all level-one and level-two predictors, respectively. To further analyze how much residual error is left at the distinct levels and to assess the amount of explained variance at the different levels in multilevel logistic regressions, we needed to bring the sequential models to the same scale [see (67)]. **Table 3** presents the rescaled variances from our multilevel logistic regression models (the full model with all parameter estimates can be found in **Table A1** in the **Supplementary Material**). We see that after including respondent characteristics at the individual level (level-one predictors) and context characteristics at the country level (level-two predictors), the residual error variance at the country level decreased compared to the intercept-only model. We can interpret the respective differences as the amount of variance explained by introducing explanatory variables at the different levels: the rescaled explained variance at the country level was about 10% after including individual characteristics and about 36% after including individual and country characteristics. This result showed that the amount of variance explained by respondent characteristics at the country level was rather small, which reflects the fact that the included level-one explanatory variables were distributed more or less equally across countries. Adding the country-level explanatory variables (i.e., confirmed deaths and duration of stay-at-home orders) did not change the residual variance at the first level because the second-level variables cannot predict individual-level variation. However, the country-level residual variance went down to 0.570, which translated into 35.8% of the explained variance at the country

level by both respondent and country predictors. Most of the predictive power of the model was hence attributable to context predictors that differed across countries.

Figure 7 graphically presents the coefficients of the respondent- and country-level predictors for the multilevel logistic regression model. We see that female and better-educated care recipients had a significantly higher probability of perceiving difficulties in receiving care since the outbreak of the pandemic. In contrast, older care recipients above 65 years of age had a significantly lower probability of perceiving difficulties in receiving care, compared to younger care recipients below 65 years of age (the reference category). Also, living alone significantly reduced the probability of indicating difficulties in receiving care. Care recipients who indicated great difficulties in making ends meet already before the pandemic as well as those with poor physical health and limitations in basic ADL, such as dressing or showering, tended to express difficulties in receiving care more frequently, although the effect was not significant at the 5% level, respectively. On the other hand, care recipients with limitations in IADL, such as shopping or making phone calls, had a significantly lower probability of indicating that they had unmet care needs since the outbreak of the pandemic. Furthermore, physical and mental health changes during the pandemic were not significantly associated with perceiving difficulties in receiving care. Regarding access to medical treatments during the pandemic, **Figure 7** shows that care recipients who canceled medical treatments by themselves for fear of a COVID-19 infection significantly more often indicated unmet care needs, while this was not true for care recipients who had a medical appointment postponed or denied by a care facility. With respect to the country-level predictors, it was evident that more confirmed deaths in a country since the outbreak of COVID-19 until the interview—although increasing the probability of perceiving difficulties in receiving care—were not significantly associated with the outcome variable. In contrast, care recipients from countries in which stay-at-home orders had been implemented for a longer period before the

TABLE 3 | Rescaled estimates of individual (σ_R^2) and country residual variance ($\sigma_{u_0}^2$) of sequential random intercept models regarding respondents' answers on difficulties in receiving care.

	Intercept-only	Random intercept with level-1 predictors	Random intercept with level-2 predictors
σ_R^2	3.290	3.084	3.084
$\sigma_{u_0}^2$	0.888 (0.298)	0.796	0.570
Explained $\sigma_{u_2}^2$ (%)	–	10.3	35.8
Deviance	2,978.1	2,855.2	2,842.9
X^2	280.6***	122.9***	135.3***

*Data: SHARE Wave 8 COVID-19 Survey 1, release version: 0.0.1 beta; SHARE Wave 8, release version: 0; and Oxford COVID-19 Government Response Tracker (n = 3092, weighted). Entries are residual variances with standard errors in parentheses for the intercept-only model. The scale correction factor for the variances was 0.937 in models with explanatory variables. Deviance was defined as −2*ln (likelihood) with the difference of the deviances following a chi-square distribution. Significance level: *p < 0.05, **p < 0.01, ***p < 0.001.*

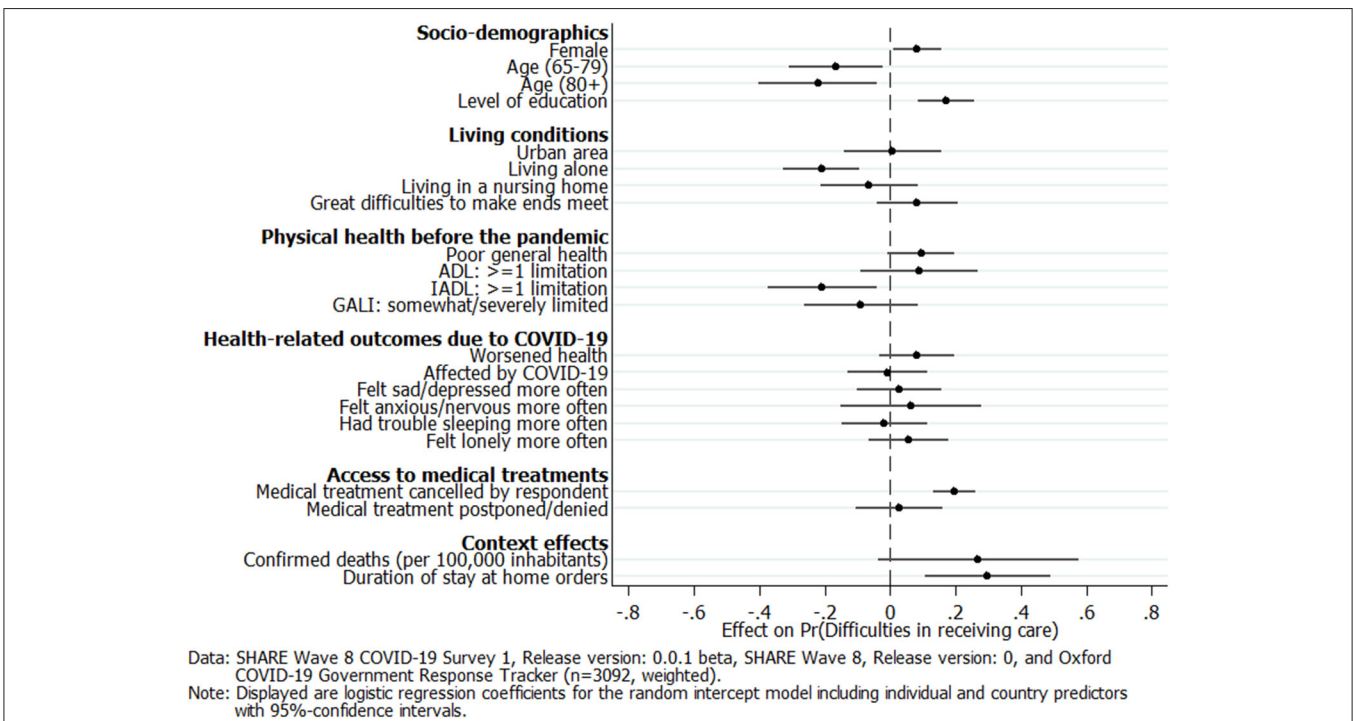


FIGURE 7 | Multilevel logistic regression coefficients of respondent and country predictors on perceived difficulties in receiving care.

interview had a significantly higher probability of perceiving difficulties in receiving care.

DISCUSSION

Informal caregivers as well as care receivers have both been hit hard by the outbreak of COVID-19. The pandemic has drastically increased many of the inherent problems of national health care systems in general and of long-term care in particular (70). The spread of the virus together with further COVID-19-related epidemiological control measures have affected the lives of those providing care to others as well as those receiving care from people outside their own household to an unprecedented extent. Against this background, we have focused in this paper on how caregivers and care recipients living at home (the non-institutionalized) have dealt with the situation across Europe. By applying adjusted predictions that controlled for a broad range of relevant respondent characteristics, we were able to present reliable results regarding the association between caregiving and care receiving on the one hand and changes in physical and mental health due to the direct and indirect effects of the pandemic on the other. In addition, our findings, based on a multilevel logistic regression model including explanatory variables at the individual and the country level, helped to answer the questions concerning which care recipients did not get adequate care during the pandemic and how countries differed in this respect.

With respect to informal caregiving, our findings first showed that COVID-19 had a substantial impact on private care networks of caregivers and the persons to whom care was being given. During the first phase of the pandemic in spring 2020, the provision of personal care to parents outside one's own household strongly increased across Europe, thus confirming hypothesis H1, while it decreased for other relatives and non-kin and in particular for children. One reason for the increase regarding parents in need for care was the reduced availability of paid services and care support due to COVID-19-related epidemiological control measures that had to be compensated for by family care. The strong decrease for children on the other hand can be seen as the reverse of the same coin and indicates a strong shift in informal care from the younger to the older generation, which is, on average, more vulnerable and more strongly reliant on informal care from their children rather than the other way round. In addition, our findings clearly showed that caregivers (compared to non-caregivers) more often felt depressed and anxious as a consequence of the pandemic and its accompanying epidemiological control measures, which is in accordance with hypothesis H2 regarding mental health. This finding was even more pronounced for parental caregivers who had increased their caregiving activities since the outbreak of the pandemic. In this population, nearly 30% of parental caregivers indicated feelings of depression more frequently and nearly 40% indicated feeling anxious. Both values were roughly twice as high compared to those for caregivers who did not increase their care activities toward their parents. These numbers strongly confirm hypothesis H3 and at the same time give cause for concern. It clearly shows the extent of the burden to which caregivers were exposed with respect to the unintended effects of the epidemiological control measures and, at the same time, suggests a great need within this population for interventions to effectively reduce the burden as well as symptoms of anxiety or depression. This holds true in particular for Southern European countries, for which we found the strongest negative effects. In contrast, caregivers' physical health remained rather stable during the period of investigation. From this, one could conclude that the direct effects of the virus itself on physical health were less pronounced for caregivers, thus contradicting hypotheses H2 and H3 regarding physical health. Whether this observation will still hold true in the long run and with further waves of the pandemic has yet to be seen and should be monitored closely. In any case, our findings point out that caregivers need compensation for the burden of providing care during the pandemic. Currently, however, they are often expected to protect even more carefully those who rely on their help. Social organizations have long called for improvements to the caregivers' situation, including an actual increase in both their reputation and their payment. Based on our findings, this now seems more reasonable than ever and should be recognized by (health) policymakers, too.

With respect to care receiving, our results showed that the pandemic also negatively affected the health of (home) care recipients. In particular, care recipients (compared to non-care recipients) rated their general physical health significantly worse and felt significantly more depressed, anxious, and lonely, which is in line with hypothesis H4. However, the differences in the adjusted predictions were smaller in absolute size than for caregivers. In addition, care recipients, overall, did not indicate a worsening of their situation with respect to pursuing planned medical treatments compared to non-care recipients. When differentiating between care recipients with and without difficulties in receiving the care they need, we saw that those perceiving difficulties reported substantially more cancellations of medical treatments by themselves due to their fear of a COVID-19 infection. The difference regarding postponements and cancellations by medical facilities between those care recipients indicating difficulties vs. those not indicating difficulties in receiving care was smaller and not significant. Thus, hypothesis H5 is only partly confirmed. This result suggests that the reporting of difficulties in receiving care was more strongly related to subjectively fearing an infection in connection with a medical treatment than objective shortages in the health care system, even though only a small proportion of respondents had actually been infected with COVID-19. This finding, however, varied across countries, with higher shares of care recipients canceling medical treatments by themselves in Southern European countries, which had been affected more in the first phase of the pandemic. In Western European countries, higher shares of care recipients had a medical treatment postponed or denied by their doctor or a medical facility, most likely due to shortages in the national health care system. Independently of its cause, it has to be seen whether canceling necessary medical and therapeutic treatments during the first phase of the pandemic will result in negative long-term consequences on health—and if yes, to what degree. Further, it is noteworthy that, overall, one out of five care recipients reported difficulties in receiving the care they need. In Southern and several Western European countries, which

had been hardest hit with respect to the number of confirmed deaths due to COVID-19 in the first phase of the pandemic, this number was even higher. On average, these care recipients also reported slightly more physical and mental health strains with a significantly higher level of anxiety as the most explicit result. This corresponds with our findings regarding caregivers. Hence, it seems that the first COVID-19 phase in spring 2020 can best be characterized by an increase in anxiety for both caregivers and care recipients. However, there is concern that indications of depression will also further increase the longer epidemiological control measures like stay-at-home orders persist (71).

When focusing more closely on the determinants of why care recipients perceived difficulties in receiving care, our results revealed that, in particular, female and more highly educated care recipients, as well as those who canceled their medical treatments by themselves for fear of an infection, had a significantly higher probability of indicating unmet care needs. In contrast, care recipients who were 65 years and older, lived alone, and already suffered from limitations in IADL (e.g., dressing or making phone calls) before the outbreak of the pandemic had a significantly lower probability of perceiving difficulties in receiving care. This indicates that those care recipients who strongly rely on personal care (oldest old, living alone) still received the care they needed during the first phase of the pandemic. In addition, our previous findings with regard to having access to medical treatments also hold in the multilevel setting: care recipients who canceled their medical treatments by themselves more frequently perceived difficulties in receiving care, while medical treatments postponed or denied by care facilities were not significantly associated with a higher probability of unmet care needs. This points out that respondents' subjective fear of a COVID-19 infection outweighed the objective problems of care facilities with respect to the association between getting access to medical treatments on the one hand and indicating unmet care needs on the other. Besides analyzing individual predictors, our analyses also allowed us to include country-specific determinants of the pandemic. Overall, differences across countries with respect to the severity of the pandemic as well as governmental control measures to mitigate COVID-19 indeed helped to explain a substantial part of the country disparities regarding the prevalence of unmet care needs, which is in accordance with hypothesis H6. Our results further revealed that the indirect effects of epidemiological control measures accompanying COVID-19, measured by the length and stringency of stay-at-home orders, turned out to be more impactful in the first phase of the pandemic than the direct effects of COVID-19, measured by the cumulative number of confirmed deaths due to the virus. The longer the stay-at-home orders had already been in place in a country, the higher the probability was of perceiving difficulties in receiving care. This is an important finding that confirms recent studies on the negative consequences of epidemiological control measures in particular for those people who are in need of personal care.

The main limitations of this study are the rather low numbers of caregivers, and even more severe is the number of care recipients who, at the same time, are in presumably good health, which allowed them to participate in the survey. We tried to circumvent this problem by geographically grouping countries to measure the varying effects of the pandemic on caregivers and care recipients across Europe. However, we are aware that more detailed typologies are needed to capture the institutional and cultural differences and also the different government responses to the COVID-19 crisis in order to fully explain the consequences of this global pandemic on caregiving and care receiving. Furthermore, with the data at hand, we lack a comprehensive understanding on the underlying causes of why mental health declined for caregivers as well as for those who intensified their caregiving activities during the first phase of the pandemic: was it the mere burden of caregiving in an unprecedented situation, in which increased care needs and reduced availability of paid services and informal support had to be compensated for by informal family care? Or have worries about care-dependent relatives been the main driver for the strong increase in mental health strains? More research is needed here that also picks up recent findings regarding the interplay between these factors. For example, Kumagai et al. (72) showed that long sleep time was an important risk factor for the recurrence of depression. However, with the current data, it was not possible singling out specific sleeping times. In addition, future research should also explore the interaction of these explanations with the severity of the pandemic, which differs between countries and hence is expected to exhibit different consequences. In this respect, our study was only a first step in answering some of these questions. Others remain, for example, possible selection effects underlying the country differences found regarding a canceling of medical treatments by care recipients themselves. Future research might investigate reasons for these differences more deeply. Finally, we should consider that our findings refer to spring/summer 2020, the first COVID-19 phase after the outbreak. The changing experience with COVID-19 and also the changed mindset with regard to how we now look at the pandemic make it more difficult to evaluate the results against the background of the first COVID-19 phase. Although the current situation is similar in some respects, it differs a lot with respect to the overall perception of the crisis as well as the long-lasting epidemiological control measures and restrictions ("lockdown fatigue"). Therefore, further waves of the pandemic are expected to put even more pressure on the persons under investigation. In this respect, it will be extremely valuable to compare our results with data from a second SHARE Corona Survey, which is actually planned for early summer 2021. This will provide valuable information to evaluate more comprehensively the consequences of COVID-19 across Europe.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: http://www.share-project.org/data-documentation/share-data-releases.html. Each wave and each release is assigned a persistent DOI. In our article we use SHARE data from Waves 1, 2, 3, 4, 5, 6, 7, and 8 (DOIs: 10.6103/SHARE.w1.710, 10.6103/SHARE.w2.710,

10.6103/SHARE.w3.710, 10.6103/SHARE.w4.710, 10.6103/SHARE.w5.710, 10.6103/SHARE.w6.710, 10.6103/SHARE.w7.711, 10.6103/SHARE.wXcvr.710, 10.6103/SHARE.w8cabeta.001) that are fully available without restrictions to all scientific users world-wide after individual registration (http://www.share-project.org/data-access/user-registration.html).

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of the University of Mannheim (until Wave 4) and the Ethics Council of the Max Planck Society. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

MB and MW contributed equally to conceptualization, methodology, and validation. MB conducted data curation, analyzed the data, and drafted the manuscript. MW reviewed the manuscript. Both authors contributed to the article and approved the submitted version.

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A preliminary version of this study, based on an earlier data version, has been published as SHARE Working Paper 59-2021 (73) and is available on the SHARE website. The current paper has been completely revised in terms of both methodology and content.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.673874/full#supplementary-material

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Evaluating the Immediate Response of Country-Wide Health Systems to the Covid-19 Pandemic: Applying the Gray Incidence Analysis Model

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The purpose of the study is to evaluate county-wide health systems using the data set of the first wave of the COVID-19 pandemic. The overall design of study comprises a literature review, secondary data, and a mathematical analysis. It is a cross-sectional quantitative study following a deductive approach. It uses the data of the first wave of the COVID-19 pandemic taken from the website of Worldometer as of April 8, 2020. The study uses a gray incidence analysis model (commonly known as Gray Relational Analysis, i.e., GRA) as its research methodology. On the basis of the results of GRA, a classification has been made under a predetermined scheme of ensigns: *much better, better, somewhat better, fair, poor, somewhat worse, and worse* health systems. There are a total 211 countries that have been divided into the seven aforementioned categories. Findings of the study show that Southern Africa Development Community (SADC) countries fall predominantly under the *much better* ensign, whereas Organization for Economic Co-operation and Development (OECD), Schengen Area (SA), and/or European Union (EU) countries fall under the *worse* ensign. Pakistan falls under the ensign of *poor*. It is an original attempt to evaluate the response of health systems based on real data using a scientific methodology. The study provides valuable information about the health systems of the countries for forming an informed opinion about the health systems herein. The study provides useful new information for stakeholders and a new framework for future research.

Keywords: COVID-19 pandemic, deaths, GRA, gray incidence analysis model, health system, tests, Pakistan

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INTRODUCTION

The COVID-19 pandemic has created serious issues for different countries, particularly those that have weak health systems (1–3). With the outbreak of COVID-19 sustainability, consciousness about healthcare systems has increased, and the need for its performance evaluation has become imperative. The whole world is passing through an abnormal state created by the outbreak of a novel virus COVID-19 from Wuhan, China. Health systems are under extraordinary pressure because of the geometric increase in COVID-19 patients. It is of utmost necessity to evaluate health systems and to revamp them to meet challenges like the current epidemic. The healthcare systems of

many countries collapsed during the first wave of COVID-19. It has become obligatory to evaluate the healthcare systems of the world afresh, particularly before embarking on a regime of reforms. The question of measurement of performance and comparison of that performance between healthcare systems of several countries has arisen as an offshoot of the COVID-19 pandemic. Answering this question is not that simple; rather, it is complex and difficult. A plethora of research has already been published on healthcare system in general across the globe, and it is important to document that the efforts have been made by different researchers on many counts, e.g., studies like those on the role of pharmacies in health system of Colombia (4), challenges faced by the national healthcare service in Italy (5), the health system of Mount Sinai, US (6), the proactive role of the public health agency of Canada (1), the strengthening of the Mexican healthcare system by addressing the environmental, social, and healthcare issues (7), the healthcare services of the Hubei province of China (8), the challenges to the Bulgarian healthcare system (9), the resilience of the Taiwanese healthcare system (10), the strained Greek healthcare care system (11), eHealth, remote consultation, and the Australia mental health care setting (12, 13), the resilience of the Spanish healthcare system (14), the strained healthcare system of Latin America (15), a care center in Pakistan (16), the risk to the Brazilian healthcare system (17), the challenges faced by the healthcare system of sub-Saharan Africa (18), and so on. Most of the countries of the world, including Pakistan, are in the process of rethinking their healthcare systems in order to cope with unforeseen epidemics like COVID-19 (19). All countries are introducing rigorous initiatives by way of establishing laboratories, dedicated quarantine facilities, large-scale awareness campaigns, and smart lockdowns to mitigate the proliferation of coronavirus (20). To address the issue of evaluation of health systems affected by the current pandemic, there is a need to develop a methodology to standardize the measurement of health systems of countries concurrently and simultaneously. Warsame et al. (21) asserted that the development of an epidemic response, and an evaluation approach based on a comprehensive evaluation framework needs to be underpinned. To be specific, the following are the research objectives of this study: (i) to evaluate the health systems of the countries using the data set of the first wave of COVID-19 pandemic; (ii) to determine the gray relational grade of countries' health systems; (iii) to group or classify the countries on the bases of the gray relational grade under pre-determined ensigns in order to provide the basis for an informed opinion to discerners; (iv) to discuss the position of selected countries against their regional blocs; (v) to evaluate the position of Pakistan qua rest of the world in general and among Asian countries in particular; and (vi) to discuss the implications for stakeholders. Where does the healthcare system of a certain country rank during the first wave of the COVID-19 pandemic? This is the prime research question this study will address. The authors considered a range of multi-criteria-decision-making techniques: *ANP, FANP, AHP, TOPSIS, DEA, GRA, VIKOR, SWARA, ISM, TISM, MICMAC, SEM,* and *Regression*. Keeping in view the nature of the study, GRA (Gray Incidence Analysis Model) was found to be appropriate since it has the capability to accommodate a large set of cross-sections and a multitude of system variables even with missing, insufficient, and/or incomplete data. Therefore, in this study, the GRA method is used to assess the performance of countries' health systems during the COVID-19 pandemic. It also has the ability to normalize the data having different units of measurement. This study is worthwhile for regulators of health departments, international institutions, frontline soldiers, researchers, political governments, and society at large. The remainder of this paper is arranged as literature review, theoretical framework, methodology, analysis, results and discussion, and concluding remarks.

TABLE 1 | Specification of system variables.

Code	Variables	Criteria
1	Total Covid-19 infections	Minimum better
2	New Covid-19 infections	Minimum better
3	Total deaths by Covid-19 infections	Minimum better
4	Total recoveries from Covid-19 infections	Maximum better
5	Active cases of Covid-19	Minimum better
6	Serious/Critical patients of Covid-19	Minimum better
7	Tot cases/1M pop of Covid-19	Minimum better
8	Deaths/1M pop by Covid-19	Minimum better
9	Total tests of Covid-19	Maximum better
10	Tests/1M pop of Covid-19	Maximum better

LITERATURE REVIEW

There is no dearth of literature on healthcare systems in general, but, in the current panorama of the COVID-19 pandemic, there is a scarcity of peer-reviewed published research on the current situation. However, there is a lot of published/unpublished upcoming literature about the health systems of different countries (22). In this context, the authors have explored the relevant databases like ScienceDirect, Emarald, JStor, Wiley-Blackwell, Taylor & Francis, etc., and have reviewed a significant number of research studies relevant to the phenomenon under study. Highly relevant studies are being reported in order to set the outset of the research: Armocida et al. (5) stated that the National Healthcare Service (responsible for providing health services in regions of Italy) was about to collapse in the Lombardy region of Italy (the most affected region) due to privatization and a €37 billion financial cut over the period of 2010–2019. Chattu et al. (1) revealed that a Canadian public health agency has proved its global health leadership by way of proactive measures taken to address this worldwide COVID-19 outbreak challenge. Chen et al. (8) stressed that pairing assistance (dedicated number of medical personnel to each city depending on the severity of COVID-19) strategy adoption alleviated the pressure on the healthcare system of China, which was a turning point in China's fight against COVID-19. De-Sousa et al. **(author?)** (2) identified 16 physical and mental health challenges being faced by low/middle-income countries and argued that if not addressed, this may get increasingly

TABLE 2 | Original country wide data set on corona virus.

Sr.	Country	1	2	3	4	5	6	7	8	9	10
1	Afghanistan	423	0	14	18	391	0	11	0.4	0	0
2	Albania	400	17	22	154	224	7	139	8	2,989	1,039
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
148	Pakistan	4,072	37	58	467	3,547	25	18	0.3	42,159	191
149	Palestine	263	2	1	44	218	0	52	0.2	15,450	3,029
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
210	Zambia	39	0	1	7	31	0	2	0.05	619	34
211	Zimbabwe	11	0	2	0	9	0	0.7	0.1	371	25

Worldometer (2020).

TABLE 3 | Reference sequence and comparable sequences.

Sr.	Country	Total	New	Total deaths	Total recoveries	Active cases	Serious/ Critical	Total Cases/ 1M pop	Deaths/ 1M pop	Total tests	Tests/ 1M pop
0	Reference sequences	1	0	0	77,279	1	0	0	0	20,82,443	105,458
1	Afghanistan	423	0	14	18	391	0	11	0.4	0	0
2	Albania	400	17	22	154	224	7	139	8	2,989	1,039
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
148	Pakistan	4,072	37	58	467	3,547	25	18	0.3	42,159	191
149	Palestine	263	2	1	44	218	0	52	0.2	15,450	3,029
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
210	Zambia	39	0	1	7	31	0	2	0.05	619	34
211	Zimbabwe	11	0	2	0	9	0	0.7	0.1	371	25

severe over time. Hsieh (10) argued that Taiwan has taken timely initiatives to mitigate the proliferation of COVID-19, including the activation of the Central Epidemic Command Center (CECC) for communication and coordination, supplying surgical masks, issuing national health insurance cards, and postponing schools' classes. Khan et al. (23) collected data from 302 healthcare workers and proclaimed that the majority of Pakistanis are not well-informed and prepared for the COVID-19 pandemic, and they are also not familiar with the measures to prevent/control contagion. Kim et al. (24) argued that "The University of Washington Medicine's Post-Acute Care Network" established a three-phase approach (initial, delayed, and surge phases) that helped clinics, hospitals, emergency medical services from becoming overwhelmed and to alleviate the spread of COVID-19 cases. Kretchy et al. (25) concluded that retail pharmacies and community pharmacists are easily accessible and are coming forward to share the burden of the healthcare system in low/middle-income countries. Similarly, Amariles et al. (4) revealed an active role of pharmacy staff and community pharmacy to lessen the burden on the healthcare system. Legido-Quigley et al. (26) claimed that Singapore, Hong Kong, and Japan outlined core dimensions for the development of resilience-oriented healthcare systems, including effective intragovernmental coordination, adaptations, allocations of finances, smooth political environment, availability of treatment, supply of medicine, and routine healthcare services. Legido-Quigley et al. (14) revealed that Spanish healthcare systems efficiently managed the first 6 weeks since the first case was identified, but as time passed, pressure built on the six building block of the Spanish healthcare system (i.e., governance, medicine and equipment, financing, healthcare workers, service delivery, and information). Lorenz et al. (27) argued that the outbreak of COVID-19 and dengue fever have caused great damage to the healthcare system in Brazil; alone, COVID-19 has the potential to swamp the Brazilian healthcare system, and a unified partnership between public and private healthcare systems is thus needed to combat this pandemic. Ma et al. (3) identified potential repercussions of the COVID-19 pandemic on health and surgical care in low/middle-income countries and stated that optimizing resources, providing accurate information/knowledge and training to healthcare workers, and protection are the only means to contain the spread of COVID-19. Menon and Padhy (28) revealed that there are some ethical dilemmas faced by healthcare workers

TABLE 4 | Normalized comparable sequences.

Sr.	Country	Total	New	Total deaths	Total recoveries	Active cases	Serious/ Critical	Tot Cases/1M pop	Deaths/1M pop	Total tests	Tests/1M pop
0	Reference sequences	1.00000	1.0000	1.0000	1.00000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	Afghanistan	0.99895	1.0000	0.9992	0.00023	0.9989	1.0000	0.9987	0.9996	0.0000	0.0000
2	Albania	0.99900	0.9964	0.9987	0.00199	0.9994	0.9992	0.9841	0.9920	0.0014	0.0099
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
148	Pakistan	0.98984	0.9922	0.9966	0.00604	0.9903	0.9973	0.9979	0.9997	0.0202	0.0018
149	Palestine	0.99935	0.9996	0.9999	0.00057	0.9994	1.0000	0.9940	0.9998	0.0074	0.0287
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
210	Zambia	0.99991	1.0000	0.9999	0.00009	0.9999	1.0000	0.9998	1.0000	0.0003	0.0003
211	Zimbabwe	0.99998	1.0000	0.9999	0.00000	1.0000	1.0000	0.9999	0.9999	0.0002	0.0002

TABLE 5 | Deviation sequences.

Sr.	Country	Total	New	Total deaths	Total recoveries	Active cases	Serious/ Critical	Tot Cases/1M pop	Deaths/1M pop	Total tests	Tests/1M pop
0	Reference sequences	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1	Afghanistan	0.00105	0.00000	0.00082	0.99977	0.00107	0.00000	0.00126	0.00040	1.00000	1.00000
2	Albania	0.00100	0.00358	0.00128	0.99801	0.00061	0.00076	0.01591	0.00798	0.99856	0.99015
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
148	Pakistan	0.01016	0.00779	0.00339	0.99396	0.00969	0.00273	0.00206	0.00030	0.97976	0.99819
149	Palestine	0.00065	0.00042	0.00006	0.99943	0.00059	0.00000	0.00595	0.00020	0.99258	0.97128
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
210	Zambia	0.00009	0.00000	0.00006	0.99991	0.00008	0.00000	0.00023	0.00005	0.99970	0.99968
211	Zimbabwe	0.00002	0.00000	0.00012	1.00000	0.00002	0.00000	0.00008	0.00010	0.99982	0.99976

even in developed countries and offered some suggestions to trounce them. Mukhtar (29) showed that well-being and mental health care are building blocks of the healthcare system, whereas social distancing/isolation and quarantine are causing potential mental health issues that need to be addressed. Rana et al. (16) explained that, being a lower-middle country, Pakistan has a poor healthcare system wherein the budget allocated to health is only 1% of the GDP. Roder-DeWan (18) argued that low-income countries are hardly able to achieve fewer than half of the elements indispensable for a high-quality healthcare system than that of high-income countries. Telemedicine and telehealth are a fast-emerging concept of health system during the period of COVID-19 to ensure the effectiveness of isolation/social distancing, helping service provision, tracking, tracing, and testing of COVID-19 cases (30–35). After the review of studies like the aforementioned, it has become imperative that we develop a theoretical framework to evaluate healthcare systems at the country level.

THEORETICAL FRAMEWORK

Theories help to explain, predict, understand phenomena, and, sometimes, to challenge or to extend our existing knowledge within the boundaries of given assumptions (36). All that is necessary to use our knowledge and understanding in more informed and effective ways (37). A theoretical framework is used to limit the scope of the relevant data. The selection of a theory depends on its appropriateness, ease of application, and explanatory power. Gray system theory is found to be appropriate in this study keeping in view the objectives of the study and research question under investigation. In order to enhance the clarity and interpretability of results, authors have extended the theoretical framework by way of introducing the system of ensigns. To evaluate the phenomena critically, it is vital to connect to the existing knowledge. The framework also helps to articulate the theoretical assumptions and to identify the limits of results' generalizations. This study uses a theoretical framework to limit the scope of the relevant data by focusing on specific variables and defining them [framework] so that researcher may analyze and interpret the data gathered. The framework also facilitates the understanding of concepts and variables according to given definitions and builds new knowledge by validating or challenging theoretical assumptions (37). The authors have selected the following variables to get on the framework of the study (**Table 1**).

TABLE 6 | Gray relational co-efficient.

Sr.	Country	Total	New	Total deaths	Total recoveries	Active cases	Serious/ Critical	Tot Cases/1M pop	Deaths/1M pop	Total tests	Tests/1M pop
0	Reference Sequences	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
1	Afghanistan	0.99790	1.00000	0.99837	0.33339	0.99787	1.00000	0.99749	0.99920	0.33333	0.33333
2	Albania	0.99801	0.99289	0.99744	0.33378	0.99878	0.99848	0.96917	0.98428	0.33365	0.33554
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
148	Pakistan	0.98008	0.98465	0.99327	0.33468	0.98099	0.99458	0.99590	0.99940	0.33789	0.33374
149	Palestine	0.99869	0.99916	0.99988	0.33346	0.99882	1.00000	0.98824	0.99960	0.33499	0.33984
…	…….	…	…	…	…	…	…	…	…	…	…
…	…….	…	…	…	…	…	…	…	…	…	…
210	Zambia	0.99981	1.00000	0.99988	0.33335	0.99984	1.00000	0.99954	0.99990	0.33340	0.33340
211	Zimbabwe	0.99995	1.00000	0.99977	0.33333	0.99996	1.00000	0.99984	0.99980	0.33337	0.33339

The variables of social sciences normally have three types of acceptable characteristics. The first type of variable may be *maximum better*, the second type of variable might have characteristics of *minimum better*, and the third type of variable may have characteristics of *target the better*. Close observation of the variables reveals that variables 1,2,3,5,6,7, and 8 possess the characteristic of *minimum better*, whereas variables 4,9, and 10 possess the characteristic of *maximum better*. With this framework, the authors opted to use the Gray Incidence Analysis Model as a solution methodology.

METHODOLOGY

This study follows positivist philosophy and deductive approach. It is a cross-sectional research study that uses data of the first wave of COVID-19 pandemic taken from the website of Worldometer as of April 8, 2020. It uses the Gray Incidence Analysis Model (commonly known as Gray Relational Analysis or simply GRA). It is a unique mathematical approach selected from the array of multi-criteria-decision-making techniques. This technique is frequently employed to use an incomplete and impure set of data for analyzing relations of a multitude of variables. It has prevails on statistical techniques like regression analysis because of their limitations and demand for large amounts of data for generating meager results (38). GRA progresses stepwise (39–43). The first step, in this model, is obtaining data; the second is the creation of a reference series; the third is the generation of a comparable sequence; the fourth is the generation of a reference series; the fifth is the generation of a normalized matrix; the sixth is the calculation of a deviation sequence; the seventh is the creation of absolute values with a difference in the reference sequence and comparable sequence; the eighth is the establishment of a co-efficient matrix of a gray relation system; the ninth is the computation of a gray relational grade; and the tenth step is the arrangement of these in a descending order. The method has been augmented with a classification of the cross-sections using the method of ensigns introduced by the authors. In this method, first, the operational definitions of ensign groups have been generated on the basis of distributing the scale into seven ensigns.

TABLE 7 | Gray relational grades.

Sr.	Country	Gray relational grade
0	Reference sequences	1.0000
1	Afghanistan	0.7991
2	Albania	0.7942
…	…….	…
…	…….	…
148	Pakistan	0.7935
149	Palestine	0.7993
…	…….	…
…	…….	…
210	Zambia	0.7999
211	Zimbabwe	0.7999

Applying Gray Incidence Analysis Model

The following steps of GRA were used to access the best performer among different countries of the world.

Step 1: We created a data set (**Table 2**) and established a decision matrix of data set denoted in the following formula:

$$x_i(k) = \begin{bmatrix} x_1(1)\, x_1(2) & \cdots & x_1(m) \\ \vdots & \ddots & \vdots \\ x_n(1)\, x_n(2) & \cdots & x_n(m) \end{bmatrix} \quad (1)$$

Step 2: We created a reference series and comparison matrix (**Table 3**) using a classical rule of reference and comparison.

Step 3: We created a normalized matrix (**Table 4**) using the following formulas for maximum better and minimum better.

For maximum better:

$$x_i^*(k) = \frac{x_i^{(0)}(k) - minx_i^{(0)}(k)}{\max x_i^{(o)}(k) - minx_i^{(o)}(k)} \quad (2)$$

For minimum better:

$$x_i^*(k) = \frac{\max x_i^{(o)}(k) - x_i^{(0)}(k)}{max\, x_i^{(0)}(k) - minx_i^{(0)}(k)} \quad (3)$$

TABLE 8 | Scheme of grouping the countries under different ensigns on the basis of gray relational grades of health systems.

Sr.	Ensign	Description
1	Much better	Countries having a gray relational grade ranging from 0.8203 to 0.7999 are considered as having an excellent health system (top thirty countries).
2	Better	Countries having a gray relational grade ranging from 0.7999 to 0.7994 are considered as having a very good health system.
3	Somewhat better	Countries having a gray relational grade ranging from 0.7994 to 0.7980 are considered as having a good health system.
4	Fair	Countries having a gray relational grade ranging from 0.7978 to 0.7947 are considered as having a satisfactory health system.
5	Poor	Countries having a gray relational grade ranging from 0.7945 to 0.7890 are considered as having a weak health system.
6	Somewhat worse	Countries having a gray relational grade ranging from 0.7889 to 0.7724 are considered as having a very weak health system.
7	Worse	Countries having a gray relational grade ranging from 0.7723 to 0.4854 are considered as having the worst health system.

For example, for Afghanistan, "*smaller is the better*"

$$x_1{}^*(1) = \frac{max\ x_1^0(1) - x_1^0(1)}{max\ x_1^0(1) - min\ x_1^o(1)} = \frac{4005249 - 423}{4005249 - 1} = 0.999895$$

Step 4: We calculated deviation sequences (**Table 5**) by using the following formula:

$$\Delta_0(\gamma) = |x_0(\gamma) - x_1(\gamma)| \quad (4)$$

For example, for Albania

$$\triangle_{02}(2) = \left|x_0^*(2) - x_2^*(2)\right| = |1 - 0.9964| = 0.0036$$

Step 5: The Gray relational co-efficient is calculated (**Table 6**) by using the following formula based on values of normalized sequences. Term ξ is the distinguishing co-efficient between 0 and 1, the usual value of which is 0.5 in literature.

$$\gamma\left[x_0{}^*(k), x_i^*(k)\right] = \frac{\Delta_{min} + \xi\Delta_{\max}}{x_{0i}(k) + \xi\Delta_{\max}},\ 0 < \gamma\left[x_o^*(k), x_i^*(k)\right] \leq 1 \quad (5)$$

For example, for Albania,

$$\gamma\left[x_0^*(2),\ x_2^*(2)\right] = \frac{\Delta_{min} + \xi\Delta_{\max}}{\Delta_2(2) + \xi_{\max}} = \frac{0 + (0.5) \times 1}{0.0036 + (0.5) \times 1} = 0.9928$$

Step 6: The weighted sum of gray relational co-efficient (Gray Relational Grade) is calculated (**Table 7**) by using the following formula:

$$\gamma\left(x_0{}^*, x_i{}^*\right) = \sum_{k=1}^{n} \beta_k \gamma\left[x_0{}^*(k), x_i{}^*(k)\right] \quad (6)$$

$$\sum_{k=1}^{n} \beta_k = 1 \quad (7)$$

For example, for Albania,

$$\gamma\left(x_0{}^*, x_2^*\right) = \sum_{k=1}^{n} \beta_k\, \gamma\left[x_0{}^*(2), x_2{}^*(k)\right]$$
$$= 0.10 \times \begin{pmatrix} 0.9980 + 0.9929 + 0.9974 + 0.3338 + 0.9988 \\ +0.9985 + 0.9692 + 0.9843 + 0.3337 + 0.3355 \end{pmatrix}$$
$$= 0.7942$$

The authors have introduced the method of ensigns to represent the gray relational ranks of the countries. The ensigns were taken on the basis of the pattern of the ordinal scale, including *much better, better, somewhat better, fair, poor, somewhat worse,* and *worse*. The operational definitions of these ensigns are given in **Table 8**. This method has been introduced to logically represent and interpret the results of gray relational analysis particularly that of the ranks of the countries qua other counterparts. This also facilitates the provision of insight into the different blocs of countries currently existing in the world. In fact, there are 211 total countries under investigation and the scale of ensigns consists of seven items, therefore, ∼30 countries are categorized in each bracket of an ensign. The bracket of gray relational grade has also been mentioned against each scale item to make the information more objective and meaningful.

Readers will find ensigns information significantly helpful in making an informed opinion about a countries' and/or blocs' health systems.

RESULTS AND DISCUSSION

Results

We measured the performance of healthcare systems in countries and compared those performances with others as an offshoot of the COVID-19 pandemic. This is important because the countries are planning to revisit the architecture of their healthcare systems, and the answer is not that simple. The healthcare systems of many countries collapsed as a result of the first wave of COVID-19, and, therefore, it is vital to evaluate health systems before any revamping. Hence the aim of this study is to evaluate healthcare systems in different countries, including Pakistan, and compare them against each other. The study uses Gray Relational Analysis (GRA) as its methodology to evaluate the system and it uses secondary data from the website of Worldometer (44). The study thus provides understanding to readers in terms of the capability of healthcare systems in different countries in responding to pandemics like COVID-19. The authors gathered a significant number of articles, reports, statistical bulletins, and official documents from authoritative websites and examined the findings to set the context of the study. Results of the analysis are given in **Table 9**.

Using the gray relational analysis (i.e., mathematical technique of data analysis with the capability of handling a multitude of

TABLE 9 | Results of gray relational analysis.

Country	Gray relational grades	Rank	Country	Gray relational grades	Rank	Country	Gray relational grades	Rank
Reference sequences	1.0000	0	Maldives	0.7992	70	Greece	0.7910	141
Much better			Suriname	0.7992	71	North Macedonia	0.7909	142
Faeroe Islands	0.8203	1	Jordan	0.7992	72	Turks and Caicos	0.7909	143
Vietnam	0.8010	2	Belize	0.7991	73	Bosnia and Herzegovina	0.7909	144
China	0.8008	3	Afghanistan	0.7991	74	Armenia	0.7908	145
New Caledonia	0.8004	4	Hong Kong	0.7989	75	Moldova	0.7904	146
Bhutan	0.8002	5	Burkina Faso	0.7989	76	Kuwait	0.7898	147
UAE	0.8002	6	Greenland	0.7988	77	Singapore	0.7894	148
Nepal	0.8000	7	El Salvador	0.7987	78	India	0.7893	149
Papua New Guinea	0.8000	8	Azerbaijan	0.7987	79	Belarus	0.7890	150
South Sudan	0.8000	9	Kazakhstan	0.7986	80	**Somewhat worse**		
Mozambique	0.8000	10	Cameroon	0.7986	81	Philippines	0.7889	151
Burundi	0.8000	11	St. Vincent Grenadines	0.7985	82	Guadeloupe	0.7889	152
Somalia	0.8000	12	Macao	0.7984	83	Martinique	0.7888	153
Timor-Leste	0.8000	13	Cuba	0.7984	84	Saudi Arabia	0.7886	154
Chad	0.8000	14	Caribbean Netherlands	0.7984	85	Falkland Islands	0.7884	155
Uganda	0.8000	15	Uzbekistan	0.7983	86	Aruba	0.7883	156
MS Zaandam	0.8000	16	Bolivia	0.7983	87	Dominican Republic	0.7882	157
Tanzania	0.8000	17	Saint Lucia	0.7983	88	Croatia	0.7881	158
Botswana	0.8000	18	South Africa	0.7981	89	Ukraine	0.7881	159
Sudan	0.7999	19	Georgia	0.7980	90	St. Barth	0.7878	160
CAR	0.7999	20	**Fair**			Serbia	0.7875	161
Myanmar	0.7999	21	Brunei	0.7978	91	Mayotte	0.7867	162
Malawi	0.7999	22	Iraq	0.7978	92	Malaysia	0.7863	163
Zimbabwe	0.7999	23	Honduras	0.7978	93	Indonesia	0.7859	164
Angola	0.7999	24	British Virgin Islands	0.7978	94	Slovenia	0.7858	165
Sierra Leone	0.7999	25	Slovakia	0.7978	95	Cayman Islands	0.7851	166
Laos	0.7999	26	Guyana	0.7977	96	Ecuador	0.7834	167
Mauritania	0.7999	27	Grenada	0.7976	97	Chile	0.7833	168
Nicaragua	0.7999	28	Egypt	0.7975	98	Czechia	0.7830	169
Syria	0.7999	29	Seychelles	0.7975	99	Bermuda	0.7825	170
Zambia	0.7999	30	Bangladesh	0.7973	100	Iceland	0.7825	171
Better			Costa Rica	0.7973	101	Poland	0.7821	172
Haiti	0.7999	31	Kyrgyzstan	0.7972	102	Estonia	0.7811	173
Benin	0.7999	32	Bahrain	0.7971	103	Mexico	0.7811	174
Namibia	0.7999	33	Trinidad and Tobago	0.7971	104	Finland	0.7796	175
Taiwan	0.7999	34	Curaçao	0.7970	105	Qatar	0.7794	176
Equatorial Guinea	0.7999	35	French Polynesia	0.7968	106	Panama	0.7764	177
Gambia	0.7999	36	Bulgaria	0.7967	107	Saint Martin	0.7745	178
Libya	0.7999	37	Uruguay	0.7966	108	Norway	0.7738	179
Western Sahara	0.7998	38	Dominica	0.7963	109	Montserrat	0.7724	180
Mongolia	0.7998	39	Tunisia	0.7963	110	**Worse**		
Cambodia	0.7998	40	Saint Kitts and Nevis	0.7962	111	Isle of Man	0.7723	181
Ethiopia	0.7998	41	Saint Pierre Miquelon	0.7962	112	Russia	0.7715	182
Eswatini	0.7998	42	Djibouti	0.7957	113	Romania	0.7708	183
Mali	0.7998	43	Oman	0.7956	114	Brazil	0.7702	184
Liberia	0.7998	44	Anguilla	0.7956	115	Liechtenstein	0.7690	185
Eritrea	0.7998	45	Colombia	0.7955	116	Gibraltar	0.7689	186
Rwanda	0.7997	46	Lebanon	0.7955	117	Canada	0.7679	187

(Continued)

TABLE 9 | Continued

Country	Gray relational grades	Rank	Country	Gray relational grades	Rank	Country	Gray relational grades	Rank
Togo	0.7997	47	Argentina	0.7949	118	Israel	0.7641	188
Nigeria	0.7997	48	Bahamas	0.7948	119	Monaco	0.7635	189
Madagascar	0.7996	49	Mauritius	0.7947	120	Channel Islands	0.7631	190
Sao Tome and Principe	0.7996	50	**Poor**			Ireland	0.7620	191
Guinea	0.7996	51	Latvia	0.7945	121	Sint Maarten	0.7610	192
Guatemala	0.7996	52	French Guiana	0.7944	122	Denmark	0.7574	193
Fiji	0.7996	53	Morocco	0.7943	123	Austria	0.7495	194
Gabon	0.7996	54	Albania	0.7942	124	Luxembourg	0.7437	195
Guinea-Bissau	0.7996	55	New Zealand	0.7940	125	Vatican City	0.7333	196
Congo	0.7995	56	Algeria	0.7940	126	Turkey	0.7319	197
DRC	0.7995	57	Australia	0.7939	127	Portugal	0.7301	198
Venezuela	0.7995	58	Pakistan	0.7935	128	Sweden	0.7221	199
Senegal	0.7995	59	Barbados	0.7935	129	Andorra	0.7061	200
Diamond Princess	0.7994	60	Japan	0.7932	130	Switzerland	0.7030	201
Somewhat better			Hungary	0.7925	131	San Marino	0.6712	202
Kenya	0.7994	61	S. Korea	0.7925	132	Germany	0.6709	203
Ghana	0.7994	62	Thailand	0.7923	133	Netherlands	0.6681	204
Niger	0.7993	63	Peru	0.7923	134	UK	0.6630	205
Sri Lanka	0.7993	64	Malta	0.7922	135	Belgium	0.6494	206
Ivory Coast	0.7993	65	Antigua and Barbuda	0.7919	136	Iran	0.6255	207
Cabo Verde	0.7993	66	Cyprus	0.7918	137	USA	0.5785	208
Jamaica	0.7993	67	Lithuania	0.7916	138	France	0.5773	209
Palestine	0.7993	68	Réunion	0.7912	139	Italy	0.5661	210
Paraguay	0.7992	69	Montenegro	0.7911	140	Spain	0.4854	211

variables, cases, and time periods), the study has characterized 211 countries of the world into seven different categories (**Table 8**). From the result of GRA, it can be learned that there are a total of 30 countries categorized as countries having a *much better* healthcare system, most of which are member countries of the Southern Africa Development Community (SADC); 30 countries are under the *better* ensign, most of which are member countries of the West African Economic and Monetary Union (WAEMU); 30 are under the ensign of *somewhat better*, most of which are member countries of Caribbean Community and Common Market (CARICOM); 30 are under the ensign of *fair*, most of which are member countries of Arabian Countries (AC); 30 are under the ensign of *poor*, most of which are member countries of Organization for Economic Co-operation and Development (OECD); 30 are under the ensign of *somewhat worse*, most of which are member countries of the Organization for Economic Co-operation and Development (OECD); and 30 are under the ensign of *worse*, most of which are member countries of the Organization for Economic Co-operation and Development (OECD), Schengen Area (SA), and/or European Union (EU). Pakistan fall under the ensign of *poor*, therefore have a weak health system.

Discussion

The purpose of the study is to evaluate the health systems at the country level using GRA. The results are classified under a predetermined scheme of ensigns. It is different on many counts from what contemporary literature says in terms of the composite measurement matrix, number of countries, methodology, data set, context, and classification. Traditional studies usually provide statistical analysis with very limited insights. This finding is consistent with on-ground realities. From the result of the study, it can be learned that the healthcare system of advanced countries, i.e., UK, USA, France, Denmark, etc. (almost whole western Europe/Schengen area/OECD), has a very poor response to the shock of COVID-19 pandemic, which is in contrast to the myth that these countries have the best healthcare systems in the world. In this way, the result of the study provides some evidence that it is the other way around. Pakistan's healthcare system, though poor, still ranks above most of the advanced countries as far as the response to the first shock of the COVID-19 pandemic is concerned (**Table 9**).

CONCLUDING REMARKS

With the outbreak of COVID-19, consciousness about the sustainability of healthcare systems has increased, and there has been a marked call for the need to evaluate its performance. The whole world is passing through an abnormal condition created with the outbreak of the novel coronavirus. Healthcare systems are under extraordinary pressure. It is of utmost

necessity to evaluate healthcare systems and to revamp them to meet challenges like the current epidemic. The healthcare systems of many countries collapsed during the first wave of COVID-19. It has become imperative to evaluate the healthcare systems of the world afresh, particularly before embarking on the regime of any reforms. The purpose of the study was to evaluate the health systems of all countries. The study also aimed to evaluate Pakistan's healthcare system against that of the rest of the world. The overall design of the study comprises literature reviews, secondary data, and mathematical analysis. It is a cross-sectional quantitative study following a deductive approach. The study uses Gray Relational Analysis (GRA) as its research methodology. The findings of the study show that there are 30 countries categorized as countries having *much better* health systems, most of which are member countries of the Southern Africa Development Community (SADC); 30 under the *better* ensign, most of which are member countries of West African Economic and Monetary Union (WAEMU); 30 are under the ensign of *somewhat better*, most of which are member countries of the Caribbean Community and Common Market (CARICOM); 30 are under the ensign of *fair*, most of which are member countries of Arabian Countries (AC); 30 are under the ensign of *poor*, most of which are member countries of the Organization for Economic Co-operation and Development (OECD); 30 are under the ensign of *somewhat worse*, most of which are member countries of Organization for Economic Co-operation and Development (OECD), and 30 are under the ensign of *worse*, most of which are member countries of the Organization for Economic Co-operation and Development (OECD), Schengen Area (SA), and/or European Union (EU). Pakistan falls under the ensign of *poor* and therefore has a weak healthcare system. The study revealed several practical and theoretical implications. The study has made several contributions to existing literature. It contributes firsthand information about healthcare systems, such as where a country stands as against reference values. It contributed gray relational grades and ranks assigned to every country using a multitude of variables. It also contributed by way of classification of healthcare systems into groups under different ensigns to making the results more simple. It provides a potential framework to guide academics and practitioners for future research. The study improves the understanding of concerned people about healthcare systems. Regulators and management can gain understanding from this study for policy decisions. The study builds awareness on systemic issues. The study also has some limitations, and it is worthwhile to mention these limitations in order to achieve clarity. Firstly, it is a cross-sectional study, and future studies may be longitudinal, using time series/panel data. Secondly, the study used a data set from the Worldometer website as of April 8, 2020; therefore, the generalizability of results is limited accordingly. Future studies may use different data sets (e.g., data of the WHO, WDI, etc.) in the same theoretical scheme to confirm/validate/substantiate the results. Thirdly, this study uses GRA the hierarchicalization technique, and there are other techniques for this purpose as well, e.g., RIDIT, AHP, TOPSIS, SWARA, VIKOR, and ISM, and future studies may thus use these methodologies. Finally, we have given equal weight to all variables; this may be changed, and future researchers may use AHP, expert opinions, or the entropy method.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MS initiated the idea and worked on gray analysis. TQ worked on the relevant literature of the topic. AK collected the data and performed the analyses. AB worked on the write up. All authors contributed to the article and approved the submitted version.

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Investigating the Links Between Vaccination Against COVID-19 and Public Attitudes Toward Protective Countermeasures: Implications for Public Health

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The COVID-19 pandemic caused by the novel coronavirus, SARS-CoV-2, is spreading globally at an unprecedented rate. To protect the world against this devastating catastrophe, vaccines for SARS-CoV-2 have been produced following consistent clinical trials. However, the durability of a protective immune response due to vaccination has not been confirmed. Moreover, COVID-19 vaccination against SARS-CoV-2 is not 100% guaranteed, as new variants arise due to mutations. Consequently, health officials are pleading with the public to take extra precautions against the virus and continue wearing masks, wash hands, and observe physical distancing even after vaccination. The current research collected data from 4,540 participants (1,825 vaccinated and 2,715 not vaccinated) in China to analyze this phenomenon empirically. The propensity score matching (PSM) model is employed to analyze the impact of vaccination against COVID-19 on participants' attitudes toward protective countermeasures. The findings showed that gender, age, education level, occupation risk, individual health risk perception, public health risk perception, social responsibility, peer effect, and government supervision are the main drivers for participants to be vaccinated with COVID-19's vaccines. The results further show that vaccination lessened participants' frequency of hand washing by 1.75 times and their compliance frequency intensity of observing physical distancing by 1.24 times. However, the rate of mask-wearing did not reduce significantly, implying that China's main countermeasure of effective mask-wearing effectively controls COVID-19. Moreover, the findings indicate that a reduction in the frequency of hand washing and observing physical distance could cause a resurgence of COVID-19. In conclusion, factors leading to the eradication of SARS-CoV-2 from the world are complex to be achieved, so the exploration of COVID-19 vaccination and people's attitude toward protective countermeasures may provide insights for policymakers to encourage vaccinated people to follow protective health measures and help in completely defeating the COVID-19 from the globe.

Keywords: COVID-19, vaccination, protective countermeasures, PSM, China

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INTRODUCTION

The COVID-19 pandemic has caused devastating harm worldwide, affecting many industries and resulting in the most severe economic recession since World War II (1, 2). According to the statistics released by Johns Hopkins University in the United States (June 5, 2021), the COVID-19 pandemic has infected 170 million people and caused 3.7 million fatalities globally. The World Health Organization (WHO) explained how the COVID-19 new variants mutate and spread rapidly. One of the mutations in the sequence of the viral receptor-binding domain of the spike protein, N510Y, is believed to enhance the viral transmissibility, and infectivity by increasing the affinity of the viral spike protein to its receptor (3). The swift virus transmission and the accelerated growth in the number of cases compelled the urgent development of an accurate and effective vaccine. It is clear that vaccinations have transformed global health and have enormous life-saving potential in their ability to boost immunity against this contagious disease. Countries worldwide are devoting themselves to develop effective vaccines against COVID-19 to effectively control the pandemic. Unfortunately, a completely effective drug has yet to be developed. Meanwhile, epidemiologists believe COVID-19 can be curbed by implementing strict countermeasures such as wearing masks, hand washing, and maintaining physical distance (4). Therefore, high anticipations are being placed on protective countermeasures in the fight to control COVID-19 and, in turn, to prevent pandemic-induced fatalities in nations worldwide.

Existing epidemiological and experimental research demonstrates that the main source of COVID-19 infections is aerosols (5), which are generally poly-dispersed droplets and particles and have many different sizes (6, 7). Infected aerosols easily spread in confined spaces through daily activities (e.g., exhaling, talking, coughing, and sneezing) and medical procedures (e.g., tracheal intubation, non-invasive ventilation, bronchoscopy, and tracheotomy) (8, 9). Accordingly, epidemiological evidence has confirmed the essential role of ventilation in reducing the risk of people exposed to aerosol infections. In an enclosed space, the airborne viral concentration from an infected person will build up over time to a level that depends on the ratio of the emission rate (10) to the number of fresh-air exchanges per hour (11). In other words, The risk then depends on the duration of exposure as well as the fresh air ventilation rate (12). The ventilation intensity depends on the perceived intervention, and not all places have good ventilation conditions limited by poor economic and environmental conditions (13). The ventilation time is also relatively uncertain about evaluating accurately and scientifically (14). Therefore, it is relatively difficult to eliminate the risk of SARS-CoV-2 transmission through aerosols (15).

Over the past one and a half years, many studies have confirmed the effectiveness of health-protective measures against COVID-19 (16, 17). Before the development of vaccines, wearing masks was regarded as an essential public health measure to halt the transmission of COVID-19 (18, 19). Based on risk management, China has provided medical staff and the public with suggestions concerning using masks with different protection levels, thereby significantly controlling COVID-19 (20). Moreover, compulsory mask-wearing has resulted in a four-fold reduction in daily mortality and a 2% daily reduction in new cases in the United States (19, 21). Mouth and nose droplets from infected patients can easily transmit to other individuals (22). In this context, a recent research by Gharpure et al. (23) confirmed that frequent handwashing is a substantial measure in reducing the transmission intensity of the COVID-19 infection. Additionally, the droplets produced by coughing or sneezing have a 1.2–2.4 m transmission distance (22). Therefore, maintaining physical distance can further reduce the spread of SARS-CoV-2 from person to person (24). An analysis in Wuhan and some lockdown cities in Italy and Spain showed that negligence in maintaining physical distancing had measurable results. The epidemic in these cities quickly peaked (25). There is also credible evidence that a physical distance policy of at least 1 meter may significantly reduce the intensity of infections. As many recent researchers have established, a distance of 2 m may be even more effective (26). However, scholars are aware that physical distancing is not a viable long-term countermeasure in relationship networks (26, 27). Wide-scale immunization and people's voluntary uptake of vaccines are what allows them to live normal lives if the immunization programs are successful (24, 28, 29). The COVID-19 vaccine is seen as one of the requirements for the true and permanent "opening up" of societies worldwide.

On April 13, 2021, the WHO reports revealed that there are currently 235 vaccines under development, 63 of which have entered clinical trials (30). Although these vaccines utilize different development platforms, including classic and mature approaches using inactivated whole virions, live-attenuated, recombinant protein, and vectored vaccines, as well as promising novel vaccines such as the DNA and mRNA vaccines, the S-spike protein is seen as a crucial target of COVID-19 vaccine (31, 32). On July 22, 2020, China officially launched the COVID-19 vaccination and prioritized special groups such as medical staff. On December 31, 2020, the WHO announced the approval of Pfizer Biotech's COVID-19 vaccine, the first emergency use vaccine authorized by the WHO. As of March 31, 2021, major countries or regions severely affected by COVID-19, such as China, the United States, Brazil, India, Japan, and the European Union, have started to vaccinate their populations against COVID-19, aiming to achieve herd immunity by promoting individual immunity against SARS-CoV-2 (1, 33).

Meanwhile, the WHO chief scientist Sumia Swaminatan appealed to those vaccinated to continue to engage in protective health measures such as wearing a mask, handwashing, and keeping physical distance. This urgent message is generally accepted and endorsed globally, chiefly for the following reasons. First, vaccine hesitancy is rising globally, and herd immunity has not yet been achieved (34). Quite a few people are afraid of and reluctant to get the COVID-19 vaccination. Latkin et al. (35) used a socio-ecological framework to explore Americans' intentions regarding the COVID-19 vaccination. The results found that only 59.1% of people intended to get the vaccination. Based on a cross-sectional research of 3,261 adults, Paul et al. (36) reported that 16% of the respondents displayed high levels of mistrust about vaccines, 14% of respondents reported their unwillingness

to get the COVID-19 vaccination, while 23% were unsure. The main reason was that some vaccines had only been authorized for urgent use after their phase II clinical trials (37). Scientific experiments still need to establish whether adverse side effects such as fever, thrombosis, and death, have a causal relationship with the COVID-19 vaccines (38, 39). The AstraZeneca and the Johnson & Johnson vaccines have been abandoned in some countries because of adverse side effects such as thrombosis. Second, the effective protection period of the COVID-19 vaccines is uncertain. Not all animal models perfectly mimic human COVID-19 infection and immune responses (40). Moreover, the longest established protection period for the existing scientifically verified vaccines is only 1 year. Millions of people have been vaccinated with multiple types of vaccines, and the level of antibodies that can effectively neutralize SARS-CoV-2 requires long-term evaluation and monitoring (39). Third, the continued mutation of SARS-CoV-2 has posed severe challenges to the protective efficacy of existing vaccines. By June 15, 2021, the WHO had been officially notified about mutations of SARS-CoV-2 since its emergence. The variants of concern are mainly related to the B.1.1.7 mutation in United Kingdom (Alpha variant), the B.1.351 mutation in South Africa (Beta variant), the P.1 mutation in Brazil (Gamma variant), and the B.1.617.2 mutation in India (Delta variant) (41, 42). Epsilon, Zeta, Eta, Theta, Iota, Kappa, and Lambda are variants of interest named by the WHO.

Although some countries such as China, France, and United States believe that, in general, the mutations of SARS-CoV-2 have not had a detrimental impact on related treatments, drugs, and vaccines, the future risk is still uncertain, and it is a matter of extreme urgency to design more targeted and effective vaccines (43). Lastly, the age for vaccination is generally accepted to be 18 years and older as determined by clinical trials. The participants' physical condition is strictly screened to exclude people younger than 18, and those who are unsuitable for vaccination in China (40, 44). However, in the USA, Pfizer–BioNTech mRNA vaccine clinical trials for children under age 12 are ongoing, and people between ages 13–16 are being vaccinated, and protection is 100%(45). The Australian health authorities recommend the vaccine for anyone 16 years old and over. Additionally, the global distribution of COVID-19 vaccines is not completely fair, especially since developing countries are unable to purchase enough vaccines (46). It can be inferred that there is still a long way to go before worldwide herd immunity is achieved (47). Therefore, although people are being vaccinated, they still need to engage in strict health-protective measures to reduce possible risks in the future.

As of March 31, 2021, in China, five COVID-19 vaccines had been approved for conditional marketing, and the number of vaccinated people reached 170 million. Although COVID-19 vaccines are free and optional in China, the above analysis indicates that vaccine hesitancy, the uncertain protection period, SARS-CoV-2 mutations, and the limited vaccination population pose several challenges for vaccine effectiveness. Consequently, the government has always asked vaccinated and non-vaccinated people to observe health-protective measures such as wearing masks, handwashing, and keeping physical distance. In the current research, we used online platforms in China to recruit 4,540 participants, and we used the propensity score matching (PSM) model to empirically analyze the impact of the COVID-19 vaccination on vaccinated participants' health-protective measures and to further discuss whether participants' protective measures had changed after vaccination. To our knowledge, no other research has examined the impact of the vaccination against COVID-19 on attitudes of people toward protective health measures. It is of crucial importance to understand the factors affecting behavior after COVID-19 vaccination. Vaccinated individuals may represent the most realistic focus of public health communication programs encouraging the continuation of the same countermeasures even after vaccination. As vaccinated individuals begin to constitute a more significant number within the population, maintaining their health-protection measures is paramount. Consequently, there is an urgent need for a more updated and nuanced understanding of attitudes toward protective countermeasures even after vaccination to provide tailored health advice for the public. The findings of this research have potential significance in helping policymakers identify and adapt interventions that increase the implementation of strict countermeasures even after vaccination. It is crucial for public health that such strategies are implemented and rolled out to maximize adherence to the measures among the general population.

The structure of the rest of the paper is as follows. The methodology section presents the data sources and the analytical strategies. Then, the estimated results are set out in the Results and Discussion section. We conclude with possible policy recommendations.

MATERIALS AND METHODS

Data Collection

The data presented in this research were collected from vaccinated and non-vaccinated individuals from the Zhejiang, Hubei, and Shaanxi provinces of China from March 1st to 21st, 2021. These provinces were selected because they represent China's eastern, central, and western economic developments. The vaccine administered in these provinces is SARS-CoV-2 vaccine (Vero Cell) manufactured by Sinovac Life Sciences Co., Ltd. This vaccine is administered in two doses 2–4 weeks apart for people over 18. The data were collected from vaccinated and non-vaccinated individuals. Only those who had received two doses were qualified to complete the questionnaire, and they were asked to upload their vaccination certificates (48). After discarding the 285 blank or invalid questionnaires, we had 4,540 valid questionnaires out of 4,825, a questionnaire efficiency of 94.09%. In the sample, 1,825 participants had been vaccinated, and 2,715 participants had not been vaccinated. Moreover, we took occupation type as the exclusion and restriction criteria for participants. The survey data were not collected from health workers because their occupational requirements, risk awareness, and personal protective measures are likely to be much higher than those of the general population. The inclusion of health workers could have led to biased results. Most importantly, participants are anonymous during the data collection and processing. This research has obtained informed

TABLE 1 | Variables' differences between vaccinators and non-vaccinators.

Variables	Definition and assignment	Vaccinators (A)	Non-vaccinators (B)	Differences (A–B)
Wearing mask	Average time of wearing mask per day in the supermarket, etc. public place (hour)	3.752	3.924	−0.172
Handwashing	Number of times of washing hands per day (times)	4.651	7.953	−3.302***
Keeping physical distancing	Compliance intensity of keeping physical distancing more than 1 meter (1 = very weak, 5 = very strong)	2.085	3.902	−1.817**
Gender	Woman = 0, man = 1	5.016	4.805	0.211*
Age	Actual age (year)	49.205	43.280	5.925**
Education level	Education time (year)	14.205	11.602	2.603***
Individual health risk perception	The COVID-19 seriously threatens individual health. (1 = strongly disagreement, 5 = strongly agreement)	4.209	3.705	0.504**
Public health risk perception	The COVID-19 seriously threatens public health. (1 = strongly disagreement, 5 = strongly agreement)	4.392	3.806	0.586**
Social responsibility	Taking health protective measures is a social responsibility. (1 = strongly disagreement, 5 = strongly agreement)	4.175	3.608	0.567*
Cultural roots	Wearing mask etc. health protective measures is belonged to behavioral culture. (1 = strongly disagreement, 5 = strongly agreement)	3.605	3.610	−0.005
Peer effect	Taking health protective measures is affected by other behavior. (1 = strongly disagreement, 5 = strongly agreement)	4.025	3.042	0.983***
Government supervision	The intensity of government supervision of individual health protective measures (1 = very weak, 5 = very strong)	3.640	3.205	0.435**
Accessibility to health-protection products	It is easy to buy products such as masks. (1 = strongly disagreement, 5 = strongly agreement)	4.016	4.475	−0.459

*, **, ***Represent the significance level of 10, 5, and 1%, respectively.*

consent concerning the scientific use of data and guaranteed participants' privacy.

Variable Selection

The variables included in the research were outcome, treatment, and covariates. The outcome variable is participants' health-protective measures, that is, wearing masks, handwashing, and keeping physical distance. Specifically, "the time spent per day wearing a mask in a public place" in the questionnaire represents wearing a mask, "the number of times of washing hands per day" represents handwashing, and "compliance intensity of keeping physical distancing of more than 1 meter (1 = very weak, 2 = weak, 3 = general, 4 = strong, 5 = very strong)." We selected the COVID-19 vaccination as the treatment variable; if the individual was vaccinated with the COVID-19 vaccine, the value was assigned as 1; if the individual was not vaccinated, the value was 0. Therefore, there were self-selection samples in the treatment variable. In line with related research conducted by Si et al. (49), we selected some other variables as covariates. The variables included gender, age, education level, individual health risk perception, public health risk perception, social responsibility, cultural roots, peer effect, government supervision, and accessibility to health-protection products.

We applied the independent sample *t*-test to analyze the differences in variables between the vaccinated and non-vaccinated individuals. **Table 1** shows that the *t*-test results reject the null hypothesis and that there is no difference between the vaccinated participants in experimental group (A) and the non-vaccinated participants in control group (B). The results in **Table 1** further reveal that compared with the non-vaccinated individuals, the number of handwashing times for the vaccinated individuals is reduced by 3.302, and the compliance intensity for keeping a physical distance of more than 1 meter was reduced by 1.817. However, there is no noticeable difference in the average time of wearing masks per day between the vaccinated and the non-vaccinated participants. Moreover, apart from cultural roots and accessibility to health-protection products, other covariates are also significantly different between the vaccinated and non-vaccinated individuals.

Because vaccination is a voluntary "self-selection" behavior, the differences among some outcome variables cannot be attributed to the COVID-19 vaccination. In addition, they may be influenced by other covariates such as gender, age, education level, individual health risk perception, public health risk perception, social responsibility, peer effect, and government supervision. Therefore, we used PSM to explore the impact of the COVID-19 vaccine on participants' health-protective measures.

Statistical Analysis

Compared with existing research methods, the reasons for using PSM to explore the impact of the vaccination against COVID-19 on participants' health-protective measures are as follows. First, the vaccination is based on the principle of voluntary action. Therefore, the division of vaccinated and non-vaccinated individuals in the sample is not random. Therefore, PSM is used to solve the problem of sample "self-selection" (50).

Second, because the initial endowments of the treatment group (vaccinated) and the control group (non-vaccinated individuals) are different, there is an obvious "selection bias." Therefore, PSM is applied to analyze the consistency of health-protective measures in the treatment group and the control group (51). Lastly, PSM can solve the "missing data" issue by constructing a counterfactual framework to observe the health-protective measures of vaccinated individuals in non-vaccination situations (52). The research steps of this paper are as follows:

The Logit model is employed to estimate the fitted value (the propensity score value) of the conditional probability of participants vaccinated.

$$PS_m = Pr\left[L_m = 1|X_m\right] = E[L_m = 0|X_m] \tag{1}$$

where $L_m = 1$ means participants who have been vaccinated with the COVID-19 vaccine $L_m = 0$ indicates participants, who have not been vaccinated with the COVID-19 vaccine. X_m signifies an observable covariate, such as gender, age, education level, individual health risk perception, public health risk perception, social responsibility, peer effect, and government supervision.

The treatment group and the control group are matched. We selected three matching methods: K-nearest neighbor, caliper, and kernel matching. In particular, K-nearest neighbor matching is based on the value of PSM among the nearest K different groups of individuals. The K was set to 4, and one-to-four matching was performed to minimize the mean square error. Caliper matching refers to matching by restricting the absolute distance of the propensity score. We set the caliper to 0.020 to match observations with a 2% difference in propensity score values. Core matching refers to matching vaccinated participants by setting a propensity score of 0.060 on the broadband and weighted average of the control group samples in the broadband.

The difference in health-protective measures between the treatment and the control group was calculated by the average treated effect (ATT). Finally, we obtained the impact of the COVID-19 vaccination on participants' health-protective measures.

$$\begin{aligned} ATT &= E\left(D_{1m}|L_m = 1\right) - E\left(D_{0m}|L_m = 1\right) \\ &= E\left(D_{1m} - D_{0m}|L_m = 1\right) \end{aligned} \tag{2}$$

where D_{1m} is the health-protective measures of participants vaccinated, D_{0m} is the protective health measures of participants vaccinated (assuming that they are not vaccinated), $E\left(D_{1m}|L_m = 1\right)$ can be directly observed, $E\left(D_{0m}|L_m = 1\right)$ cannot be directly observed, and it is a counterfactual result. Therefore, PSM is an appropriate approach to construct the corresponding substitute index.

Common support domain and balance tests were also conducted. The common support area test determines whether the control and treatment groups have a common support area and a large overlap in the value range. The balance test judges the matching quality by comparing significant differences in covariates between the treatment and the control groups.

RESULTS AND DISCUSSION

Estimation of Participants Selecting the COVID-19 Vaccine

A matching environment with the highest similarity was created to screen suitable covariates. The Logit model was employed to estimate the selection equation for participants' vaccination intention to ensure PSM quality. **Table 2** shows the estimated results of the model. The findings show that gender, age, education level, occupation risk, individual health risk perception, public health risk perception, social responsibility, peer effect, and government supervision can actively drive participants to be vaccinated with the COVID-19 vaccine. Specifically, due to the heterogeneity of perceived risk and fear of death, there was a marked gender difference in vaccine attitudes (53). Consistent with Chu's and Liu (33) related research, our research confirms the enthusiasm and initiative of men in the COVID-19 vaccination. However, previous studies have also reached the opposite conclusion, just as Latkin et al. (35) hold that females generally express greater intentions to obtain a COVID-19 vaccine than males. These findings further suggest that vaccination campaigns should consider gender differences in attitudes and acceptance. The elderly are the primary susceptible group. Statistical data from China, United States, and India also show a higher mortality rate among elderly COVID-19-infected persons (29, 54, 55). Consequently, the older the people are, the stronger they have the intention to be vaccinated. Many studies have reached a more consistent conclusion, that is, the higher the education level of people, the more scientific and comprehensive they will evaluate the safety, effectiveness and side effects of the COVID-19 vaccine. Eventually, they will respond to the government's call and actively vaccinate (48, 56). In our research, we innovatively divide health risks into individual health risks and public health risk perception. Consistent with Cohen and Rodgers (57) and Chen et al. (58) research results, in terms of the prevention and control

TABLE 2 | Estimation results of vaccination selection equation based on logit model.

Variables	Selection of the COVID-19's vaccine	
	Coefficient	Standard error
Gender	1.025*	0.563
Age	0.894***	0.344
Education level	0.626**	0.292
Individual health risk perception	0.902***	0.347
Public health risk perception	0.407*	0.226
Social responsibility	0.702**	0.319
Cultural roots	0.528	0.340
Peer effect	1.505***	0.501
Government supervision	1.024***	0.379
Accessibility to health-protection products	0.305	0.195

*, **, ***Represent the significance level of 10, 5, and 1%, respectively.*

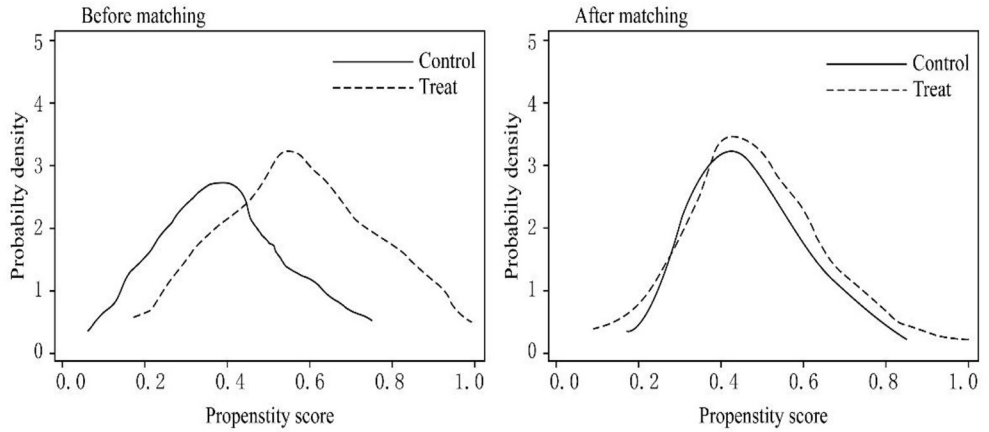

FIGURE 1 | Common support domain of control and treat groups.

of COVID-19, individual health risks and public health risk perception are interrelated and supported. Furthermore, the path from individual health risk perception to public health risk perception is mainly individual social responsibility (59). Moreover, formal social norms (government supervision) and informal social norms (peer effect) have become essential factors to lead people to vaccinate. Our research further confirms the views of Andrews et al. (60), who considered that individual public health behavior has strong externalities, and government supervision and peer effect are reasonable paths to realize the internalization of externalities.

Cultural roots and accessibility to health-protection products have no significant influence on participants' vaccination intention. Cultural roots are the deepest driving force of individual behavior intention and decision (61, 62). Epidemic experience and environmental pollutions are key reasons people wear masks and are embedded in China's behavioral culture and social patterns (63, 64). Thus, cultural roots may conceal the impact of vaccination on people wearing masks and the limitation is discussed in research limitation part. As discussed above, many studies have also confirmed the importance of wearing masks and health-protective measures to prevent and control the spread of COVID-19 (65–67). Therefore, it is believed that under strict health-protective measures, the risk of exposure to SARS-CoV-2 is relatively low, and the time of COVID-19 vaccination can be delayed. Moreover, at the beginning of the COVID-19 outbreak, health-protective products such as masks became strategic materials for competition among countries, thereby underlining the significance and effectiveness of health-protective measures (57, 68). However, the current market supply of health-protective products is relatively sufficient, and participants' enthusiasm for vaccination is not as high as it should be. Consequently, cultural roots and the accessibility to health-protective products cannot drive participants to get vaccinated. Therefore, the current research excluded these variables before PSM to ensure the quality of matching.

TABLE 3 | Result of sample matching.

	Vaccination equation		
	Unmatched sample	**Matching sample**	**Total**
Control group	246	2,469	2,715
Treatment group	52	1,773	1,825
Total	296	4,242	4,540

The Tests of Common Support Domain and Balance

Common Support Domain Test

To ensure the quality of matching, we further discussed the common support area of the control group (Control) and the treatment group (Treat). We drew function density graphs before and after PSM (**Figure 1**). It is apparent from the propensity score values that matched vaccinated individuals and non-vaccinated individuals mostly overlapped, and the overlapping area is the common support area. Therefore, the data employed in the current research have better common support domain conditions; most of the observations are within the common value range. Additionally, in terms of the three different matching methods, the difference in sample loss is small. **Table 3** shows the maximum loss of sample size. The treatment group lost 52 samples, the control group lost 246 samples, and 2,469 samples participated in the matching.

Balance Test

After sample matching (**Table 4**), the overall standardization deviation of the covariate variables was <5%, significantly reducing the overall bias. In addition, the likelihood ratio (LR) value dropped significantly from 46.250 to 7.015–7.270, and the P–R^2 value dropped from 0.615 to 0.024–0.027 after matching in the vaccination equation. The results show that PSM significantly reduces the covariate differences between the treatment

TABLE 4 | Results of balance test.

Matching method	Vaccination equation		
	P–R^2	LR value	Standardization deviation
Before sample matching	0.615	46.250	12.301
K-nearest neighbor matching	0.024	7.270	4.506
Caliper matching	0.027	7.015	4.302
Kernel matching	0.026	7.172	4.206

TABLE 5 | The effect of the COVID-19 vaccination on participants' health-protective measures.

Matching method	Health protective measures	*ATT*	Standard deviation	*T*
K-nearest neighbor matching	Wearing mask	−0.102	0.066	1.54
	Handwashing	−1.749***	0.663	2.64
	Keeping physical distancing	−1.241**	0.577	2.15
Caliper matching	Wearing mask	−0.104	0.667	1.56
	Handwashing	−1.752***	0.656	2.67
	Keeping physical distancing	−1.238**	0.571	2.17
Kernel matching	Wearing mask	−0.102	0.066	1.55
	Handwashing	−1.750**	0.668	2.62
	Keeping physical distancing	−1.240**	0.574	2.16
Mean	Wearing mask	−0.103		
	Handwashing	−1.750		
	Keeping physical distancing	−1.240		

*, **, ***Represent the significance level of 10, 5, and 1%, respectively.*

and the control groups, and the sample matching quality is appropriate.

The Effect of Vaccination Against COVID-19 on Participants' Health-Protective Measures

Table 5 shows the effect of vaccination against COVID-19 on participants' health-protective measures based on three different matching methods. Although various matching methods are applied, the direction and degree of the COVID-19 vaccination influencing participants' health-protective measures are the same, indicating that the estimated results have good robustness.

COVID-19 vaccination does not have a significant influence on participants' mask-wearing, indicating that, in China, regardless of whether people are vaccinated or not, they still choose to wear masks in public places, even in the post-epidemic era (69, 70). Consistent with the research by Liao et al. (71) and Ma et al. (72), our research also confirms that consistent mask-wearing behavior is contributing to the success of China in fighting the COVID-19 outbreak, and it provides a good example for other countries of how to cope effectively with the COVID-19 resurgence. Furthermore, we propose the possible reasons for mask-wearing as follows: First, regardless of the risk level of the COVID-19 epidemic and the degree of herd immunity realization, the Chinese government strictly implements a policy of wearing masks in public places, making mask-wearing a necessary condition for people accessing goods and services (73–75). Second, the epidemic experience is an important driving factor that affects people's behavioral changes. Unlike the traditional rational behavior theory, bounded rationality theory emphasizes forces other than individual welfare that influence behavior (76, 77). Wearing masks may affect people's subjective well-being, such as the perceived need to absorb the fresh air. However, the epidemic experience can make people pay more attention to health safety measures after their vaccination and consistently wear masks in public places (78, 79). Finally, as other scholars have emphasized, wearing masks may be limited by the cultural traditions of different countries (80, 81). If policy interventions are gradually relaxed, the probability of wearing masks will decrease. This situation is more likely to happen after vaccination (73). Consequently, given that herd immunity has not yet been formed, countries should take continuous measures to compel or motivate people to wear masks (82).

COVID-19 vaccination significantly decreases the number of times participants washed their hands by 1.75 per day. It is difficult for people to avoid being in an environment with hidden risks of SARS-CoV-2 infection, such as vegetable markets, supermarkets, and subway stations. No one knows whether an infected person has touched public facilities like railings, elevator buttons, and access switches. Therefore, washing hands frequently has been highly recommended by the WHO in the COVID-19 era. Two aspects can explain the reason for less frequent handwashing after vaccination.

On the one hand, Gharpure et al. (23) argued that, compared with the mask-wearing policy, it is difficult for the government to set out a handwashing policy and to set a minimum standard for handwashing per day. Therefore, handwashing is not a core part of government intervention measures. The number of times for handwashing depends on epidemic risk, living habits, and government messaging (22, 83). Contrarily, vaccination reduces the psychological fear of the risk of exposure to the virus. Studies have confirmed that vaccination can alleviate people's mental states of loneliness, fear, anxiety, and depression during infectious disease outbreaks, strengthening people's conscious performance of health-protective behaviors such as handwashing (84–87). Additionally, other scholars also confirmed that other public health supplies such as hand sanitizer provided by the government after large-scale vaccination have been gradually reduced, which also reduces the number of times people wash hands to some extent (88, 89).

COVID-19 vaccination significantly reduces participants' compliance intensity, reducing physical distancing of more than 1 meter by 1.24 times per day. In public places in China, red lines painted on the ground ensure that, when waiting in line, people comply with physical distancing generally of more than 1 meter. Related research by some scholars has shown that the COVID-19 outbreak extends people's physical and psychological distance (89, 90). The obstacles to implement the policy of

maintaining physical distance are linked to the management and control of public health and of people's needs for close emotional communication (91). Studies have confirmed that the balance point for maintaining public welfare and emotional needs depends on the risk level of COVID-19 (92). Specifically, China has already controlled the epidemic well, and the quick roll-out of vaccination has caused people's risk awareness to decrease gradually. People are no longer limited by space restrictions and by the need for online communication. As a result, social activities have increased significantly (56, 58). Additionally, vaccination has reduced people's exposure to SARS-CoV-2, and the reduction in infections has encouraged their complacency to return to their pre-pandemic physical distancing (93).

As of April 2020, China had controlled the COVID-19 spread. Nevertheless, during the recovery process, there were clusters of COVID-19 cases, indicating a possible fall-off in the intensity of people's protective measures such as handwashing and maintaining physical distance leading to potential COVID-19 resurgence. Despite the current large-scale vaccination program in China, the protection period and effectiveness of the vaccine still require long-term scientific observation. Therefore, it is still necessary for the government to promote health-protective measures with the resumption of work and production.

Research Limitations

Here, we outlined the limitations of our study. First, different vaccines have different efficacies, which calls for different strategies to combat unforeseen variants, such as Alpha, Beta, Gamma, and Delta variants (94). Currently, mRNA vaccines are considered the most protective vaccine with 90–100 efficacy (47). With the increased rate of vaccinations in the USA, the CDC has recommended that inoculated Americans can meet without wearing masks. Consequently, the research is not globally representative. Second, our research does not distinguish among mask-wearing for anti-COVID-19 or for air pollution. This public propensity for protection against air pollution such as smog may have conditioned them to continue wearing face masks. Consequently, the effect of vaccination against COVID-19 on wearing mask may be over-estimated. Third, ventilation is a primary control strategy for infectious diseases, which promotes the air dilution around a source and the removal of respiratory viruses (95). Recommendations have been introduced to reduce the transmission risk of virulent airborne viral particles by increasing ventilation rates, expressed in air-changes-per-hour (ACH), effectively improving the dilution of airborne pathogens via mechanical ventilation (96). However, limited to the original data acquisition, this research did not analyze the impact of the COVID-19 vaccination on ventilation measures. Finally, the PSM model is employed to analyze the net effect of vaccination against COVID-19 on participants' attitude toward protective countermeasures. However, the PSM model cannot simultaneously address the effects of other variables such as gender, age, education level, individual health risk perception, public health risk perception, social responsibility, peer effect, and government supervision on participants' health-protective measures. These shortcomings provide exciting avenues for future research.

CONCLUSIONS AND IMPLICATIONS

The tremendous damage caused by COVID-19 to global economic and social development is beyond statistical estimation. It is a matter of grave concern that SARS-CoV-2 traceability network is not yet in place. Human experience in combating infectious diseases shows that vaccines are the most fundamental measure. Unfortunately, the vaccine's protective efficacy, protection period, and the constant threat of variants challenge to the effectiveness of the COVID-19 vaccination. There is still a long and difficult path to the formation of worldwide herd immunity.

Consequently, vaccinated and non-vaccinated individuals should continue to engage in personal health-protective measures. This paper collected data from 4,540 individuals (1,825 vaccinated and 2,715 not vaccinated) in China and applied the PSM model to analyze the impact of vaccination against COVID-19 on participants' health-protective measures such as wearing masks, handwashing, and keeping physical distance to answer whether participants' protective measures against a resurgence of SARS-CoV-2 were weakened after their vaccination.

The main findings show that participants' gender, age, education level, individual health risk perception, public health risk perception, social responsibility, peer effect, and government supervision are the main factors affecting their vaccination choice. However, cultural roots and accessibility to health-protection products do not significantly influence participants' vaccination intention. Vaccination against COVID-19 significantly decreases participants' handwashing frequency by 1.75 times per day and reduces the compliance intensity of the observation of physical distancing of more than 1 meter by 1.24 times per day. Surprisingly, vaccination against COVID-19 does not have a significant influence on mask-wearing. Although China has controlled the COVID-19 outbreak well, people still choose to wear masks, providing a valuable example to other countries to successfully combat the epidemic. Of course, the compliance behavior model of mask-wearing may be strengthened by the COVID-19 experience, or due to culture, air pollution, and previous public health education impact. However, we should also accept that handwashing and keeping physical distance have gradually weakened, indicating that until herd immunity is achieved, China is still threatened by another outbreak of COVID-19.

Restoring economic activities around the world and strengthening people's health-protective measures are complementary rather than contradictory aims. The current research provides suggestions for policymakers to sustainably prevent and control COVID-19. First, the government should continually strengthen interventions related to people's health-protective measures. Specifically, the government should use multiple channels to promote the importance of frequent handwashing for reducing SARS-CoV-2 spread. In addition, the government should continue to strengthen the practice of physical distancing in public places to reduce the risk of human-to-human transmission of the virus. Second, the government

should continue to increase the free supply of hand sanitizer, masks, in public places to reduce the cost to people of taking health-protective measures. Finally, the government should continue to trace the source and mutations of SARS-CoV-2, design and develop targeted vaccines, continuously improve the effectiveness of the COVID-19 vaccines, and finally achieve group immunity.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

RS and YY contributed to the conception and design of the research. XZ and QL performed the statistical analysis. NA wrote sections of the manuscript. All authors participated in obtaining data, contributed to the article, and approved the submitted version.

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A Local Health Situation Room for COVID-19: Recommendations for Decision-Making From a Higher Education Institution in Mexico

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Introduction: The Situation Room is a physical or virtual space where experts systematically analyze information to characterize a health situation, especially during emergencies. Decision-making processes are made toward solving health needs and promoting collaboration among institutions and social sectors. This paper presents the context and circumstances that led the University of Guadalajara (UdeG) to install a local health situation room (HSR) to address the COVID-19 pandemic at this institution based in the state of Jalisco, Mexico, a narrative is also made of its working processes and some of its results.

Methods: The design of this situation room for COVID-19 was based on the methodology established by the Pan American Health Organization (PAHO)/WHO. This local-type situation room was installed on February 12, 2020. The health problem was characterized, and strategic lines, objectives, and goals were established; the first analysis was derived from an action plan deployed at the UdeG. The strategic lines were situational diagnosis, preventive actions, and containment strategies.

Results: The situation room influenced the activities of the UdeG before the epidemic cases started in the state. One of the actions with the greatest impact was developing a mathematical model for predicting COVID-19 cases. Subsequently, new models have been developed according to the epidemiological evolution of the disease, helping manage the epidemic in the state. Another important result was the early closing of face-to-face university activities, reducing contagion risks and the mobility of more than 310,000 students, faculty, and administrative personnel throughout Jalisco.

Conclusions: A consequence of the closure was that the confinement generated by the pandemic was the change to virtual meetings from April 2020 to date; but at the same time, this working format was a strength, since it influenced the decision of the

university board to change all the academic activities to virtual format before other educational, economic, and social activities in the state did. By April 2020, the situation room transcended its institutional boundaries and was invited to participate at the Jalisco State's Health Committee. Its recommendations have helped to maintain the state with one of Mexico's lowest COVID-19 incidence and mortality rates.

Keywords: COVID-19, public health, decision making, pandemics, epidemiology

INTRODUCTION

The Health Situation Room (HSR) is a term adopted from "war rooms", which refers to closed physical spaces, which were housed in some secret place during wars where the military chiefs with knowledge about war strategies, international political conflicts, specialists in political communication, and key members of the government gather to analyze and decide the actions to take during war conflicts (1). It has been reported that there was a war room during World War II installed by Winston Churchill and that probably helped him to win together with the allied countries.

According to the WHO and the Pan American Health Organization (PAHO), epidemiology is a health science that is responsible for studying the distribution and the determinants of disease or health events and their application for the control of diseases and other health problems (2, 3). Epidemiology has successfully applied some terms and strategies that are used in wars to carry out its work, considering that the disease or event that affects populations is the enemy to be overcome. In this sense, the "war room" is a military strategy that has been transferred to the health field by the international organizations and some countries to attend to their health contingencies or emergencies, epidemic outbreaks, whether they be disturbing phenomena (natural, artificial disasters, etc.), administration of sanitary risks, epidemiological surveillance, cost-benefit analysis, and other events. By adapting these processes and activities, the "war rooms" were transformed into "HSR" (4) that are installed to carry out a situational health diagnosis (5) intended to respond to the health events through decision-making, based on timely and accurate information, and the experience of its members.

The situational health diagnosis later evolved to be called Health Situation Analysis (HSA). PAHO points out that HSA is the production of scientific evidence to support decisions on health issues (3). The generation of this evidence can occur through the collection of morbidity and mortality data, the analysis of these data, and the dissemination of the information obtained from the analysis. In many cases, the evidence comes from the results of research based on different studies used in health, such as population studies (3). But HSA has also been identified as management tools that serve to plan and prioritize health actions, optimizing economic, physical, and human resources, in addition to being an instrument that calls for intersectoral work. The goal of the HSA, therefore, is to contribute to the decision-making that allows solving the health needs of the population (6), with the intention of facilitating health management in a proactive, timely, and participatory manner, in addition to promoting collaboration with various actors and social sectors (7).

On the other side, the HSR is defined generically as the space where the HSA takes place. Even more, HSR is understood as "the physical and virtual space where health information is systematically analyzed by a work team to characterize the Health Situation of a population, especially during emergency situations. The information is presented and disseminated in various formats, such as tables, graphs, maps, technical documents, or strategic reports to make decisions based on the evidence; in this way, the HSR becomes an instrument for institutional management, political negotiation, the identification of needs, the mobilization of resources, and for the monitoring and evaluation of health interventions" (4). The main objectives of an HSR are to promote the use of epidemiology for health management, strengthening analytical capacities at different levels of the health system, respond to emergency situations based on epidemiology and HSA, make decisions based on evidence, and lay the foundations for the development of an epidemiological intelligence service with daily analysis of the health situation beyond the crisis (4).

The University of Guadalajara (UdeG) is the second-largest higher education institution in México with more than 310,000 students and is based in the state of Jalisco, Mexico. It is organized in 16 higher education centers (*campi*), more than 170 high schools, and one virtual education system, distributed all over the state. This conglomerate of *campi* and schools conform to what is called the University Network of Jalisco. The Health Science Center integrates more than 130 educational programs in the area of health, based at the *campus* located in the city of Guadalajara, capital of Jalisco.

The Council of the Health Sciences Center of UdeG approved, on February 14, 2020, the installation of an HSR to attend the COVID-19 pandemic under the Agreement Point 47/2020, which established that its creation was authorized for the purpose of "identifying, analyzing, proposing, notifying, coordinating, operationally and technically, the study, prevention, and intervention actions in different areas and levels of the university's community and the society, and regarding of the advance and development of the ongoing pandemic by SARS-CoV-2" (8). Therefore, the members of this HSR set the objectives of this work:

- The grounds and circumstances on which the UdeG installed a local-type HSR to attend the COVID-19 pandemic at the beginning of 2020 and the elements that were taken into account for its creation are first presented;

- The narrative of the initial analysis and decisions taken inside the room to lead the pandemic's attending efforts are then mentioned;
- Later, the account of the actions taken is made, along with its working processes and the main results obtained to date.
- Finally, the limitations of its results and the near future position of this higher education institutional health tool are described.

METHODS

The design of the UdeG's HSR for COVID-19 (UdeG-HSR) was based totally on the implementation methodology of Situation Rooms established by PAHO/WHO for the Region of the Americas (4). According to this methodology, there are four types of HSRs: local, county, state, and national. The one we are reporting here is a local-type HSR.

The objectives of an HSR should be (a) detecting and responding to communicable health problems on a timely, complete, and regular basis, (b) handling high-quality information, early detection, and prediction of epidemics, (c) providing an intervention plan during epidemics, and d) efficiently monitoring the planned intervention. These objectives are achieved through the implementation of four very precise actions: (1) training in epidemiology, (2) strengthening laboratories, (3) making communications more efficient in the health sector, and (4) giving special attention to health systems as a front line for health surveillance. According to these definitions, the operation of a situation room is based on three elements: the collection and processing of data, the analysis of the data, and the generation of the analysis products.

Therefore, installing this UdeG-HSR followed the next procedure, based on the aforementioned PAHO/WHO recommendations:

1. An initial request from the Provost of the Health Sciences Center was issued to the Department of Public Health, for the UdeG-HSR design and integration.
2. Invitations to the participants that would integrate at the UdeG-HSR.
3. Select the sources of information, the indicators that would be worked, and the databases that would be consulted.
4. Enable the physical space and the necessary resources to access valid and reliable data and information to carry out the HSA. This implied the use of statistical analysis systems, geographic information systems, trends, and inequity analysis systems.
5. The initial collection of the data available at the time of start-up and selection of the indicators that would be analyzed at the UdeG-HSR.
6. Encourage the analysis process so that the members of the HSR made the appropriate decisions based on evidence, with all the computer and communication resources during the sessions at the physical space, or remotely.
7. Constant and permanent collection of the data that would be generated and updated of the indicators subject to analysis by the participants.
8. Generate the elements to obtain an initial diagnosis, identify its determinants and risk factors, define priorities, carry out preventive actions, and identify potential needs for technical cooperation.
9. Generate specific prevention and effective communication actions for the entire community of the UdeG.

These recommendations were set at the forefront strategy of the UdeG-HSR with only minor adjustments. Nevertheless, the authorities and coordinators imprinted their particular operative functioning due to the conformation of the University Network and the local-type configuration of this HSR.

At the request of the provost of the Health Sciences Center, two meetings were held in early February 2020. During the first meeting, the pertinency for the creation of an HSR was identified, also the advantage of having that local-type HSR, according to the classification of PAHO/WHO (4), as a response tool for the University; another action at that first meeting was the profile definition of those who would participate at the room. In the second meeting, the invitation letters were delivered, and the roles of the invited faculty members, the characteristics of the meetings, and the physical working areas were defined. In this way, on February 12, 2020, the first formal meeting took place, aimed at installing it, and having the first working session at UdeG.

RESULTS

Initial Analysis and Decision-Making

In January 2020, the Health Sciences Center and the whole University Network had already undertaken some prevention and sanitary actions for all the institutions, but it was not until the UdeG-HSR was formally installed that a catalog of data-based measures was communicated to all the institutional networks. To make this, the room was organized into two groups: the analysis group of the HSR (HSR-AG) and the HSA-extended group (HSA-e). The HSR-AG was integrated by a president (the President of UdeG), a general coordinator of The Provost of the Health Science center, an executive coordinator (the Chief of the Public Health Department), and six more specialists, while the HSA-e group was integrated by a technical coordinator, two PhD students, and 14 more members (9). After being informed of the existence of the UdeG-HSR, the Governor of Jalisco invited the president and the general coordinator of the HSR-AG, to participate at the State's Health Committee, to contribute to the analysis of the pandemic development at the state and dictate the actions to control it there. The comments and inputs made by these two representatives were the results of the HSR-AG and the HSA-e group's work.

It is worth mentioning that among the members of the HSA-e group, there were four epidemiologists, two molecular virus diagnosis researchers, three infectious diseases researchers, an expert in community nursing, one applied psychology, and one immunology researcher. During the meetings held over the first month, the pandemic problem at UdeG was elucidated and the strategic lines, objectives, and goals were

established, which resulted in an Action and Execution Plan (10). This Plan was presented to the university general council on March 17, 2020, and distributed to all the University Network for its execution. The strategic lines presented on that Action and Execution Plan for the UdeG-HSR were the following:

1. Preventive actions (information for the university community). This strategic line allowed to estimate the intended coverage of the exposed population groups of the community, applying the most appropriate prevention or control measures, such as health protection, sanitation, and epidemiological surveillance.
2. Control strategies. Measures aimed at the prevention and protection of community health, necessary to adapt and create a culture of prevention.
3. University's Situational Diagnosis. Analyzing the new reality in the face of the COVID-19 pandemic, for decision-making, articulation, and directionality of plans, training programs, control, and monitoring.
4. Identification of the determinants and risk factors. Analysis of the indicators of determinants for the health status of the university community, recording vital activities and surveys for data administration.
5. Contact and support of suspected cases. Deployment of a surveillance program for those positive and suspected cases, by analyzing the data to provide care recommendations, and presentation of a proposal to strengthen prevention and containment measures.
6. Technical reports. Generation of analysis and results reports from the meetings, directed to the HSR-AG and the general council. Those reports contributed to the preparation of periodic messages to the university community.
7. Epidemic monitoring. Provide health information to all the University Network, monitoring the trends of the COVID-19 cases, through the analysis, interpretation, and contextualization of national, state, and local data.
8. Priority definition. The analysis allowed identifying priorities and offering interventions for decision-making aimed at evaluating the results and the impact it generated in the university community.
9. Evaluation. In terms of evaluation, the UdeG-HSR undertook a combination of quantitative and qualitative methodologies in order to promote compliance with the programs for the improvement of health actions, contributing to the orientation of strategies, fulfillment of the goals, and applying the planned methods and procedures with constant monitoring of the event.

These nine strategic lines guided the work of the UdeG-HSR, keeping its main objective in view and achieving the established goals. The main objective of the situation room was "to define the actions that will be carried out by the UdeG to attend the COVID-19 epidemic by SARS-CoV-2, both for the prevention of contagion and the diffusion of information toward the university community and the adequate handling of suspicious cases on the part of the dependencies of the Network." Furthermore, four specific objectives were identified:

1. Disseminate the preventive messages of COVID-19 throughout the University Network.
2. Implement the infrastructure and resources to apply effective actions for the management of suspected COVID-19 cases.
3. Reduce the risk of contagion by COVID-19 at the university areas.
4. Continuously evaluate compliance with the objectives of the Action and Execution Plan.

Finally, the goals established at that time were the following:

1. An Action and Execution Plan for the prevention and management of suspected cases of COVID-19 was distributed to all the University Network on March 17, 2020.
2. All the University Network disseminating the information material on COVID-19 as of March 16, 2020.
3. All the University Network with access to a service area for suspected cases of COVID-19 as of March 20, 2020.
4. All the University Network with access to trained personnel to handle suspected cases of COVID-19 as of March 20, 2020.
5. All cases throughout the University Network with acute respiratory symptoms suggestive of COVID-19 were timely attended and adequately referred.

These elements were the starting work for three consecutive meetings in the generation of the Action and Execution Plan that served as the basis for the activities and recommendations that this HSR issued to the university authorities to face the COVID-19 pandemic in a timely manner and prevent, as established in the general objective, contagion among members of the university community, and the timely dissemination of quality information for their care. As of that date, the participants met every week 26 more times, physically until March 17, and virtually through videoconference, from March 24 to date.

Working Procedures and Activities

The UdeG-HSR soon had direct involvement in the actions of UdeG. One of the elements with the highest impact was the implementation of the predictive model of COVID-19 cases, which was based on the incidence of cases and the national population parameters, to predict the possible number of cases that would occur on the following days/weeks. Section 3.4 will detail these models.

As of March 19, when the University closed its doors, the UdeG-HSR continued having weekly virtual meetings through a videoconference platform. This implied that the members became familiar with these platforms but did not restrict the wealth of contributions and observations that were generated to inform the university authorities about the pandemic evolution and support them in making decisions for the community.

As established in the strategic lines of the room, three technical reports were issued during 2020, which contained a series of recommendations for the management of the pandemic at the University. The characteristics of each report are:

- Technical Report no. 1. Issued on March 19, 2020, and recommended that university authorities recognize that COVID-19 was a real threat against which they should disseminate the appropriate information and be prepared

to act; promote the active participation of the university community in actions for the prevention and containment of COVID-19 cases in accordance with the state, national, and international guidelines, and apply the guidelines of the Action and Execution Plan issued by this UdeG-HSR (not published and used for internal purposes only).

- Technical Report no. 2. Issued on April 7, 2020, and recommended that the university authorities continued with the academic activities of the 2020-A term in a virtual format until the end date of the courses scheduled by the General Coordination of School Control. Maintain administrative activities to a minimum in all *campi* of the University Network until the close of the 2020-A term and suspend the previously scheduled academic activities of the 2020 summer term, so that this period could be used for regularization activities of the 2020-A term, privileging non-contact modalities. Finally, integrate a Specialized University Committee to update the Institution's Educational Model that allowed to face this and other types of contingencies in a timely and flexible way, without affecting the performance of students, teachers, and administrative personnel (not published and used for internal purposes only).
- Technical Report no. 3. Issued on October 22, 2020, with the annual activity report of the UdeG-HSR, in which all the work carried out, the projects that derived from it and the communication and dissemination work of scientific and preventive information for the university community was reported (not published and used for internal purposes only).

Weekly reports were carried out in which data were collected by selecting the population indicators for epidemic surveillance based on the most appropriate sources of information, through the constant updating of databases and from the information that came from the different agencies, such as the Ministry of Health (both federal and state levels) official technical communications. Subsequently, an analysis was carried out to support the management of the monitoring and evaluation of the scenario. Those reports were created based on the preparation of information sheets, in addition to carrying out the corresponding preparation of the presentations for each session. Those presentations included fundamental sections where the agenda of the day was presented.

In addition, these activities were made: a series of TV, journals, and radio interviews were given by the members of the UdeG-HSR; a dissemination plan for the university community where active participation in the mass-media was carried out; on a preventive basis, information campaigns were designed and published by the Social Communication Office with prevention measures, official announcements, and news, for example, "take care of COVID-19" and "protect yourself", among others. The General Provost handed nine reports and memos related to the work of the UdeG-HSR, 12 press conferences were organized by the UdeG Media office, 68 press releases highlighted by the UdeG press office, and about 200 "Coronavirus, The Pandemic" TV programs cast by channel 44 (UdeG official TV channel). The official communication website was created to publish all the information generated; in addition, Google Trends reported 873 direct searches with the word "Test COVID UdeG", 384 direct searches with the word "COVID UdeG", 32,800 results associated Google with a "UdeG Situation Room", and 125,000 results associated with the "UdeG Situation Room", with 350 interviews in different media. All this activity occurred to sensitize the university community to maintain prevention measures and actions against the COVID-19 pandemic.

Most Remarkable Results

One of the actions that have had the highest response on our university community was advising the different *campi* and high schools on how to proceed to prevent the disease. This information, together with the Action Plan designed by this HSR, was implemented through the operative teams. These teams were called Operative Rooms or Auxiliary Commissions at the different centers of the University Network depending on their physical and community size.

During the execution of the Action Plan, a large number of direct and indirect results were obtained, some of the direct results are the abovementioned predictive models that estimate the magnitude of the epidemic in the state of Jalisco and the University Network, with monthly updates of the disease; the Geospatial Analysis of Jalisco and the central-western region of Mexico, through 24 presentations and 11 special reports published on the official website of the pandemic, focusing on the analysis of suspected and confirmed cases, and incidence and mortality rates at different levels of disaggregation; permanently monitoring the epidemiological panorama at international, national and state levels, and the preparation of a weekly synthesis and epidemiological report, was presented at every meeting of the HSA-e group. Another activity was the training of the University Network teams, based on the Operative Model of the University Network creating a MOOC-type course-workshop which allowed to face from the beginning any eventuality and handling of suspected cases at the university network, this activity could not be deployed without the collaboration of the Medical Unit of UdeG. The Integral Psychological Care for Well-being Clinic (CAPIB) was created offering online psychological counseling for students, free of charge, with 24/7 service; the Strategy for the Diffusion and Dissemination of Science program was created to develop the information campaigns aimed at the university's and state's community; also, the HSR-AG designed the University Epidemiological Surveillance Project, establishing the bases and guidelines for epidemiological surveillance at the return to personal classes at the university facilities; other research projects that are in process from the departments of Molecular Biology, Public Health, and Applied Psychology, these projects are detailed below.

Indirect results obtained by the work of the UDG-HSR are the following: a Call-Center was established at the UdeG that, as a support for the Ministry of Health of the Government of Jalisco, which goal was to help the population to identify the risk of having the disease and, when appropriate, schedule them for the RT-PCR, antigen or antibody tests at the COVID-19 diagnostic laboratories; the COVID-19 Diagnostic Laboratories was organized in a Diagnostic System, which came into operation on April 16, 2020 and included 10 diagnostic laboratories at

the University Network where they run the tests as a Drive-Thru service; this system also includes the Rapid Test Center for antigens and antibodies detection. Another indirect result is the participation at the Radar Jalisco strategy, coordinated by the Ministry of Health of Jalisco, where the laboratories of UdeG and the Civil Hospital of Guadalajara collaborated in the application of RT-PCR tests and reporting the results. Another important result is the online system that evaluates the risk of contagion, designed by a group of researchers at the Engineering Sciences Center, this system is offered on a website that is linked to the Ministries of Health (state and federal) where individuals can evaluate the infection risk on recent days and make specific recommendations according to the result obtained. The project proposal "Am I a COVID-19 case?" with the collaboration of a group of physicians working at the Civil Hospital of Guadalajara that addresses the crisis or lack of information in the population about the symptoms and the procedures to follow in case of being virus carriers or having health complications.

The Predictive Models and Other Research Projects

To estimate the magnitude of the pandemic, as described before, the HSR-AG developed several predictive models. The first model was presented on February 28, 2020, as a written report at the HSA-e group meeting, this model was based on epidemiological data from the John Hopkins University & Medicine, Coronavirus Resource Center (11), and the Mexican Ministry of Health data resource site (12) monitoring systems. This model located the day on which there would be a turning point for the increase in cases, from which the HSR-AG raised a recommendation to close the University on March 19, 2020. On March 30, the HSR-AG invited a group of mathematical modeling experts from our University and data science associations to create a new model. Its objective was to estimate the increase in infections in the following days and the level of citizen participation in the prevention measures implemented by the state, based on the SEIR model (which considers the susceptible, exposed, infected, and recovered population). Based on this analysis, a 40% citizen participation in prevention measures was estimated. The model recommended implementing measures to achieve 60% participation, estimated to avoid exceeding the state's hospital capacity. Consequently, the state authorities considered this recommendation and strengthened the supervision of prevention measures and communication of risks to the population.

Later this year, the REPLICA model was created in collaboration with researchers from the University of California and the University of Georgia (13). The REPLICA model contributed to decision-making for the economic reactivation of the state in a staggered manner and according to the geographical distribution of economic activities in the state. The model showed that closing schools and using face-masks would maintain contagion below the line of saturation of health services. Authorities of Jalisco State implemented the measures and kept Jalisco with one of the three lowest incidence rates in Mexico last year that otherwise will put in trouble the health system. The detailed technical reports on the construction of these models and the recommendations issued from them are published on the website of the UdeG (14) and were disseminated through press conferences.

These reports had a high influence in determining the academic activities at the university, advising to continue online classes, and keeping students and teachers at home, to avoid or reduce the risk of contagion. These reports served also as input to the Health Committee of Jalisco for the decisions and actions that took place at the state level. The main limitation of these models was the imprecision due to the different factors involved. However, they gave an overview of trends, which contributed to more informed decisions.

Scientific progress during the health contingency was also essential to know the behavior and development of the pandemic. For this reason, some members of the HSR-AG along with other UdeG researchers developed a group of scientific projects that contributed to this aim, and their results have already been published or still in press. Some of these projects are:

- Vitamin D and COVID-19: A review on immunomodulatory effects of vitamin D in the prevention of severe COVID-19 (15);
- Vitamin D Levels in COVID-19 Outpatients from Western Mexico: Clinical Correlation and Effect of Its Supplementation (16);
- Association of Food Intake Quality with Vitamin D in SARS-CoV-2 Positive Patients from Mexico: A Cross-Sectional Study (17).
- Factors related to COVID-19: COVID-19 Screening by Anti-SARS-CoV-2 Antibody Seropositivity: Clinical and Epidemiological Characteristics, Comorbidities, and Food Intake Quality (18).
- COVID-19 diagnosis: RT-qPCR Assays for Rapid Detection of the N501Y, 69-70del, K417N, and E484K SARS-CoV-2 Mutations: A Screening Strategy to Identify Variants With Clinical Impact (19).
- Effect of vaccination against COVID-19: Neutralizing Antibodies Titers and Side Effects in Response to BNT162b2 Vaccine in Healthcare Workers with and without Prior SARS-CoV-2 Infection (20).

DISCUSSION

The main results of the UdeG-HSR implementation were (1) creating an HSR based on the PAHO/WHO model to respond to health problems as other Latin American countries have done; (2) organize its members in two groups, the HSR-AG and the HSA-e groups; (3) the support to the institutional and state's governmental levels; and (4) effective communication of the results to the university network and the community of Jalisco.

UdeG-HSR Compared to Other Latin American HSRs

The PAHO/WHO model for HSRs defines a specific set of principles. According to the level of application, they can be national, state, county, or local type. In comparing the functioning and results of UdeG-HSR with other Latin American

experiences we found that in Argentina, Brazil, Costa Rica, Venezuela, and Mexico, there have been similar efforts, following the same PAO/WHO model but sometimes with different objectives (not everyone attending COVID-19). In Argentina to start, the federal government installed a state-type HSR on each one of its departments, aimed to analyze the situations of departments and to generate actions according to each department's characteristics (21), but following the same steps as the UdeG-HSR. From that point, a National Program of Healthy Cities, Municipalities, and Communities was created to identify health problems in their departments, prioritize them, and define the plans and programs that would be implemented, all from the perspective of healthy municipalities and communities (6, 21).

A different experience took place in Brazil in 2010, when they promoted the use of data to offer dynamic diagnoses and improve the health of the population through a National-type HSR, thus making it possible to prepare plans that were compatible with the identified needs, to promote the improvement of the health care system which results allowed the application of new public health policies (22). In Costa Rica, they used to have expert meetings whose main purpose was the discussion toward consensus for the standardization and dissemination of guidelines in health services for daily practice. A methodological proposal was developed which included the development of strategic lines, as UdeG-HSR did, that resulted in the description of the historical, political, socioeconomic, and demographic context of the population, in addition to the analysis of the quality monitoring statistics. The data on the life and wellbeing of the population served for the identification of priorities proposing health interventions to be able to evaluate the impact of public policies, programs, and health services promoting social participation (23).

The National-type HSR created in Venezuela in 2018 intended to have a better interpretation of the health and disease processes. All the administrative processes could be understood in a better way since the planning prior to the intervention at the cities and departments. Analyzing data in a more accurate way for the main causes of morbidity and mortality, health promotion, and approach to public policies to meet local, national, and regional indicators (24).

Regarding the current pandemic, again in Argentina a COVID-19 National-type HSR was created, where an epidemiological analysis of the disease situation was carried out at the international, regional, and national levels (25). All the cases were studied and reports were issued for the federal government and recommendations were communicated to the community. Epidemiological and genomic surveillance reports were also made every month to provide updates on the current situation of the disease. They have been reporting since March 2020, like UdeG-HSR. The government of Costa Rica created a National HSR on July 28, 2020, in response to the COVID-19 pandemic. They hold a permanent meeting, as the HSA-e group has made, where the Ministry of Health and the Social Security were converted to emergency care areas. Permanent evaluations of the epidemiological indicators are carried out in quantitative analysis (23).

Finally, in Mexico, the response to the disease involved timely and immediate actions by various states of the Republic, operating manuals for the epidemiological and sanitary intelligence units were published by the Mexican Ministry of Health, where the implementation of Crisis Rooms and Intelligence Rooms constituting another epidemiological tool for decision-making in Public Health based on Evidence (26), however, the federal government did not call them HSRs. Such is the case of Oaxaca, a southern state of Mexico, where a crisis room was implemented as part of a COVID-19 Health Operational Command (27), whose purpose was intersectoral integration, generating a link with the "Emergent Plan of Comprehensive Approach for the Prevention and Control of Respiratory Infection by COVID-19 in the state of Oaxaca", where joint agreements were reached establishing the objectives and strategies to carry out the corresponding activities.

As can be seen, these Latin American countries have implemented situation rooms at different levels, they all used the same PAHO/WHO model as the UdeG-HSR. The grounds and processes remain similar along with these countries, though some operating activities and implementation have been different. In the end, the results are very similar: a group of experts addressing a health situation based on quality data, adequate analysis, and a strong methodology and support from the authorities.

Organization and Limitations

The UdeG-HSR has worked under the situation room model generated by PAHO/WHO for more than 1 year. Though it followed the recommendations for its organization and operation, this HSR was organized into two groups: the HSR-AG and the HSA-e groups. This arrangement was considered to widen its scope at the university network because the first group was focused on the analysis of the evolution and impact of the pandemic, and the second was to recommend the strategies and operative activities at the institution.

However, in light of the different contexts where HSR have been implemented in other Latin American countries (28), we identify that this room would be limited in its actions because of the Local-Institutional type, that is, it was not installed by a county, state or federal health ministry; therefore, the impacts may not reflect the actions as widely and adequately as we would expect. Another situation is that not all the faculty or experts who make decisions at the University Network participate in the room, and this can constrain the decisions taken or the actions derived from it. The impact, as mentioned before, maybe reduced for these and other reasons, but it can only be measured when the corresponding evaluation will be carried out at the end of 2021 as planned.

The University Network is ready to receive students and faculty, the return to the university has been delayed until October 15, 2021, however, the UdeG-HSR and the authorities have declared that the control of the epidemic lies in joint responsibility with the university community. A return-to-classes plan has already been prepared to keep everyone safe when the conditions are set properly in Jalisco and Mexico. At the beginning of 2021, the Provost of the Health Sciences Center authorized the continuity of the situation room for this year,

with the agreement of the University's President. Both groups will continue working with minor changes and additions in their integrating members and their functions.

Government Support and Indirect Results

Most of the reported projects are concluded, but there are some other research projects and publications in planning or development, they are focused on the epidemiologic, molecular biology, public health, and psychology characteristics of the disease. The internal activities will also continue and the two groups will maintain their collaboration with the state's Health Committee and with other Universities or Institutions, to support a positive Public Health impact on the population, containing or controlling the pandemic. The indirect results of the UdeG-HSR were mainly over the activities of the state, thanks to the openness of the ministry of health and the governor of Jalisco. It is clear that an institutional local-type HSR cannot limit its work for in-house benefit only; therefore, the results and impact will go beyond its boundaries and surely will affect the near society.

Communication and Impact on the Community

In sum, the creation of the local-type UdeG-HSR had a positive impact as it provided data-based decisions and communication resources to issue the necessary recommendations and strategies as a response to the COVID-19 pandemic, whose main focus was monitoring and responding to a health problem with public health measures, identifying the risk factors and predicting its spread rhythm and time.

One of the most evident impacts of the UdeG-HSR is the incidence and mortality rates at the state of Jalisco, reported among the lowest in the country by the time this article was written. For instance, in January 2021, the federal government reported that there were 53,810 confirmed cases and 6,254 deaths in Jalisco due to COVID-19, the fifth-highest (out of 32) in Mexico in both indicators (29). In spite of these absolute numbers, the preventive measures implemented at the state took the incidence rate to 31.9 cases per 100,000 inhabitants, and the death rate was 74.3 deaths per 100,000 inhabitants, which located Jalisco at the 13th and 28th positions in Mexico, respectively (29, 30), both of them below average, and among the middle and lowest in the country.

CONCLUSIONS

This study shows the actions taken by the UdeG-HSR in face of the COVID-19 pandemic. The conclusions are:

1. This HSR was created as a local-type room, therefore, its scope was limited to the institution's boundaries. However, due to the relationship with the state government, its actions and recommendations went beyond it.
2. The timely installation and work of the UdeG-HSR helped the state of Jalisco to maintain one of the lowest incidence and mortality rates in the country, in part because the institution maintained virtual activities since last year avoiding the mobilization of more than 310,000 students, faculty, and administrative personnel.
3. There were direct and indirect products of the situation room, one of the most important was the mathematic models to analyze the pandemic evolution, which has evolved.
4. Communicating campaigns and programs were effective to target the university community; the response was immediate and kept everyone at home.
5. The evaluation of impact and effectiveness has not been done, yet it has been scheduled for late 2021. This evaluation requires a validated methodology and analysis criteria that are at a preparation phase, as mandated at the Action and Execution plan.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

JM and GM contributed to the conception of the UdeG-HSR. JM, GM, IR, DR, and AL contributed to establishing its fundament. JM is the general coordinator of the UdeG-HSR, represents it in the health group of the State Government, and has managed its relationship with different sectors. GM is the executive coordinator of the ISS analysis group and has represented it in the state government health group. IR was the technical coordinator for the expanded UdeG-HSR group. IR, DR, and AL wrote the first draft of the manuscript. All the authors contributed to critically reviewing it for important intellectual content and approved the submitted version.

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Why Canada Is in Court to Protect Healthcare for All: Global Implications for Universal Health Coverage

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Countries worldwide are currently endeavoring to safeguard the long-term health of their populations through implementing Universal Health Coverage (UHC), in line with the United Nation's 2015-30 Sustainable Development Goals (SDGs). Canada has some of the world's strongest legislation supporting equitable access to care for medically necessary hospital and physician services based on need, not ability to pay. A constitutional challenge to this legislation is underway in British Columbia (BC), led by a corporate plaintiff, Cambie Surgeries Corporation (CSC). This constitutional challenge threatens to undermine the high bar for UHC protection that Canada has set for the world, with potential adverse implications for equitable international development. CSC claims that BC's healthcare law—the Medicare Protection Act (MPA)—infringes patients' rights under Canada's constitution, by essentially preventing physicians who are enrolled in BC's publicly-funded Medicare plan from providing expedited care to patients for a private fee. In September 2020, after a trial that ran for 3.5 years and included testimony by more than 100 witnesses from around the world, the court dismissed the plaintiffs' claim. Having lost their case in the Supreme Court of BC, the plaintiffs' appealed in June 2021. The appellate court's ruling and reasons for judgment are expected sometime in 2021. We consider the evidence before the court from the perspective of social epidemiology and health inequalities, demonstrating that structural features of a modern society that exacerbate inequalities, including inequitable access to healthcare, can be expected to lead to worse overall societal outcomes.

Keywords: sustainable development goals (SDGs), Canada health act, global health policy, health inequalities, Universal Health Coverage (UHC)

KEY MESSAGES

- Canada has some of the world's strongest legislation to support equitable access to care for medically necessary hospital and physician services based on need, not ability to pay.
- Structural features of a modern society that exacerbate inequalities, including inequitable access to healthcare, can be expected to lead to worse overall societal outcomes.
- Societies that achieve Universal Health Coverage (UHC), with low or no fees at point of care, have taken a critical step toward safeguarding long-term population health, in line with the 2015-30 Sustainable Development Goals.
- The current constitutional challenge to British Columbia's Medicare law threatens to undermine the high bar for UHC protection that Canada has set for the world, with potential implications for equitable international development.

INTRODUCTION

On September 10, 2020—nearly 4 years after starting of the "Cambie Trial" to determine the constitutionality of British Columbia's (BC) law protecting its universal "Medicare" system—the Supreme Court of BC handed down its 880-page Reasons for Judgment in *Cambie Surgeries Corporation v. British Columbia* (1). The plaintiffs, led by Cambie Surgeries Corporation, claim that BC's Medicare Protection Act (MPA) infringes patients' rights under the Canadian Charter of Rights and Freedoms. BC's Supreme court dismissed the plaintiffs' claim against the Attorney General of BC. It found that, on the balance of probabilities, the evidence before the court supported BC's law on grounds aligned with both equity and sustainability of its universal healthcare system.

The plaintiffs immediately launched an appeal in the BC Court of Appeal, the highest provincial court, which was heard June 14-18, 2021. The court's ruling and reasons for judgment are expected later in 2021. Meanwhile, the appellants also obtained an injunction to temporarily prevent BC's Medical Services Commission (MSC, which manages BC's single payer Medical Services Plan (MSP) on behalf of the BC Government in accordance with the MPA) from enforcing the law's "extra-billing" provisions in private surgical clinics for patients whose surgery has been scheduled beyond, or has not taken place by, the Ministry of Health's wait time benchmark, due to insufficient capacity in the public system (2). This case is expected to go all the way to the Supreme Court of Canada, settling it once and for all, but potentially jeopardizing Canada's federated (pan-provincial) system of Medicare.

An analysis of the massive body of global evidence accumulated and extensively analyzed during the trial on both sides of this debate (57,000 pages including exhibits from expert reports, affidavits, and research studies, plus 15,000 pages of transcripts, and nearly 1,400 pages of closing arguments) is beyond the scope of this article but is well-summarized in the court's Reasons for Judgment (1). The aim of our analysis is three-fold: (1) explain the origins of this Canadian legal struggle; (2) summarize the scientific evidence that supports the prohibition (or, at minimum, the strong regulation) of privately-funded care in countries with publicly-funded universal-coverage care systems; and (3) outline our perspective on the potential global implications of this trial for Universal Health Coverage (UHC) and our opinion on how this might influence international development.

WHAT IS THE PURPOSE OF BC'S MEDICARE LAW?

The purpose of BC's law is to preserve a publicly-managed and fiscally sustainable healthcare system, in which access to necessary medical care (mainly hospital and physician services) is based on need and not on an individual's ability to pay. "Medical necessity" is a guiding principle; the precise scope of services covered is not defined by statute or legislation. BC's law prohibits physicians enrolled in BC's single payer Medical Services Plan from charging patients who are MSP beneficiaries—nearly all residents of BC—for medically necessary services. This includes extra billing, user charges, and duplicative private insurance that covers care already included under MSP. It also prohibits, *de facto*, dual practice, such that physicians enrolled in MSP may not provide insured services to both public pay and private pay patients. Physicians in BC may, however, choose not to enroll in MSP, in which case they can charge patients directly for medically necessary care at whatever rate the market will bear, so long as they do not treat patients in hospitals or community care facilities. Although Canada's federal health legislation—the Canada Health Act (CHA) (3)—itself was not directly challenged, its principles were because they parallel those of BC's law. Thus, the Attorney General of Canada intervened in the trial to support BC's legislation and the principles of the Canada Health Act embedded in it.

WHAT IS THE GLOBAL RELEVANCE OF *CAMBIE SURGERIES CORPORATION v. BRITISH COLUMBIA*?

Many nations are moving steadily toward Universal Health Coverage (UHC), one of the United Nation's Sustainable Development Goals. Initially, this push arose from within the World Health Organization (4–6). More recently, key international development authorities, such as the World Bank, have also supported UHC (7). This is rather remarkable, given that some of them had previously advised global nations to pursue policies antithetical to the spirit of UHC, such as user fees at point of care (8). UHC is now seen as a critical policy plank in moving countries forward, in terms of equitable socio-economic development (9).

The implications of this legal battle therefore may extend far beyond Canada's borders. Canada has one of the strongest legislative protections in the entire world to support equitable access to care by preventing private payment for medically necessary services. Indeed, Canada ranks highest in the world on the UHC Service Coverage Index, at 89 on a scale of 0 to 100, surpassing comparator countries such as Australia, New Zealand,

Norway, the UK, the Netherlands, Sweden, and other G-7 nations including the USA, France, Germany, Italy, and Japan (10–12). BC's constitutional challenge threatens to undermine the high bar for healthcare equity that Canada has set for the world. If the corporate plaintiffs are successful in their bid to overturn key provisions of BC's provincial law, then the implication for Canada's other provinces and territories is uncertain given that they all have similar healthcare laws. If, for example, the Canada Health Act itself were to become unenforceable as a consequence of this litigation or subsequent legal challenges, there would be profound implications for the rest of Canada. Globally, although Canada's healthcare system is far from perfect, it is one of the "oldest and most celebrated in the world" (13), recognized for its global leadership on health, and seen as a "beacon of light" (14) for countries aspiring to UHC. Thus, when the trial began on September 6, 2016, the Government of British Columbia entered into a legal battle with Cambie Surgeries Corporation—a private, for-profit, investor-owned corporation—that may shape the future of Canada's healthcare system and influence the design of UHC globally.

WHAT HISTORY UNDERPINS *CAMBIE SURGERIES CORPORATION v. BRITISH COLUMBIA*?

Canadian provincial governments have occasionally faced legal challenges to provincial laws—such as BC's MPA—that parallel the Canada Health Act e.g., *Chaoulli v. Québec* (15) and *Allen v. Alberta* (16). For 37 years, however, the CHA has endured as an effective piece of federal legislation for ensuring equitable access to care, by controlling the growth of private funding for medically necessary care otherwise insured under each of Canada's 13 provincial and territorial publicly-funded Medicare plans. Designed "to protect, promote and restore the physical and mental well-being of residents of Canada and to facilitate reasonable access to health services without financial or other barriers," the CHA was passed by Parliament in 1984, under the charismatic leadership of then-Health Minister Monique Bégin and Prime Minister Pierre Elliot Trudeau (17).

Although many countries attempt to limit the growth of a private market for physicians' services, the CHA and provincial/territorial laws makes Canada virtually unique among liberal democracies, effectively outlawing physicians enrolled in the public plan from "extra billing" patients directly for insured health services, whether *via* patients' personal out-of-pocket payments or through private duplicative health insurance. The term "effectively" is used because a province or territory may only qualify for the full federal cash contribution, *via* the Canada Health Transfer, if no extra billing occurs. The federal CHA is ingeniously designed to penalize any provincial or territorial government allowing extra billing, by clawing back federal cash and tax-transfers, dollar for dollar, equivalent to the amounts billed in contravention of the Act. Without the federal transfer, most Canadian provinces and territories could not afford to publicly fund their Medicare systems (17). Provincial and territorial governments are, thus, highly incentivized to prevent extra billing (18).

Both federal (CHA) and provincial/territorial restrictions on privately-funded care in Canada worked effectively for 20 years, until a court decision in Québec in 2005 (15). That claim was initially dismissed by both Québec's Superior Court and Québec's Court of Appeal, but these decisions were later overturned in a controversial decision by the Supreme Court of Canada (19). That ruling led to a distinct "watering down" of the CHA's effect, but *only* in Québec. Private duplicative health insurance to cover the costs of three elective procedures (hip and knee replacements and cataract surgeries) was thus made legal in Québec under Bill 33 (20). However, no market for duplicative private insurance has emerged in Québec for these three procedures, mainly because (a) the incentive to develop a commercial insurance market was significantly reduced by new regulations to limit wait times for those procedures, and by enactment of regulations prohibiting, (b) physician dual practice (i.e., being paid by the public purse while also providing privately-funded services that would otherwise be covered under the public plan), and (c) co-mingling of participating (state-funded) physicians and non-participating (privately-funded) physicians in the same surgical facilities (21, 22). The result is that a profitable insurance market is simply not there, (at least not yet). Nevertheless, growth in private investor-owned surgical facilities has followed in Québec, as has growth in the number of Québec's physicians not participating in Medicare. It has been challenging for Québec to enforce these regulations at the public/private interface ever since (23).

Legal scholars have argued about the propriety of the courts' interpretation and application of the Charter of Rights in the Chaoulli case (24, 25). Some experts have criticized that decision as having ignored the empirical health economic and health services research evidence that was adduced in the courtroom, with the judges favoring instead their own views of what healthcare Québec's residents should be able to purchase privately (26).

In May 2007, BC's Medical Services Commission informed CSC that they were concerned about CSC's extra billing of patients. In September 2008, the MSC advised CSC of its intent to audit their records and employ its investigation powers. In January 2009, CSC filed a Writ of Summons against the MSC, in an attempt to outflank the BC Government by legally attacking the constitutionality of BC's law. The plaintiffs' claim is that the MPA infringes Canadians' rights under Canada's constitution, including rights to life, liberty, and security of the person under Section 7 of the Canadian Charter of Rights and Freedoms. In essence, CSC claims that the MPA puts unfair limitations on access to the health services Canadian citizens can purchase privately—particularly where they assert the wait-times for elective surgery in Canada's publicly-funded care system are too long.

WHAT ARE THE CONTRASTING POSITIONS OF THE TWO PARTIES?

In the assembly of multiple expert opinions sought by counsel for both sides of this newsworthy case (27), there are two opposite points of view, summarized as follows:

VIEW #1: *Private health insurance and privately-funded healthcare are "normal" and desirable features of nearly all liberal democracies' national health systems, even where the state is providing comprehensive, publicly-funded care for the majority; no serious harm results from such dual systems of care*. The plaintiffs' expert witnesses supporting this view acknowledged that, in most of these dual-systems, public-sector regulators rein in the less-desirable aspects of privately-funded care—such as its impact on equity or its tendency to charge whatever the market will bear—creating an inflationary pressure on physician fees paid in both the public pay and private pay systems (25). In addition, some OECD countries, such as The Netherlands, heavily regulate private health insurance to reduce discriminatory practices, such as risk selection, including refusal of coverage due to pre-existing health conditions. Some of these experts contended that much good accrues to the public care system through the existence of private pay services, such as the purported "steam valve" effect for elective procedures. In their view, the private system siphons off paying patients from the public system, reducing total caseload and overall public expenditures on health, whilst also shortening public system wait-times (28).

VIEW #2: *Privately-funded healthcare tends to increase socio-economic and health inequalities in any system that is otherwise publicly-funded and universally accessible. This has adverse consequences for the health status, wellbeing, and productivity of the population, for total care-system cost, and for efficiency of healthcare spending* (**Box 1**) (29, 30). Expert witnesses for the defendants and the Government of Canada argued that siphoning off selected private-pay, lower-risk, patients, in favor of less complicated—but often higher-priced, high volume—elective procedures has negative consequences for patients and for the operation of the publicly-funded healthcare system. They cite the diversion of scarce medical resources (especially skilled surgeons' and other healthcare providers' time) to the private sector from the public one. The overall result, these experts said, is a fundamental change in who receives timely care—toward care being meted out on the basis of ability to pay, as opposed to clinical need and priority (24–26). These experts were also concerned that allowing privately-funded providers to essentially "charge what the market will bear" could also inflate costs in the public pay system—for example, *via* having to entice surgeons to continue practicing in the public-pay system through higher fees per procedure. [To be fair, some experts have also pointed out that much international evidence on such issues is irrelevant to Canada's virtually unique care system and funding model (31)].

WHAT IS THE CONVERGING EVIDENCE ON THE BROADER IMPACTS OF INEQUALITY?

Box 1 summarizes the remarkable convergence now occurring, across diverse literatures spanning many research disciplines, concerning the pernicious societal effects of inequality *in and of itself* (29, 30).

This body of evidence suggests that any structural feature of a modern society which fosters increased inequality—including enabling wealthier or more privileged persons to access higher-quality or faster medical care than is available for the majority of citizens—can be expected to lead to worse overall societal outcomes. A wide range of indicators of a healthy, creative, productive, and generally successful society are typically made worse by higher levels of income and social inequality. The increased provision of privately-funded healthcare, in any society where it has been historically tightly regulated (as in Canada) can thus be expected to produce negative impacts on that society. Remarkably, it seems that the mere public perception of unfairness in the provision of healthcare, matters just as much as the reality (29, 30). In settings with long-established, publicly-funded, free-at-point-of-care systems, such as Canada's, it is reasonable to conclude that any significant expansion of privileged care for those who can pay for it privately might well trigger some negative effects beyond the health sector.

In *Cambie Surgeries Corporation v. British Columbia* the court essentially agreed with View #2, as follows:

> "[2655] Overall, I find that there is evidence to suggest that duplicative private healthcare would exacerbate wealth and health inequality. I also accept the evidence...that socioeconomic status is a significant determinant of overall health and well-being and poor health status disproportionately affects lower income individuals. Further, duplicative private healthcare and the creation of a two-tier system, where access to preferential treatment would be based on the ability to pay, would exacerbate health inequity in terms of access to healthcare, utilization of healthcare and health outcomes" (1).

WHAT ARE THE BROADER IMPLICATIONS FOR UHC GLOBALLY?

The relative merits of these two contrasting points of view were fought out in a Vancouver courtroom when the proceedings commenced in 2016. A legal adjudication process is inherently very different from its closest scientific analog: conducting a rigorous structured systematic review of the empirical evidence (26). The final outcome of the case—whether after the first appeal heard in June 2021, or potentially again at the Supreme Court of Canada—may or may not conform to what the most eminent scholars in the field believe the evidence says. If BC's Medicare Protection Act were to be struck down on appeal, BC would lose what has been a remarkably effective policy by most global standards, opening a crack in Canada's ever-popular publicly-funded Medicare system. The giant global for-profit care and health insurance industry, much of it based just across Canada's shared border with the USA, would be the clear victor. In that event, other countries may want to consider whether they have sufficient safeguards to protect their own UHC from commercial forces likely to increase inequality and inequity through the further global spread of user-pay privately-funded care.

Both health policy experts and international agencies now advocate the extension of UHC to the entire globe. Once a society has achieved widespread UHC (with low or no fees at point of care), it has taken a critical step to invest in its population's long-term health, in the most effective, efficient, and egalitarian manner (4, 5, 32). The dismantling of legal or regulatory controls on privately-funded care, or failure to enforce existing controls, can only be regarded as retrograde, and likely to impede social and economic development—and especially the equity of that development across society.

BOX 1 | Pan-sectoral effects of increasing inequality.

- Increased levels of violence, including but not limited to homicide
- Lower economic growth
- Lower levels of child development and educational attainment by adulthood
- Worse psychometric indicators of social capital/cohesion, trust, and civic engagement/societal participation
- Worse levels of population indices combining diverse measures of both health and social problems, including outcomes such as life expectancy, literacy, infant mortality, teen births, obesity, mental illness, imprisonment, social mobility

CONCLUSION

We suggest that global health professionals, researchers, policy analysts, scholars, citizenry, and governments familiarize themselves with the scientific and legal aspects of the Cambie trial in Canada, as an exemplary threat to the effective and efficient operation of established and emerging UHC systems globally. Active participation in such debates can constructively support the maintenance and growth of UHC systems as a critical tool in equitable international development. Without such active support, UHC systems could easily fall prey to powerful and wealthy forces worldwide, seeking to make healthcare just another profitable business commodity.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JF, KSP, CP, CD, and KEP contributed to the conceptualization, analysis, interpretation, drafting, and critical review of the manuscript for important intellectual content. All authors contributed to the article and approved the submitted version.

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Whether Urbanization Has Intensified the Spread of Infectious Diseases—Renewed Question by the COVID-19 Pandemic

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The outbreak of the COVID-19 epidemic has triggered adiscussion of the relationship between urbanization and the spread of infectious diseases. Namely, whether urbanization will exacerbate the spread of infectious diseases. Based on 31 provincial data from 2002 to 2018 in China, the impact of urbanization on the spread of infectious diseases from the dimensions of "population" and "land" is analyzed in this paper by using the GMM (generalized method of moments) model. The empirical study shows that the population increase brought by urbanization does not aggravate the spread of infectious diseases. On the contrary, urban education, employment and entrepreneurship, housing, medical and health care, and other basic public services brought by population urbanization can help reduce the risk of the spread of infectious diseases. The increasing density of buildings caused by land urbanization increases the risk of the spread of infectious diseases. Moreover, the impact of urbanization on the spread of infectious diseases has regional heterogeneity. Therefore, the prevention and control of disease play a crucial role.

Keywords: population urbanization, land urbanization, infectious diseases, public health, GMM model

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INTRODUCTION

Public health is not only related to the national economy and the livelihood of the people but also concerns national security and social stability (1), especially during the COVID-19 pandemic. Therefore, the research on urban public health is of great importance for both country and people. The outbreak of the COVID-19 epidemic has triggered the discussion of the relationship between urbanization and the spread of infectious diseases. One hypothesis attributes the intensified transmission of COVID-19 to the "urban diseases" caused by the rapid urban expansion, such as increased population ratio, dense building, environmental pollution, and deteriorated sanitation by many people, which finally threatens residents' public health. The main basis of this hypothesis is that there is a significant gap in the number of confirmed COVID-19 cases between urban and rural areas in various cities. Especially in Hubei Province, most of the confirmed COVID-19 cases appeared in central urban areas, such as the urban areas of Wuhan City as well as the downtown areas of Xiaogan and Huanggang, both of which are near Wuhan. On the contrary, the morbidity rate in rural areas in Hubei Province is relatively low. They also found that since the government locked down Wuhan, most of the new cases in Hubei also appeared in Wuhan's urban area.

The hypothesis owed the spread of COVID-19 to a "large population and too many buildings in big cities" and even claimed that the government should be restricting the population flow into large cities, evacuating urban populations, and reducing the building area, so as to prevent the spread of infectious diseases. Therefore, is the spread of Category B infectious diseases[1] like SARS and COVID-19 really caused by a large population and building density in large cities? will urbanization exacerbate the spread of infectious diseases? In the context of the prevention and control of COVID-19, the answers to these questions have important reference value for correctly understanding and grasping urban public health safety, prevention, and treatment of infectious diseases, so as to propel the sustainable development of urbanization.

To explore the answers, we matched provincial data with health data to construct panel data in China's 31 provinces from 2002 to 2018, with a view to investigating the relationship between urbanization and the spread of infectious diseases.

The marginal contributions of this paper can be summarized as below. Firstly, the paper differentiates between population urbanization and land urbanization. "Population urbanization" is measured by the proportion of urban population, which is fundamentally different from "population density." "Land urbanization" is measured by the proportion of built-up area, which can reflect the density of urban buildings to some extent. Secondly, the morbidity and mortality of Category A and B are used to reflect the spread of infectious diseases. The morbidity and mortality of Category A and B infectious diseases are significantly different from the population mortality (2), life expectancy per capita (3), newborn mortality (4), and prevalence of underlying diseases (5, 6) in the previous literatures. The former belongs to infectious diseases, which have the characteristics of "human-to-human transmission." It is more easily to measure the spread of infectious diseases. The latter is mainly to measure life health, which is a composite indicator. But the mortality and the ultimate lifespan and prevalence of underlying diseases do not belong to infectious diseases, and the death and lifespan may be determined by the infectious diseases or by other reasons. Therefore, the former index is more accurate, scientific, and suitable for the subject. Moreover, this is more in line with the theme of this study.

The remainder of the analysis is organized as follows: the Literature Review section shows a review of related papers. The model construction and variable selection of urbanization and the spread of infectious diseases is shown in the section Model and Variables. The data is presented in the Data section. The empirical analysis is presented in the Empirical Results section. This paper's research is summarized in the Conclusions and Policy Advice section. The limitations of the study are presented in the section Limitation.

[1]Category B infectious diseases include COVID-19, SARS, AIDS, pertussis, diphtheria, neonatal tetanus, malaria, H7N9 avian influenza and other 27 infectious diseases.

LITERATURE REVIEW

The spread of infectious diseases is the key area of urban public health and the weak link in the development of urban public health in recent years. The outbreak of COVID-19 in 2019 sounded an alarm for urban public health and safety. Research on the spread of infectious diseases initially belongs to the field of medical research, because medicine is committed to the treatment of diseases, to ensure people's life and health. Some scholars discussed the spatial distribution of the avian influenza (H5N1) outbreak (7), the regional differences of AIDS (8), the epidemic trend of pertussis (9), the regional distribution of neonatal tetanus cases (5), the dengue outbreak (10, 11), the transmission of COVID-19 (12–20) and other class A and B infectious diseases. These literatures mostly study the causes, laws, epidemic trends, and medical measures of infectious diseases from the perspective of medicine. This paper mainly discusses the impact of urbanization on the spread of infectious diseases from the perspective of sociology.

Many scholars have studied the social factors behind the spread of infectious diseases. Among them, the level of medical facilities is the most direct factor affecting the spread of infectious diseases. Mody et al. (21) based on the data of nursing homes in Michigan, found that the level of medical facilities in nursing homes is inversely proportional to the risk of disease infection of the elderly: that is, the higher the level of medical facilities in nursing homes, the lower the risk of disease infection of the elderly. Toda et al. (22) investigated the fatal cases of infectious diseases among children in Japan's top three hospitals and found that strengthening the construction of medical facilities can significantly reduce the proportion of children who died of infection. However, the level of economic development affects the regional medical level and then has an impact on the spread of infectious diseases. Bai et al. (23) uses the panel data of 29 regions in China to explore the impact of EPU on medical expenditure and finds that EPU has a positive spatial spillover effect on medical expenditure. Su et al. (24) found that there was an inverted U-shaped correlation between economic growth and health, and the health promotion effect of economic growth decreased significantly when it exceeded the threshold.

In addition, aging is also an important factor affecting the spread of infectious diseases (25). Hence, 2019 novel coronavirus pneumonia is mostly found in the elderly, and the death cases are mostly elderly. This is mainly because as age increases, people over 45 years old will gradually show the characteristics preceding old age, such as slow metabolism, decreased resistance, decreased physiological function (26, 27), poor awareness of disease prevention, and become a susceptible and high-risk group for infectious diseases. Heravi et al. (28) collected cases of infectious diseases in 65 year old patients who were treated in a hospital in Turkey for the years 2010–2011. It was found that the elderly were susceptible to infectious diseases, and the incidence rate and mortality rate were generally higher. The incidence rate and mortaity rate of 45 notifiable infectious diseases in China were assessed by Yang et al. (29). It was found that the incidence and mortality of notifiable infectious diseases in the

elderly population were significantly higher than that in young people in the period 2004–2013.

In recent years, many scholars found that air pollution has become an important factor affecting the spread of infectious diseases. Jang et al. (30) collected 660,000 infectious diseases data in Korea and studied the relationship between air pollution level and the incidence rate of notifiable infectious diseases in that country. It was found that the incidence rate of infectious diseases was highly correlated with air pollution. Mody et al. (21) found that respiratory diseases and the spread of infectious diseases are related to the level of air pollution. The higher the level of air pollution exposure, the higher the risk of respiratory diseases and the spread of infectious diseases. Maji et al. (31) and Zeng et al. (32) found a similar view when studying the impact of PM2.5 on the spread of infectious diseases. However, different from the previous literature, this paper focuses on the impact of urbanization on the spread of infectious diseases.

Urbanization, as an important factor discussed in this paper, has a controversial impact on the spread of infectious diseases. Some scholars believe that the promotion of urbanization has produced an agglomeration effect, which has brought "urban diseases" such as housing congestion, traffic congestion, environmental pollution and health deterioration (33, 34), and increased the risk to urban residents (26). The incidence rate and mortality rate of malaria in Africa were studied by Hay et al. (35), which quantified the malaria burden in Africa. The cities' accelerated urban lifestyle increased malaria incidence and mortality in Africa. Wu et al. (36) compared the differences of avian influenza outbreaks between developing and developed countries and found that the interaction of urbanization, income growth, and globalization exacerbated the spread of infectious diseases.

Other scholars believe that urbanization will increase residents' income (37), improve medical facilities and security systems (38), and improve medical standards and services (39), thereby reducing the incidence rate and mortality of infectious diseases (40). Neiderud (41) compared the development of economy, health, environment, infrastructure, and other social aspects between urban and rural areas, and found that the living conditions of the urban environment are generally better than that of the rural environment, and better housing, health, ventilation, and social services play a positive role in the prevention and control of infectious diseases.

In addition, the ability to monitor and control projects, and the effect of prevention and public knowledge projects or campaigns in cities is much better than that in rural areas, and they are more able to respond to sudden infectious diseases in a timely manner. Wood et al. (42) evaluated the spatial-temporal relationship of infectious disease data in 60 medium-sized countries and found that urbanization improved urban health and medical conditions, increased medical investment, and helped to reduce the burden of the spread of infectious diseases. Bauer et al. (43) found a similar view using population data and general practitioner practice data in England. These literatures mostly investigate the impact of urbanization on public health; there is a lack of research on the relationship between urbanization and the spread of infectious diseases, and few literatures study this problem from the perspective of heterogeneous urbanization. This paper studies these two aspects.

MODEL AND VARIABLES

Based on the health production function proposed by Grossman (44) and referring to the method of Shao et al. (34), this paper integrates relevant factors affecting public health into the model and takes urbanization as an important factor affecting the spread of infectious diseases. The provincial health panel data of China's 31 provinces between 2002 and 2018 are used to empirically test the impact of urbanization on the spread of Category A and B infectious diseases. The empirical analysis model is expressed as follows:

$$\ln\text{disease}_{it} = \alpha_0 + \alpha_1 \ln\text{urbanisation}_{it} + \alpha_2 \ln X_{it} + \mu_{it} \quad (1)$$

where i represents China's 31 provinces and cities and t represents the year. disease reflects the spread of infectious diseases, urbanization represents the level of urbanization, X_{it} represents the control variable group, and μ is a random disturbance item. The indicators of each variable in the model are set as follows:

(1) **The explained variable.** This paper uses the morbidity and mortality of Category A and B legally reported infectious diseases to measure the spread of infectious diseases (disease). This is different from the population mortality (2), average life expectancy, and newborn mortality (3) in the previous literatures. The former belongs to the infectious diseases, which have the characteristics of "human-to-human transmission" and can better measure the spread of such infectious diseases. The lower the morbidity and mortality of Category A and B legally reported infectious diseases, the slower the spread of infectious diseases and the better the control.

There are three specific reasons for selecting indicators of Category A and B infectious diseases for this paper. Firstly, COVID-19 has been classified as a Category B infectious disease. This paper is aimed to provide decision-making and reference for the prevention and control of COVID-19 through studying the previous data of Category A and B infectious diseases. Secondly, the morbidity and mortality of Category A and B infectious diseases are significantly different from the population mortality, average life expectancy, newborn mortality, and the prevalence of underlying diseases in the previous literatures. Thirdly, the indicators of Category A and B infectious diseases as used in this paper can also better respond to the hypothesis at the beginning of the article, which is also the author's original intention.

(2) **Core explaining variables.** Most of the literatures have used the ratio of urban population to total population in various regions to measure urbanization (2, 3). The indicator is fundamentally different from "population density," as it reflects the increase of population proportion brought by the acceleration of the urban process, but population density

refers to the number of people per unit area. This paper mainly discusses whether the population proportion increase brought by the urbanization process exacerbates the spread of infectious diseases. Therefore, the former index could yield a more accurate result. Although this measurement index conforms to the study that "urbanization leads to too many people" mentioned above, it does not involve the dimension that "urbanization leads to too dense buildings" above. Therefore, on the basis of the existing literatures, this paper measures urbanization not only by using the proportion of urban population to the total population from the dimension of the "population," but also based on the proportion of the built-up area of a city to the total land area of the city area from the "land" dimension. To a certain extent, land urbanization can reflect the urban building density.

(3) **Control variables.** This paper uses the logarithm of the urban population density of different provinces and cities to measure population density, and compares it with the indicator of population urbanization, the main core explaining variable. In this paper, the dependency ratio of the elderly population in provinces and cities is used to measure the level of population aging (age) (3). Immunity is an important factor to resist infectious diseases. The elderly are worse than the young in terms of physical quality and physiological function (27), so their ability to fight against viruses is also naturally worse. The middle-aged and the elderly are more easily attacked by COVID-19, and most of the deaths are among the elderly. Moreover, in recent years, the problem of "getting old before getting rich" in China has constantly impacted regional economic growth, public health investment, and residents' medical consumption (45), which has a far-reaching impact on the health levels of residents. Per capita GDP (rgdp), which reflects the level of economic development and affects the income of residents, affects residents' health expenditure and health level (24), which affects the spread of infectious diseases. In this paper, the proportion of health expenditure to the total financial expenditure of provinces and cities is used to represent the public health input (expend), reflecting the importance of public health in the region. The medical development level (medical) is measured by the logarithm of the number of health technicians per 1,000 populations in cities, reflecting the regional medical construction level. The improvement of this indicator is conducive to the prevention, diagnosis, and treatment of infectious diseases. In this paper, the logarithm of the number of days with air quality reaching and better than level 2 in provinces and cities is used to measure the air quality level (air). Air is directly related to the spread of a great variety of respiratory diseases. Some of the pathogens can spread in the air freely, with the usual diameter of 5 microns. They can float on the surface dust in the air, floating in the air for a long time, and move for a long distance (46). The SARS virus in 2003 and COVID-19 in 2019 have the same principle. Therefore, air quality directly determines the speed and extent of disease spread.

TABLE 1 | The descriptive statistics of variables.

Variables	Observations	Mean	Standard	Min	Max
Morbidity	527	5.495	0.357	4.513	6.604
Mortality	527	0.609	0.382	0.068	2.122
Population urbanization	527	0.499	0.154	0.005	0.896
Land urbanization	527	0.154	0.104	0.006	0.637
Population density	527	7.341	0.796	5.231	8.608
Age	527	0.125	0.027	0.067	0.219
Rgdp	527	10.211	0.777	8.089	11.851
Expend	527	0.061	0.019	0.027	0.106
Medical	527	1.542	0.359	0.693	2.738
Air	527	5.638	0.242	3.892	5.903

DATA

This paper builds health panel data of China's 31 provinces between 2002 and 2018 by matching the provincial data and health data. All data studied in this paper are from *China Statistical Yearbook, China Health Statistical Yearbook, Statistical Yearbook of Provinces and Cities, National Economic and Social Development Statistical Publication,* National Research Network Database, and Guotai Junan database. The descriptive statistics of variables in the model are shown in **Table 1**.

To reflect the relationship between population urbanization, land urbanization, and the spread of infectious diseases more intuitively, this paper draws the figures for the fitting relationships between population urbanization and land urbanization and the morbidity and mortality of Category A and B infectious diseases, which is shown as **Figures 1**, **2**, respectively. As can be seen from **Figure 1**, the level of population urbanization is significantly negatively correlated with the morbidity and mortality of Category A and B infectious diseases. Moreover, the degree of negative correlation between population urbanization and the morbidity of Category A and B infectious diseases is significantly higher than that of mortality, indicating that with the increase of population urbanization rate, the morbidity and mortality of Category A and B infectious diseases are decreasing. As can be seen from **Figure 2**, the level of land urbanization is significantly positively correlated with the morbidity and mortality of Category A and B infectious diseases, indicating that with the increase of land urbanization rate, the morbidity and mortality of Category A and B infectious diseases are on the rise. The correlations between population urbanization and land urbanization and the morbidity and mortality of A and B infectious diseases are completely opposite, and urbanization in different dimensions may vary in terms of the spread of infectious diseases. Therefore, for the purpose of testing the real causal relationship between population urbanization and land urbanization and morbidity and mortality of Category A and B infectious diseases, this paper will construct the provincial

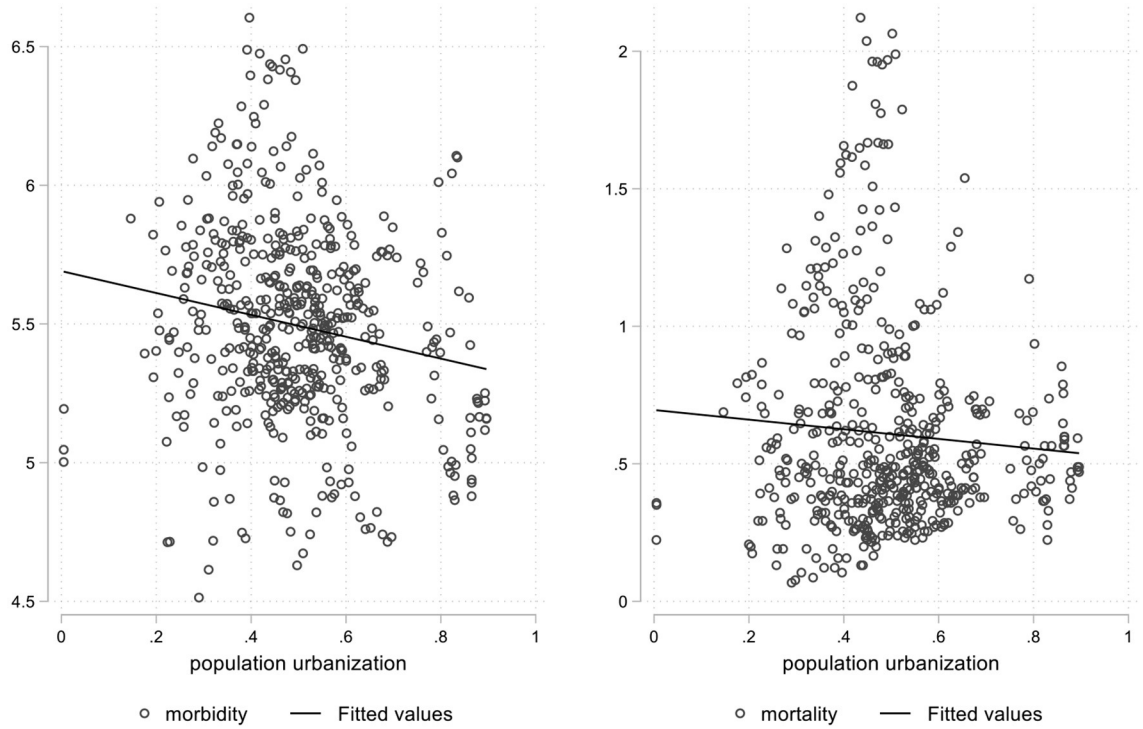

FIGURE 1 | Fitting relationships between population urbanization and the morbidity and mortality.

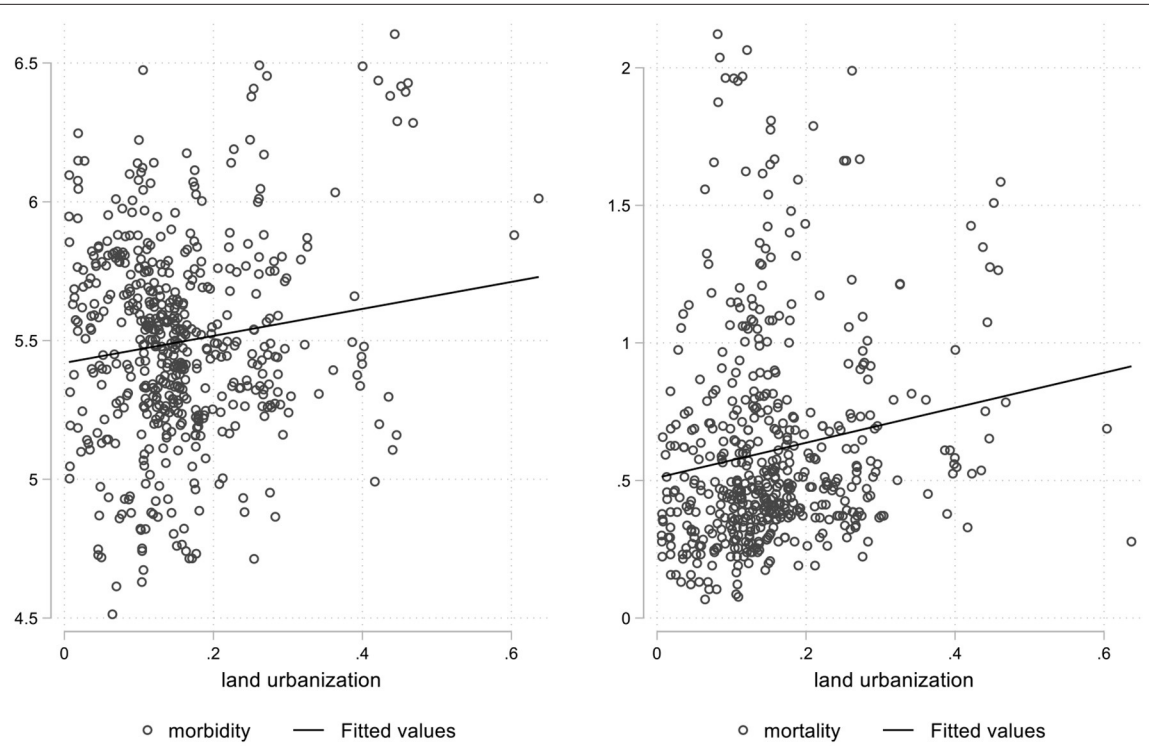

FIGURE 2 | Fitting relationships between land urbanization and the morbidity and mortality.

TABLE 2 | Baseline regression results of urbanization on the spread of infectious diseases.

Variables	SYS-GMM				DIFF-GMM			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality
Population urbanization	−0.359***	−0.174***			−0.364***	−0.060**		
	(−6.219)	(−2.987)			(−2.872)	(−2.013)		
Land urbanization			0.081**	0.070**			0.100**	0.089**
			(2.447)	(2.530)			(2.187)	(2.049)
Population density	5.617	2.223	6.839	2.603	2.608	7.713	3.413	7.823
	(1.548)	(1.603)	(1.255)	(1.077)	(1.038)	(1.213)	(1.461)	(1.131)
Age	1.119***	1.539***	0.958***	1.479***	1.330***	0.242	1.341***	0.017
	(3.095)	(6.776)	(3.416)	(6.268)	(4.208)	(0.965)	(4.121)	(0.062)
rgdp	−0.020	0.020	−0.064	0.007	0.021	0.199***	−0.009	0.213***
	(−0.741)	(1.362)	(−0.536)	(0.451)	(0.583)	(3.531)	(−0.344)	(3.839)
Expend	−0.504	−2.063***	0.179	−2.110***	−1.898***	−1.282***	−1.646***	−1.367***
	(−1.072)	(−6.220)	(0.556)	(−6.583)	(−3.291)	(−3.867)	(−3.115)	(−4.215)
Medical	0.043	−0.057***	0.018	−0.075***	−0.034	0.050	−0.083**	0.064
	(1.035)	(−2.850)	(0.553)	(−3.898)	(−0.820)	(1.284)	(−2.170)	(0.732)
Air	−0.026**	−0.005	−0.031**	−0.016	0.014	0.004	0.016	0.008
	(−2.072)	(−0.431)	(−2.346)	(−1.213)	(0.875)	(0.274)	(0.960)	(0.494)
L.disease	0.683***	0.776***	0.653***	0.797***	0.552***	0.287***	0.518***	0.314***
	(27.481)	(59.622)	(21.355)	(48.795)	(10.064)	(3.863)	(8.790)	(4.141)
AR_1	0.0069	0.0007	0.0065	0.0006	0.0092	0.0696	0.0081	0.0479
AR_2	0.6825	0.7024	0.5544	0.7616	0.8279	0.5552	0.7203	0.4926
Sargan text	0.4797	0.4137	0.4581	0.4475	0.459	0.4177	0.4278	0.433
Observations	527	527	527	527	527	527	527	527

****, **, *The significance level of 1, 5 and 10%, respectively. The numbers with asterisks in the corresponding rows of all variables in the table represent the estimation coefficients, and the values in the parentheses are the corresponding T statistical values, and the P values of AR_1, AR_2, and Sargan test are provided respectively.*

dynamic panel data GMM model in the next section for further empirical analysis.

EMPIRICAL RESULTS

The static panel estimation method is first adopted to estimate the panel data of China's 31 provinces between 2002 and 2018. The Hausman test for the endogeneity of explaining variables is also conducted. The *P* value of the Hausman test is 0.0043, rejecting the null hypothesis where all explaining variables are exogenous at the significance level of 1%. Therefore, on the basis of static panel regression, this paper adds the first-order lag term of the explained variable to construct the provincial dynamic panel data GMM model for estimation.[2] To overcome the endogeneity in the model, generalized moment GMM is selected to estimate the full sample data.

The specific estimated results are shown in **Table 2**, where, Equations (1)–(4) represent the GMM estimation results of the system, while Equations (5)–(8) represent the difference GMM estimation results. *P* values provided by AR_2 of all the equations in **Table 2** accept the null hypothesis at the significance level of 10%, indicating that the residual sequence of the difference equation in the model has only first-order sequence correlation and no second-order sequence correlation. The model has passed the autocorrelation test. The *P* values provided by Sargan test in **Table 2** also accept the null hypothesis at the significance level of 10%, indicating that all instrumental variables are strictly exogenous and valid. Therefore, the estimation results of difference GMM and system GMM are consistent and reliable. The significance and direction of the regression coefficients of the core explaining variables and control variables in **Table 2** for the morbidity and mortality of Category A and B infectious diseases are roughly the same, which further indicates that the empirical results are reliable.

The results of both system GMM and differential GMM regression show that population urbanization has a significant negative impact on the morbidity and mortality of Category A and B infectious diseases, while land urbanization has a significant positive impact on the morbidity and mortality of both above. Taking the empirical results of system GMM as an example, the morbidity and mortality will be reduced by 0.359 and 0.174%, respectively, with a 1% increase in population urbanization. The morbidity and mortality will be

[2]Based on the moment condition, the GMM method constructs equations with parameters. It does not need to assume the distribution of variables, and does not need to know the distribution information of random interference terms, so it can effectively solve the endogenous problem.

increased by 0.081 and 0.07%, respectively, with a 1% increase in land urbanization. This indicates that the improvement of population urbanization is conducive to reducing the morbidity and mortality of Category A and B infectious diseases, while the improvement of land urbanization increases the morbidity and mortality of both above.

Population urbanization does not aggravate the spread of infectious diseases. This is because people rush to big cities to secure more job opportunities, better job welfare, higher incomes, more favorable education and health care services, etc. (47), which can be summarized as "the people's aspiration for a better life" as called by President Xi. The development of urbanization essentially lies in "humans," and "human needs." The increasing urban population has brought the development of urbanization, which contributes to the economic effect, income effect, scale effect, rich medical and health resources, improves the demand for health, and forms health consciousness, etc. (36–39). These channels all reduce the risk of the spread of infectious diseases.

Land urbanization increases the risk of the spread of infectious diseases. This is because land urbanization certainly reflects the degree of "urban building density," including the density of urban building land, industrial land, construction area, etc., which can directly affect the living environment, air quality, and health status of urban residents. With the enhancement of land urbanization, industrial building area, environmental pollution, and the decrease of ecological green space (48), the living environment and breathing air quality of citizens continuously deteriorate, which makes it possible to spread infectious diseases.

From the perspective of control variables, population density has no significant effect on the morbidity and mortality of Category A and B infectious diseases, indicating that the spread of infectious diseases has little relationship with population density. In the spread of infectious diseases, population density refers to the density in the sense of clustering. Even if you live in rural areas and the overall population density is not high, the disease will still spread if you live in groups. On the other hand, in areas with high population density in large cities, if efforts are made to avoid clustering and contact between people, there will be no transmission. So, disease prevention and control play a crucial role. Population aging has a significant positive impact on the morbidity and mortality of Category A and B infectious diseases, and the increase in the level of aging significantly increases the morbidity and mortality of Category A and B infectious diseases, exacerbating the spread of infectious diseases. The reason may be that, compared with the young, the elderly have weaker constitution and a lower awareness of disease prevention, making them vulnerable and the high-risk groups for the spread of infectious diseases. This is consistent with the views of scholars Song and Yang (49). This is also the reason why the morbidity and mortality of COVID-19 are mainly among the middle-aged and the elderly. Therefore, attention shall be fully paid to the population aging. Per capita GDP has different influences on the morbidity and mortality of Category A and B infectious diseases but has no influence on the spread of infectious diseases. However, in the differential GMM model, per capita GDP has a positive influence on the mortality of Category A and B infectious diseases. The reason is probably that the level of economic development increase is coupled with more serious environmental pollution, which is harmful to residents' health, induces diseases, increases the economic burden, and damages the labor ability. Thus, people will fall into poverty and be unable to bear the corresponding medical costs, eventually lost in the "poverty trap" of environmental health (50) and increasing the risk of death from infectious diseases. Level of investment in public health, medical development, and air quality on morbidity and mortality of Category A and B infectious diseases have significant negative effects, which suggests that the increase of the public health investment, medical development, and the improvement of air quality significantly reduce the morbidity and mortality of Category A and B infectious diseases, inhibiting the spread of infectious diseases.

The existing literature studies have shown that regions vary largely in terms of economic development, medical facilities, degree of aged individuals, and urbanization, leading to the obvious imbalance of health levels in different regions of China (1). To investigate the regional differences of the impact of Category A and B infectious diseases on urbanization, this paper divides all the samples into three regions, namely, the east, central and west parts, and tests the impact from the dimensions of population urbanization and land urbanization, respectively. **Table 3** shows the estimated results of regional differences in the impact of population urbanization on Category A and B infectious diseases under the systematic GMM model.

As indicated by the results in **Table 3**, the *P* values provided by AR_2 and Sargan tests both verify the null hypothesis at the significance level of 10%, which further proves the reliability of the regression results. Population urbanization in eastern China has a significant negative impact on the morbidity and mortality of Category A and B infectious diseases, indicating that the improvement of population urbanization in eastern regions is conducive to reducing the risk of infectious disease spread, which is consistent with the results of the full sample estimation. The impact of population urbanization on the morbidity and mortality of Category A and B infectious diseases in the central and western regions is negative but insignificant. The positive effect of population urbanization on the prevention and control of infectious diseases in the central and western regions has not been shown. The main reason may be that, compared with the central and western regions, the eastern regions have relatively developed health levels, abundant education and medical resources, relatively intact public health systems, a high education level and income of residents, and more rigorous requirements for living environment and health. All of the above will indirectly improve the quality of life of the inhabitants, the prevention and control of infectious diseases, and health consciousness. The most important thing is that the residents' needs for higher material and cultural levels and a better and healthy life in the eastern region can be satisfied much faster than that of the population gathering in the eastern region. Therefore, the urbanization of the eastern region has a more negative impact on the spread of infectious diseases.

Table 4 shows the estimated results of regional differences in the impact of land urbanization on the spread of Category

TABLE 3 | Regional differences in the impact of population urbanization.

Variables	SYS-GMM					
	Eastern region		Central regions		Western regions	
	(1)	(2)	(3)	(4)	(5)	(6)
	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality
Population urbanization	−0.6308*	−0.2719**	−0.3562	−0.4020	−0.3042	−0.6780
	(−1.957)	(−2.316)	(−0.086)	(−1.216)	(−1.446)	(−0.909)
Population density	3.1638	−7.4401	−6.6646	−8.8899	5.5022	2.4767
	(1.245)	(−1.232)	(−0.905)	(−0.910)	(0.778)	(0.395)
Age	0.8588	1.0626	2.7547**	1.0209	0.1665	0.6464*
	(1.101)	(0.182)	(2.035)	(1.178)	(0.017)	(1.845)
rgdp	0.2820	−0.1240	0.6602*	−1.2548	−1.1821**	−0.9506
	(1.061)	(−0.519)	(1.799)	(−0.706)	(−2.268)	(−1.308)
Expend	−1.0228*	−0.3583	−1.1218	1.9069	−1.9507*	0.7748
	(−1.836)	(−0.156)	(−1.549)	(1.191)	(−1.720)	(0.671)
Medical	−0.2009**	−0.4367**	−0.3246*	−0.4469	−0.1684	−0.4895
	(−2.225)	(2.138)	(−0.493)	(−1.078)	(−0.725)	(−0.396)
Air	−0.0461	−0.0440	−1.1638**	−0.3371	−1.0795	−0.1793
	(−1.294)	(−0.640)	(−2.114)	(−1.074)	(−1.472)	(−1.494)
L.disease	0.6021***	0.2870***	−1.2830**	−1.1777***	−1.0159**	3.4958**
	(6.033)	(3.038)	(−2.503)	(−2.976)	(−2.329)	(2.537)
AR_1	0.0644	0.0221	0.0189	0.0168	0.0822	0.0243
AR_2	0.4952	0.6207	0.349	0.9265	0.7641	0.4104
Sargan text	0.9998	1.0000	1.0000	1.0000	1.0000	1.0000
Observations	204	204	153	153	170	170

****, **, *The significance level of 1, 5 and 10%, respectively. The numbers with asterisks in the corresponding rows of all variables in the table represent the estimation coefficients, and the values in the parentheses are the corresponding T statistical values, and the P values of AR_1, AR_2, and Sargan test are provided respectively.*

TABLE 4 | Regional differences in the impact of land urbanization.

Variables	SYS-GMM					
	Eastern region		Central regions		Western regions	
	(1)	(2)	(3)	(4)	(5)	(6)
	Morbidity	Mortality	Morbidity	Morbidity	Mortality	Morbidity
Land urbanization	−0.9601***	−0.4067	0.6192**	0.7437*	0.0177**	0.1575**
	(−2.880)	(−0.597)	(2.326)	(1.829)	(2.017)	(2.349)
Population density	3.3630	−1.1657	−3.3557	−2.0959	4.2387	7.3419
	(1.166)	(−0.928)	(−0.480)	(−0.483)	(0.186)	(1.182)
Age	0.8765	0.3759	2.5570**	−6.1144	3.2429	1.3849**
	(0.969)	(0.053)	(2.284)	(−0.516)	(0.100)	(2.347)
rgdp	0.1287	−0.1024	0.6453	0.4276	−0.7296	−1.8042
	(0.721)	(−0.709)	(1.628)	(0.641)	(−0.164)	(−1.470)
Expend	−0.1328**	−1.2658	−1.0627*	−1.5019	−1.2157	1.8885**
	(−2.218)	(−0.316)	(−1.810)	(−0.409)	(−0.211)	(2.083)
Medical	−0.4360**	0.0076	−5.6163*	1.2861	2.4147	0.5866
	(−2.190)	(0.099)	(−1.930)	(0.515)	(0.157)	(0.533)
Air	−0.0752**	−0.0040	0.5108	0.0017	−0.2058	−0.1424
	(−2.090)	(−0.077)	(0.982)	(0.017)	(−0.101)	(−0.405)
L.disease	0.5941***	0.4867***	−1.1119***	1.4820***	−0.1200***	3.2418**
	(5.983)	(3.199)	(−3.330)	(2.994)	(−4.053)	(2.323)
AR_1	0.0374	0.015	0.0163	0.0146	0.0662	0.0209
AR_2	0.4325	0.9854	0.2254	0.2385	0.7247	0.5320
Sargan text	0.9998	1.0000	1.0000	1.0000	1.0000	1.0000
Observations	204	204	153	153	170	170

****, **, *The significance level of 1, 5 and 10%, respectively. The numbers with asterisks in the corresponding rows of all variables in the table represent the estimation coefficients, and the values in the parentheses are the corresponding T statistical values, and the P values of AR_1, AR_2, and Sargan test are provided respectively.*

A and B infectious diseases under the system GMM model. It can be seen from **Table 4** that land urbanization in the eastern region has a significant negative impact on the morbidity of Category A and B infectious diseases, which reveals that the increase in land urbanization in the eastern region can help reduce the risk of infectious disease spread. It is not consistent with the estimated results. The impact of land urbanization on the morbidity and mortality of Category A and B infectious diseases in the central and western regions is significantly positive, indicating that the improvement of land urbanization in the western regions increases the risk of the spread of infectious diseases. The cause of the regional differences may be as follows:

In the process of urbanization, the eastern region adheres to the industrial transformation with the industrial structure level higher than that of the central and western regions. It strengthens the intensive utilization of land, protects the ecological environment of the cities, improves the urban living environment, and highlights green and healthy urbanization (48), so as to produce a positive "interactive" relationship between the land urbanization rate and infectious diseases prevention and control. Compared with the eastern region, the central and western regions have a lower level of economic development and threshold for environmental regulation. They undertake the transfer of some polluting industries in the eastern region and face the threat of pollution transfer from the eastern region (51). The easily destroyed ecological environment, the increased environmental pollution, and the deteriorated urban living environment and air quality have augmented the risk of the spread of infectious diseases (52).

To test the conclusion robustness of this study, the differential GMM model is used to estimate the regional heterogeneity of population urbanization, land urbanization, and the spread of infectious diseases. The specific regression results are shown in **Tables 5**, **6**. To be specific, **Tables 5**, **6** show the robustness test results of the impact of population urbanization and land urbanization on the spread of infectious diseases, respectively. According to the regression results in **Tables 5**, **6**, the direction and significance of the regression coefficients of population urbanization and land urbanization on the morbidity and mortality of Category A and B infectious diseases are roughly the same as those in **Tables 3**, **4**, except for coefficients which are different. It further proves that the research conclusions of this paper are robust and reliable.

TABLE 5 | The robustness test of population urbanization.

Variables	DIFF-GMM					
	Eastern region		Central regions		Western regions	
	(1)	(2)	(3)	(4)	(5)	(6)
	Morbidity	Mortality	Morbidity	Morbidity	Mortality	Morbidity
Population urbanization	−1.0352*	−2.1906*	−0.8034	−1.4020	−1.1195*	−0.4863
	(−1.853)	(−1.755)	(−1.062)	(−1.259)	(−1.686)	(−0.107)
Population density	1.9029	−5.1416	1.6359	−2.8899	2.4529	6.5785
	(1.642)	(−1.319)	(1.549)	(−0.946)	(1.589)	(1.387)
Age	1.1913	3.1623**	0.2904	57.0209	2.2026	−0.3496
	(1.315)	(1.966)	(0.038)	(1.216)	(0.270)	(−0.103)
rgdp	0.4467**	0.7777*	1.6158**	−1.2548	−0.9862	−0.4307
	(2.026)	(1.689)	(2.097)	(−0.725)	(−1.072)	(−1.175)
Expend	−2.7409	−0.3739	0.8189	1.9069	−0.4761	1.2627
	(−1.128)	(−1.318)	(0.795)	(1.246)	(−1.621)	(1.418)
Medical	−0.3118***	0.0167	−1.8586	−3.4469	8.0402	2.3041
	(−3.072)	(0.200)	(−0.804)	(−1.130)	(1.494)	(1.243)
Air	−0.0220	−0.0677*	−0.5670	0.3371	−0.9307	−0.1791
	(−0.618)	(−1.688)	(−1.074)	(1.121)	(−1.349)	(−1.087)
L.disease	0.5536***	−1.2917**	0.5408***	−1.1777***	−0.9155***	−0.1776***
	(5.062)	(−2.067)	(2.912)	(−3.037)	(−3.321)	(−4.259)
AR_1	0.0519	0.0364	0.0217	0.0926	0.0866	0.0658
AR_2	0.528	0.518	0.1518	0.1422	0.2762	0.2693
Sargan text	0.8934	0.9953	1.0000	1.0000	1.0000	1.0000
Observations	204	204	153	153	170	170

****, **, *The significance level of 1, 5 and 10%, respectively. The numbers with asterisks in the corresponding rows of all variables in the table represent the estimation coefficients, and the values in the parentheses are the corresponding T statistical values, and the P values of AR_1, AR_2, and Sargan test are provided respectively.*

TABLE 6 | The robustness test of land urbanization.

Variables	DIFF-GMM					
	Eastern region		Central regions		Western regions	
	(1)	(2)	(3)	(4)	(5)	(6)
	Morbidity	Mortality	Morbidity	Morbidity	Mortality	Morbidity
Land urbanization	−0.9252***	−1.6577	0.6192**	0.7437	0.1210***	0.0378**
	(−2.776)	(−0.768)	(2.402)	(1.339)	(2.934)	(2.390)
Population density	8.7626	2.0615	−3.3557	−2.0959	6.8670	3.3015
	(0.950)	(0.405)	(−0.544)	(−0.543)	(1.071)	(0.709)
Age	1.0876	−1.0846	2.5570**	−6.1144	1.3447	7.4087*
	(0.769)	(−0.640)	(2.474)	(−0.590)	(1.599)	(1.862)
Rgdp	0.1413	0.3092	0.6453*	0.4276	−0.7101**	−0.9036
	(1.047)	(0.975)	(1.825)	(0.716)	(−2.277)	(−1.019)
Expend	−0.2799	−2.8727	−1.0627**	−1.5019	−1.1651	1.3852
	(−0.087)	(−0.461)	(−2.043)	(−0.468)	(−1.456)	(1.635)
Medical	−0.2358**	0.1492*	−0.6163**	1.2861	0.1989	0.1083
	(−2.178)	(1.819)	(−2.133)	(0.579)	(1.007)	(0.156)
Air	−0.1463	0.0500	0.5108	0.0017	−0.1499	−0.0555
	(−0.969)	(1.297)	(1.103)	(0.017)	(−1.055)	(−0.228)
L.disease	0.5321***	−0.8979***	−1.1119***	1.4820***	−0.3722***	1.8112***
	(4.658)	(−2.998)	(−3.528)	(3.098)	(−2.949)	(3.643)
AR_1	0.0267	0.018	0.0407	0.0131	0.0162	0.0129
AR_2	0.1346	0.5454	0.204	0.1463	0.2434	0.4116
Sargan text	0.7656	0.8976	1.0000	1.0000	0.9995	0.9683
Observations	204	204	153	153	170	170

****, **,*The significance level of 1, 5 and 10%, respectively. The numbers with asterisks in the corresponding rows of all variables in the table represent the estimation coefficients, and the values in the parentheses are the corresponding T statistical values, and the P values of AR_1, AR_2, and Sargan test are provided respectively.*

CONCLUSION AND POLICY ADVICE

The COVID-19 pandemic renewed a question of whether the increase in population and the dense construction caused by urbanization increases the spread of infectious disease? To explore the relationship between urbanization and the spread of infectious diseases, this paper matches provincial data and health data to construct the panel data of China's 31 provinces between 2002 and 2018. Also, a GMM model is used to empirically evaluate the impact of urbanization on the morbidity and mortality of Category A and B infectious diseases from the dimensions of "population" and "land." Findings are listed as below:

Firstly, the full sample regression results show that population urbanization and land urbanization have opposite effects on the morbidity and mortality of Category A and B infectious diseases. Higher population urbanization reduces the morbidity and mortality of Category A and B infectious diseases and inhibits the spread of infectious diseases. On the contrary, a higher land urbanization rate increases the morbidity and mortality of Category A and B infectious diseases and intensifies the spread of Category A and B infectious diseases.

Secondly, according to the results of regional heterogeneity regression, due to the developed medical level, rich educational and medical resources, public health system, and high quality of living environment and health requirements in eastern regions, the negative impact of population urbanization level on the spread of infectious diseases in eastern regions is more obvious than that in central and western regions.

Thirdly, population density has no obvious impact on the spread of infectious diseases so disease prevention and control play a crucial role. To a certain extent, the increase of the aging population and per capita GDP enhances the risk of the spread of infectious diseases. The enhancement of investment in public health, medical development, and air quality make the spread of infectious diseases less risky.

The policy inspirations of the conclusion in this paper mainly involve the following several aspects:

Firstly, China should continue to promote the "people-oriented" new urbanization construction and expand the positive effects of population urbanization on the prevention and control of infectious diseases and public health. In the face of the increasing proportion of urban population brought by urbanization, the government should not limit the inflow of population but improve the level of urban technology and

management by adjusting production and lifestyle, so that people's demands for a better and healthier life can be met faster than population growth. The reform of the household registration system is particularly important, so efforts should be made to actively promote the adjustment and improvement of the points-based household registration policy in megacities and supercities. A mechanism has been established to link the basic public services such as urban education, employment and entrepreneurship, and medical and health care to the permanent population, so as to avoid the influence of population mobility on the epidemic spread. In this way, China can actively cope with the challenges to the prevention and control of infectious diseases and public health brought by the increase of urban population.

Secondly, China should have the consciousness of "safety blank" for the urban development, that is to optimize the urban space layout without blind expansion and excessive land development, so as to make the production space more intensive and efficient. Protecting the urban ecological and living environment can make land urbanization bring a positive "interactive" relationship with the prevention and control of infectious diseases and public health, thus maximizing the sustainability of urban development.

Thirdly, China should build infrastructure services such as health care, education, and old-age care that are compatible with urbanization, and improve the public health management system and the "diversified" old-age security system. In this way, the negative effects of urbanization on the public health of residents can be reduced, and high-quality public resources can better serve local residents, so as to deal with public health emergencies such as the outbreak of infectious diseases more calmly.

Fourthly, when formulating the policies with regard to the prevention and control of infectious diseases and public health, the government should consider the impact of regional differences and the local realities. In particular, efforts should be made to strengthen the input of public resources such as medical treatment, health, and education in the central and western regions. China should strengthen environmental regulation thresholds, protect the ecological environment, promote equal access to public health services in all regions, improve the ability to prevent and control infectious diseases and the health of residents, so as to achieve healthy and balanced development in all regions.

LIMITATION

This article has two limitations: firstly, this paper uses the previous data to discuss the relationship between urbanization and the spread of infectious diseases. It would be better if it could be combined with the latest COVID-19 data. However, the dimensions of urbanization and COVID-19 data are different, so it is impossible to conduct empirical analysis. Therefore, the research of this paper can provide a reference for related research in the future. Secondly, there are many factors affecting the spread of infectious diseases. Only some factors can be controlled in this paper, and there is no way to comprehensively consider the impact of other factors on the results in this paper, such as ecological fallacy, solar radiation, and so on. These are the focus of our next research.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

DY: data curation, conceptualization, methodology, and writing—reviewing and editing. XL: data curation and writing—original draft preparation. JY: visualization and investigation. XS: writing—original draft preparation and investigation. PL: validation and writing—reviewing and editing. PT: writing—reviewing and editing. All authors contributed to the article and approved the submitted version.

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COVID-19 in Saudi Arabia: An Overview

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Background: Saudi Arabia, a prominent Arabian country, has 35. 3 million persons living in 2.2 million square kilometers, undergone serious threats recently due to the COVID-19 pandemic. With the built-in infrastructure and disciplined lifestyle, the country could address this pandemic.

Aims: This analysis of COVID-19 cases in Saudi Arabia attempts to assess the situation, explore its global percentage share, percentage of population affected, and local distribution from the beginning of infection until recently, tracing historical developments and changes.

Data and Methods: This analysis made use of data released by the Ministry of Health on a daily basis for a number of parameters. They are compiled on an excel sheet on a daily basis: the dataset has undergone rigorous analysis along with the trends and patterns; proportion to the world statistics and geographic distribution.

Results: COVID-19 spread rapidly in the country with periodic variations, during June-August, 2020. But, recoveries accelerated in the period, thus bridging the gap of increasing infections. In comparison with the world statistics, the country proportions are lower, while the percentage of population affected is similar. It appears that the intensity varied across all 13 administrative areas.

Conclusion: COVID-19 transmission since March 2020 is considered to be widespread, creating excess burden on the public health system, delineated into stages (early infection, rapid spread, declining, stabilizing, and second wave). Control measures are set, stage-wise, without impinging upon normal life but to ensure that the proportion of globally affected persons is lesser than the population share: credit goes to the Ministry of Health. Area-wise spread depends largely on population density and development infrastructure dimensions. Ultimately, the disciplined life in compliance with law and order paved the way for effective program implementation and epidemic control.

Keywords: epidemiology, proportions to world, percentage of population, local distributions, administrative areas

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INTRODUCTION

The COVID-19 pandemic spread rapidly across the world, including Saudi Arabia, which led to a severe health emergency (1–5). There are many facets of spread in the country with variations across populations, geographies, and families. Despite all efforts of the government health system and responsible residents, the pandemic spread faster but was controlled through intervention strategies of the Ministry of Health such as digital health, social distancing, suspending gatherings,

temporary closures, and imposing curfew at commercial and service utilities (6–8). Simultaneously, interventions were phased out at the national level considering infections, mortality, and recovery with geographic importance (9–14).

The epidemic period combined with health emergencies created tensions in family units, especially under poor conditions of infrastructure and crowded living arrangements due to restrictions on family and social life, interpersonal contact, and affective gestures adhering to the strict discipline of social distancing and face masks (5). This lead to containment: quarantine, lockdowns, and curfews in turn creating conflicts, tensions, and violence manifesting upon contact with infected persons (1, 15, 16). Consequently, it leads to an overall breakdown of the individual, family, and society with enormous changes and unparalleled consequences-financial and medical (17, 18). Moreover, there are economic, social, and community impacts (10, 19) despite the assessments and investigations from the medical perspective and daily data release from the Ministry of Health.

Saudi Arabia, a large country in terms of geographic area, is divided into five planning regions, 13 administrative areas, and 118 governorates. It borders five Arabian Gulf countries and a few other Arab countries, and accommodates a combined native and foreign population of 35.3 million across 2.2 million square kilometers. This predominantly urban country built residential, commercial, educational, medical, and other infrastructure to encourage community living, which expedites the possibility of faster infection (8, 20, 21). Floating population, despite the efforts of containing, isolating, social distancing, and closing, causes the spread of COVID-19 in a new form of Middle East Respiratory Syndrome Coronavirus (MERS-CoV) that plagued the Middle East, although a majority of cases were reported in Saudi Arabia (3, 22–27). These reports of this worldwide pandemic in Saudi Arabia are attributed to population size, resisted through strategic interventions and mitigation measures characterized by swift community action and hospital preparedness (3, 10, 26, 28–31). This aligns with vision 2030 that positions the country as a business and tourism hub (8, 32).

Against this backdrop, this research aims at an epidemiological analysis of COVID-19 cases reported on a daily basis to highlight changes, patterns, and trends over a period from March 21, 2020 to November 22, 2021. With the limitations of the national-level data available for analysis, this research elucidates the path of COVID-19 infection in the country, from its very beginning until recently. Such an elaboration, which has not yet been attempted, might enlighten researchers, policymakers, and practitioners to track historically and to learn lessons from a successfully implemented infection control program. Not only does this elaboration exposes the Saudi Arabian experience to global readers, but also it gives data and insights to the rest of the world, especially the Arab countries.

DATA AND METHODS

This empirical study adopting ex-post facto approach is based solely on daily status reports of the Ministry of Health of Saudi Arabia published since March 21, 2020. Calculations were done to determine:

a. daily changes in infection
b. daily differences between reported and recovered cases
c. daily changes in active cases and critical cases
d. case fatality rate (deaths until date per 1,000 infections until date)
e. new and active cases, recovery and mortality as a percentage of global
f. infections, recoveries, and deaths per 100,000 population

Data published contained city-wide data till November 28 2020; thereafter it was by the 13 administrative areas till September 25, 2021; and at national level totals there. There were reports of global figures too till September 25, 2021. It was owing to the substantial decline in infection that these changes in the data structure are enacted by the Ministry of Health. Furthermore, adopting population size (35,575,968 for October-November; 35,484,062 for September; 35,439,591 for August and 34,543,959 for others as cited on www.worldometers.info) as a denominator, indicators such as (a) daily reported cases, (b) total cases and total recoveries, (c) total deaths, (d) critical cases, (e) active cases, and (f) vaccinations are calculated for a base population of 100,000.

These analyses were based solely (as a source of data) on daily reports of COVID-19 cases published on the Website and through social media platforms (Facebook) by the Ministry of Health, Saudi Arabia. These reports from March 21, 2020 to November 22, 2021 are compiled on an Excel worksheet for consolidated analyses and illustrations.

RESULTS

Results of this analysis are presented under various headings: epidemiology, proportion to world statistics, percent of the population affected, and spread by administrative area.

Epidemiology

A total of 392 cases of COVID-19 recorded on March 21, 2020, increased to 549,518 on November 22, 2021 showing a rapid spread in a population of 35.3 million; unexpected and unafforded to the public health system. Fortunately, there were reductions in reported infection per day from 4,757 on June 18, 2020 to 220 on November 28, 2020; 328 on February 28, 2021; 1,161 on June 7, 2021 and 39 on November 22, 2021 (**Figure 1**). Along with this decrease in the infection was the mortality due to the pandemic, which declined with the infections but at a lesser proportion. From a single death reported on March 24, 2020, daily deaths increased to 58 on July 5, 2020. The death toll per day remained high at 13 on November 28, 2020; 6 on February 28, 2021; and 15 on June 7; 2021 but declined to 2 on November 22, 2021. Together with these indicators are the daily recoveries, which exceeded new cases since May 12, 2020, but with minor fluctuations. It appears that the gap between active cases and recovery existed during June - July 2020 started to decline slowly since October 2020, and rapidly thereafter.

Two of the important indicators are active cases and critical cases: the former, as reported, increased from 22,444 on June 3,

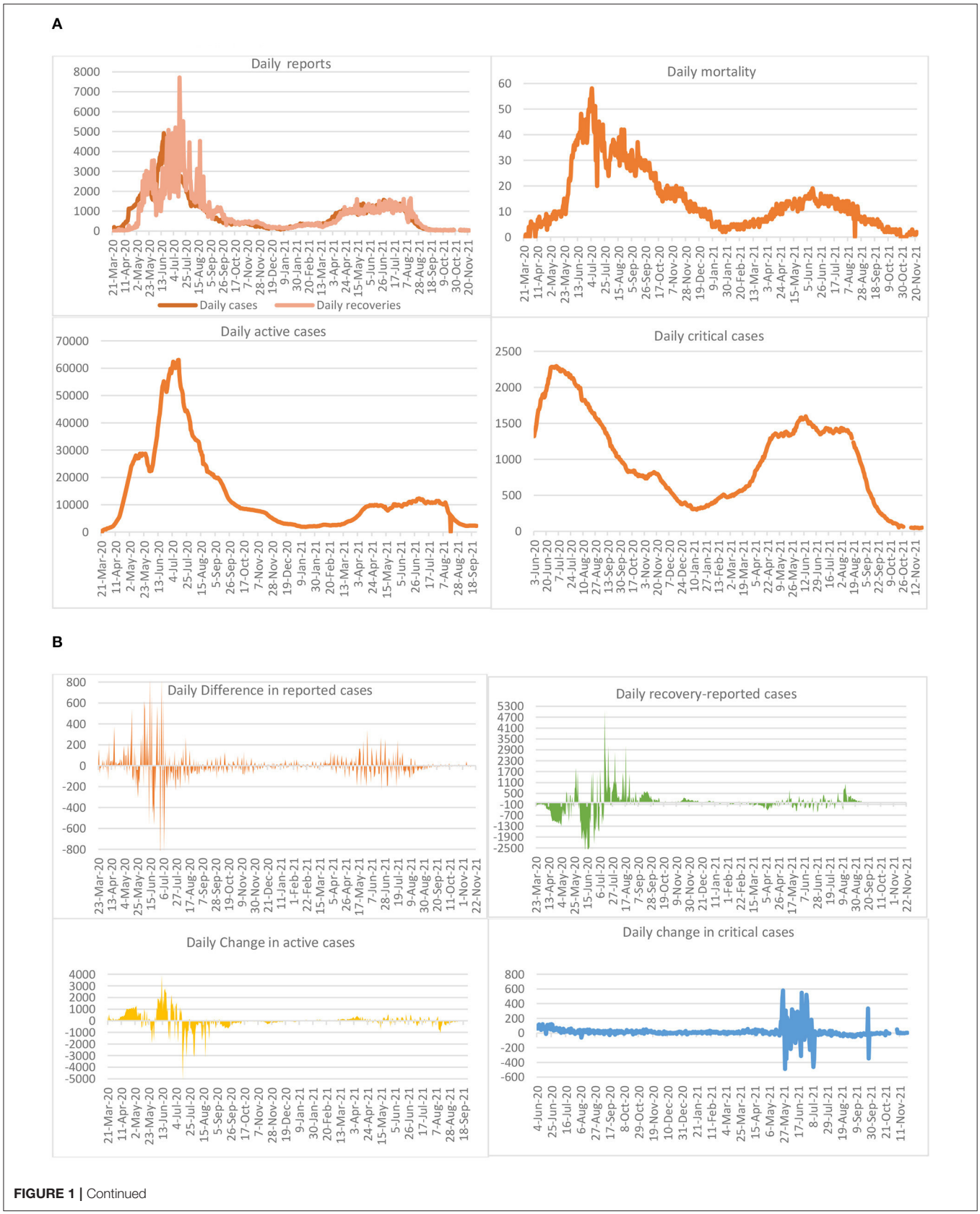


FIGURE 1 | Continued

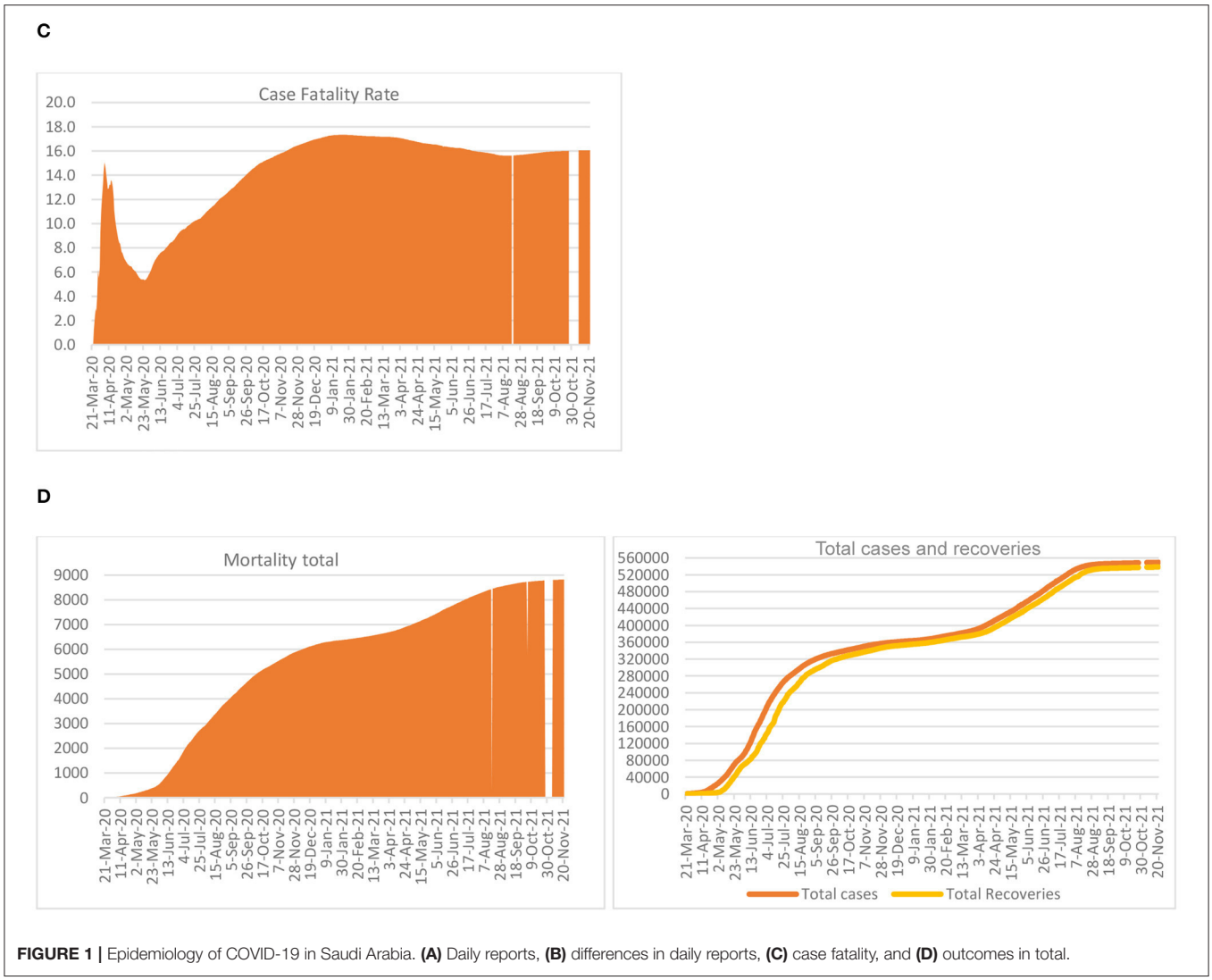


FIGURE 1 | Epidemiology of COVID-19 in Saudi Arabia. **(A)** Daily reports, **(B)** differences in daily reports, **(C)** case fatality, and **(D)** outcomes in total.

2020, to 63,026 on July 13, 2020, but declined sharply thereafter. While the increase from June 3 to June 19 was sharp, it slowed down thereafter, reaching 45,157 on July 22, 2020; 23,687 on August 23, 2020; and 8,487 on October 19, 2020; 1,894 on January 16, 2021; and 2,296 on September 25, 2021. On November 28, 2020, there were 5,018 active cases (1.4% of infected cases, leaving 1.6% deaths), which declined to 2,584 by February 28, 2021; 2,581 on March 4, 2021 but thereafter increased to 9,376 on June 7, 2021. While the rapid increase in active cases noted during March 21-June 12, 2020 could be considered as part of the first phase, those noted in 2021 could be explained as part of the second phase. The total number of infections and recoveries has been varied but bridged the gap since October 2020. Moreover, the gap widened and shortened depending upon the daily reports. On the contrary, dwindling changes in the critical cases were recorded on a daily basis until the end of January, and started to climb up thereafter. For example, on June 3, 2020 there were 1,321 critical cases that increased to a peak of 2,295 on July 4, 2020, decreased to 352 on January 30, 2021 and thereafter increased to 1,579 on June 7, 2021. The same started falling slowly, thereafter, reaching a figure of 52 on November 22, 2021.

Increases in the daily number of infected cases were in multiples of hundred during the early days of COVID-19. For example, on March 24, 2020, the number of new cases was increased by 154. But on July 3, 2020 the highest daily increase was reported as 810, which reduced from August onwards. On the contrary, there were reductions too, for example, on April 8, 2020, there was a reduction of 135 cases. Along with the spread of infections, mitigation also took place resulting in recoveries from the episodes. As of February 28, 2021, 368,305 cases have been recovered out of a total number of infections of 377,383 cases reported, representing a 97.6% recovery rate, leaving 6,494 (1.7%) deaths, which shows a prevalence of 0.7%. During the early days, that is, March and April 2020, daily recoveries were lower than reported cases, which is the reason for a huge increase showing negative recovery-reported case statistics. For example, on March 24, 2020, this difference was 196, with 9 recoveries out of 205 cases. On May 4, 2020, this figure of recovery-reported

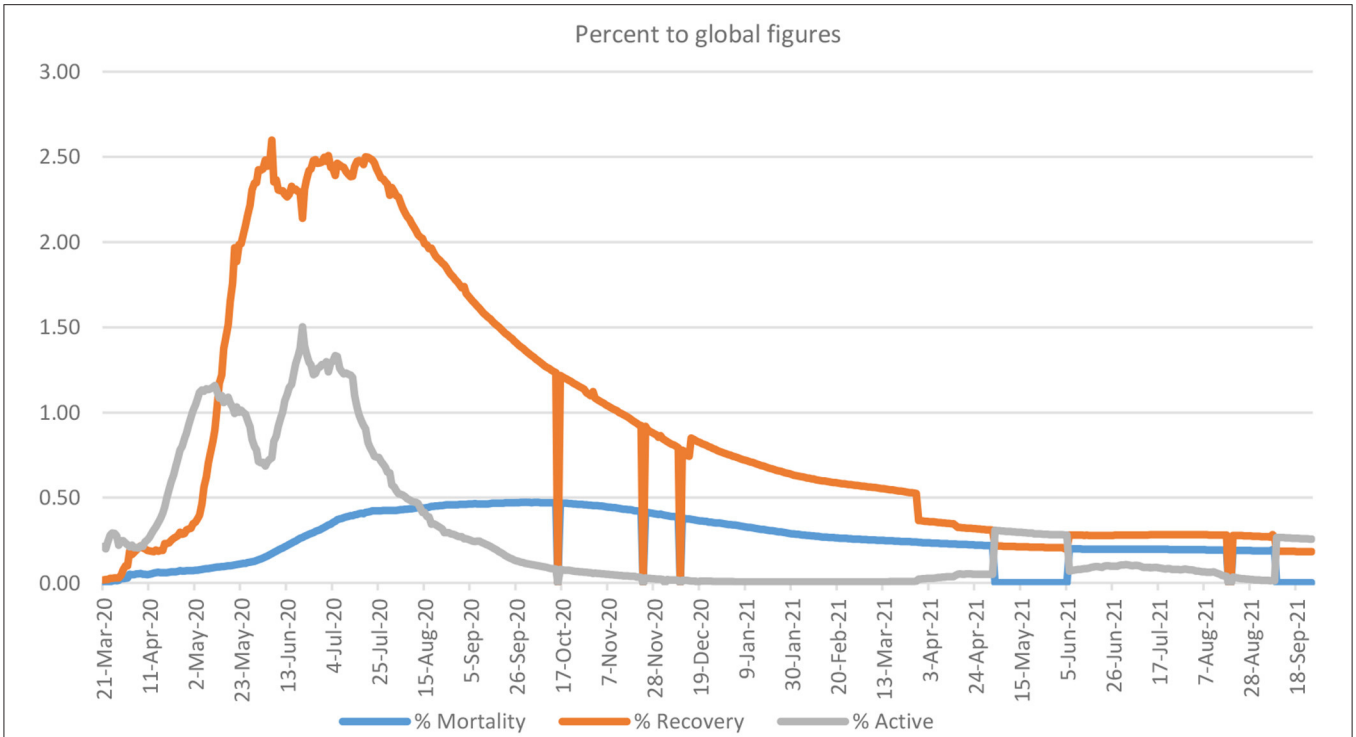


FIGURE 2 | Global comparisons of COVID-19 statistics.

cases reached −1,303 and on June 12, 2020 it reached a peak of 2,911 cases, adding up to active cases. On the other hand, there were recoveries exceeding new cases from May 12, 2020 onwards but were zigzagging: the highest on July 14, 2020 with a difference of 5,026 cases (7,718 recoveries as against 2,692 new cases).

The case fatality rate, calculated as total deaths to 1,000 total infected cases, reached 16.3 on June 7, 2021. It was recorded as 15.1 on April 6, 2020, which declined to 5.4 by May 23, 2020. However, case fatality was recorded at a high of 17.3 during January 6–February 16, 2021, and 8,826 on 22 November, 2021 depending mostly on the positive cases and deaths reported. The total number of deaths reached 7,471 on June 7, 2021 with a daily mortality of 16. The highest number of deaths of 58 was reported on July 5, 2020.

Proportion to World Statistics

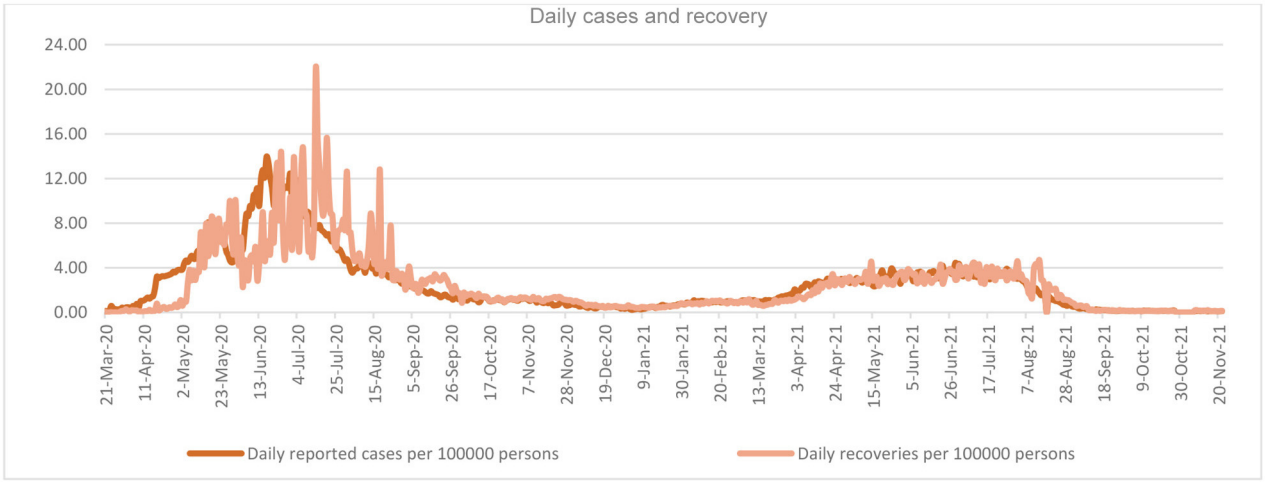
Saudi Arabia, the largest country in the Arabian Gulf and second largest in the Arab World, has an area and population that are both 0.4% of the world. Saudi Arabia started with 0.2% of the world's COVID-19 cases on March 21, 2020, which increased to 1.5% by June 20, 2020, but declined to 0.02% by November 28, 2020, 0.01% by February 28, 2021, and even less than that thereafter, following various phases of intervention over that period (**Figure 2**). Recoveries were low from March 21 to May 4, 2020, sharply increased during May 5–20, fluctuating with high recoveries until August 4, 2020, and lower recoveries thereafter. Still, the percentage of patients recovered fluctuated between 0.02 and 2.5% of global figures.

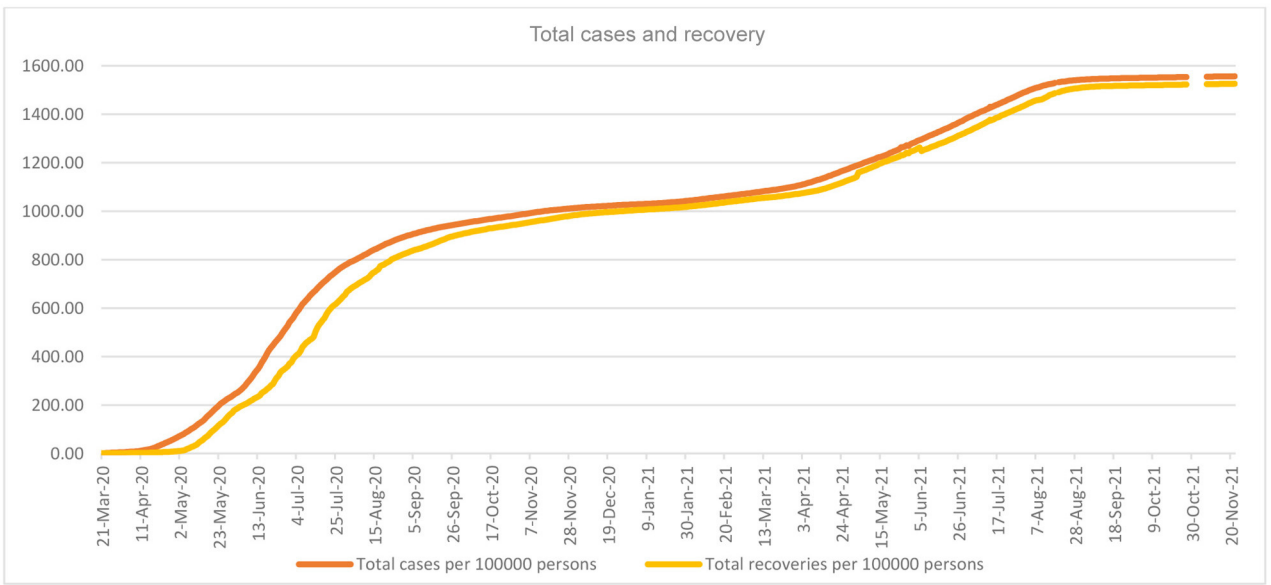
Share of the Population Affected

There are a total of 549,518 infected cases, as of November 22, 2021 (1,556 per 100,000 persons); higher rates of infection but almost all recovered (538,640; 1,526 per 100,000 persons). Thus, having a very narrow gap between infected and recovered persons (**Figure 3**). It is the mortality from COVID-19, that receives greater concern in the country, especially due to its higher number per 100,000 persons. Daily reports of cases also show reductions but with intermittent increases. While applying the total population as the denominator, daily infection of COVID-19, as plotted, reached its peak point of 14 per 100,000 persons on June 17, 2020 on the day of the highest number of infections of 4,919 in the country. This percentage declined sharply thereafter to 1 on February 28, 2021; 3 since April 8, 2021, but was negligible by November 22, 2021. While the daily cases declined to the lowest (0.23 per 100,000 persons) on January 3, 2021, it shoots up thereafter for a short period. Similarly, the total cases had declined to 1,028 on January 3, 1,043 on February 28, 1,182 on April 30, and 1,299 on June 7, per 100,000 persons: total recoveries were 1,018, 1,058, 1,151, and 1,269; and total deaths were 18, 19, 20, and 21 per 100,000 persons, respectively.

Spread by Administrative Areas

Some of the administrative areas, especially major commercial, educational, residential, and developmental zones, reportedly have a higher number of COVID-19 cases (**Figure 4**). In Riyadh, there was an upsurge of cases during May-July, 2020 but this has come down since August 2020, reducing to a low by





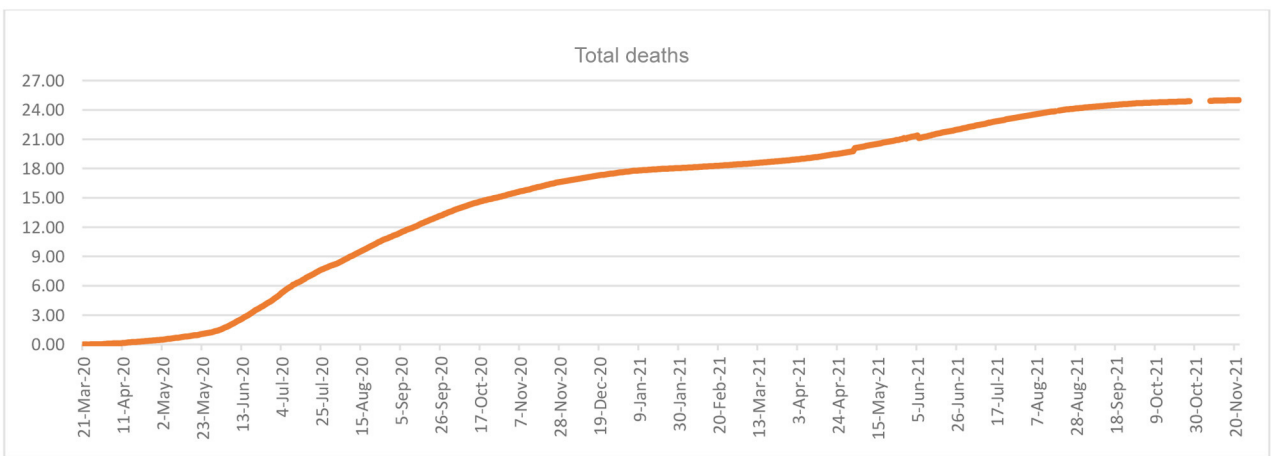


FIGURE 3 | COVID-19 Infections in per 100,000 persons in Saudi Arabia.

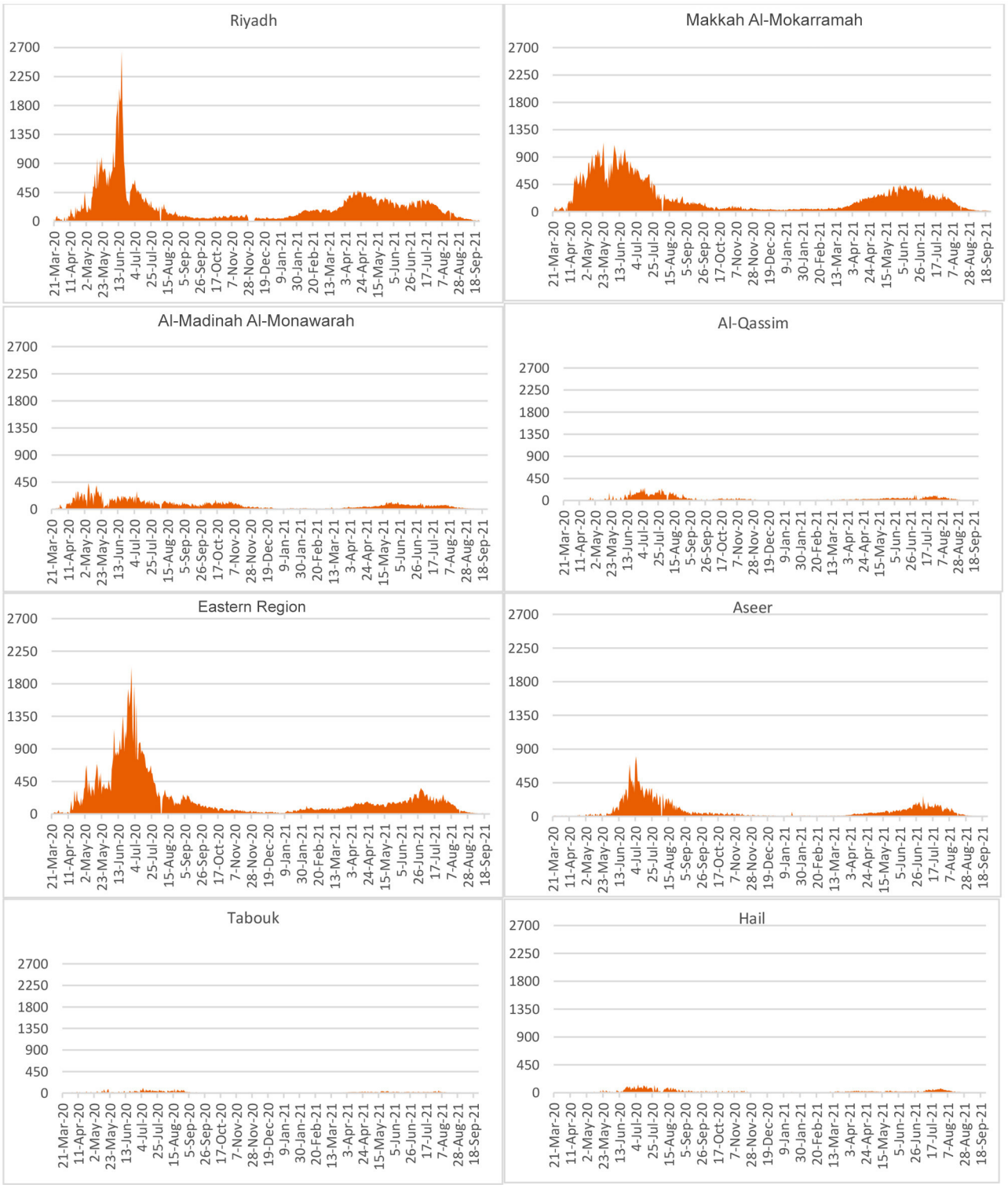


FIGURE 4 | Continued

FIGURE 4 | Spatial distribution of infections reported daily.

January 2021 but with a slight increase thereafter. Following Riyadh are the Eastern Region and Makkah Al-Mokarramah administrative areas, having been affected seriously. These three administrative areas have higher population pressure and also the proportion of the population affected (1,586, 23,647, and 1,496 per 100,000 population, respectively) than other administrative areas. However, differences across the administrative areas on population size produce differing proportions of infected. This paper has no scope for such a detailed analysis across the geographical divisions.

DISCUSSIONS

COVID-19, the most critical health issue humans have ever experienced over the last decade, vary across countries in intensity raising global issues by creating severe health and socioeconomic concerns, thus precipitating global disruption and emergencies affecting other aspects of life, including travel, material, and financial resources, and psychosocial wellbeing (3, 24–26, 33–35). The fast spread of COVID-19 in Saudi Arabia created panic responses from individuals, families, and social groups to adjust with strategies and control measures, including welfare and relief (6). Fast increases followed by reductions on daily new cases and mortality coupled with recoveries periodically, monthly, explicitly displays enactment and adherence of the various strategies of COVID-19 control, in the country, after September 2020 (4, 33). Such a decreasing trend in active cases continued further until February 2021. While the new cases increased with lesser recoveries were characteristic of March-April,

2020, the situation reversed thereafter bringing recoveries exceeding new cases. Moreover, infrastructure created by the public health system for screening, controlling, containing, and quarantine paved way for swift community action and hospital preparedness thereby minimizing the widespread transmission risk enabling a reduction in further spread (1, 4, 9, 30, 36).

Chronologically, risk assessment was followed by suspension of religious, recreational, sports, and commercial gatherings and thereafter public transport regulations leading to a partial curfew. There were enforced restrictions of inter-regional and international and national movements, local curfews based on daily reports, and national level lockdown. Connections are maintained through e-services. Repatriation of citizens, isolation of districts, remote teaching procedures, and rules carrying reprimands for the violation of control measures were also introduced. The private sector and expatriates were offered financial and welfare support along with special terms during Ramadan. Control measures were lifted slowly, step by step, depending upon the locational volume of spread. Mass testing strategies were initiated and, thereafter, normal living was regained in Saudi Arabia. There were a few other control measures put in place during the second wave too, although the spread was less intense. Slowly, there were reductions in the spread and thereby control measures were removed in the Kingdom. By this time, immunization programs gained momentum and it became mandatory for movement, especially in public places and offices. As an outcome, by September 2021, almost all control measures were withdrawn, observing a noticeably low spread of COVID-19. There exist restrictions on international travel and the entry of non-immunized people into the country. This is based on the lessons gained about the onset of the disease carried to the country by frequent travelers of the Eastern Region.

Mortality, measured as case fatality, was observed to be high, which increased rapidly until January 2021: such higher mortality rates might have resulted from population age distribution, the age of infected persons, life expectancy, comorbidity, treatment-seeking behavior, and other risk factors (37). However, an increase in case fatality could be probably attributed to the rapid decline in infected cases, the denominator. Overall mortality levels increased by around 2,000 cases in 2020 compared with that of 2019, which may be specifically attributed to COVID-19. Such hikes in mortality by a specific cause exerts a heavy burden on the public health system.

COVID-19 spread to more than 200 locations in Saudi Arabia, and thus gripped the country for a period, which was addressed through medical and legal intervention. This reduced not only the gap between infection and recovery but also the proportion to global infection, recovery, and mortality. While the global figures continue to increase rapidly, the share of Saudi Arabia declined, which may be credited to the mitigation efforts.

Population size and density are potential sources of COVID-19 infection (38), especially in the Arab culture. This applied to Saudi Arabia, especially the major cities characterized by a modern lifestyle under nuclear families, affecting the traditional family togetherness and cohesiveness. But in comparison to the global scenario, the country's levels are below its population proportions in terms of infections and mortality, which explains the national scenario including implementation of control measures. Such a positive mitigation outcome likely explains the change in lifestyle in line with legal and cultural regulations and COVID-19 control strategies.

There were increases in the overall total cases and mortality, which are attributed to the waves of this epidemic on a global basis. But, threats are limited as revealed by the affected persons as a percentage of the population. Thus, population rates are more meaningful than the absolute numbers for understanding the impact of COVID-19 on societies. These rates show the extent COVID-19 impacts the population regarding distribution, economy, behavior, and cohesiveness, directly and indirectly. These achievements of continued decline are geared by strenuous efforts of healthcare intervention including daily detection tests and vaccination.

Saudi Arabia has gone through highs and lows; based on population size, urban growth, infrastructure in place, and economic sectors. For example, a high spread of disease reported in administrative areas such as Riyadh, Makkah Al-Mokarramah, and the Eastern Region corresponds to this view. The second set of administrative areas are Al-Madinah Al-Monawarrah, Aseer, Al-Qassim, and Jazan. The other areas had few infected cases. These variations across administrative areas could directly relate to urbanization, social and religious festivities, commercial activities, and livelihoods despite effectively implementing various containment measures all over the country (8, 20, 23, 39). Almost all administrative areas passed the peak stage of infection and thereby marked declines with substantial public health measures put in place, which are capable to confront political, monetary, and social difficulties (3, 26, 32). Moreover, a majority of the cases are travelers from other countries in the case of the Eastern Region, and from contacts in the case of Riyadh, Makkah Al-Mokarramah, and Al-Madina Al-Monawarah; apart from medical professionals (40).

CONCLUSION

COVID-19 in Saudi Arabia witnessed increases and decreases epidemiologically, in terms of new cases, mortality, active cases, and critical cases, delineating phases of early infections (March-May, 2020), heightened spread (June-July, 2020), fast decline (July-September, 2020), stabilization (September, 2020-April, 2021), second-wave (April-September, 2021), and full control (October 2021 onwards). While country statistics show remarkable control, credit goes to the committed efforts of the Ministry of Health, Saudi Arabia, and disciplined adaptations by the public. Overall, the percentage of population affected is low, comparatively, but should be kept in view for continued efforts to control the virus. Mitigation along with infection control strategies should go hand in hand in a strengthened manner.

Geographically, administrative areas with higher pressures of population migration and socioeconomic development are more affected, especially the major cities such as Riyadh, Jeddah, Makkah, Buraydah, Dammam, and Madina. Finally, it is the

disciplined life in compliance with a law and order situation under a government of utmost accountability that enabled the achievement of goals and targets in time.

This research has many limitations, especially those related to data. Still, with this available data on the national scenario, the overall situation is explained for the global audience. It would have been more insightful had there been detailed data on age and sex specificity of infections, recoveries, and mortality. Such details could also be beneficial for analysis across geographic locations.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

AS: initiation, concept development, data compilation, analysis, and writing. RA-K: advisory in data compilation and methodology, reviewing and revising, and enabling supportive mechanisms. IE: assisting in data compilation, helping in analysis and literature review, and reviewing and suggesting improvements. All authors contributed to the article and approved the submitted version.

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POLICY BRIEF
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Six Drivers to Face the XXI Century Challenges and Build the New Healthcare System: "La Salute in Movimento" Manifesto

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The aging of the population, the burden of chronic diseases, possible new pandemics are among the challenges for healthcare in the XXI century. To face them, technological innovations and the national recovery and resilience plan within the European Union can represent opportunities to implement changes and renovate the current healthcare system in Italy, in an effort to guarantee equal access to health services. Considering such scenario, a panel of Italian experts gathered in a multidisciplinary Think Tank to discuss possible design of concepts at the basis of a new healthcare system. These ideas were summarized in a manifesto with six drivers for change: vision, governance, competence, intelligence, humanity and relationship. Each driver was linked to an action to actively move toward a new healthcare system based on trust between science, citizens and institutions.

Keywords: data analysis, digital technology, health, healthcare system, science literacy, COVID-19

INTRODUCTION

Health is a central concept for human beings, and good health is both a necessity and a right. The World Health Organization defines health as "a state of complete physical, mental, and social well-being not merely the absence of disease or infirmity" (1). Accordingly, health includes both the prevention of diseases and maintenance of well-being in every aspect of life, from physical to mental health and the ability to participate in social activities.

The XXI century has already posed important challenges for the management of health. The COVID-19 pandemic highlighted the strong interconnections between health, policy decision making and professional and social activities, underlining critical points of the current European and Italian healthcare systems. Indeed, COVID-19 has stressed healthcare system globally, urging a series of interventions spanning from economic policies to governance and ethics, implying collaborations between countries and among different institutions within the same country (2, 3). This unprecedented event added additional challenges for the healthcare system, such as the stable

increase of the world's population (4) and its aging (5) together with the growing burden of chronic diseases (6).

The development of a new, composite healthcare system represents the path for health management in the new century with the need for programs that facilitate the approach to the dimension of health (7, 8). In addition, the pandemic has shown how new digital solutions (telemedicine, wearables, artificial intelligence) can help in improving the quality of health and well-being. These new technologies have provided strategic support for healthcare systems to reach a greater proportion of the population, assuring more streamlined monitoring and assistance within both the national context and in a shared European scenario (9, 10). The recent finalization of national recovery and resilience plans within the European Union (11, 12) is an unprecedented opportunity for development and reforms for Italy to implement and renovate its public administration and healthcare system, in the effort to minimize social differences and guarantee equal access to health services.

To provide suggestions aiming to reach these goals with specific reference to the Italian healthcare system, a multidisciplinary Think Tank was set up by several representatives of Italian Institutions, private company, academia and associations within the social project called "La Salute in Movimento". Starting from the general evaluation of the current Italian situation, and with an eye to the international scenario, the Think Tank explored new ideas and proposals to be implemented in the Italian healthcare system. Herein, we report the statements of the project, which calls for objectives and actions that may be helpful to policymakers to highlight the need for a systemic approach to health issues, to contribute to the generation of a more modern and sustainable healthcare system.

POLICY OPTIONS AND IMPLICATIONS

The Six Drivers for Change: The Pillars for a New Concept of Health

A panel of experts and key opinion leaders belonging to different areas within the Italian society (academia, medicine, pharmaceutical industry, philosophy, psychology, technology, non-profit organizations) gathered in a multidisciplinary Think Tank to discuss ideas and critical points to face the new challenges of the XXI century, and to design a vision for a renewed Italian healthcare system. This discussion started from considerations on the building blocks of the health system as described by the WHO (service delivery, health workforce, health information systems, access to essential medicines, financing, and leadership/governance) (13) and followed the related issues pointed out by each discussant.

The panelists organized their discussion into a manifesto summarizing the features of global, sustainable, inclusive healthcare in six actions, named the drivers for change, to improve the Italian healthcare system and to propel the transition toward it: vision, governance, competence, intelligence, humanity and relationship.

Artificial intelligence (AI) and data analysis are tools crossing the different fields, and identified as strategic to create opportunities for the challenges toward concrete actions.

Vision

The vision for the future of the healthcare system considers health as a dynamic process, which is connected to science, social relationships, education and technology. The link between health and science must be re-discovered by the general public. This new perception will likely contribute to prevent mistrust about new discoveries, resulting in practical advantages to the healthcare system and society. To reach this goal, it is crucial to promote a global health literacy alliance, bolstering the ability to access, understand and make use of scientific information by the population (8, 14, 15). Without the ability to understand the benefits provided by treatment, even the most advanced therapies fail in providing care, because they are likely ignored or avoided. Indeed, several lines of evidence have demonstrated the connection between low health literacy and overall low utilization of healthcare solutions, thus resulting in worse health outcomes for the population (16). This is particularly true in Italy, and recent studies highlighted the overall inadequate health literacy of the population compared to other European countries (17, 18). This situation exacerbated during the pandemic as demonstrated by the limited literacy concerning, for instance, vaccines and their potential benefit for the society (19).

The scientific method, being experimental, transparent and repeatable, is a solid means of producing the knowledge which is at the basis of our societies. The clashes about the COVID-19 response have revealed that the scientific method is largely ignored, and that this ignorance has in-depth, heavy social effects. Therefore, we need to popularize the scientific method (20). Spreading knowledge about the scientific method to the public requires an efficient communication plan that involves the educational system; only through diffuse intervention can the general public possess the tools needed to augment trust toward the scientific process and its applications to healthcare. This will lead to informed participation about health-related issues, allowing to better overcome the challenges of both communicable and non-communicable diseases. A critical part of this process consists in the definition of effective and reliable tools to monitor and measure health literacy, and identify the critical factors that may interfere with the implementation of the process (e.g., ability to discern correct information, reverse the lack of confidence of individuals in using information) (21).

Governance

An efficient health system is based on efficient governance that ensures the development of strategic plans for health assistance. The improvement of health policies has been faced by European countries and can be reached by an appropriate governance (22). One of the main issues for the Italian healthcare assistance is a plan for the territorial primary care providing patients with the possibility to be assisted at home. There is the urgent need to better integrate the activities of local general practitioners with hospitals to ensure adequate assistance, especially in case of health emergencies and chronic disease. A territorial

health service, managed with the support of telemedicine and remote patient monitoring, will likely allow equal access to therapies and increase adherence to treatment. The efficiency of telemedicine has been reported after COVID-19 pandemic in several countries, and a similar effect is foreseen also for the Italian scenario (23). The strengthening of home care and territorial organization of the healthcare service is one of the indications included in the Italian National Recovery and Resilience Plan (NRRP) (12, 24).

Competence

Digital technology is a powerful tool to enhance the quality and efficiency of healthcare and the WHO recommended the use of digital interventions for the implementation of health systems (25, 26). Nevertheless, the ability of the healthcare system and healthcare professionals (HCPs) in adopting digital health solutions to implement services and patient assistance has been reported to be slow in US, Europe and Australia (27–29). Studies analyzing the main gaps that prevent the embracement of digital health have highlighted the need of appropriate and up-to-date competencies and digital literacy among primary care providers (30, 31). Interestingly, the improvement of basic IT knowledge and skills for HCPs are reported to be central facets (31). Despite the great advances undertaken upon the pandemic, the young generation of Italian physicians is still in need of an adequate education and training with respect to digital competence (32).

To take advantage of scientific and technological innovations, the Italian national health system should invest, considering the directions of NRRP and collaboration with private partners, in a wide digital education training plan directed to all HCPs, aiming to optimize their contribution to this new model of healthcare.

The need for health literacy should also be considered for stakeholders such as policy makers as a competence shared within all sectors involved in the healthcare system that results in generalized effective improvement and equity of the system (33). The development of a technological ecosystem integrated within national institutions that can be used for digital education has been already translated into practice in some realities, as it happened in Brazil following the pandemic. In that case, among other interventions, an online platform shared among the stakeholders and the institutions was useful to organize and capillary spread the right information about the pandemic. The technological ecosystem allowed the education and update of local HCPs, reducing the potential differences in the access to information due to different geographical areas, which would introduce disparities in case of face-to-face education (34).

Universities play a crucial role in education of new generations in fostering human centered innovation, adopting open science policy and strengthening civic engagement (35), as well as adapting their offer to cope with the new needs in the healthcare. In Italy, new courses based on multidisciplinary curricula (e.g., medical and technical schools, combining medicine and engineering) could educate the new HCPs of the future. The aim is also to enable systematic and easier creation of multidisciplinary medical teams like those that were forcedly improvised during COVID-19 and which will be required by the more sophisticated treatments that the future will bring.

Intelligence

AI and machine learning are believed to become essential components of medical research and improve healthcare efficiency (36). Nevertheless, current evaluation of the impact of AI and machine and deep learning in clinical practice reveals the limitations of such algorithms. The use of machine learning is mainly done in retrospective studies, and both the type of input data and the lack of transparency by which the output is generated are currently a major drawback in the broad application of this technique (37). To overcome these limitations, human intelligence should walk side by side with AI to deal with the possible bias generated by machine algorithms, without delegating decisions to them (38). Telemedicine and digital therapies rapidly spread in daily health management with the COVID-19 emergency and are here to stay (23). New advanced digital tools provide HCPs with an unprecedented amount of data that needs to be safely collected and analyzed for real-world evaluations, without forgetting ethical aspects (39, 40). This data represents a valuable driver of innovation in medicine and healthcare when they are rigorously collected and used according to appropriate methodology and ethical aspects (41). The presence of a government body for the technical and operative support of healthcare policies (national agency for regional health services, AGENAS) is a peculiarity of the Italian system and should be better exploited as a reference for data collection and analysis. This would contribute to assure reliable and high-quality health outcomes.

Humanity

Health is an inclusive concept. The new health system should take advantages from new technologies without forgetting human values, social justice and the environmental impact (33). Healthcare services should be delivered through improved cooperation of both healthcare and social services and be inclusive (42). COVID-19 highlighted the value of humanity, collaboration and inclusion for global well-being, with the necessity to build an accessible healthcare system that guarantees the best treatment for everyone (43). One of the aspects seen during the COVID-19 pandemic is the value of caring patients at home. Remote home monitoring and care for different pathologies increased during the pandemic also in Italy (44, 45), but there is still room for amelioration of the service. Indeed, a review analyzing the experience of remote home care revealed how the models proposed lack standardization and acquisition of proper data, and need a strong and inclusive patient engagement to become effective (46).

Relationship

An efficient healthcare system relates to scientific institutions and governments (22). The positive interaction between the patient and all the physicians involved in the care process is at the basis for proficient management of any condition, as well as the trustworthy cooperation between HCPs and policy makers, and the connection and strong relationship between local care activities and the hospital system (47). The establishment of functional relationships between all stakeholders should influence the definition of best practice and therapeutic paths

with the involvement of patient associations and caregivers (48–50). The health system should be evaluated according to the feedback from patients and the improvements that such indications can provide to HCPs and the general service offered (51).

Call to Action

How should a new global, human health system be designed? The panel of experts defined some actions to be taken to reach this bold objective. These actions are in accordance to the NextGenerationEU project (24) and have constituted the subject of a broader debate in a virtual 2-day event, Agorà, with stakeholders, healthcare and academia professionals, policy makers, patient representatives and the general public.[1] Within each of the manifesto's six overarching principles, the discussants worked in breakout sessions to define these actions. The use of the new technologies represented a common factor, given that innovation is central in the development of a new concept of health.

The final outcomes of each of the initial six principles are presented below.

Vision: Develop a Modern Scientific Communication Model

The Faro Convention encourages "citizens to recognize the importance of cultural heritage objects and sites through the meanings and values that these elements represent for them" (52). The broader and contemporary perspective we are promoting requires that these objects and sites, as well as cultural practices and values, include not only those of art but also those of science, since they contribute to both individual and social well-being. Thus, the concept of cultural heritage should be extended to medications and scientific innovation to underline their central role in the development of a culture of wellness.

The dissemination of health concepts, science and scientific research needs to be facilitated by the use of a new format based on the current popular language, from TV series to videogames, with the aim of reaching the widest possible audience. New accessibility to science will re-shape the public's perception, making it clear that scientific progress is reached based on evidence that is collected through a trial-and-error path.

A new perception of science will stimulate reciprocal empathy and trust of citizens toward HCPs and scientists, encouraging citizens to actively participate in the management of their health.

Governance: Build a New System for the Challenges of the Future

Establish a new Scientific and Technological Impact Assessment Body, an institutional organization to support policy makers in both legislative and executive functions. Indeed, the massive scientific and technological changes in the healthcare scenario urge for the need of scientific support for decision makers. A capable and dedicated scientific institutional body is also needed for the proficient management of funds from the national recovery and resilience plan, as it is necessary to have broad knowledge of the scientific scenario to sustain informed solutions.

Competence: Promote Health Culture as a Source for Solutions to Complex Issues

Creation of a new platform, through collaboration with scientific faculties of universities that is accessible to HCPs for both working and training. This platform, which we suggest can be called Formative Ecosystem for Healthcare Innovation (FEHI), will allow a constant update of the requested competencies for HCPs (31), delivering services such as the acquisition of certifications, both online (providing educational activities through Universities, IRCSS/Centers of Excellence, private societies), and in physical presence (building of a network of centers that will assist in the organization of educational activities). The platform will bring the available competencies to the attention of policy makers and the national healthcare system to match professionals with the correct job function. The new professionals should be trained to better understand and use new technologies, data science, AI and behavioral change models. The need for a more comprehensive inclusion of digital health-related topics has been also highlighted by the European Medical Students Association and described as a result of a recent study (53).

Intelligence: Human and Artificial Intelligence Must Cooperate in Data Management

Obtaining wide access to healthcare data from the entire country, collecting it from both public and private structures through the different 21 regional electronic health record systems ("Fascicolo Elettronico Regionale") (54) can be a new mission for the national healthcare system. Data organized in a centralized national system that is accessible to all healthcare centers will allow its utilization for its primary use (i.e., make it available to the patient and physicians when needed) as well as for secondary uses (i.e., research).

Moreover, the healthcare system should promote the creation of a network of specialists, general practitioners, patients and med-tech companies that shares valuable data for public health. Neglected use of the available data may result in a loss of efficacy for the healthcare system, with a waste of both resources and opportunities (55), even if any access to private information should take place according to ethical principles and current EU privacy regulations (56).

Lastly, the use of AI should be considered as a tool to increase the scale of care, through the identification of models or algorithms on which to base patient care in the daily practice in order to provide the same access to treatment to every patient, thus reducing inequities (57).

Humanity: Building a Healthcare System That Is Closer to the Patient

An integrated home assistance service for non-self-sufficient elderly, children and frail subjects should be favored. This should go beyond the idea of the hospital as the only feasible place of care, thanks to the help of new technologies and the development of digital platforms to provide room for storytelling (24). This

[1] https://lasaluteinmovimento.it/

objective is central in the NRRP (12), which clearly states the need to create conditions that will allow the patient to be cured at home, strengthening home assistance and use of telemedicine. In this light, patients and pathologies suitable for home treatment have to be defined, together with the identification of parameters that can be remotely monitored and alerting systems that allow remote interaction between patients, caregivers and HCPs.

Relationship: Overcoming Individual Visions in the Healthcare System

A "logbook" of the patient to establish a network of connections within the healthcare system should be implemented. This network will easily allow for constant updates with the healthcare activities of each patient, and will provide indications on the type of procedure needed or performed, the HCP in charge of the procedure and the outcome. The new "logbook" function will integrate the personal electronic health record that is already in use within the different regional healthcare systems.

CONCLUSIONS

Herein, we have outlined proposals to build a renewed model of healthcare for Italy that is deeply inspired by two basic principles that characterized the project "La Salute in Movimento": relationship, with its scope of collaboration and sharing, and trust, as an essential step to achieve innovation. These principles need to be structurally implemented on three fronts: data governance, status of algorithms and digital skills. Notably, technical and digital improvements are actually needed to humanize healthcare. Besides the limitations of the current study, which was carried on without following a structured methodological approach, the participation of experts in different areas involved in the development, support and maintenance of healthcare solutions and the integration of the diverse perspectives made the presented points of value in the current policy debate for the improvement of health care in Italy, and could serve as inspirational also for other similar efforts in different countries.

We aim to contribute to the implementation of the six actions of the manifesto to build the new system:

1. The infosphere consists of a network of "intelligent" nodes. The era of closed and self-referential contexts is no longer viable. Debate is public and takes place on different platforms.
2. Open debate can foster communication among scientists, and between the scientific community and the public (Open Science).
3. Communication matters. Scientists do not always know how to communicate.
4. It is important to spread the culture of science (health literacy and science literacy).
5. It is important to understand the scientific method, its complexity and foster critical thinking.
6. There is the need for education aimed at social platforms, places of communication and participation.

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FB, EC, MC, DD, MM, VP, GP, FP, and ES conceptualized, wrote the original draft, reviewed, edited, and approved the final manuscript. All authors contributed to the article and approved the submitted version.

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BRIEF RESEARCH REPORT
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Re-engineering the Cypriot General Healthcare System for Syndemics

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To date in Cyprus, there is no dedicated "Quality Improvement" body or Public Health authority. The long-awaited general healthcare system (known as GeSy or GHS) has been completed, mid-stream of the COVID-19 pandemic. A recently proposed resilience plan in response to the lessons learnt from the pandemic was put forward by the Government of the Republic of Cyprus to strengthen the capacity of the GHS and support public health defense. The negotiator of GeSy and Health Minister 2015–2018 also provided his view that the health system needs a holistic transformation of service provision. Recognizing failures and thinking from a syndemogenesis perspective how the envisioned patient-centric healthcare delivery can be achieved, we propose that the public health response could also be linked to a politico-economic one in shielding GeSy. We make such case for a syndemic strategy (simultaneous management of COVID-19 and pre-existing epidemics on the island) and the development of the five-district model where each main district hospital is to complement the activities of the GHS through developing: 1. A training Center for training and sharing of best practices for COVID-19 and other public emergencies. 2. A public health body. 3. A quality improvement institute. 4. A commissioning center on planning and streamlining healthcare services. 5. A clinical trial platform. The rationale is based on the management literature and use of existing resources and capabilities for transforming the GeSy and generating value.

Keywords: re-engineering, healthcare system, syndemic approach, non-communicable chronic disease (NCD), COVID-19

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INTRODUCTION

To date in Cyprus, there is no dedicated "Quality Improvement" body or Public Health authority. When the novel coronavirus SARS-CoV-2 responsible for the respiratory disease known as COVID-19, hit the island, the Government response was quick in designating the Ammochostos General Hospital (AGH) as the reference hospital for COVID-19 cases (1). Another notable example of the immediate response included the set-up of a Scientific Advisory Committee (SAC) by the President of the Republic, comprised of experts in epidemiology, infectious diseases and virology, to provide advice to the Government (2). The decision-making process for handling COVID-19 on the island was very centralized at the level of the Council of Ministers and the President of the Republic. The decisions were mainly in the form of decrees and protocols issued

by the Ministry of Health (MoH). These were then circulated, and the relevant information and guidelines disseminated by the MoH to the various authorities, governmental and/or non-governmental organizations. The action for the set-up of the SAC however, was a temporary decision, with plans to dismantle this as soon as the pandemic would shift to the endemic level. No further plans for the sustainment of the SAC or a similar function board were made, shifting back to a pre-pandemic public health strategy.

THE CYPRIOT HEALTH-POLICY CONTEXT

The MoH in Cyprus is the responsible body for the organization and the provision of equitable access and effective healthcare delivery through its hospitals and staff, with a mission to continuously improve population health. The Medical and Public Health Services (MPHS) Department of the MoH is responsible for health promotion and treatment of diseases encountered by the Cypriot population. The Health Monitoring Unit (HMU) has been developed to support health policy making, strategic planning, healthcare resources management, scientific research, and public health awareness. The pandemic has perhaps resurfaced the importance of such a Public Health body in response to health protection and prevention at the population level, in providing a more effective communication strategy to inform the public, combating fake news and dealing with other public health issues such as vaccination campaigns. However, no additional actions were made in setting-up and sustaining such a body. Further, mid-stream of the pandemic, the long-awaited general healthcare system (3–5) (known as GeSy or GHS) has been completed. This was done in two main phases as introduced by the Health Insurance Organization (HIO): phase one in June 2019 with the introduction of primary care and outpatient care and phase two in June 2020 with the introduction of inpatient care, as the foundation of universal care provision.

HEALTHCARE AND POPULATION HEALTH IN THE POST COVID-19 ERA

We recently calculated the impact of the mortality and morbidity burden from COVID-19 compared to non-communicable diseases and showed that Cyprus is at the very low end, compared to similar small state islands and big European countries (1, 6). Following the first wave, COVID-19 was not a syndemic on the island of Cyprus; for a short period of time, it was not a pandemic either. However, with the re-opening of schools in September 2020 and an increase of infection cases reported in nursing care homes, a higher second and an even worse third wave of cases occurred, leading to further lockdowns from November 2020 until May 2021. Delayed efforts for the re-introduction of masks in public places in August 2020, enforcement of non-pharmaceutical interventions and hygiene protocols, restricted citizen movement and others may be a result of the lack of a Public Health foundation. Overall, within 21 months of the COVID-19 epidemic in Cyprus, we witnessed less than 50 deaths until December 2020. Then despite the introduction of the publicly available vaccines against COVID-19 in Cyprus and a well-supported strategic public health plan put forward by the SAC and the MoH for the vaccination of the public, a soaring 550 deaths occurred between January to November 2021. The fact that 89% of deaths occurred during the second and third waves, demonstrates how important the public health prioritization on the island is; the majority of deaths occurred in patients with pre-existing conditions such as cancer, diabetes, and cardiovascular diseases, except for a few cases, as well as in unvaccinated people. Therefore, we make a case for the set-up of a Public Health foundation on the island and the use of a syndemic approach where the patient is given a holistic management approach i.e., simultaneous management of priority NCDs and COVID-19 (acute and post-acute).

A SYNDEMIC STRATEGY

Syndemics have been defined as the clustering of two or more diseases and the dynamic relationship between the biological and social elements that are at play (7) while the cumulative vs. multiplicative effects of such syndemics (between COVID-19 and NCDs) on the healthcare system strategy are yet to be explored (8). As context matters (9), recognizing failures and thinking of a syndemogenesis from a strategic perspective, achieving the envisioned patient-centric healthcare delivery could also be linked to a politico-economic response in shielding GeSy. A recently proposed resilience plan in response to the lessons learnt from the pandemic was put forward by the Government of the Republic of Cyprus (10) with 6% of the total budget (74.1 million euros) to be allocated on strengthening the capacity of the GHS and supporting public health protection. From this plan, the concept of dealing with syndemics, until now, is missing (11).

A key actor in the political context who had a catalytic role to the introduction of GeSy was the former Health Minister (2015–2018), George Pamboridis, who stated to us that "*the expected resilience of GeSy is to be formed through a bottom-up approach; there is an immense need for co-ordinating the rest of the healthcare services, as part of a transformative change to achieve its full potential. GeSy is at the core of this, but there are peripheral aspects that need to be addressed. The current proposed plans of the government are a great fuel for the healthcare system, but it is not the means to an end. Instead, we should be thinking about how we can create the appropriate conditions to achieve an equilibrium of the healthcare market based on demand and supply. The Cypriot population suffers from Covid-19, but this is an acute state; what about chronic non-contagious diseases? This remains the greatest challenge*" (12). Further, Pamboridis added "*the autonomy of the hospitals should be part of this equation. Such as introducing University hospitals; having an independent body to oversee commissioning of services; having an accreditation system in place.*" The case for re-engineering (13) based on eight pillars, was previously made, including the set-up of an independent body: the Cyprus Quality Improvement Institute. In this work, we make a case through the introduction of a conceptual model on how this can potentially be achieved in practice, following the literature on strategic management and leadership. Further research work however remains to test the exact parameters that

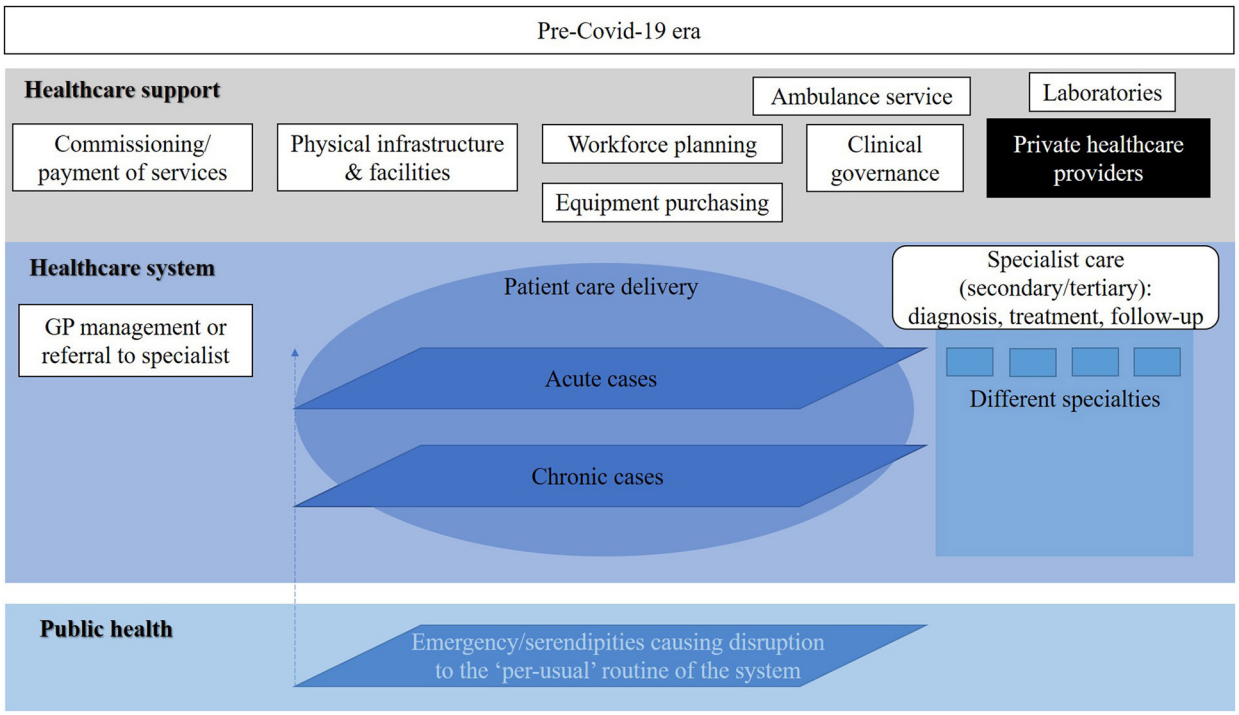

FIGURE 1 | The pre-COVID-19 era Cypriot health service model.

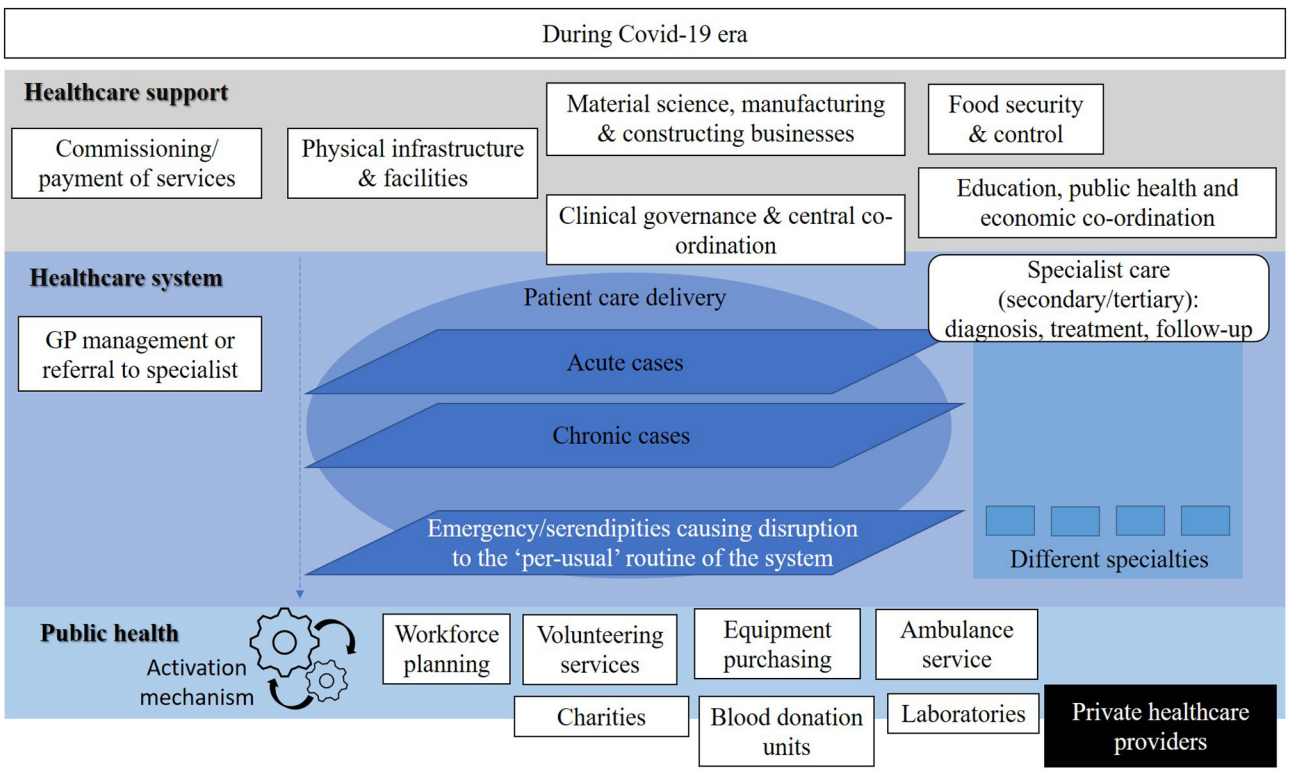

FIGURE 2 | The 'acute' phase of the Cypriot healthcare system following the introduction of the COVID-19 pandemic.

this proposed model can be achieved and its potential impact on the health system.

THE FIVE-DISTRICT MODEL AND THE CYPRIOT GENERAL HEALTHCARE SYSTEM

For the past 30 years, the estimated burden of disease, across all age and gender groups in Cyprus, remained stable for the following conditions: ischemic heart disease, cancer, low back pain and diabetes (type 2) (14). Based on the need to prioritize the management of patients with these chronic conditions, and shifting resources towards COVID-19 and other emergencies, we propose the development of the five-district model (FDM). FDM is to complement the activities of the new GHS, where a dedicated district and its main hospital will be responsible in collaboration with HIO for the following activies:

1. The development of a Center for training and sharing of best practices for COVID-19 and other public health emergencies.
2. The set-up of a public health body responsible for overseeing public health measures affecting the population.
3. The development of quality improvement practice, clinical practice guidelines and protocols.
4. The planning of healthcare services, resource allocation and co-ordination of efforts.
5. The set-up of a clinical trials platform in the design, conduct and analysis of clinical trials on new or re-purposed drugs.

Healthcare delivery is at the core of the system, where the syndemic strategy is introduced. Streamlining services and introducing telemedicine on a routine basis are some of such recommended process reconfigurations. Translating "know-hows" of the healthcare professionals into best practice guidelines for patient care are examples of such transformations targeting health system performance. Both virtual and physical infrastructure can be redesigned to allow patient access to the system and reduce disparities between patient groups. Efforts to develop a model to enhance patient care quality, speed up the uptake of innovations in practice and translate findings from research into healthcare delivery has been made through the development of the Integrated Delivery Systems test bed in the US healthcare system (15). Transferring this concept over to the Cypriot healthcare, part of the FDM solution is the securing of appropriate equipment and medical supplies, the increase in workforce capacity such as intensive care specialists, and the re-organization of teams and services to support the newly implemented GeSy and support the syndemic strategy, such as acute hospital admissions or exacerbation of syndemic

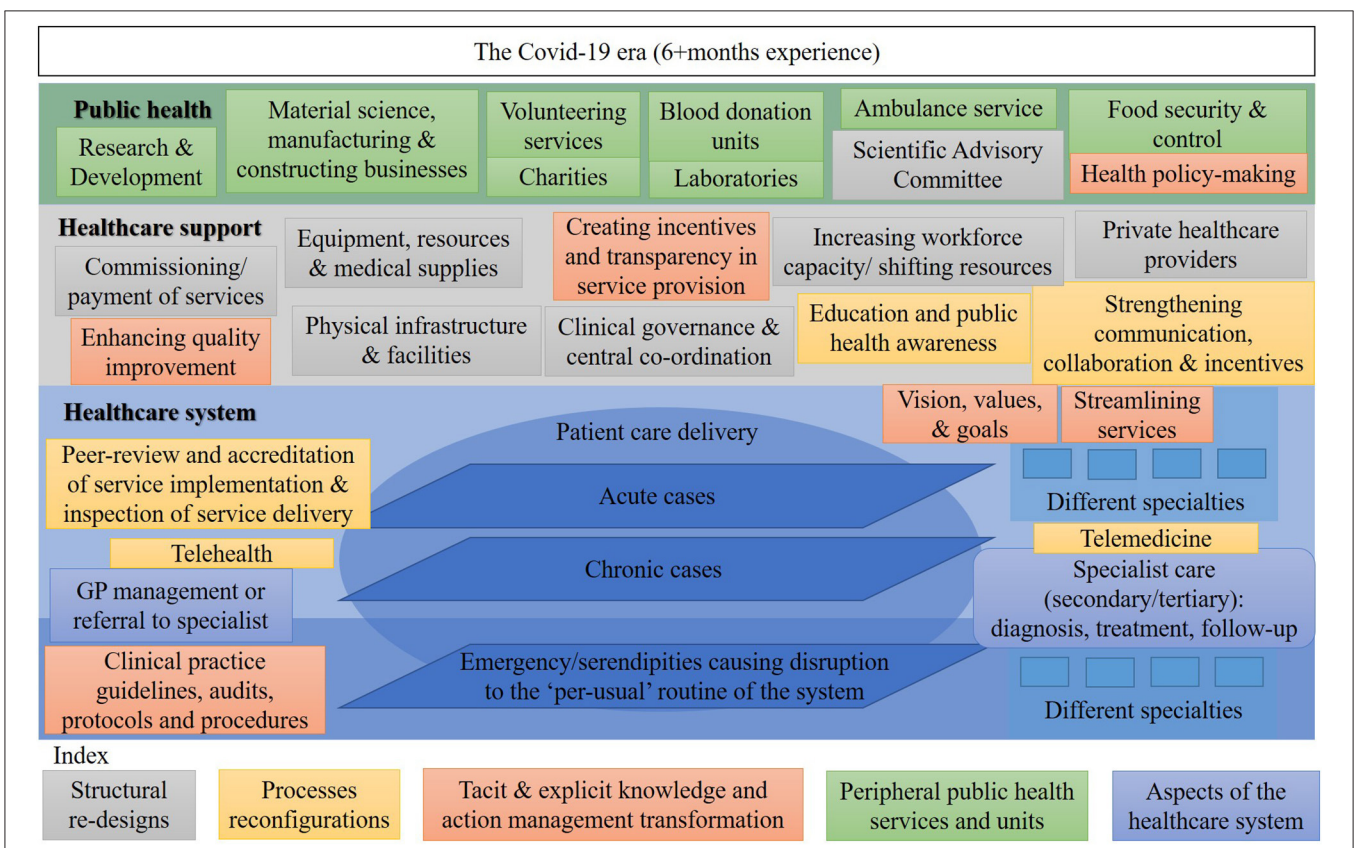

FIGURE 3 | The shifted healthcare service model six+ months into the COVID-19 pandemic in Cyprus.

interactions *e.g.,* psychological–biological interactions afflicted from COVID-19 on mental health. Finally, public health can be enhanced through communication strategies and a scientific advisory committee acting as external support mechanisms. The proposed FDM can be translated into fundamental pillars in any geographical setting (smaller and larger countries) to establish an evidence based syndemic approach. A limitation of our conceptual model is that it has not previously been tested and hence a transformation like this may take time for implementation. However, the strength of the proposed FDM is that it is based on an analysis of the existing healthcare landscape and the proposed reconfigurations are for existing resources as available within the Cypriot system, rather than acquisition of new ones.

Figures 1–3 show the resources, workforce capacity, and service organization and planning at three time points. The healthcare system and healthcare support activities appear to be separated from public health priorities as shown in **Figure 1**. Then a slight integration occurs as shown in **Figure 2** as a result of the pandemic. Further, we envision that by shifting the response from the acute and chronic cases (pre-COVID-19 model) in **Figure 1** to the one in **Figure 2** of COVID-19 cases (during COVID-19 early March to September) through a more co-ordinated and balanced effort, a third state of a healthcare

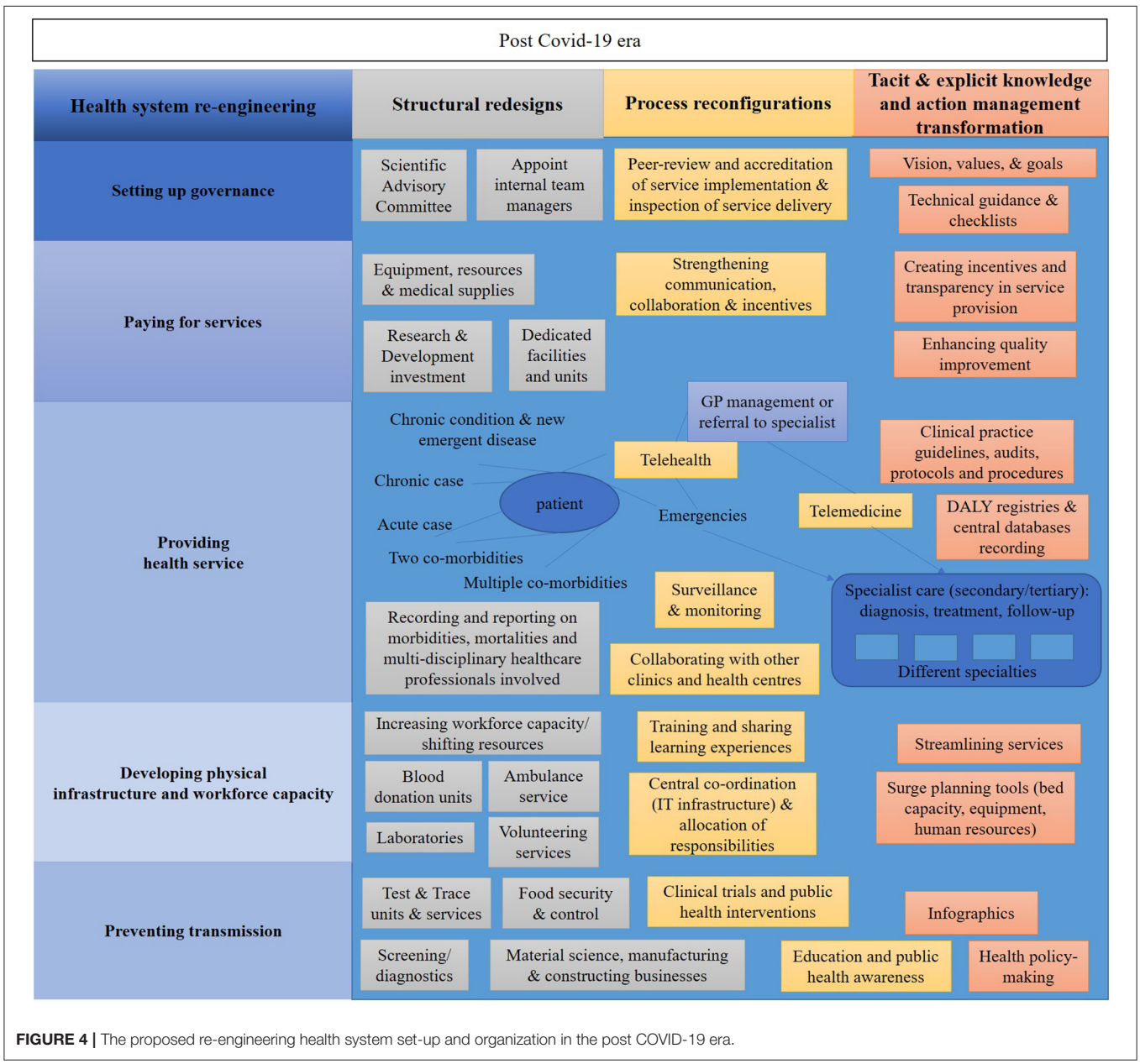

FIGURE 4 | The proposed re-engineering health system set-up and organization in the post COVID-19 era.

system can be proposed. This proposal is shown in **Figure 3** where the transition state model is to be translated into a re-engineered syndemic model. This is to be achieved by adequately shifting resources and redesigning aspects of the health system to support its sustainable performance, reducing inequalities and handling issues in care provision to achieve full population coverage of syndemic interactions.

Figure 4 maps the findings targeting the redesign of the existing health system in Cyprus through three dimensions: (i) process reconfigurations (yellow) (ii) structural redesigns (grey) and (iii) knowledge management transformations (orange).

COVID-19 AND THE CYPRIOT HEALTHCARE LANDSCAPE

There is an immense need for the Cypriot public health system to set up the five districts as priority areas. It is encouraged that the Cypriot government and other states with a similar population or geographical distribution to consider the transformation for public health emergency preparedness and transition to a working syndemic model. Specific research programmes like implementation research or quality improvement evaluation, as well as pilot research studies through focus groups with healthcare professional groups can commence to explore the impact of the proposed model upon the reconfiguration of the resources and delivery of the services within a syndemic concept. We applaud the Presidency of the Republic of Cyprus for the initiative and plan on strengthening the healthcare system and population health. We further call for the funding to be invested in such research in testing the FDM and remain optimistic that the above recommendations can support this effort.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

SC and EP designed the study. AH provided the COVID-19 statistics. PK described the epidemiological situation. JH evaluated the FDM dimensions. GW analyzed the public health function of the GHS. MK and MT provided the political context of the response to the pandemic. All authors have contributed to the study methodology, validation, writing, editing, as well as reviewed the final submitted manuscript.

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ORIGINAL RESEARCH
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Effect of the Universal Health Coverage Healthcare System on Stock Returns During COVID-19: Evidence From Global Stock Indices

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The increased uncertainty caused by a sudden epidemic disease has had an impact on the global financial market. We aimed to assess the primary healthcare system of universal health coverage (UHC) during the coronavirus disease (COVID-19) pandemic and its relationship with the financial market. To this end, we employed the abnormal returns of 68 countries from January 2, 2019, to December 31, 2020, to test the impact of the COVID-19 outbreak on abnormal returns in the stock market and determine how a country's UHC changes the impact of a sudden pandemic on abnormal returns. Our findings show that the sudden onset of an epidemic disease results in unevenly distributed medical system resources, consequently diminishing the impact of UHC on abnormal returns.

Keywords: coronavirus disease (COVID-19), abnormal return, universal health coverage, total confirmed cases, global stock market

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INTRODUCTION

The first death due to the coronavirus disease (COVID-19) occurred on January 11, 2020, in China. Subsequently, the COVID-19 outbreak spread rapidly worldwide in early 2020. Thailand reported a confirmed case on January 13, 2020, the first case outside China. On August 5, 2021, the largest proportionate increase in new cases was reported by the Americas (14%) and the Western Pacific Region (19%), with 1.3 million and over 375,000 new cases reported, respectively (1). The recent delta variant of COVID-19 is creating global concern, highlighting the risks faced by people who do not have access to primary healthcare *via* universal health coverage (UHC). This system enables everyone to obtain fair access to health services, including prevention and treatment, with no extra cost incurred, especially during the COVID-19 crisis period.

The spread of COVID-19 in over 190 countries has prompted an in-depth look at the various health effects and responses to COVID-19 in the marketplace due to long-ignored global health risks. Every country has begun focusing on the defense against novel viruses by providing full access to the medical system during the COVID-19 outbreak (2). Strong health systems, based on primary health care and UHC, are the foundation for an effective response to COVID-19. Specifically, where health coverage is linked to employment, an economic shock that leads to a loss of formal sector jobs also has negative consequences for the financial market. Therefore, in countries that have historically relied on contributory, employment-linked coverage, it is essential to inject general budget revenues into the system to reduce the system's vulnerability to job losses and ensure that the essential actions needed to respond to COVID-19 can be implemented.

Regarding panic selling, the sudden, large-scale sale of securities caused a significant decline in stock prices in the short term. The COVID-19 outbreak has also directed scholarly attention to exploring the impact of macroeconomic factors on stock returns, especially in the short term. Goodell and Huynh (3) and Shahzad et al. (4) suggest that the COVID-19 outbreak had a major impact on the financial market, which has been identified as having negative abnormal returns. Additionally, many scholars have empirically shown a link between major events and stock returns. In turn, they have revealed stock price fluctuations related to a specific event, such as an election (5), terrorist attacks (6), and disease outbreaks, specificallyanimal diseases, severe acute respiratory syndrome (SARS), and Ebola (7–9). He et al. (10), Alam et al. (11), and Mazur et al. (12) showed that the United States, Australia, and China all had negative abnormal returns in the stock market due to the COVID-19 outbreak. Liu et al. (13), Alali (14), and Singh et al. (15) examined multiple severely infected countries, finding that COVID-19 caused abnormal returns, not only in the examined country but also influencing numerous others.

Dongarwar and Salihu (16) reported that the COVID-19 death rate in a country with UHC is twice as low as that in a country without UHC. Apergis and Apergis (17) and Song et al. (18) used the growth rate of confirmed COVID-19 cases as a proxy and found that when the number of confirmed cases increased, the market index in China and America decreased. Ashraf (19) and Khan et al. (20) proved that an increase in the number of confirmed cases also affects the market index of each country. Concurrently, the worldwide rate of unexpected confirmed COVID-19 cases is increasing; the Centers for Disease Control and Prevention (CDC) reported that the infection and transmission rates of COVID-19 are much higher than expected. An influenza carrier can infect up to 1.3 people, while a COVID-19 carrier can infect 5–6 people (21). As a result of the increased number of confirmed COVID-19 cases, medical resources will be unevenly distributed, which will eventually affect the stock market.

This study aims to test the response of abnormal returns to a sudden pandemic disease and how the national UHC of a country changes the impact of sudden pandemic diseases on abnormal returns. Unlike previous studies that only examined specific events and their effects on the stock market in the short term, our study considers the UHC's effects on the stock market in relation to the COVID-19 outbreak in the long term. Consistent with the studies of Goodell and Huynh (3) and Shahzad et al. (4), the results suggest that the COVID-19 outbreak had a major impact on the financial market. This fills a gap in the current literature by providing an empirical framework demonstrating the healthcare system's connection to a sudden pandemic disease and its effects on the stock market in the long term.

The remainder of this paper is organized as follows. Section 2 discusses the Relevant Literature, and Section 3 presents the Data and the Methodology used. Section 4 discusses the Empirical Results of the findings. Finally, Section 5 concludes the study.

RELEVANT LITERATURE

The Correlation Between the COVID-19 Outbreak and Abnormal Returns

Efficient market theory states that stock prices reflect all information, and consistent alpha generation is impossible. The sensitivity of any information and unexpected events in the stock market will eventually reflect or force stock prices upward or downward. Since the COVID-19 outbreak was confirmed in 2019, various stock market indices have collapsed and intensified worldwide (10, 22, 23). It was revealed that, after China officially notified the WHO of the epidemic's outbreak on January 23, 2020, both Shanghai A shares and Shenzhen A shares had negative abnormal stock returns, especially in the transportation, mining, entertainment, and tourism industries. In addition, similar results were found after the first confirmed case was discovered in Australia on February 27, 2020, and after the announcement of COVID-19 as a global pandemic in the United States on March 11, 2020 (11, 12).

Alali (14) examined the top five Asian stock market indices (Shanghai Composite Index, Nikkei 225, Mumbai Sensitive 30 Index, Hang Seng Index, and South Korea Composite Stock Index) to test their reaction to the WHO's announcement of COVID-19 as a global pandemic. The empirical results show that the announcements have a significantly negative relationship with the cumulative abnormal returns in all stock market indices. In addition, Heyden and Heyden (24) and Bash (25) studied Europe and the United States and the top 30 countries most severely impacted by confirmed cases of COVID-19, finding negative abnormal returns in the stock markets. Moreover, Liu et al. (13) studied 21 significantly infected countries, and Singh et al. (15) studied 20 badly affected countries and found that the pandemic had a negative impact on their respective stock markets and generated negative abnormal returns.

Recently, Pandey and Kumari (26) collected 49 stock indices from both developed and emerging markets worldwide and found significant negative abnormal returns on global stock markets after the WHO declared COVID-19 a public health emergency of international concern. Among these, Asian stock markets fared the worst among the 49 stock indices.

Prior studies indicate that a sudden pandemic disease is followed by negative abnormal returns in a certain country or region (5, 6, 8, 9). Bouri et al. (27) that assets' connectedness of returns varied before and after the COVID-19 outbreak. Similarly, negative abnormal returns occurred in each country after its first confirmed case was reported, and when the WHO declared COVID-19 a global pandemic on March 11, 2020 (10–12, 14). Consequently, this study considers the COVID-19 outbreak a global pandemic, confirmed by the WHO, which eventually spread globally and generated negative abnormal returns in stock markets worldwide. Thus, we construct Hypothesis 1 as follows:

Hypothesis 1: The spread of the COVID-19 outbreak worldwide generates negative abnormal returns in global stock markets.

The Correlation of Abnormal Returns With COVID-19 and Universal Health Coverage

Broad coverage from a good healthcare system improves health indicators, reduces health inequalities, and enhances economic development. The COVID-19 outbreak has amplified the progress of the establishment of strong and resilient health care systems. A recent study by 16 indicated that countries with UHC had a lower number of confirmed COVID-19 cases. The study by Djilali et al. (28) has evidently shown that vaccination is a strategy to limit the spread of the COVID-19 disease; the high number of vaccination rates can decrease the infection and fatality rates, as does UHC. Additionally, the World Health Organization (2) announced that UHC allows governments to effectively address hazards caused by COVID-19 worldwide, either directly or indirectly. Such a significant market response is not mirrored in the instance of a reduction in cases. Empirical evidence by Benjamin (29), McKibbin and Fernando (30), Banik et al. (31), and Bentout et al. (32) show that a robust and resilient healthcare system helps mitigate the exposure risk to COVID-19. This is because a healthcare system has a greater positive impact on the spread of the virus in less developed, high population-density countries and decreases fatality rates in countries with high infection rates. The healthcare system is consistent with a statement from Bill Gates, co-chair of the Bill & Melinda Gates Foundation, who said that a multi-specialty Global Epidemic Response and Mobilization (GERM) team helps to strengthen health systems in an effort to build a resilient system that will help reduce the damage of the next pandemic. So, the capacity to produce billions of vaccines has been initiated; the funding to pay for them and the systems to deliver them everywhere are vital to the global fight against the pandemic.

Additionally, recent studies have revealed that a well-organized healthcare system can mitigate the negative outcomes of COVID-19 (29–31). Few previous studies have investigated the impact of UHC on the stock market or tested the correlation effect; hence, this study develops the following hypothesis:

Hypothesis 2: UHC is positively correlated with abnormal returns.

The Effect of a High Rate of Confirmed COVID-19 Cases on UHC and Its Link to Abnormal Returns

When an epidemic occurs, the basic healthcare system is disrupted or damaged by the sudden influx of numerous patients. Therefore, medical treatment no longer fulfills the needs of society or individuals to maintain their daily lives. Chaos and panic ensue because of insufficient or limited resources. Liu et al. (13) stated that an increase in confirmed COVID-19 cases enhances investors' pessimistic emotions toward the stock market and creates market uncertainty, which, in turn, affects stock prices and generates negative abnormal returns. A study by Ashraf (19) involving 64 countries also showed that the impact of the number of confirmed cases on stock prices was greater than that of the number of deaths. Once the number of confirmed COVID-19 cases showed an upward trend, the volatility of stock prices followed a downward trend. Khan et al. (20) also discovered that the growth rate of new weekly diagnoses was significantly negatively correlated with stock prices. As the number of new diagnoses rises by 1% in a week, stock market returns fall by 0.24%.

Apergis and Apergis (17) and Saif-Alyousfi (33) studied the increase in confirmed cases or deaths as proxy variables for COVID-19; they found that an increase in confirmed cases or mortalities was significantly negatively correlated with stock returns in China. Moreover, Song et al. (18) reported that an increase in diagnoses was significantly negatively correlated with stock returns in the United States, especially in the catering industry. Furthermore, Pandey and Kumari (26) found that the total number of confirmed cases and fatalities has a negative impact on cumulative abnormal returns in developed and emerging markets.

With the increased number of confirmed COVID-19 cases, UHC as the primary healthcare system will, due to a sudden and large increase in the number of patients, eventually affect the stock market negatively. The increase in the number of confirmed COVID-19 cases is based on the theory of insufficient resource allocation. The public will panic and cause the collapse of the medical system, and the UHC function may also be weakened by abnormal returns. Thus, a strategy of either the government issuing public interventions, such as a lockdown (33), or a full coverage of vaccines for people is needed to reduce the epidemic damage that could be brought by the serious COVID-19 outbreak as well as to stop the virus spreading to others (34, 35). Based on the results of prior studies, we expect an increase in the diagnoses of COVID-19 to overwhelm the UHC and weaken its positive impact; therefore, the study constructs the following hypothesis:

Hypothesis 3: A high number of COVID-19 diagnoses will affect the impact of UHC on abnormal returns.

DATA AND METHODOLOGY

Data

This study collected major global stock indices divided by region, namely Asia, Europe, America, Africa, and Oceania, as shown in **Table 1**. The stock market index in Europe was weighted as 35%. Asia, America, Africa, and Oceania are weighted as 33, 14, 16, and 2%, respectively, excluding those countries whose data were not fully available[1]. **Table 1** represents the stock indices in 68 countries, and it was decided to use these indices to investigate the influence of the COVID-19 outbreak.

The study employed a market model to calculate abnormal returns in each region. Therefore, the MSCI All-Country World Equity Index, an international benchmark index representing global market performance, was used to calculate the abnormal returns of all the stock markets listed in **Table 1**. Daily closing prices were collected from the website investing.com, which offers free historical data from January 2, 2019, to December 31, 2020, in all regions' indices.

[1]This study did not include indices from countries whose data were not fully available or whose data were not completely publicly available (e.g., a country that is not a member of the WHO, such as Taiwan, Bahrain, Uganda, etc.).

Methodology

In this study, we adopted event study method to evaluate stock reaction to a specific event. Thus, in order to precisely capture the effect of UHC during the COVID-19 outbreak, we have adopted a short-term (5 days), mid-term (10–60 days), and long-term (180 days) to test stock movement. By doing so, this study is aiming to precisely capture the volatility of stock abnormal returns during COIVD-19 outbreak.

Universal Health Coverage Definition

Universal health coverage service coverage index, established by the WHO, aims to ensure that people receive adequate healthcare without an undue burden on their finances. This study uses the WHO UHC database to collect UHC data for 68 countries. The 34 provides the following explanation for UHC:

"The goal of universal health coverage is threefold:

Equity in access: everyone who needs health services should receive them, not only those who can pay for services.
Sufficient quality: health services should be of sufficient quality to improve the health of those receiving the services.
No undue financial risk: the cost of using health services should not put people at risk of financial harm." (p. 2)

The UHC calculation approach is shown in **Figure 1**.

Event Study

Many methodologies have been used to model event studies to evaluate abnormal returns. However, the event study method used to examine the impact of COVID-19 on the volatilities of all affected countries is the most suitable for capturing stock price movements. Previous studies used event studies to test the impact of certain events, such as initial public offerings, seasoned equity offerings, and stock splits on a company's stock (36, 37). Nevertheless, in recent years, an increasing number of scholars have used the event study method to capture the impact of unexpected events, such as SARS, Ebola, and Middle East Respiratory Syndrome (MERS), on stock prices (8, 9).

Bash (25) and Heyden and Heyden (24) stated that a single event day in the market could not accurately capture the influence of COVID-19 on abnormal returns. Therefore, they used the first confirmed case in each country as an event day to test for abnormal returns. Nevertheless, Alali (14) found that, after the WHO's official declaration, stock prices fell sharply compared to that of 30 days before and after the report of the first confirmed case in each country. To precisely capture the impact of stock movement on COVID-19, this study adopted the official WHO declaration of COVID-19 as a global pandemic on March 11, 2020, as an event day to test the response of global stock markets.

Measure of Returns and Hypothesis

Market Model of Abnormal Returns

$$AR_{i,t} = R_{i,t} - \left(\alpha_0 + \alpha_1 \times R_{m,t}\right) \quad (1)$$

$AR_{i,t}$ and $R_{i,t}$ are the abnormal return and the real return of stock market i on day t, respectively; $R_{m,t}$ is the market return of the MSCI all-country world equity index on day t, with α_0 and α_1 as the coefficients of the ordinary least squares (OLS) from the estimation period (−150, −1). In the stock market, the accurate event date or time of abnormal return is difficult to define; thus, a period of observation is needed to define the event date or time of abnormal return. Hence, cumulative abnormal return (CAR) is where stock market i from t_0 to t_1 is calculated based on Equation (2) to verify whether COVID-19 leads to negative abnormal returns:

$$CAR_i\,(t_0,\ t_1) = \sum_{t=t_0}^{t_1} AR_{i,t} \quad (2)$$

where t_1 is defined as the event days of 5, 10, 30, 60, and 180.

TABLE 1 | Major stock market indices.

Country/area	Stock index	Country/area	Stock index
Austria	ATX	Netherlands	AEX
Australia	S and P ASX 200	Norway	OSE Benchmark
Argentina	S and P Merval	New Zealand	NZX 50
Belgium	BEL 20	Namibia	FTSE NSX Overall
Bulgaria	BSE SOFIX	Nigeria	NSE 30
Brazil	Bovespa	Poland	WIG 30
Bangladesh	DSE 30	Portugal	PSI 20
Croatia	CROBEX	Peru	SandP Lima General
Canada	S and P TSX Composite	Pakistan	Karachi 100
Chile	S and P CLX IPSA	Philippines	PSEi Composite
Colombia	COLCAP	Qatar	QE General
China	Shanghai Composite	Romania	BET
Denmark	OMX Copenhagen 20	Russia	MOEX
Ecuador	Guayaquil select	Serbia	Belex 15
Egypt	EGX 70 EWI	Slovakia	SAX
France	CAC 40	Slovenia	Blue-Chip SBITOP
Germany	DAX	Spain	IBEX 35
Greece	AGC	Sweden	OMX Stockholm 30
Hungary	Budapest SE	Switzerland	SMI
Iceland	ICEX Main	South Korea	KOSP
Ireland	ISEQ Overall	Saudi Arabia	Tadawul All Share
Italy	FTSE MIB	Singapore	FTSE STS
India	BSE Sensex 30	Sri Lanka	CSE All-Share
Indonesia	Jakarta SEC	South Africa	Top 40
Iraq	ISX Main 60	Thailand	SET Index
Israel	TA 35	Turkey	BIST 100
Japan	Nikkei 225	Tanzania	All Share
Jamaica	JSE Market	Tunisia	Tunindex
Kazakhstan	KASE	Ukraine	PFTS
Kenya	NSE 20	United Kingdom	FTSE 100
Lebanon	BLOM Stock	United States	SandP 500
Mexico	SandP BMV IPC	UAE	ADX General
Malaysia	FTSE KLCI	Vietnam	VN
Morocco	Moroccan All Shares	Zambia	LSE All Share

FTSE STS, FTSE Straits Times Singapore; AGC, Athens General Composite; UAE, United Arab Emirates.

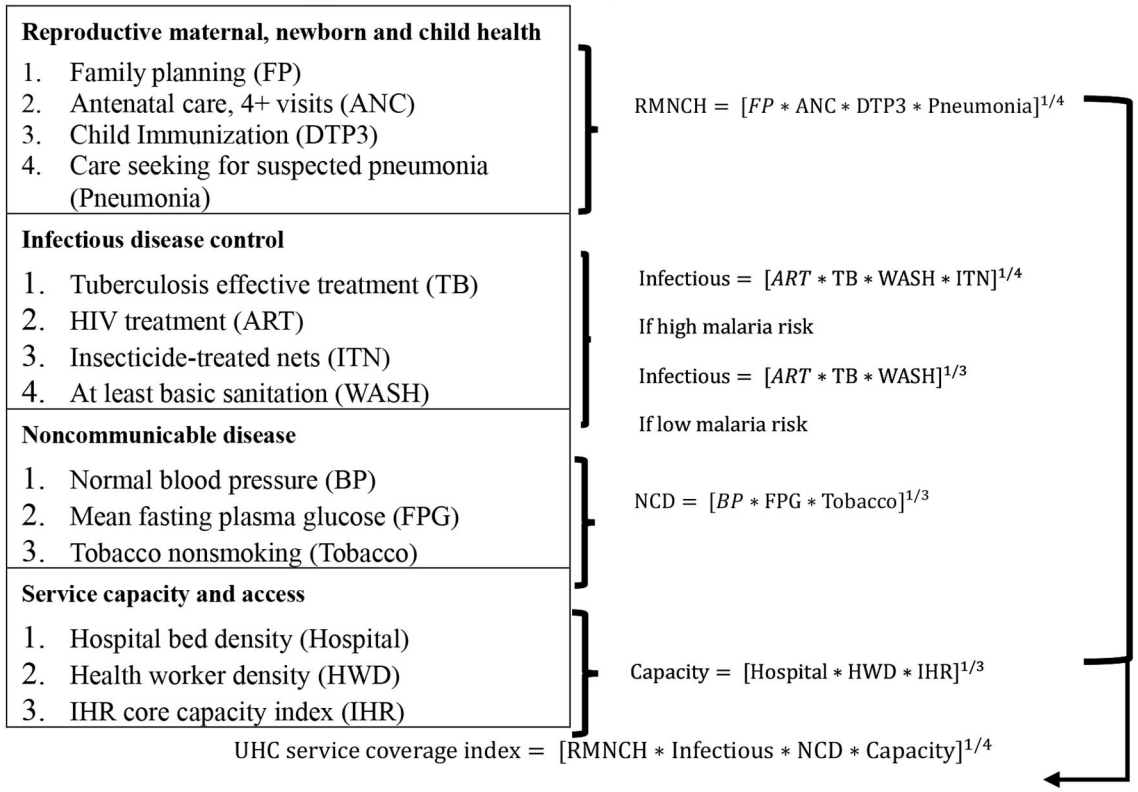

FIGURE 1 | UHC service coverage index (2)[2].

Universal Health Coverage Impact on Abnormal Returns

This study mainly aims to examine the relationship between UHC and abnormal returns and whether there was a positive relationship between UHC and abnormal returns during the COVID-19 outbreak. Therefore, the study expects a positive ($\theta_1 > 0$) relationship between UHC and CAR by testing Equation (3), as follows:

$$CAR_i^N = \theta_0 + \theta_1 UHC_i + \beta X_i + \varepsilon_i \quad (3)$$

CAR_i^N is the CAR during a specific period before and after the event day with N for (0, 5), (0, 15), (0, 30), (0, 60), and (0, 180). UHC_i denotes that country i has UHC; X_i is defined as the control variables, such as log (gross domestic product), uncertainty avoidance index, net domestic credit divided by gross domestic product (GDP), log (population), political stability and no violence, and regulatory requirements. Log (GDP) and Credit/GDP are taken from the World Bank Open Data, and they measure the level of economic development (38). The uncertainty avoidance index is taken from the study by Hofstede et al. (39) on cross-country differences in national culture and measurement of the degree of investor uncertainty aversion.

[2]Universal Health Coverage Index encompasses two values: SDG indicator 3.8.1 and SDG indicator 3.8.2. However, WHO (2) only gave the formula for the first indicator; therefore, the calculation of UHC was not revealed entirely.

Log (population) is taken from the World Bank Open Data and measures the size of each stock market (20). Both political stability and no violence and regulatory requirements, which also represent the quality of political safety, are taken from the World Bank's GOV Data 360 (20). These control variables jointly capture the cross-broader differences in stock market returns caused by country governance or macroeconomic differences between countries. ε_i is the residual.

Impact of High COVID-19 Infection Rates With UHC on Abnormal Returns

To verify the impact of high rates of COVID-19 infection on CARs, we modified the baseline regression to examine the indirect impact of UHC on abnormal returns as Equation (4) to investigate Hypothesis 3: whether the severity of COVID-19 weakens the positive impact of UHC on abnormal returns.

$$CAR_i^N = \theta_0 + \theta_1 UHC_i + \theta_2 TC_i + \theta_3 UHC_i \times TC_i + \beta X_i + \varepsilon_i \quad (4)$$

where TC_i is the cumulative confirmed cases of stock market i from the date of diagnosis of the first patient in each country to that of the research event. Total confirmed cases are taken from the website *Our World in Data*, which discloses the number of fatalities and confirmed cases in all countries globally. The interaction term $UHC_i \times TC_i$ is a dummy variable that divides the total confirmed cases into three groups, which is lowest,

TABLE 2 | Descriptive statistics of major countries' stock market indices.

Country	Stock index	Obs	Mean	SD	Min	Max	Country	Stock index	Obs	Mean	SD	Min	Max
Argentina	S and P Merval	764	0.00	0.01	−0.21	0.04	Morocco	MAS	780	−0.00	0.01	−0.09	0.05
Australia	S and P ASX 200	798	0.00	0.01	−0.10	0.07	Namibia	FTSE NSX Overall	786	0.00	0.01	−0.04	0.04
Austria	ATX	790	−0.00	0.02	−0.15	0.10	Netherlands	AEX	805	0.00	0.01	−0.11	0.08
Bangladesh	DSE 30	727	−0.00	0.01	−0.06	0.10	NewZealand	NZX 50	918	0.00	0.01	−0.06	0.07
Belgium	BEL 20	805	−0.00	0.01	−0.15	0.07	Nigeria	NSE 30	782	−0.00	0.01	−0.06	0.06
Brazil	Bovespa	777	0.00	0.02	−0.16	0.13	Norway	OSE Benchmark	648	0.00	0.01	−0.09	0.05
Bulgaria	BSE SOFIX	777	−0.00	0.01	−0.11	0.04	Pakistan	Karachi 100	782	0.00	0.01	−0.07	0.05
Canada	S and P TSX Composite	790	0.00	0.01	−0.13	0.11	Peru	SandP Lima General	794	0.00	0.01	−0.11	0.05
Chile	S and P CLX IPSA	782	−0.00	0.01	−0.15	0.08	Philippines	PSEi Composite	769	−0.00	0.01	−0.14	0.07
China	Shanghai Composite	763	0.00	0.01	−0.08	0.06	Poland	WIG 30	784	−0.00	0.01	−0.14	0.06
Colombia	COLCAP	767	−0.00	0.01	−0.13	0.12	Portugal	PSI 20	805	−0.00	0.01	−0.10	0.08
Croatia	CROBEX	779	−0.00	0.01	−0.11	0.06	Qatar	QE General	786	0.00	0.01	−0.10	0.05
Denmark	OMX Copenhagen 20	784	0.00	0.01	−0.08	0.04	Romania	BET	784	0.00	0.01	−0.12	0.07
Ecuador	Guayaquil Select	771	0.00	0.00	−0.04	0.04	Russia	MOEX	793	0.00	0.01	−0.09	0.07
France	CAC 40	805	0.00	0.01	−0.13	0.08	Saudi Arabia	Tadawul All Share	789	0.00	0.01	−0.09	0.07
Egypt	EGX 70 EWI	765	0.00	0.01	−0.08	0.05	Singapore	FTSE STS	789	0.00	0.01	−0.09	0.07
Germany	DAX	794	0.00	0.01	−0.13	0.10	Serbia	Belex 15	818	−0.00	0.01	−0.07	0.07
Greece	AGC	782	−0.00	0.02	−0.14	0.11	Slovakia	SAX	783	0.00	0.01	−0.07	0.06
Hungary	Budapest SE	777	0.00	0.01	−0.12	0.06	Slovenia	Blue–Chip SBITOP	780	0.00	0.01	−0.09	0.06
Iceland	ICEX Main	781	0.00	0.01	−0.08	0.04	South Africa	Top 40	789	0.00	0.01	−0.10	0.09
India	BSE Sensex 30	780	0.00	0.01	−0.14	0.09	Spain	IBEX 35	805	−0.00	0.01	−0.15	0.08
Indonesia	Jakarta SEC	764	−0.00	0.01	−0.07	0.10	Sri Lanka	CSE All–Share	725	0.00	0.01	−0.08	0.05
Iraq	ISX Main 60	618	0.00	0.01	−0.13	0.09	Sweden	OMX Stockholm30	789	0.00	0.01	−0.11	0.07
Ireland	ISEQ Overall	803	0.00	0.01	−0.10	0.07	Switzerland	SMI	788	0.00	0.01	−0.10	0.07
Israel	TA 35	776	0.00	0.01	−0.07	0.07	Tanzania	All Share	780	−0.00	0.01	−0.15	0.15
Italy	FTSE MIB	796	0.00	0.01	−0.18	0.08	Thailand	SET Index	769	−0.00	0.01	−0.11	0.08
Jamaica	JSE Market	741	0.00	0.01	−0.05	0.05	Tunisia	Tunindex	784	0.00	0.01	−0.04	0.03
Japan	Nikkei 225	764	0.00	0.01	−0.06	0.08	Turkey	BIST 100	790	0.00	0.01	−0.08	0.06
Kazakhstan	KASE	766	0.00	0.01	−0.05	0.03	Ukraine	PFTS	739	0.00	0.01	−0.02	0.11
Kenya	NSE20	786	−0.00	0.01	−0.05	0.03	UAE	ADX General	790	0.00	0.01	−0.08	0.08
South Korea	KOSP	774	0.00	0.01	−0.09	0.08	UK	FTSE 100	798	−0.00	0.01	−0.12	0.09
Lebanon	BLOM Stock	637	−0.00	0.01	−0.12	0.13	US	SandP 500	792	0.00	0.01	−0.13	0.09
Malaysia	FTSE KLCI	770	−0.00	0.01	−0.05	0.07	Vietnam	VN	784	0.00	0.01	−0.07	0.05
Mexico	SandP BMV IPC	791	−0.00	0.01	−0.07	0.05	Zambia	LSE All Share	778	−0.00	0.01	−0.09	0.05

MAS, Moroccan All Shares; FTSE STS, FTSE Straits Times Singapore; AGC, Athens General Composite; UAE, United Arab Emirates; UK, United Kingdom; US, United States.

medium, and largest, and then sets the highest equal to 1 and the others equal to 0. The main variable of θ_3 denotes UHC reactions to abnormal returns in relation to the total number of confirmed COVID-19 cases. Thus, the expectation of the relationship between the interaction variable of θ_3 and CAR is negative ($\theta_3 < 0$).

EMPIRICAL RESULTS

Description of Samples

Table 2 presents the descriptive statistics of the stock market index variables for all the sample countries. This study analyzed a sample of 68 countries. The mean variable of stock market indices is either 0.00 or −0.00, which indicates that all sample countries had zero present returns in stock markets, which is consistent with the random walk property of stock market returns (19). In addition, the minimum and maximum values of all 68 countries ranged from −0.21 to 0.15, which indicates that all sample returns were from −21 to 15% during the COVID-19 outbreak. Among these, Argentina, Italy, and Brazil had the lowest stock returns of −0.21, −0.16, and −0.18, respectively.

Results of Abnormal Returns and the COVID-19 Outbreak

Table 3 reports the summary CARs statistics over 5, 15, 30, and 60 days during the COVID-19 outbreak. Among these, the mean of CAR (0, 5), CAR (0, 15), CAR (0, 30), and CAR (0, 60) were all negative (−0.09, −0.05, −0.04, −0.03) during the outbreak. The evidence shows that the impact of a sudden disease outbreak is longer for a period and also gives investors a negative sign in terms of investment. However, a half year after the coronavirus

TABLE 3 | Descriptive statistics of main variables.

Variable	Obs	Mean	SD	Min	Max
CAR (0,5)	68	−0.09	0.08	−0.31	0.07
CAR (0,15)	68	−0.05	0.08	−0.26	0.12
CAR (0,30)	68	−0.04	0.09	−0.28	0.19
CAR (0,60)	68	−0.03	0.09	−0.21	0.30
CAR (0,180)	68	0.06	0.16	−0.32	0.61
UHC per person	68	0.09	0.29	0.00	2.38
Total cases in 5 days	68	2,442.01	10,408.67	0.00	81,033.00
Total cases in 15 days	68	7,340.65	18,955.41	8.00	86,613.00
Total cases in 30 days	68	22,662.40	68,674.13	16.00	514,855.00
Total cases in 60 days	68	56,571.60	168,623.31	16.00	1,337,777.00
Total cases in 180 days	68	370,111.53	1,025,489.17	509.00	6,294,257.00
Log (GDP)	68	26.60	1.50	23.24	30.70
Credit/GDP	68	713.61	4,041.66	0.44	32,780.99
UAI	68	65.19	22.80	8.00	100.00
Log (Population)	68	17.10	1.53	12.77	21.05
PSNV	68	0.02	0.90	−2.56	1.53
RQ	68	3.51	1.41	0.00	5.00

Cumulative abnormal return (CAR) is measured as the cumulative return in a country's major stock index over a period. Total cases on different days are measured as a given country's total confirmed COVID-19 cases at different periods. Universal health coverage (UHC) per person is measured as the basic health service that a person can obtain in a country. Log gross domestic product (GDP) and Credit/GDP are taken from the World Bank Open Data and represent the level of economic development. The uncertainty avoidance index (UAI) was taken from the study of Hofstede et al. (39) to control for cross-country differences in uncertainty aversion among investors. Log (Population) is taken from the World Bank Open Data and controls for the difference in the total number of residents among countries. Political stability and no violence (PSNV) and regulatory requirements (RQ) are taken from the World Bank's GOV Data 360 and indicate the quality of political safety in a country.

outbreak, the stock market began to recover by itself where the mean of CAR (0,180) became positive at 0.09.

The standard deviation values of CAR (0, 5), CAR (0, 15), CAR (0, 30), CAR (0, 60), and CAR (0,180) were 0.08, 0.08, 0.09, 0.09, and 0.16, respectively, where CARs (0, 180) had the highest fluctuation between positive and negative abnormal returns. The minimum and maximum values of abnormal returns were −0.32 and 0.61, showing that CARs ranged from −32 to 61% and that negative CARs will return to normal within half a year after the COVID-19 outbreak.

Table 4 illustrates the CAR results of the global stock market indices measured in different event windows. It also indicates that most CARs are significantly negative in the short term and insignificant in the long term, highlighting that COVID-19 generates negative CARs, supporting Hypothesis 1 in this study. The study results are consistent with the findings of previous studies that stock markets respond negatively to COVID-19 outbreaks because the spread of the virus encourages social distancing, causing the shutdown of financial markets. Furthermore, the high uncertainty regarding the degree of severity of the outbreak could lead to a flight to safety among investors (13, 14, 40, 41).

In addition, the result of CAR (0, 60) in **Table 4** verifies that the stock market recovery time is six months after the spread of COVID-19. The results appear to be the same in Bangladesh (coefficient = 0.2124; $p < 0.05$), Egypt (coefficient = 0.5750; $p < 0.01$), Iceland (coefficient = 0.2990; $p < 0.05$), South Korea (coefficient = 0.2922; $p < 0.05$), and Nigeria (coefficient = 0.6110; $p < 0.01$), where their CARs are all significant and positive. However, the Jamaican market shows the opposite result of CAR (0, 180), which is negative and significant (coefficient = −0.321; $p < 0.05$). As the Jamaican healthcare system has worsened during the COVID-19 outbreak, the government has adopted a stricter lockdown policy to prevent its spread (42, 43).

A few countries had no significant CARs during our selected data period, including Argentina (S&P Merval), Belgium (BEL 20), China (Shanghai Composite), Ecuador (Guayaquil Select), Israel (TA 35), Italy (FTSE MIB), Lebanon (BLOM Stock), Norway (OSE Benchmark), Portugal (WIG 30), Saudi Arabia (Tadawul All Share), Singapore (FTSE STS), Sweden (OMX Stockholm 30), Ukraine (PFTS), and the United Kingdom (FTSE 100). Consistent with the study by Ashraf (19), there were 14 countries in our sample that had been affected by COVID-19 before the event day of March 11, 2020. Therefore, CARs were not significant in these countries.

To test whether the spread of COVID-19 had negative abnormal returns in global stock markets, this study took the average CARs and examined whether COVID-19 led to negative abnormal returns in market indices. Our empirical results showed that COVID-19 generated negative returns for half a year after the outbreak, verifying Hypothesis 1.

Results of the Relationship Between UHC and CARs

Table 5 reports the estimation result of Equation (3) regarding the relationship between CARs and UHC. We expected a positive and significant relationship between UHC and CARs. As shown in **Table 5**, the UHC per person variable was positive and significant at CAR (0, 15) (coefficient = 0.034; $p < 0.1$), CAR (0, 30) (coefficient = 0.045; $p < 0.05$), CAR (0, 60) (coefficient = 0.065; $p < 0.01$), and CAR (0,180) (coefficient = 0.188; $p < 0.01$). The exception was CAR (0, 5), which was longer than the previous period. The results have proven that CAR is positively correlated with a person who has access to adequate basic health care, consistent with Hypothesis 2. While CAR (0, 5) is not significant, the other four periods are significant and positive in relation to UHC. The empirical evidence shows that the UHC healthcare system is effective in its impact on sudden disease outbreaks in a country.

McKibbin and Fernando (30) indicated that countries that invest more in the public health system could reduce the negative impact of COVID-19, especially in countries with insufficient public health systems and high population density. **Table 5** also shows that CARs react positively to the health system during an epidemic. The health system is a protective influence for a country in its fight against the virus and usually shows its effectiveness several days after an outbreak.

Results of Confirmed Cases and CARs During the COVID-19 Outbreak

Table 6 presents the total confirmed cases and the interaction variable of UHC × total cases, along with other control variables, to test the moderating effects of high rates of COVID-19 infection

TABLE 4 | CARs for all stock market indices.

Country	Stock index	(1) CAR (0,5)	(2) CAR (0,15)	(3) CAR (0,30)	(4) CAR (0,60)	(5) CAR (0,180)
ACAR	All Indices	−0.0958***	−0.0525***	−0.0379***	−0.0230***	0.0689***
Argentina	SandP Merval	−0.0936	0.0503	0.1580	0.2981	0.0735
Australia	SandP ASX 200	−0.1773***	−0.0886***	−0.1136***	−0.0188	0.0836
Austria	ATX	−0.2354***	−0.1190***	−0.1110***	−0.1447**	−0.0798
Bangladesh	DSE 30	−0.0738***	0.0116	0.0057	−0.0252	0.2124**
Belgium	BEL 20	−0.0336	−0.0017	−0.0137	−0.0665	−0.0298
Brazil	Bovespa	−0.1394***	−0.0997**	−0.0798	−0.1322	−0.1449
Bulgaria	BSE SOFIX	−0.1648***	−0.1447***	−0.1266***	−0.1031**	−0.1250
Canada	SandP TSX Composite	−0.1406***	−0.1115***	−0.0540***	−0.0719**	−0.0331
Chile	SandP CLX IPSA	−0.2392***	0.0071	0.0304	−0.0326	0.0024
China	Shanghai Composite	−0.0242	−0.0039	0.0025	0.0155	0.1019
Colombia	COLCAP	−0.3126***	−0.0798***	−0.1429***	−0.1965***	−0.0527
Croatia	CROBEX	−0.1838***	−0.0815***	−0.1032***	−0.0637*	−0.0068
Denmark	OMX Copenhagen 20	−0.0073	0.0798**	0.0863*	0.1047	0.1437
Ecuador	Guayaquil Select	0.0234	0.0189	0.0111	0.0195	−0.0572
France	CAC 40	−0.0488***	0.0081	−0.0137	−0.0701	−0.0346
Egypt	EGX 70 EWI	−0.1523***	−0.0871**	0.0652	0.1358*	0.5750***
Germany	DAX	−0.0552***	−0.0090	−0.0155	−0.0337	−0.0297
Greece	AGC	−0.1402***	0.0157	0.0445	−0.0252	0.1714
Hungary	Budapest SE	−0.1850***	−0.1871***	−0.1925***	−0.1640**	−0.1603
Iceland	ICEX Main	−0.0613**	0.0478	0.0756*	0.0678	0.2990**
India	BSE Sensex 30	−0.1784***	−0.1439***	−0.0397	−0.0293	0.1776
Indonesia	Jakarta SEC	−0.1587***	−0.0155	−0.0898**	−0.0418	0.1074
Iraq	ISX Main 60	−0.0206	−0.0271**	0.1942***	−0.0466**	0.1431
Ireland	ISEQ Overall	−0.1406***	−0.1175***	−0.1017**	−0.1507**	0.1279
Israel	TA 35	0.0083	−0.0054	−0.0181	−0.0335	−0.0885
Italy	FTSE MIB	−0.0081	−0.0018	−0.0345	−0.0807	0.0066
Jamaica	JSE Market	−0.1243***	−0.1481***	−0.2254***	−0.2068***	−0.3210**
Japan	Nikkei 225	−0.1119***	−0.1265***	−0.0875*	0.0290	0.2535
Kazakhstan	KASE	0.0121	0.0460	0.0483	0.0443	0.2316*
Kenya	NSE 20	−0.0966***	−0.0714**	−0.1016**	−0.0735	−0.0369
South Korea	KOSPI	−0.1475***	−0.1017***	−0.0806*	−0.0186	0.2922**
Lebanon	BLOM Stock	−0.0353	−0.0335	0.0294	−0.0149	0.1027
Malaysia	FTSE KLCI	−0.1449***	−0.0624***	−0.0321	0.0938**	0.1776*
Mexico	SandP BMV IPC	−0.0563***	−0.1418***	−0.1153***	−0.1342**	−0.0198
Morocco	MAS	−0.2253***	−0.2591***	−0.2747***	−0.2029***	−0.0202
Namibia	FTSE NSX Overall	−0.1492***	−0.1356***	−0.1209**	−0.1047	−0.0410
Netherlands	AEX	−0.0418***	0.0163	0.0091	−0.0181	0.0180
New Zealand	NZX 50	−0.1282***	−0.1028***	−0.0198	−0.0352	0.0175
Nigeria	NSE 30	−0.0834***	−0.1636***	−0.0662	0.1019	0.6110***
Norway	OSE Benchmark	−0.0232	0.0475	0.0507	0.0448	0.1360
Pakistan	Karachi 100	−0.1796***	−0.1615***	−0.1296*	−0.0724	0.2311
Peru	SandP Lima General	−0.1032***	−0.2235***	−0.1639***	−0.0768	0.0831
Philippines	PSEi Composite	−0.1585***	−0.1500***	−0.1469***	−0.0309	0.0925
Poland	WIG 30	0.0037	0.0906***	0.0624	0.0629	0.0637
Portugal	PSI 20	−0.0224	−0.0321	−0.0419	−0.0895	−0.0484
Qatar	QE General	0.0653***	0.1201***	0.1046**	0.1361**	0.0518
Romania	BET	−0.1431***	−0.1570***	−0.1533***	−0.0726	0.0400
Russia	MOEX	−0.0919***	0.0324	−0.0011	−0.0370	0.0040
Saudi Arabia	Tadawul All Share	−0.0267	0.0525	0.0233	0.0753	0.1265
Singapore	FTSE STS	−0.0267	0.0525	0.0233	0.0753	0.1265
Serbia	Belex 15	−0.1292***	−0.1431***	−0.1142***	−0.0853	0.0188
Slovakia	SAX	−0.0681***	−0.0267	0.0018	0.0914	0.0984
Slovenia	Blue-Chip SBITOP	−0.1578***	−0.1459***	−0.1058***	−0.0149	0.0636

(Continued)

TABLE 4 | Continued

Country	Stock index	(1) CAR (0,5)	(2) CAR (0,15)	(3) CAR (0,30)	(4) CAR (0,60)	(5) CAR (0,180)
South Africa	Top 40	−0.1252***	−0.0147	0.0160	0.0204	0.0371
Spain	IBEX 35	−0.0312	−0.0396	−0.0867**	−0.1258**	−0.0413
Sri Lanka	CSE All-Share	−0.0481***	−0.1137***	−0.1145***	−0.0384	0.3453***
Sweden	OMX Stockholm 30	0.0221	0.0243	0.0413	−0.0516	−0.0531
Switzerland	SMI	0.0191	0.0801***	0.0622**	−0.0110	−0.1439
Tanzania	All Share	−0.0798**	−0.1267**	−0.1292*	−0.1095	0.0805
Thailand	SET Index	−0.1620***	0.0002	0.0713**	0.1302**	0.1832
Tunisia	Tunindex	−0.1199***	−0.1415***	−0.1312***	−0.0558	0.0289
Turkey	BIST 100	−0.0640	−0.0907*	−0.0885	−0.0502	0.2180
Ukraine	PFTS	−0.0241	−0.0364	−0.0338	−0.0177	−0.2371
UAE	ADX General	−0.1430***	−0.0706**	−0.1088**	−0.1300*	−0.0594
UK	FTSE 100	−0.0254	−0.0341	−0.0281	−0.0398	−0.0303
US	SandP 500	0.0342***	0.0197**	0.0263**	0.0160	−0.0544
Vietnam	VN	−0.0879***	−0.0296	−0.0198	0.0798	0.3280*
Zambia	LSE All Share	−0.0086	−0.0013	−0.0198	−0.0412	−0.0277

Cumulative abnormal return (CAR) is measured as the cumulative return in a country's major stock index over a period. Average cumulative abnormal return (ACAR) is measured as the average cumulative return of all country indices.

MAS, Moroccan All Shares; FTSE STS, FTSE Straits Times Singapore; AGC, Athens General Composite; UAE, United Arab Emirates; UK, United Kingdom; US, United States.

****, **, and * represent statistical significance at the 1, 5, and 10% levels, respectively.*

TABLE 5 | Results of direct impact of UHC on cumulative abnormal returns.

Variables	Cumulative abnormal return				
	(1) CAR (0,5)	(2) CAR (0,15)	(3) CAR (0,30)	(4) CAR (0,60)	(5) CAR (0,180)
UHC per person	0.003	0.034*	0.045**	0.065***	0.188***
	[0.869]	[0.069]	[0.019]	[0.001]	[0.000]
Log (GDP)	0.036***	0.039***	0.048***	0.020*	0.005
	[0.002]	[0.002]	[0.001]	[0.077]	[0.781]
UAI	−0.071	0.405	0.279	0.281	0.095
	[0.856]	[0.414]	[0.579]	[0.630]	[0.921]
Credit/GDP	0.005	0.028***	0.025**	0.033***	0.071***
	[0.667]	[0.001]	[0.018]	[0.001]	[0.000]
Log (Population)	−0.033***	−0.033**	−0.042**	−0.007	0.031
	[0.006]	[0.016]	[0.013]	[0.584]	[0.104]
PSNV	−0.014	−0.008	−0.033	−0.000	−0.020
	[0.347]	[0.582]	[0.118]	[0.987]	[0.549]
RQ	−0.020**	−0.014*	−0.016**	−0.019*	−0.022
	[0.010]	[0.082]	[0.047]	[0.065]	[0.119]
Constant	−0.412**	−0.509***	−0.566***	−0.399**	−0.549
	[0.012]	[0.005]	[0.003]	[0.040]	[0.158]
Observations	68	68	68	68	68
Adjusted R^2	0.079	0.105	0.122	0.011	0.141
R^2	0.176	0.198	0.213	0.114	0.231

Cumulative abnormal return (CAR) is measured as the cumulative return in a country's major stock index over a period. The total number of cases on different days is measured as a given country's total number of confirmed COVID-19 cases at different periods. UHC per person is measured as the basic health service a person can obtain in a country. Log gross domestic product (GDP) and Credit/GDP are taken from the World Bank Open Data and represent the level of economic development. The uncertainty avoidance index (UAI) was taken from the study of Hofstede et al. (39) to control for cross-country differences in uncertainty aversion among investors. Log (Population) is taken from the World Bank Open Data and controls for the difference in the total number of residents among countries. Political stability and no violence (PSNV) and regulatory requirements (RQ) are taken from the World Bank's GOV Data 360 and indicate the quality of political safety in a country. P-values are given in parentheses.

***, **, and * represent statistical significance at the 1, 5, and 10% levels, respectively.*

and its connection with CARs and UHC. In this study, the total number of cases in a country is used as a proxy to denote high- and low-infected countries. The regression results in the interaction term of UHC × total cases had a negative and significant effect on CAR (0, 60) (coefficient = −0.770; $p < 0.01$) and CAR (0, 180) (coefficient = −3.367; $p < 0.05$). The results indicate that the positive impact of health coverage on CAR diminishes as the number of cases diagnosed in a country increases. The negative and significant coefficient on the interaction variable of UHC × Total cases also confirms Hypothesis 3 that the high number of diagnoses of COVID-19 may affect the impact of UHC on abnormal returns. The empirical evidence is consistent with that of Baker and Wurgler (44), Chen et al. (45), Yu and Yuan (46), and Narayan (47). They conclude that high numbers of confirmed cases will have a negative impact on markets because the increased number of cases overwhelms the primary UHC healthcare system, unevenly distributing its resources and eventually affecting the stock market in the long term.

CONCLUSION

To the best of our knowledge, this is the first study that adopted the healthcare system to evaluate its effect during the COVID-19 outbreak on the stock market. The ongoing COVID-19 pandemic has attracted attention in every country with regard to its impact on people's daily lives. The UHC healthcare system enables everyone to avoid risk exposure, including prevention and treatment in the COVID-19 crisis period. In particular, a significant shock in the stock market is often triggered by an event that significantly reduces trust in investors in a security market because major global events or crises have impacted the global economy and financial markets (48). Our findings addressed the important points of the correlation between healthcare

TABLE 6 | Indirect impact of UHC on CARs during the COIVD-19 pandemic.

Variables	Cumulative abnormal return				
	(1)	(2)	(3)	(4)	(5)
	CAR (0,5)	CAR (0,15)	CAR (0,30)	CAR (0,60)	CAR (0,180)
UHC per person	−0.003	0.045**	0.048**	0.050**	0.197***
	[0.886]	[0.014]	[0.031]	[0.021]	[0.000]
Total cases	0.010	0.007*	−0.087	−0.578	−0.496***
	[0.146]	[0.070]	[0.934]	[0.332]	[0.005]
UHC ×Total cases	0.057	0.445	0.108	−0.770***	−3.367**
	[0.723]	[0.163]	[0.752]	[0.006]	[0.010]
Log (GDP)	0.033***	0.026*	0.046***	0.032**	0.033*
	[0.010]	[0.071]	[0.006]	[0.011]	[0.068]
UAI	−0.028	0.646	0.296	−0.002	0.163
	[0.944]	[0.137]	[0.565]	[0.997]	[0.852]
Credit/GDP	0.007	0.031***	0.024**	0.030***	0.065***
	[0.527]	[0.001]	[0.021]	[0.009]	[0.001]
Log (population)	−0.034***	−0.023*	−0.039**	−0.018	0.021
	[0.008]	[0.098]	[0.035]	[0.159]	[0.304]
PSNV	−0.017	−0.006	−0.033	0.001	−0.051
	[0.251]	[0.645]	[0.137]	[0.935]	[0.125]
RQ	−0.017**	−0.015*	−0.016*	−0.021**	−0.021
	[0.032]	[0.095]	[0.050]	[0.034]	[0.139]
Constant	−0.331*	−0.363	−0.570***	−0.494**	−1.100**
	[0.088]	[0.109]	[0.010]	[0.035]	[0.011]
Observations	68	68	68	68	68
Adjusted R^2	0.066	0.118	0.093	0.046	0.262
R^2	0.191	0.236	0.215	0.175	0.362

Cumulative abnormal return (CAR) is measured as the cumulative return in a country's major stock index over a period. The total number of cases on different days is measured as a given country's total number of confirmed COVID-19 cases at different periods. UHC per person is measured as the basic health service a person can obtain in a country. Log gross domestic product (GDP) and Credit/GDP are taken from the World Bank Open Data and represent the level of economic development. The uncertainty avoidance index (UAI) was taken from the study of Hofstede et al. (39) to control for cross-country differences in uncertainty aversion among investors. Log (Population) is taken from the World Bank Open Data and controls for the difference in the total number of residents among countries. Political stability and no violence (PSNV) and regulatory requirements (RQ) are taken from the World Bank's GOV Data 360 and indicate the quality of political safety in a country. P-values are given in parentheses.

****, **, and * represent statistical significance at the 1, 5, and 10% levels, respectively.*

system and stock prices' movement by showing how a country's UHC responds to a sudden disease outbreak through abnormal returns and makes it more susceptible to citations from the academic literature.

The empirical results of this study reveal that each country's stock index had significantly negative abnormal returns in the short term but not in the long term. Thus, the CAR reacted significantly at the beginning of the pandemic. This is because people may lose confidence or panic because of the shock of the sudden outbreak of a pandemic, incurring negative investor sentiment in the stock market. However, once the UHC is working optimally, the negative reaction to the stock market will disappear in the long term. We also examined the direct and indirect impact of health coverage on CARs during the pandemic. To this end, we ran an OLS regression to calculate the correlation between UHC and CARs on the event days of 5, 10, 30, 60, and 180. The results showed that the effectiveness of UHC remained positive and strongly significant after a period of the COVID-19 outbreak. Nevertheless, the impact was reversed in countries with a higher number of confirmed cases. In reality, when the healthcare system can no longer fulfill the needs of society or individuals to maintain their daily life, chaos and panic ensue due to insufficient or limited resources.

The findings of this study provide several perspectives on financial markets. CARs emerge at the early stages of the pandemic, signifying that the strategy of investment as a sudden reaction to the outbreak is normally at the beginning of the pandemic and that a well-organized UHC system is a key factor in avoiding the risk of damage to stock markets as a result of a sudden outbreak. Further, the results also show that UHC can gradually reduce CARs in the long term, whereas the COVID-19 outbreak has a negative impact on stock markets in the short term.

Although our analysis reveals some important insights into the correlation of UHC and abnormal returns in a short-term response during a pandemic disease, it disregards the effects of lockdown, vaccination coverage in a population, its connection with stock markets in a long-term reaction, and the impact on socio-economics as well. This limitation can be addressed in future studies to assess various measures used to limit the spread of COVID-19, and relieve the pressure on health care systems, travel, consumption and investment, and logistics, causing so-called socio-economic impacts at the market.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

C-HT contribution is reflected in the choice of specialized literature, the definition of research hypotheses, investigation, writing-original draft preparation, visualization, and editing. Y-HL contribution is reflected in the definition of the sample, testing of hypotheses, statistical data processing, resources, and discussion. WL contribution is reflected in the data collection, formal analysis, and conclusions. LW helps to organize the literature review. Y-HL and WL contributed in interpretation of results. All authors have read and agreed to the published version of the manuscript.

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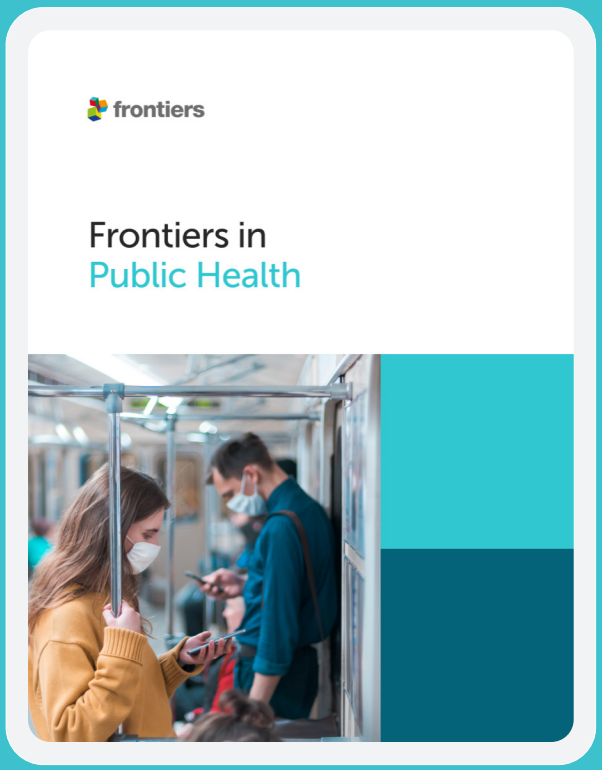

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