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Epidemiology of COVID-19 and effect of public health interventions, Chennai, India, March–October 2020: an analysis of COVID-19 surveillance system

Jagadeesan M,[1] Parasuraman Ganeshkumar,[2] Prabhdeep Kaur ,[3] Hemalatha Masanam Sriramulu,[1] Manikandanesan Sakthivel,[4] Polani Rubeshkumar ,[4] Mohankumar Raju ,[4] Lakshmidevi Murugesan,[1] Raajkumar Ganapathi,[1] Mahalakshmi Srinivasan,[1] Aswini Sukumar,[3] Kumaravel Ilangovan ,[4] Madhusudhan Reddy,[1] Divyadharshini Shanmugam,[1] Prakash Govindasamy,[1] Manoj Murhekar [2]

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JM and PG are joint first authors.

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For numbered affiliations see end of article.

Correspondence to
Dr Prabhdeep Kaur; kprabhdeep@gmail.com

ABSTRACT

Objectives To describe the public health strategies and their effect in controlling the COVID-19 pandemic from March to October 2020 in Chennai, India.

Setting Chennai, a densely populated metropolitan city in Southern India, was one of the five cities which contributed to more than half of the COVID-19 cases in India from March to May 2020. A comprehensive community-centric public health strategy was implemented for controlling COVID-19, including surveillance, testing, contact tracing, isolation and quarantine. In addition, there were different levels of restrictions between March and October 2020.

Participants We collected the deidentified line list of all the 192 450 COVID-19 cases reported from 17 March to 31 October 2020 in Chennai and their contacts for the analysis. We defined a COVID-19 case based on the real-time reverse transcriptase-PCR (RT-PCR) positive test conducted in one of the government-approved labs.

Outcome measures The primary outcomes of interest were incidence of COVID-19 per million population, case fatality ratio (CFR), deaths per million, and the effective reproduction number (R_t). We also analysed the surveillance, testing, contact tracing and isolation indicators.

Results Of the 192 450 RT-PCR confirmed COVID-19 cases reported in Chennai from 17 March to 31 October 2020, 114 889 (60%) were males. The highest incidence was 41 064 per million population among those 61–80 years. The incidence peaked during June 2020 at 5239 per million and declined to 3627 per million in October 2020. The city reported 3543 deaths, with a case fatality ratio of 1.8%. In March, R_t was 4.2, dropped below one in July and remained so until October, even with the relaxation of restrictions.

Conclusion The combination of public health strategies might have contributed to controlling the COVID-19 epidemic in a large, densely populated city in India. We recommend continuing the test-trace-isolate strategy and appropriate restrictions to prevent resurgence.

Strengths and limitations of this study

- We observed the burden of COVID-19 and the pattern of spread over time after implementing feasible community-centric public health strategies in a large, densely populated metropolitan city in India with limited resources.
- Given the ongoing multiple waves of COVID-19 and the difficulty in controlling the transmission, our experience and lessons learnt will be valuable for policy-makers and scientific advisors globally, especially the low-income and middle-income countries.
- We could not report the severity of illness among admitted patients as we analysed the data available from the Greater Chennai Corporation database and not from the hospitals where patients with moderate-to-severe illness were admitted.
- We could not document the timeliness of contact tracing and compliance to infection control practices during home isolation.
- We could not ascertain the causal association between the public health interventions and the control of the outbreak, as many other factors at the policy and individual levels could have influenced the outcomes.

INTRODUCTION

COVID-19, reported from Wuhan, China, on 31 December 2019, has spread across the globe, affecting over 100 million individuals and causing over two million deaths by March 2021.[1] India reported its first case on 30 January 2020, with over 11 million confirmed cases and 158 856 deaths as of 16 March 2020.[1] Major cities have been major hubs for outbreaks worldwide,[2] which has posed challenges in controlling transmission and mitigating economic and social hardship. Early in the pandemic, metropolitan areas reported the highest incidence of COVID-19.[3] Six months after the start of the pandemic, nearly 95% of COVID-19 cases reported globally were from urban areas.[2] In India, five cities accounted for nearly half of the COVID-19 cases reported through May 2020, with Chennai contributing about 10%.[4]

To control the spread of COVID-19 in the country, the Government of India (GoI) imposed a complete country-wide lockdown on 25 March 2020. The lockdown was in place until 3 May 2020, following which several relaxations were permitted to help sustain the economy. Despite the lockdown, it was difficult to control the spread of COVID-19 in Chennai, the capital city of the southern state of Tamil Nadu. Chennai has an estimated population of over 8 million, with 31.5% residing in slum areas.[5] The city reported its first case of COVID-19 on 17 March 2020, and 192 450 confirmed cases and 2452 deaths were reported by 31 October 2020.

The city health department had to overcome several challenges, including lack of adequate human resources for public health activities, large slum population, lack of awareness about disease symptoms, and fear of being isolated/quarantined. Unlike rural India, which has a more structured public healthcare system with an extensive network of community health workers,[6] urban health systems are more fragmented, with many people seeking care in private facilities.[7] Closure of most private clinics and hospitals made passive surveillance difficult and led to overcrowding of patients at government tertiary care hospitals seeking medical care and COVID-19 testing. Laboratories were overloaded, increasing the turnaround time of test results. The movement of people after relaxation of restrictions posed challenges in contact tracing. The density of population, predominance of intergenerational families, and frequent socialising of extended families and friends made it challenging to control transmission. Similar to Chennai, cities across the globe have been facing challenges in combating the COVID-19 pandemic.[8–10]

Understanding these challenges, several health organisations paid additional attention and issued separate guidelines for mitigating COVID-19 transmission in urban settlements.[11–14] Besides policy-level changes, the guidelines recommended mobilisation and capacity building of additional public health and healthcare workforce from different sources, community mobilisation and engagement, protecting and monitoring the vulnerable population, intensification of risk communication, establishing a call centre for coordination of public health response, setting up community-based testing sites, and data-driven decision making. According to their context, several cities adopted different strategies to control the pandemic. Describing such public health strategies, challenges in their implementation and the impact of these interventions would help policy-makers make informed decisions during similar future situations in an urban setting. In this paper, we described the public health interventions undertaken to control the COVID-19 epidemic in Chennai, India, from March to October 2020 and examined the relationship between these interventions and the spread of COVID-19.

METHODS

Study design and population

We analysed the COVID-19 data of Greater Chennai Corporation (GCC) from March to October 2020. GCC is the civic (government) body governing Chennai city. Administratively, Chennai is divided into 3 regions (North, Central and South) and further divided into 15 administrative zones. Each zone has 10–15 divisions, with a total of 200 divisions within the city. Several densely populated areas and large wholesale markets for various commodities characterise Northern Chennai. The central region has crowded wholesale fruit/vegetable markets, commercial areas and office buildings. South Chennai is relatively less densely populated, with various software and information technology offices. The city has a well-structured public health system with a Zonal Health Officer for each of the 15 zones, who is responsible for the surveillance and response during epidemics. Each zone has a dedicated health workforce for Medical and Public Health activities. Sanitary officers and sanitary inspectors are the frontline workers for all field-based public health activities.

Description of interventions

GCC implemented a comprehensive public health strategy for controlling COVID-19, including surveillance, testing, contact tracing, isolation and quarantine (online supplemental table 1). The interventions were designed on the core principle of a community-centric patient-friendly approach. The central strategy was to conduct surveillance and testing closer to home, including field-based contact tracing in the streets when a cluster of cases was reported. Since Chennai had a human resource-limited urban public healthcare system, implementation of the community-centric public health strategies required the mobilisation of additional resources. GCC identified over 10 000 volunteers from the local community. They visited each household in the city at least thrice a week to look for symptoms related to COVID-19. They also carried an infrared thermometer and pulse oximeter to measure temperature and blood oxygen levels when necessary. Doctors and nurses examined symptomatic patients, collected samples in fever camps at 500+ locations daily, covering all streets in rotation. All individuals who tested positive for COVID-19 were offered free transport and free admission if necessary to government COVID-19 hospitals and COVID-19 care centres (CCC). However, the patients were free to opt for admission in designed private COVID-19 hospitals at their expense. Another innovative strategy was identifying 3500 young adults to be Friends of COVID-19 persons Under Surveillance volunteers in their own communities. They visited the patients in home isolation with all precautions and ensured compliance with isolation and quarantine. They also assisted the families in purchasing groceries,

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medicines for their livelihood. They reported the visits and any violation of isolation and quarantine in an android application. They also assisted in transporting those who violated the home isolation or quarantine to facility isolation or quarantine for free of cost. Tamil Nadu has a well-structured well-staffed state-level public health department with a highly trained workforce catering predominantly to the rural population. This workforce was mobilised to support various managerial and field-level activities such as outreach camps, contact tracing, sample collection, data analysis, clinical care and strategic planning in Chennai. To monitor the spread of the disease and implementation of the public health activities, we established an integrated data management system that pooled the information from laboratories, hospitals and field-level staff. The real-time data enabled daily and weekly analysis of cases up to the street level to identify the areas where surveillance and testing needed to be intensified.

The Tamil Nadu state government implemented several non-pharmaceutical interventions between March and October 2020 (online supplemental table 2). Between 5 February and 23 March 2020, international travel restrictions were in place. The GoI announced a complete lockdown across the country from 24 March to 14 April, further extending till 3 May 2020. All government and private institutions exempting essential services were closed during this period. All transport services were suspended with the exception of essential goods. All the educational and training institutes, worship places and functions/gatherings were closed/suspended without exemption. Wearing masks while in public was compulsory since mid-April, and those who did not wear masks appropriately could be fined. International travellers who visited after 15 February 2020 were tested for COVID-19 with RT-PCR and were quarantined for 14 days at home. The GoI announced partial relaxations for offices from 4 May 2020 onwards, and partial travel resumed from 25 May 2020, with online registration and approval. From 1 June 2020, all private offices, showrooms, restaurants, tea shops, salons and taxis were permitted to operate at 50% capacity. Owing to a continuous increase in cases, the government enforced a complete lockdown between 19 June and 5 July 2020. From July to October, the government relaxed the restrictions in stages—increasing the maximum number of people who could attend weddings and funerals, increasing the number of domestic rail lines and flights operating, and unrestricted interstate and interdistrict travel from 14 August 2020. Starting from 1 September, the government opened public parks and places of worship for public use, allowed government and private offices to operate at 100% capacity, allowed hotels to accommodate guests and reopened interdistrict bus travel.

Operational definitions

COVID-19 case

Any individual diagnosed with COVID-19 by testing the throat or nasal swab by an RT-PCR technique. We used only RT-PCR as the diagnostic test to avoid misclassification, as the rapid antigen test had less sensitivity.

Contact of COVID-19 case

Any individual who had potential exposure to a COVID-19 case during the infectious period (3 days before to ten days after the date of onset of illness or the date of testing in case of asymptomatic cases). The potential exposures included staying in the same household, exposure within 6 feet/more than 10 minutes, direct physical contact, providing care without using personal protective equipment, sharing food, travelling nearby for more than 15 min in a taxi or public or own transport, and sharing the same room such as meeting room and office room for more than 15 min or within six feet distance.

COVID-19 care centre

The centres which offered care only for patients that had been clinically assigned as mild cases.[15]

COVID-19 hospital

The hospitals that offered comprehensive care primarily for those clinically assigned as severe.[15]

COVID-19 death

Any death due to a clinically compatible illness in an RT-PCR confirmed COVID-19 case unless there is an alternative cause of death that cannot be related to COVID-19 diseases such as trauma. There should be no period of complete recovery from COVID-19 between illness and death.[16]

Home isolation criteria

The COVID-19 confirmed individuals who were asymptomatic or had mild symptoms were eligible for home isolation after evaluation at screening centres, except for immunocompromised individuals, the elderly and those with comorbid conditions. The doctors allowed home isolation only for those COVID-19 positive individuals whose house has at least one separate bedroom with an attached bathroom, as certified by the sanitary inspectors after a direct visit to their house. An information sheet with infection control practices was given to those permitted for home isolation. All individuals given home isolation were considered discharged after 10 days of symptom onset or date of testing (if asymptomatic) and no fever for 3 days. After this period, the patients were advised to isolate and self-monitor their health for a further 7 days.[17]

Quarantine policy

All contacts, as defined earlier, were asked to quarantine at home for 14 days from the date of contact with a confirmed case.[18]

Sources of data

We collected the line list of all the patients with COVID-19 reported till 30 October 2020 from the GCC surveillance database. The line-list variables included the date of RT-PCR confirmatory report, age, sex, zone of residence, hospitalisation status and outcome. We retrieved daily testing data from the RT-PCR portal, a uniform nationalised data management platform for RT-PCR testing. We collected data regarding contact tracing, hospital occupancy, home isolation and quarantine data from an integrated online portal developed exclusively for COVID-19 response. We removed personal identifiers before data extraction.

Outcomes of interest

The study outcomes included incidence per million, case fatality ratio (CFR), death rate and the effective reproduction number. The incidence of COVID-19 was measured as the number of RT-PCR confirmed cases per million. The case-fatality ratio was estimated as the number of deaths among the COVID-19 cases reported divided by the number of COVID-19 cases. The death rate was defined as the number of COVID-19 deaths per million population. The effective reproduction number (R_t) was defined as the number of cases emerging from one index case in the population.

We analysed the surveillance indicators, including the number of outreach camps and the proportion of all samples collected in camps or sample collection centres. We analysed the average number of tests per million population per day, and test positivity %, defined as the number of tested positive among tested. The complete data on testing was available only from May 2020, when the entry of sample collection data in a centralised data entry portal and mobile application was made mandatory for sample collection centres and laboratories. We assessed the contact tracing activity by estimating the median number of contacts traced per COVID-19 case from July 2020, when contact tracing data were integrated into the online portal developed exclusively for COVID-19 response. We categorised the contacts as home (household) contacts and extended (non-household) contacts. We calculated the average bed occupancy rate per month by taking an average of the daily bed occupancy rate.

Data analysis

We described RT-PCR confirmed COVID-19 cases and COVID-19 deaths by time, place and person characteristics. We described time distribution by plotting the epidemic curve using the date of reporting. We estimated COVID-19 incidence, CFR and the death rate by age and gender. To describe the spread of COVID-19 across the geographical zones over time, we used qGIS software V.3.14.0 to plot maps with the incidence per million population. We used Friedman's test to test the difference in incidence across the age groups and gender over time. We assessed the age and gender difference in incidence and deaths using the χ^2 test. We used the 'COVID-19 Estimator' developed by WHO-Pan American Health Organization office to estimate effective reproduction number (R_t) with 95% credible interval.[19] The estimator was developed using the 'EpiEstim' R package.[20] The estimator used the number of COVID-19 cases reported daily to estimate R_t, assuming parametric serial interval distribution based on a mean (SD) of 4.8 (2.3) days.

Patient and public involvement

We collected the deidentified data directly from the GCC surveillance database. The study team did not access the information such as patient identifiers or other personal data. We did not involve the patients or public directly in the study design, outcome measures, data analysis or interpretation of the results.

RESULTS

Descriptive analysis of cases and deaths

Chennai reported 192 450 RT-PCR confirmed COVID-19 cases from 17 March 2020 until 31 October 2020, of which 114 889 (60%) were males, 74 635 (39%) were 21–40 years of age and 66 616 (35%) 41–60 years (online supplemental table 3). The daily number of cases increased in May and peaked in June, after which it gradually declined through to the end of October (figure 1).

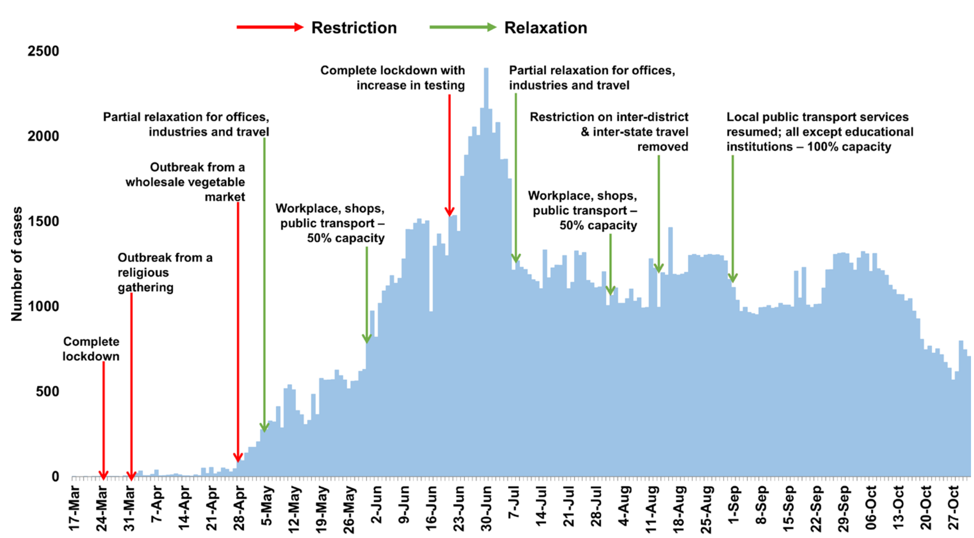

Figure 1 Distribution of RT-PCR confirmed COVID-19 cases by date of notification, Chennai, India, March to October 2020.

Table 1 Incidence per million population and case fatality ratio (CFR) of COVID-19 by age and gender, Chennai, India, March to October 2020

Characteristics		March 2020	April 2020	May 2020	June 2020	July 2020	August 2020	September 2020	October 2020	Overall
Incidence per million population										
Sex	Male	4	147	2210	6751	6134	5447	4731	4799	30 223
	Female	2	86	1473	4640	4509	3762	3146	3086	20 705
Age group	≤20	1	46	636	1619	1923	1581	998	872	**7677**
	21–40	3	139	2102	5929	5371	4696	3882	3831	25 952
	41–60	2	147	2566	8328	7433	6515	5843	6017	36 852
	61–80	11	120	2048	8935	8236	7039	7114	7562	41 064
	>80	12	110	1400	6596	6608	5757	6986	6207	33 675
Total incidence		**3**	**107**	**1694**	**5239**	**4894**	**4235**	**3623**	3627	23 422
CFR in %										
Sex	Male	6.7	2.9	2.7	3.2	2.2	1.8	1.6	**1.2**	**2.1**
	Female	0.0	0.0	2.2	1.9	1.5	1.3	1.1	**0.8**	**1.4**
Age group	≤20	0.0	0.0	0.1	0.1	0.1	0.0	0.0	**0.0**	**0.1**
	21–40	0.0	0.5	0.4	0.4	0.3	0.1	0.1	**0.0**	**0.2**
	41–60	0.0	4.2	3.0	2.5	1.6	1.3	1.0	**0.2**	**1.6**
	61–80	14.3	8.9	12.2	9.8	7.6	6.4	4.5	**1.2**	**6.9**
	>80	0.0	22.2	19.1	23.6	18.8	18.8	10.3	**3.7**	**16.8**
Total CFR		**4.2**	**2.5**	**2.5**	**2.7**	**1.9**	**1.6**	**1.3**	**1.1**	**1.8**

As of 31 October 2020, the cumulative incidence of COVID-19 per million population was 23 422, with males (30 223 per million) reporting a higher incidence (p value<0.001) than females (20 705 per million) (table 1). Among various age groups, the 61–80 years age group had the highest cumulative incidence (41 064 per million), and the less than 20 years age group had the lowest cumulative incidence.

The city reported 3543 deaths during the same period. Among them, 2452 (69%) were males, and 1852 (52%) were of age group 61–80 years (online supplemental table 3). Overall CFR was 1.8% as of 31 October 2020 (table 1). CFR was higher among males than females (2.1% and 1.4%, respectively, p value<0.001). CFR increased with age (p value<0.001) and was highest among people over 80 years (16.8%), followed by 61–80 years (6.9%).

The overall crude death rate of COVID-19 in Chennai city was 431 per million between March and October 2020. In line with CFR, the death rate was also higher among males (645 per million) than females (291 per million). The age-specific death rate increased with age increase, the highest being reported among people over 80 years (5635 per million), followed by 61–80 years age group (2817 per million).

Effect of public health interventions

From the initial case (March 17) till 3 May 2020 (period of complete lockdown)

The GoI implemented a complete nationwide lockdown from 24 March to 3 May 2020. The incidence of COVID-19 was 3 per million during March 2020 and 107 per million during April 2020. All the zones reported an incidence of less than 2300 per million during this period (figure 2). The incidence was comparable in the 21–40, 41–60 and

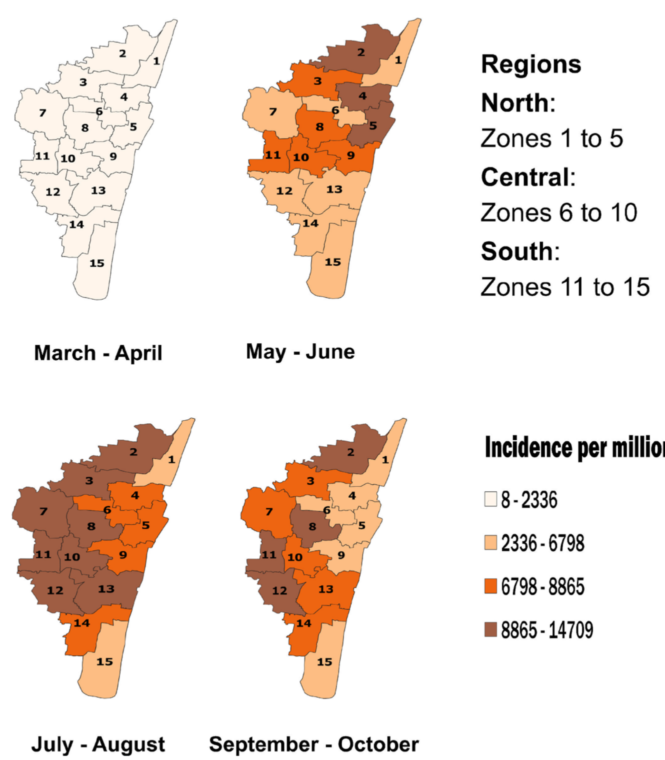

Figure 2 Incidence per million population by zone and month, Chennai, India, March–October 2020.

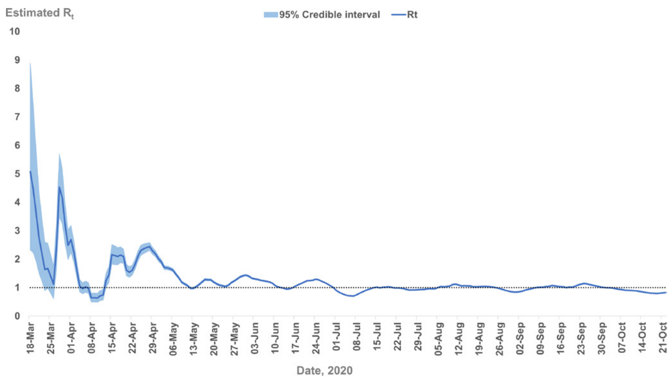

Figure 3 The effective reproduction number (R_t) estimates based on RT-PCR confirmed COVID-19 cases in Chennai, India, March–October, 2020.

61–80 years age group. CFR was 4.2% during March 2020 and reduced to 2.5% in April 2020. The effective reproduction number (R_t) was 4.2 during March due to a superspreader event from a religious gathering[21] and reduced during April 2020 to reach 2.1 (figure 3). At the end of April, there was a sudden increase in transmission due to another superspreader event from a wholesale market (figure 1).[22] This increased the R_t to 2.4 towards the end of April (figure 3). The data on testing, contact tracing and bed occupancy were unavailable for this period.

Period of partial lockdown (4 May to 18 June 2020)

The workplaces and domestic interstate travel started operating with limited capacity (10%–50%) on May 4. The capacity increased to 50% in June with the resumption of intracity bus services at 50% capacity. Following partial relaxation for domestic travel and workplaces and a super spreader event from the wholesale market,[22] the incidence increased from 107 per million in April to 1694 per million in May. After the wholesale market closure, the R_t reached 1.4 at the end of May 2020 (figure 3). To increase testing, the GCC started outreach fever camps (17 camps per day) in May and established 35 sample collection centres closer to the community for wider testing and easy accessibility. On average, GCC conducted about 417 tests per million per day during May, with the help of 18 RT-PCR labs (six public and 12 private). In May, the average daily test positivity was 12% (figure 4). However, the incidence continued to increase at the beginning of June, with an increase in CFR from 2.5% in May to 2.7% in June. In June, the test positivity increased from 12% to 25% (figure 4). The incidence was higher among adults above 40 years and in 3 zones in the northern region (figure 2). The proportion of active patients under home isolation increased from 4% in May to 22% in June. The average bed occupancy rate (total COVID-19 beds—10 469) in public and private sectors increased over 75% and 50%, respectively. Contact tracing data for this period were not available.

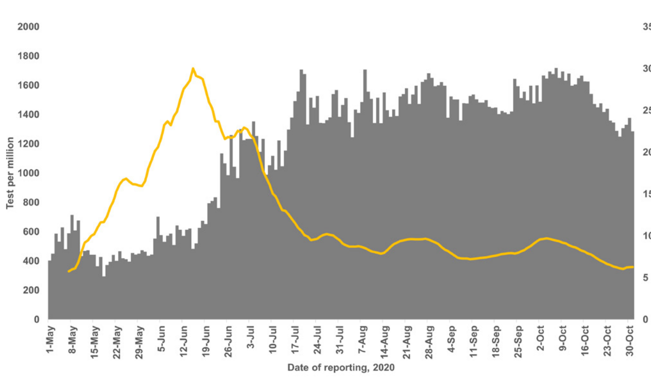

Figure 4 Test per million and positivity % by date of reporting, Greater Chennai Corporation, May–October 2020.

Period of complete lockdown (19 June to 5 July 2020)

Given the continued rise in incidence and bed occupancy, the state authorities implemented another complete lockdown to reduce the transmission. All except essential services and essential travel were stopped. During this period, the number of outreach fever camps per day increased from 17 to 326 and RT-PCR labs from 18 to 26. This led to an increase in the average number of tests done per million per day from 417 to 553. The daily reported cases peaked on 30 June 2020 (figure 1), with an incidence of 5239 per million. The test positivity declined from 25% to 21% at the end of the lockdown period (figure 4). The maximum R_t during this period was 1.3 on 24 June 2020, and declined thereafter to below 1.0 in the first week of July (figure 3). The average bed occupancy rate (total COVID-19 beds—10 469) reduced from over 75% to 69% in public and 50% to 46% in private. The oxygen bed occupancy was 70%, and Intensive Care Unit (ICU) occupancy ranged from 41% in public to 68% in private. Contact tracing data for this period were not available.

Period of relaxation (6 July to 31 October 2020)

From July 6, the workplaces and domestic travel resumed at 50% capacity. Since August 14, there was no restriction on interdistrict and interstate travel. In September and October, public bus transport and metro rail services resumed, and all except educational institutions were permitted to operate at 100% capacity. After the relaxation of restrictions similar to the prelockdown period, surveillance was intensified with 497 outreach fever camps per day in July and maintained over 400 until October. The number of sample collection centres increased from 35 to 56 in August. A total of 52 labs (13 public and 39 private) enabled average daily testing of over 800 per million and a decline in the test positivity from 21% to 8% (figure 4). More than half of the collected samples were from the outreach camps and dedicated sample collection centres. The city traced and quarantined over a million contacts between July and October. In July, the ratio of extended contacts to home contacts was two and increased to three between August and October. The median (IQR) number of contacts traced per case detected in July was 11 (6–17). The median increased to 13 (8–17) in August 2020 and remained at the same level until October 2020.

The incidence gradually declined from 4894 per million in July to 3627 per million in October. From July to October, the incidence was highest among the 61–80 years age group, followed by the 41–60 years age group. The change of incidence from March to October was significantly different across the gender (p value – 0.04) and age groups (p value<0.001).

The incidence increased above 8800 per million in 8 out of 15 zones in all three regions (north, central and south) during July–August. By October, only three zones in the central and southern region and one in the northern region reported incidence above 8800 per million. Of 13 zones, which had incidence above 6800 per million during July–August, 4 reported a decline during September–October (figure 2). The CFR gradually decreased from 1.9 in July to 1.1 by October (table 1). The R_t maintained at lower levels after the first week of July, though it fluctuated around 1.0 and reached 0.8 towards the end of October (figure 3).

The total bed capacity, including oxygen and ICU beds in both public and private COVID-19 hospitals, increased to over 14 000 by July and declined to nearly 10 000 by the end of October. This change was mainly due to a 50% decline in the private sector owing to low bed occupancy. However, the average total bed occupancy declined from 58% in June to 42% in July and 31% in October. The oxygen bed occupancy in COVID-19 hospitals declined from 70% in June to below 20% by October. The ICU bed occupancy reduced from 40% in July to 24% in October in public and from 57% to 43% in private. The number of non-oxygen beds in CCCs maintained over 15 000 throughout the period, with a decline in occupancy from 33% in June to 2.8% in October.

DISCUSSION

We documented the COVID-19 response in a large metropolitan city in south India. Our analysis showed that implementing a combination of interventions might have led to decreased transmission despite easing restrictions. Studies have shown that lockdown measures in China and European countries led to a decline in cases.[23–28] In India, as elsewhere, effective pandemic control required adaptation of mitigation strategies to the local setting, and this was particularly challenging in highly congested urban slums. Therefore, we designed and implemented a community-centric public health strategy to improve early detection of cases through active door-to-door surveillance, access to free testing closer to the residence and free hospital-based care. This people-centric response was possible due to strong political will, good governance, extensive public sector hospital and laboratory infrastructure and dedicated human resources. Besides, a dedicated state-level procurement agency enabled rapid and timely procurement of PPE, consumables, laboratory equipment and other hospital-based requirements.

We observed unique epidemiological characteristics such as higher incidence in the older age group as the epidemic progressed. The incidence remained low among the <20 years age group irrespective of the month. Low incidence might have been due to the closure of educational institutions throughout the period. To begin with, the incidence was comparable across the age groups. However, as the cases increased rapidly from June onwards, the elderly (>60 years) experienced a high burden. The pattern contrasts with the pattern observed in the USA and Europe, which reported a higher incidence in the younger age group as the epidemic progressed.[29] The multigenerational joint family system or frequent interactions of the elderly with other age groups at the societal level possibly facilitated the transmission. Given the asymptomatic or mild symptomatic status of younger people with COVID-19, they might have passed the infection to the elderly without their knowledge. The elderly were also more likely to have a symptomatic infection and hence higher chances of being tested and diagnosed.

There was a decline in CFR, possibly due to early identification of hypoxia in outreach camps, improved management protocols, and awareness among patients regarding the need to seek care for COVID-19 like symptoms. However, the CFR continued to be high in older age groups, as witnessed in other cities and countries.[30–33] Despite the differences in overall CFR across the countries, age-specific CFR was considerably higher among individuals>60 years, as witnessed in this study and in China and Italy.[31] Individuals with age >80 years succumbed to death more than other age groups. In Chennai, the CFR in this age group was 16.8%, comparable to China (14.8%) and Italy (17.9%).

We responded to the pandemic by evolving strategies to better the community's acceptance of interventions such as test-trace-isolate and COVID-19 appropriate behaviours. Mobilisation of a vast network of paid volunteers from the same community helped them connect easily with the people and families in home isolation. The support of the volunteers in procuring essential goods to the families under isolation and facilitating linkages with the health system improved the acceptance of public health interventions at the community level. In addition, a highly trained health workforce from rural districts was mobilised to support managerial and field-level activities. The rapid scale-up of test-trace-isolate strategies with additional resources could have helped control the outbreak. A similar community-based strategy helped Dharavi, India's largest slum, reduce the spread of the infection.[34] Increased testing closer to home effectively reduced the cases and test positivity, indicating a slowdown in the transmission. A similar pattern was observed in other places such as New York, South Korea, New Zealand in the early phase of the epidemic.[35–37]

The data-driven decision-making anchored the public health response to the pandemic in our setting. The regular analysis documented the gradual shift in higher incidence from northern Chennai to central and southern regions as the pandemic progressed. Accordingly, the programme managers could rapidly shift the resources to control emerging hotspots. We learnt from other cities such as New York and Singapore, which had data-driven approaches evident from the dashboards available on their websites.[38 39] We reviewed the key indicators recommended in the literature and adapted the relevant indicators to our setting.[40–43] In our experience, test positivity, incidence by geographical areas, and % bed occupancy were extremely useful in assessing the situation and adapting the strategies. The incidence of cases was the first indicator to change, followed by test positivity%, which required few weeks of persistent change. The increase in incidence and test positivity triggered the health system to look for clusters. The geographical areas or populations with an upward trend were prioritised for increasing case search and testing. The oxygen bed occupancy was the most important indicator to make decisions regarding restrictions and lockdowns.

Strengths and limitations

One limitation was that we analysed the data available from the GCC database and not from the hospitals where patients with moderate-to-severe illness were admitted. Hence, we could not report the severity of illness among admitted patients. Second, the COVID-19 incidence might have been underestimated while testing was low in the early phase. Third, we could not document the timeliness of contact tracing and compliance to infection control practices during home isolation. Fourth, we could not ascertain the causal association between the public health interventions and the control of the outbreak, as many other factors at the policy and individual levels could have influenced the outcomes. The strength of our study was the comprehensive analysis of COVID-19 strategies and outcomes in a large, densely populated metropolitan city in India. The lessons learnt are relevant to similar settings in low-income and middle-income countries.

CONCLUSION

We conclude that the community-centric public health strategies might have contributed to controlling the COVID-19 outbreak in a large, thickly populated city in India. These efforts led to control in the short term. However, COVID-19 is an opportunity to strengthen the public health and primary healthcare system for the urban poor. Since only one-third of the population antibodies for COVID-19 in October,[44] a large proportion of the population remained susceptible. Therefore, there is a resurgence risk due to new variants,[45] and poor compliance to COVID-19 appropriate behaviours. We need to sustain the public health surveillance, expand the public health workforce, educate communities regarding COVID-19 appropriate behaviours, sustain the test-trace-isolate strategies and vaccinate the public as and when the COVID-19 vaccine becomes available to prevent the resurgence of COVID-19 in Chennai.

Author affiliations

[1]Greater Chennai Corporation, Government of Tamil Nadu, Chennai, Tamil Nadu, India

[2]Division of Epidemiology, ICMR - National Institute of Epidemiology, Chennai, Tamil Nadu, India

[3]Division of Non-communicable Diseases, ICMR - National Institute of Epidemiology, Chennai, Tamil Nadu, India

[4]Field Epidemiology Training Program, ICMR - National Institute of Epidemiology, Chennai, Tamil Nadu, India

Twitter Polani Rubeshkumar @drrubesh and Kumaravel Ilangovan @drKumaravel

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ORCID iDs

Prabhdeep Kaur http://orcid.org/0000-0002-2605-3739
Polani Rubeshkumar http://orcid.org/0000-0002-0418-7592
Mohankumar Raju http://orcid.org/0000-0001-9316-8977
Kumaravel Ilangovan http://orcid.org/0000-0003-0111-511X
Manoj Murhekar http://orcid.org/0000-0002-1720-7628

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