

Public health response to COVID-19 in selected countries – Hits and misses

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ABSTRACT

Background: Lack of a cure or vaccine of COVID-19 forced us to rely on public health interventions (PHIs) for combating the pandemic. The main objective of the study to assess the PHI in selected countries and relate the various factors related to the intervention with the case load of the country. **Methods:** An ecological analysis was conducted using secondary data on PHIs and disease burden extracted from official documents and press releases of the respective countries. Disease transmission was described based on calculated doubling time. PHIs were classified into 14 categories within three domains. An intervention score was calculated to reflect the number and stringency of the PHIs. Correlations between intervention scores, daily new cases and doubling time were presented. **Results:** Brazil and the USA had the lowest intervention scores while South Korea had the highest scores. The median doubling time was negatively correlated with the rapidity of the escalation of the PHIs. **Conclusion:** Dynamic government policies and timely PHIs, which are locally relevant and ably supported by the public are key to successful containment of the COVID-19 pandemic.

Keywords: COVID-19, pandemic, public health interventions

Introduction

Pandemics of infectious diseases have been observed throughout history. The ongoing pandemic of Novel Corona Virus Disease (n-COVID-19) caused by the severe acute respiratory syndrome coronavirus2(SARS-CoV-2) has wreaked havoc in terms of morbidities, mortalities and socioeconomic instability across the world. The first case of COVID-19 was reported in December 2019 in Wuhan, Hubei Province, China, following

which the infection has spread to at least two countries with almost 33 million cases and 1 million deaths across the world.^[1,2]

Combating a pandemic requires a multifaceted approach including commitments from medical, social and political sectors. Unavailability of drugs and vaccine to combat this novel virus leaves the medical and public health community with only public health interventions (PHIs) to mitigate the burden of COVID-19. PHIs intended to break the transmission chain include bans on public gatherings, mandatory home stay policies, closures of schools and nonessential businesses, compulsory use of face mask in public places, quarantine and cordon sanitaire (i.e., a defined quarantine area from which those inside are not allowed to leave), mass screening of passengers at airports and other entry points and ban on international transport, among others.^[3] These measures aim to reduce disease transmission both locally and

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globally and thereby reducing the spread of infection, the peak demand for hospital beds, and the total number of infections, hospitalizations, and deaths.^[4]

Historical data and recent evidence suggest that reducing contacts between infected and uninfected persons through these PHIs to mitigate the impact of a pandemic is effective. Quarantine and social distancing during influenza pandemic in 1918 reduced spread and mortality significantly.^[5] Similarly, during SARS and Ebola outbreaks, health agencies and hospitals limited disease spread by isolating symptomatic patients, quarantining patient contacts, and improving hospital infection control practices.^[6,7] PHIs like surveillance, establishing quarantine and isolation, international travel bans along with a coordinated effort of engaging the public has led to generation of win-win situation during past epidemics.^[8-10]

The COVID-19 pandemic had a staggered entry into different countries dictated by their closeness and connectivity to the Wuhan epicentre. Countries had varying time to react and implement responses – while some were caught unaware, others were fortunate enough to have some time to respond & use their past experiences. In the current study, we appraise the timeliness, stringency, escalation and comprehensiveness of PHIs and their correlation with the course of COVID-19 pandemic in selected countries.

Methods

Study design and population

We conducted an ecological study using secondary data of 13 countries. Two categories of countries were selected based on their respective epidemic curves during the study period. These included studies that exhibited early signs of having contained pandemic like China, Sri Lanka, Japan, Singapore, Germany, United Kingdom, South Korea and those who were yet to do so, namely, United States of America, France, Italy, Iran and India.

Data sources

We analysed data on PHIs, disease burden and transmission. Data on PHIs and disease burden (daily new cases and deaths) were extracted from official sources such as the ministries of health and press releases of the respective countries. Disease transmission was represented by case doubling time calculated based on actual cases reported in the respective countries.

Statistical analysis

A country-wise detailed list of PHIs was generated and classified into 14 categories within three domains namely source control, blocking disease transmission and multipronged approach.[Box 1] A positive score of 1, 2 or 3 was awarded for each intervention based on whether it was implemented locally, focally or nationally. A negative score of the same magnitude was awarded for withdrawal of any of the interventions. We reported overall and domain-wise intervention scores for each country. We also

reported the number out of total interventions implemented by each of them.

We calculated case doubling time from the daily cumulative caseload using the formula, doubling time = $\ln(2)/\ln(x)$, where x = today's caseload/yesterday's caseload. The median of this doubling time was calculated excluding zero growth days. The operational definitions for the various indicators are given in Box 1.

We plotted the intervention scores against the epidemic curve and made inferences about their temporal association. Scatter plots between the intervention scores and daily new cases, doubling time were plotted and Pearson's correlation coefficient was calculated.

Ethical concerns

The data used here were aggregate summaries shared by the countries in their respective official websites. No data on individuals were collected. The data do not contain identifying information of any individuals. Thus, no ethical clearance was taken.

Results

Case load across countries

Although the first case of COVID-19 was identified on 31 December 2019 in Wuhan, China, officially started reporting cases only from 17 January 2020, which was the epicentre of the pandemic. Singapore and the USA reported cases 4 days later. All the study countries reported start of the pandemic in January except Iran and Brazil. By end of February the number of cases reported by China gradually decreased, whereas it increased in rest. This shows that the pandemic evolved at different periods in the study countries. As of 20 April 2020, the total number of cases reported by the study countries was 1.3 million with the USA reporting the maximum (661,712 cases or 47%), followed by Italy. Sri Lanka reported the fewest cases (3699 cases or 0.02%). We categorised the study countries into four incidence groups: those with daily new cases <1000 (low – Sri Lanka, Australia, South Korea and Singapore), 1000-3500 (moderate – Brazil, Iran and India), 3500-10,000 (high – England, Germany, Italy and France) and >10,000 (very high – the USA and China)[Table 1].

Intervention score

The intervention score captures both the total number of interventions implemented and their stringency. Among the study countries, the maximum score (40) was achieved by South Korea, followed by India (39) and the lowest score (16) was obtained by the USA and Brazil. In the source control domain, the maximum score (12) was achieved by India, South Korea and Germany while five countries India, Sri Lanka, Singapore, England and Italy achieved the maximum score of 21 and South Korea, England and Germany achieved the maximum (9) in multipronged approach [Table 2].

Box 1: Domain of public health interventions (PHIs) and the definitions of indicators used in the study

Domains and their respective PHIs

Block Transmission

- Restrict local transportation
- Restrict workplace
- Restrict public gathering at public places
- Restrict gathering at religious places
- Restrict public transport
- Closure of educational institutes
- Closure of other non-essential services

Control Source of Infection

- Restriction of foreign travel
- Restriction on entry from foreign
- Screening for cases
- Health system preparedness

Multipronged Approach

- Funding for vaccine research/medicine research
- Public awareness activity
- Public health laws enforcement

Study definitions

Day “0” of Epidemic: The day when the first case of COVID-19 reported

Public Awareness: Any advisory that informs general public regarding the mode of transport of disease and asks them to do certain activities which prevents or prohibits spread of disease in the community including establishment of helpline for the general public

Implementation of public health laws: Implementation of any law that enforces individuals or general public to act in a certain way (both enacting new laws or enforcing the old laws)

Screening of cases: Any method of screening whether it is from history or clinical features among the contacts or suspects or thermal screening among the suspects.

Outside the country restrictions: Travel restrictions imparted on the people of the country to travel outside the country through land, or water or air route.

Local travel restrictions: Restriction imparted on the citizens for travel one place to another, from city to city or from one district to other or one state to other.

Restriction in use of public transport: Any advisory restricting the number of passengers travelling on local transport or preventing travel of general public in the public transport.

Restriction in religious places: Any advisory restricting gathering of or use of religious places.

Closure of educational institutions: Any advisory restricting the opening of educational institutions.

Restricting use of public places: Any advisory restricting number of persons using public places like malls, restaurants, cafeteria etc.

Preparedness of health institutions: Any advisory that is provided to the health institutions to monitor, observe and notify a health situation reported to the hospital.

Non-essential services: All services except hospitals, selling food products, medicines etc.

Zero growth days: Days where no increase in cases were found

Doubling time: Time is taken to double the caseload from the case load of a defined time

Time to initiate intervention: Time difference between 1st response by the country between 1st case officially reported by Wuhan Province or declaration of Public Health Emergency by WHO or 1st case reported by the country

Time to reach the maximum intervention score: time taken by the country to reach the maximum intervention score for the country

Table 1: Burden indicators

Country	No. of cumulative cases as on the last date of the study period	Maximum no. of cases reported in a day during the study period	Time to reach maximum number of cases reported in a day during the study period (force of morbidity)	Median Doubling time excluding the zero case days
India	11481	1463	75	5.1
Sri Lanka	236	21	63	12.4
South Korea	10188	909	39	59.2
China	83640	15152	26	396.5
Singapore	3699	447	83	9.9
USA	661712	43438	75	3.4
Germany	123541	6294	59	5
France	103512	7578	66	4.5
UK	88622	8719	72	4.2
Italy	165157	6557	50	5.6
Iran	76428	3186	40	8.2
Australia	6447	460	63	4.6
Brazil	28220	3058	49	3.8

Table 2: Intervention indicators

Country	Timeliness			Escalation			Comprehensiveness			Magnitude - overall and domain wise			
	No. of days since reporting the first case response was initiated	Time to initiate response since declaration of health emergency (in days)	Time to initiate response since declaration of pandemic (in days)	Time to reach maximum score since first case was reported (in days)	Average duration between subsequent interventions (in days)	Total number of interventions initiated (out of 14)	Number of interventions initiated in domain 1 (out of 4)	Number of interventions initiated in domain 2 (out of 7)	Number of interventions initiated in domain 3 (out of 3)	Maximum stringency score during the study period	Maximum stringency score for source control domain (4 intervention)*	Maximum stringency score for transmission block domain (7 intervention)*	Maximum stringency score for multipronged approach domain (3 intervention)*
India	-13	18	0	52	8.1	13	4	7	2	39	12	21	6
Sri Lanka	-2	27	-7	54	7.3	11	4	6	1	35	11	21	3
South Korea	0	21	-10	58	5.3	14	4	7	3	40	12	19	9
China	NA	21	NA	39	8.6	10	3	5	2	27	9	15	6
Singapore	4	28	-2	64	6.7	8	2	5	1	30	6	21	3
USA	0	22	-9	65	6.5	6	2	3	1	16	6	7	3
Germany	-6	23	-2	64	6.4	11	4	4	3	30	10	11	9
France	-2	24	-5	52	9	11	4	6	1	33	12	18	3
UK	0	32	1	53	10.6	11	1	7	3	31	1	21	9
Italy	-9	23	1	59	11.3	12	3	7	2	34	7	21	6
Iran	4	55	20	47	10.8	8	2	6	0	22	6	16	0
Australia	-2	24	-5	67	9.9	6	3	2	1	18	9	6	3
Brazil	-28	30	-2	29	14.3	10	2	5	3	16	2	5	6

Interventions plotted on the epidemic curve

Most countries with low incidence started multipronged interventions and interventions to control source in the early stages. These were followed by transmission-blocking interventions. [Figure 1a] In Brazil, the initial interventions were mainly multipronged, whereas in Iran, the initial interventions were transmission blocking followed by those controlling the source of infection. India's initial intervention was linked to the multipronged approach followed by those controlling the source of infection and eventually followed by those linked to transmission blocking. [Figure 1b] In countries with high incidence, that is, UK, Germany, Italy and France, the initial responses were limited to controlling the source of infection; whereas subsequent interventions were linked to multipronged approach to contain the infection followed by transmission blocking interventions [Figure 1c]. The USA and China reported very high incidence of cases. The USA's initial interventions were mainly linked to controlling the source of infection whereas China's initial interventions were mainly multipronged. The rest of the interventions in both the countries were transmission-blocking interventions [Figure 1d].

Timeliness

Timeliness of interventions was assessed by four indicators, that is, time taken to initiate response since reporting the first case,

since the Wuhan outbreak, since declaration of the public health emergency by WHO and since declaration of the pandemic by WHO.

Among all countries, Brazil responded promptly to the situation and started response 28 days before reporting of their first case. However, countries like Singapore and Iran responded only after their first reported case, that is, 4 days. When measured since the Wuhan outbreak, Iran was found to have responded late (after 55 days), whereas India responded very promptly. On 30 January 2020, WHO declared COVID-19 to be public health emergency of international concern. Iran responded 20 days after that, whereas Australia and France had initiated response even before this declaration. South Korea, very promptly, initiated their response to COVID-19 51 days prior to the pandemic declaration. [Table 2]

Escalation

Escalation of interventions was measured by two indicators like time to reach maximum intervention score since the first reported case and average duration between subsequent interventions. Time to reach maximum intervention score of the country was highest for Australia which took around 67 days, followed by the USA, Germany and Singapore. Lowest time taken to reach

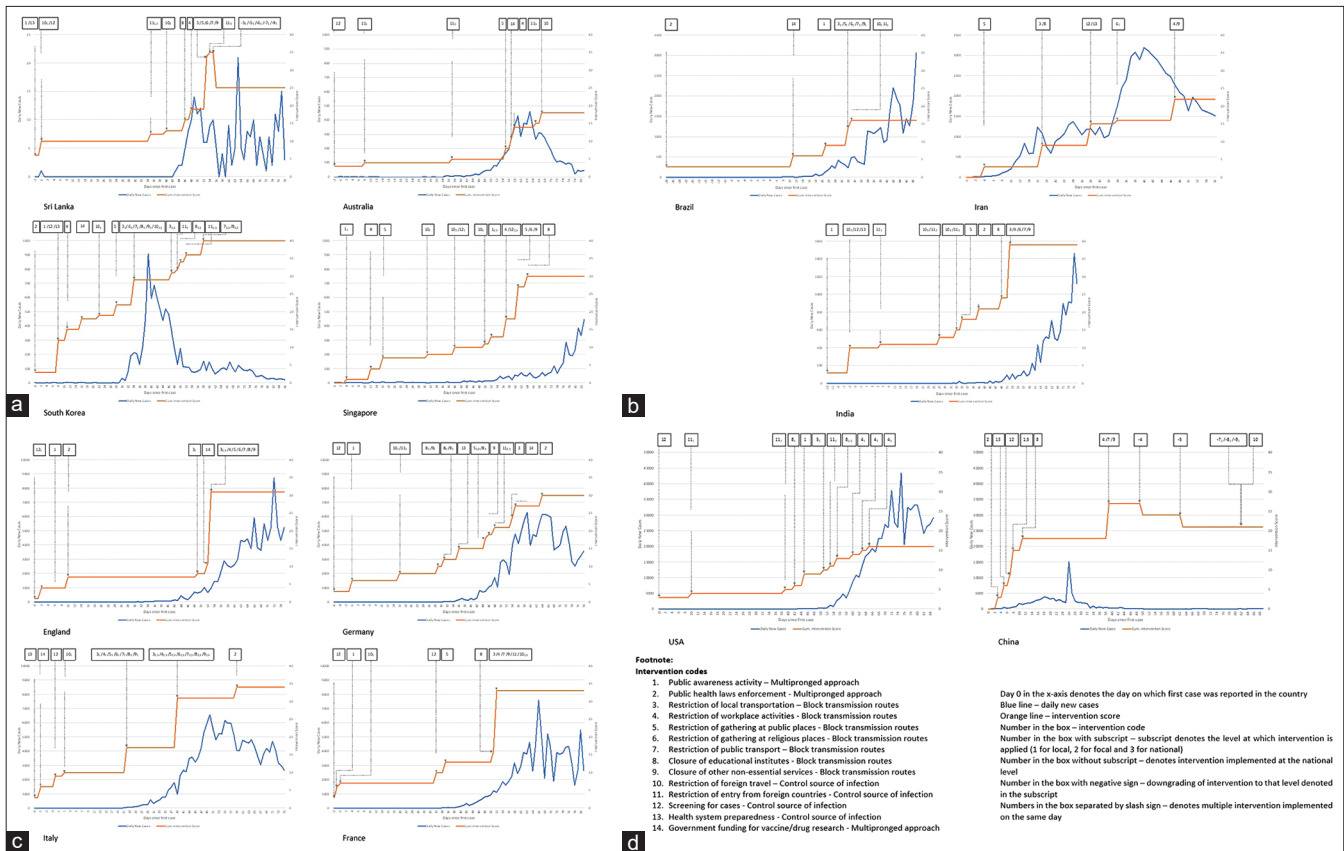


Figure 1: (a) Daily new cases and PHIs during COVID-19 pandemic in low incidence countries (daily new cases < 1000). (b) Daily new cases and PHIs during COVID-19 pandemic in moderate incidence countries (daily new cases 1000-3500). (c) Daily new cases and PHIs during COVID-19 pandemic in high incidence countries (daily new cases 3500-10,000). (d) Daily new cases and PHIs during COVID-19 pandemic in very high incidence countries (daily new cases >10,000)

highest intervention score was by Brazil with 29 days. Average duration between two subsequent interventions was highest for Brazil with 14.3 days, whereas the same was lowest for South Korea i.e., with days [Table 2].

Comprehensiveness

Out of the 14 interventions types studied, all were carried out by South Korea, whereas India had implemented 13 interventions. Lowest number of interventions was implemented by Australia and the USA (6 out of 14). Countries like India, Sri Lanka, South Korea, Germany and France have carried out all the transmission-blocking interventions, whereas rest of the countries implemented fewer such interventions. India, South Korea, the UK and Italy implemented all the source control activities. South Korea, Germany, the UK implemented all three types under the multipronged intervention domain.[Table 2]

Doubling time

The median doubling time was the highest for China (396.5 days) followed by South Korea in a distant second place and the lowest in the USA (3.4 days). All countries showed an increasing trend of median doubling time except Singapore where the median doubling time remained more or less constant.

Correlation between intervention and disease burden indicators

Four intervention indicators and two disease burden indicators were analysed for correlation. Cumulative caseload was positively correlated with duration between start of the intervention and the first case reported, time between first intervention and pandemic declaration, average duration between interventions and intervention score. Median doubling time was positively correlated with duration between start of intervention and first

case reported and intervention score while it was negatively correlated with duration between subsequent interventions and duration between first intervention and pandemic declaration. [Figure 2]

Discussion

In this study, we have compared the PHIs in relation to COVID-19 disease burden and transmission indicators in 13 countries that are currently in different phases of the pandemic and have achieved varying levels of control. Countries like Australia, Brazil and the USA had the lowest intervention score while South Korea, India, and France had the highest scores. Correlations between the case burden and the various intervention indicators were in favour of stricter and more PHIs. The median doubling time was negatively correlated with the rapidity of the escalation of the PHIs.

Among countries that reported a lower-case burden, Sri Lanka, South Korea and Singapore, had implemented multi-pronged interventions in the early phases of the outbreak while Australia had majorly of interventions focused on source control. In moderate burden countries like Brazil and India targeted source control first, whereas in Iran, the major initial strategy was transmission blockade. In countries with high and very high incidence, the most common initial strategy was source control followed by multipronged interventions. For example, in the USA, the initial steps were source control followed by blocking of transmission. The initial intervention in China was multipronged followed by source control and transmission blockade. A study by Flaxman *et al.* studying the impact of non-pharmacological intervention on R_0 found that multiple interventions together lead to a decrease in R_0 and each intervention had some effect in reducing R_0 .^[11] Thus, interventions (like lockdown) which act in multiple ways along

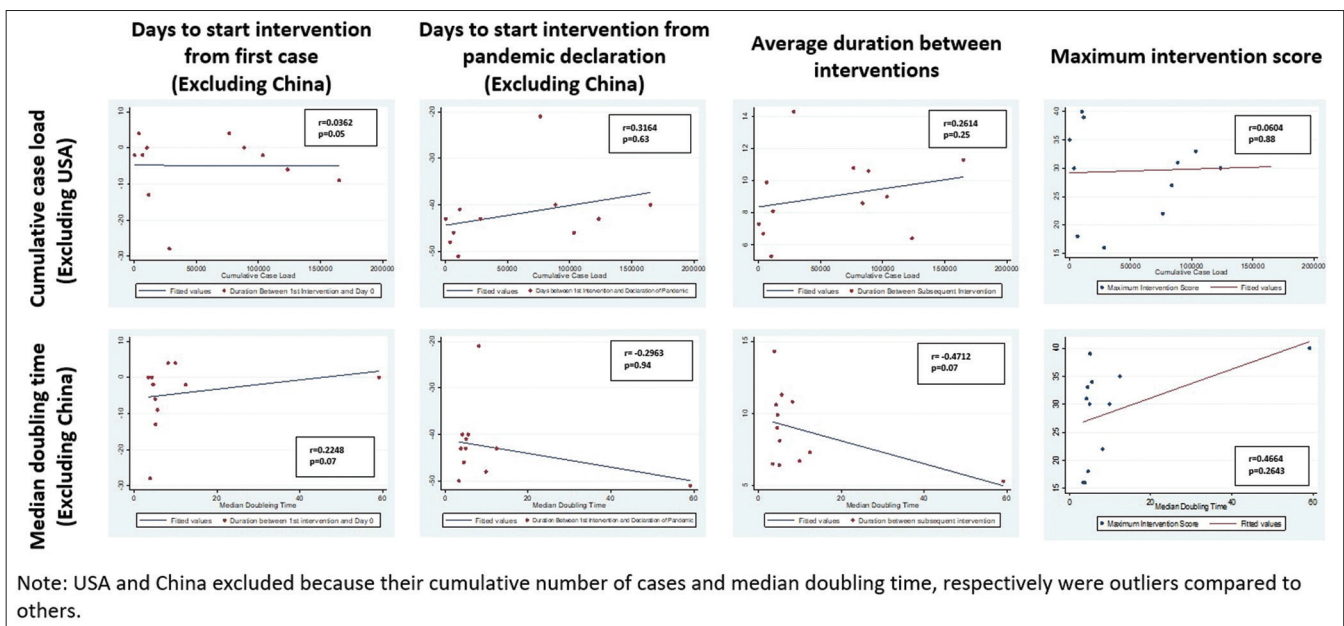


Figure 2: Correlation between various intervention and disease burden indicators

with the rapidity with which the interventions were conducted might have resulted in low incidence in certain countries.^[12-14] Similarly, another study by Walker *et al.* found that infection control interventions result in lower case load at the hospitals.^[15] A study by Cowling *et al.* in Hong Kong found that multipronged actions like public awareness also produces a great impact on the COVID-19 transmission.^[16] This may be due to higher baseline awareness of the people regarding the disease characteristics.

All countries except Singapore and Iran implemented interventions before or on the day the first case was reported. Though USA initiated the interventions late the average duration between subsequent intervention decisions was 6.5 days next only to Singapore (5.3 days) and Germany (6.4 days). The longest interval between two subsequent interventions was observed for Brazil (14.3 days). In our study, maximum intervention score was positively correlated with the median doubling time and caseload. Similar results were found by Hale *et al.* in their study on the tracking government response.^[17] Hale *et al.* found the stringency scores and the number of cases were positively correlated.

Although countries implemented similar interventions there was no clear-cut pattern in the sequence and rapidity. The fact that the maximum intervention score was found to be correlated with median doubling time shows that the comprehensives of interventions was possibly more important than any individual intervention. Although the sequence of interventions differed by country, a general observation that can be made countries which controlled the source of infection (testing, treating and isolating the cases) and restricted the import of cases had a slow rise in incidence except the USA. A modelling study by Costantino *et al.* confirmed the effectiveness of an early travel ban in Australia.^[18] This seems logical because in countries other than China the initial spread was mainly due to imported cases.^[19-21] An early introduction of travel ban reduced the load of imported cases decreasing the force or rapidity of spread of infection in the local communities. The scale of interventions initially adopted by many countries like Sri Lanka was mainly local. Local or focal interventions may have helped contain the initial spread and allowed the rest of the country to function normally.

Timeliness of PHIs is an important determinant in the containment of an epidemic/pandemic.^[22,23] In our study, we found that timeliness of interventions to initiate response since the first reported case was directly related to the cumulative caseload and inversely related to the median doubling time. This was also the case with days to initiate a response since WHO's declaration of a public health emergency. Timeliness of response is guided by many factors like trade and travel with affected countries, public health preparedness based on previous experiences (e.g. Singapore and South Korea) of a pandemic level threat. Countries like Singapore, South Korea and China who have been already exposed to similar diseases in the past are likely to have better disease preparedness and better public awareness and compliance with stringent rules compared to naïve countries (e.g., the USA and Italy) in this respect.^[24] Therefore,

countries with similar intervention scores may still have different effects because of the variations in population compliance. A similar effect was observed in the Kerala state of India, which had a stronger public health preparedness and flattened the curve earlier than the rest of the country on account of its previous experience with the Nipah virus outbreak.^[25]

Rapid escalation of response is another important aspect in pandemic response. In our study, it was found that the prompt escalation of responses represented by the meantime gap between two subsequent interventions found to be directly related to the caseload and inversely related to median doubling time. Kuehn BM while recounting the lessons learnt from the SARS pandemic touched upon the requirement of international cooperation for escalating prompt responses for such epidemics.^[26]

Limitations: Our analysis has few limitations. This is an ecological comparison study, and therefore, biases associated with this design cannot be ruled out. Therefore, we refrain from providing any statistical interpretations of the correlations between the countries. another important limitation is the inclusion of very few countries in the study. Our analysis extends only up to 20 April 2020, but the idea was to examine these countries at different risk levels and try to understand how they have responded to the pandemic so far. Although we obtained detailed information on the interventions, we did not examine the level of implementation and the compliance of the citizens to the same. All interventions were equally weighted but in reality, this may not be so. This is a limiting factor as various interventions in different scenarios may have different effects on the caseload and median doubling time. Testing protocols were also different in different countries, which may have led to differential caseload in the countries and thus might have affected the relation between intervention and disease burden. Interventions that were taken at the end of the study may not have affected the caseload as there wasn't enough time for the intervention to show effect.

Strengths: This study is one of the few studies which compared the PHI of countries accounting for the highest caseload in the world. The strength of the study lies in the diverse nature of countries included in the study, which varied in the timeline of the pandemic, age structure, population and economic condition.

Conclusion

The current study found that the responses of the countries varied in many ways but similarities existed. Although "one size doesn't fit all", some basic principles need to be followed and the responses must be tailored for each country. These interventions have been guided by the economy, public awareness, health system and political factors. Comprehensiveness and sequence of interventions seem to be important factors to contain the pandemic. Cross-learning by countries who were exposed to similar situations in the past and being prepared for such situations also determine the response and control.

Proactive government policies, appropriate and timely interventions along with support from the local authorities, primary care physician, frontline health workers and the public is key to the successful containment of a pandemic. Learning from other countries and preparing for future pandemics by strengthening the public health system are indispensable, which may include training and retraining of the primary care physicians and frontline health workers in early identification and measures to contain the pandemic at the local level. Exposure to similar disease outbreaks in the past and a national level preparedness plan might have helped a few countries in rapidly controlling this novel disease outbreak.

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Conflicts of interest

There are no conflicts of interest.

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