Effective response strategy to a hospital cluster of the B.1.617.2 delta variant of concern during the COVID-19 pandemic

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Abstract In Singapore a hospital cluster of COVID-19 occurred owing to the highly transmissible SARS-CoV-2 B.1.617.2 variant. To contain the outbreak, a three-pronged response strategy of containment, segregation and reset was adopted. These strategies resulted in the successful control of the cluster within a month. The cluster was followed by a review process, which yielded two important insights. The first was to strengthen lines of defence by early identification of COVID-19 cases through the principles of test, monitor and protect. The second was to develop an enhanced preparedness protocol, categorised into contingency, communications and care (3Cs), that could be readily activated should another hospital cluster of COVID-19 occur.

KEYWORDS: hospital cluster, outbreak, COVID-19, containment, segregation, reset, variant of concern

INTRODUCTION

The COVID-19 pandemic, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has affected more than 229 million lives, causing 4.7 million deaths.[1] The majority of symptomatic

patients present with mild symptoms of acute respiratory infection (ARI), making it difficult to distinguish from other common respiratory pathogens.[2] An estimated one-third of infections are asymptomatic,[3] and presymptomatic transmission of SARS-CoV-2 has been reported.[4]

In December 2020, the COVID-19 situation worsened all across the world owing to the emergence of several variants of interest and concern. In particular, the B.1.617 variant (and its lineages B.1.617.1, B.1.617.2 and B.1.617.3), which was first detected in India, led to an exponential rise in cases there from March to April 2021. This variant was first detected in travellers entering Singapore in January 2021, and the first case of local transmission was described on 16 April 2021. The World Health Organisation (WHO) labelled the B.1.617.2 as the delta variant and a variant of concern, associated with increased transmissibility.[5]

Singapore has chosen a containment strategy during this pandemic as of August 2021.[6] Nationally, the ministry of health (MOH) coordinates and leads responses to health crises such as the COVID-19 pandemic. The country has undertaken a variety of measures such as contact tracing through digital platforms,[7] social distancing and public mask wearing.[8] To further minimise interactions, home-based learning for students and working from home were default arrangements. Essential services such as healthcare were subjected to frequent testing as a strategy for prompt detection to safeguard the front-liners and community. About 83 per cent of the population has been vaccinated with at least one dose as of the end of August 2021.[9]

Singapore has 18 acute hospitals, 10 of which are public.[10] These public hospitals are owned by MOH[11] and provide the majority of the acute care services in the country.[12] Hospitals in Singapore ramped up preparedness and response measures from the start of the pandemic. By working with various hospitals, MOH coordinated capacity management and load-balancing measures as part of its overall COVID-19 response. These measures are feasible because Singapore is relatively small and highly urbanised. It has an excellent road network, and all public hospitals are strategically located near major expressways.

Tan Tock Seng Hospital (TTSH) is one of Singapore's largest acute hospitals, with over 1,500 beds, and is integrated with the National Centre for Infectious Diseases (NCID), a 330-bed purpose-built facility for emerging infectious diseases management. TTSH was designated the SARS Hospital in 2003 and, together with NCID in 2020–2021, supports Singapore's pandemic response to COVID-19. As a focal hospital for outbreak responses, load balancing through ambulance diversion and deferment of non-urgent procedures were undertaken by TTSH. To protect staff, risk-based use of personal protective equipment (PPE) was employed and surveillance of fever and sickness was rapidly scaled up through a one-stop online platform, 'Staff Health Surveillance System' (S3), for reporting of twice-daily temperature-taking and sickness absenteeism.[13]

EVENTS OF THE HOSPITAL CLUSTER AND RESPONSE

The index case of the cluster was a ward nurse who sought medical treatment after developing fever. COVID-19 was detected on her swab test and reported on 28 April 2021. Phylogenetic studies of the cases in the cluster subsequently revealed a single cluster of cases belonging to the B.1.617.2 variant, which suggested a single introductory event. On the basis of the epidemic curve, the primary case who introduced the event to the ward concerned was an inpatient who had been cared for by this nurse. The patient had been admitted for fever and headache on 18 April 2021. His COVID-19 polymerase chain reaction (PCR) test was not detected on admission, and his chest x-ray was clear.

He was treated for bacterial sinusitis and improved with antibiotics. During his admission, he subsequently had a new onset of fever, for which he was being investigated. His swab test on 28 April 2021 was positive.

By 29 May 2021, two incubation periods (28 days) since the last confirmed case with exposure to the ward, there were a total of 47 confirmed cases linked to the COVID-19 cluster at the hospital ward. These comprised 29 patients, 9 staff and 9 visitors/household contacts. Of the 47 cases, 44 were detected through active contact tracing, and they tested positive while entering or in quarantine. This was Singapore's first hospital COVID-19 cluster, comprising staff, patients, household contacts and ward visitors. The hospital cluster was declared over by the MOH on 6 June 2021.

Knowledge of a possible hospital cluster on 28 April triggered an immediate response by hospital management aimed at containing the outbreak, ensuring quality of care delivered to all inpatients and resuming hospital services and support for the pandemic. Risk-based approaches formed the foundation of all measures that were adopted through the containment, segregation and reset response strategy.

CONTAINMENT STRATEGY

To halt the spread of SARS-CoV-2 in the hospital, containment measures such as isolation, quarantine and case detection were swiftly implemented. These measures targeted both the affected wards and the wider hospital campus and were organised in six containment rings (Figure 1).

Containment Ring 1 targeted those with the highest risk of onward transmission. On 28 April, an immediate hospital order was issued to stop all patient movement in or out of the ward where the index case had been cared for. All inpatients in the affected ward were tested for SARS-CoV-2. Additionally, all patients in the affected ward and patients in other wards who were identified as close contacts of the confirmed cases were quarantined in isolation rooms within the hospital to facilitate their continued inpatient care.

Staff and visitors who were close contacts were identified and placed on quarantine by the MOH. Close contacts were defined as individuals exposed to confirmed cases within a 2-m distance during their infectious period for a cumulative duration of 15 minutes or more. As an added precaution, MOH quarantined staff who had spent a cumulative duration of 15 minutes or more

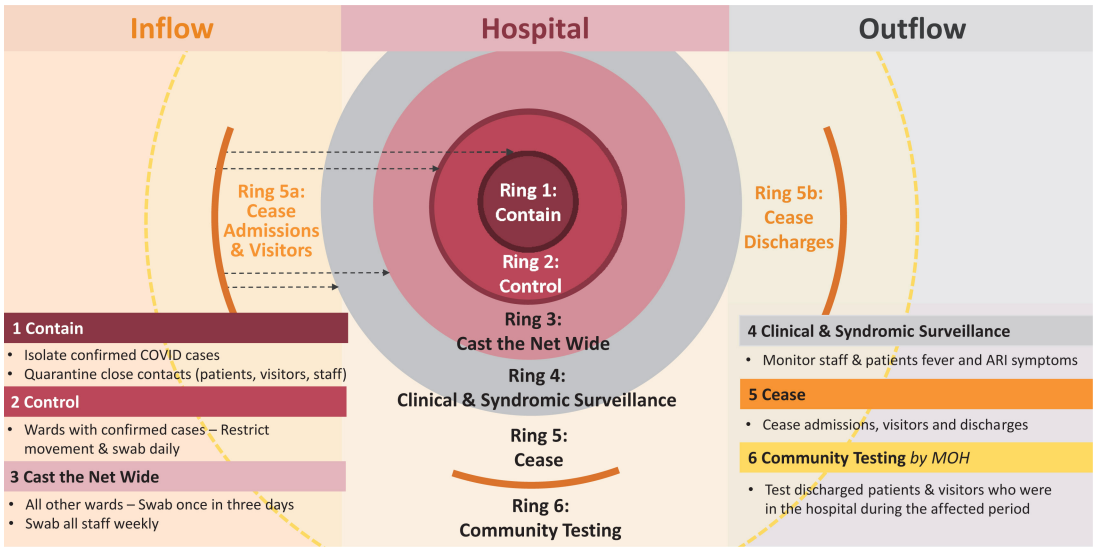

Figure 1: Containment rings for elimination of the risk of spread.

in the affected ward over the 10 days when the primary case was lodged in the ward, even though they may not have been within 2 m of a positive case. Contact tracing leveraged existing hospital clinical epidemiological capabilities (such as detailed interviews for activity mapping and data extraction from patient and visitor registration systems and electronic medical records) and was augmented by the national digital contact tracing application, TraceTogether.

To mitigate the risk of possible transmission from transient contacts, Containment Ring 2 was set up to control patient movement in wards where a positive COVID-19 case had been detected. While the confirmed COVID-19 positive case was immediately isolated and close contacts quarantined, other patients in these wards were kept in situ with no movement in or out, except for specific clinical indications that required urgent need of care. Patients in these wards underwent daily nasal and throat swabs for the COVID-19 PCR test for 14 days. The PPE of staff working in these wards was stepped up from surgical masks to full PPE (N95 respirator, eye protection, gloves and gown) as a precautionary measure.

Considering the possibility of asymptomatic SARS-CoV-2 transmissions, case detection was then cast to a wider population. In Containment Ring 3, swab testing for SARS-CoV-2 for all remaining inpatients was performed once in three days and weekly for all staff and external vendors deployed within the hospital grounds. Approximately 12,000 staff were tested for SARS-CoV-2. The PPE for staff working in all other wards was stepped up from surgical mask to N95 respirator with eye protection.

Containment Ring 4 focused on clinical and syndromic surveillance, where patients and staff were monitored for ARI symptoms and fever. Patients' temperatures were monitored via remote automated technological systems while all staff logged their temperature twice daily onto the S3 platform. Enhanced vigilance was maintained to ensure that staff with ARI symptoms seek medical consultation immediately, report to their supervisors and record their medical consult information onto S3.[14]

Admissions to inpatient wards, ward visits and discharges to intermediate and long-term care (ILTC) facilities were stopped. Patients who were medically fit for discharge but who required further quarantine were transferred to the government's quarantine facility. These measures formed Containment Ring 5. MOH also suspended emergency ambulance conveyance to the hospital for two weeks. Ceasing admissions would prevent the introduction of new patients who would mix with inflight patients; this ensured that the hospital could focus on its containment of the cluster. Given ongoing community transmission, this also reduced the risk of introducing new undiagnosed cases that would confound the containment efforts. To prevent inadvertent transmission to the vulnerable elderly population in nursing homes, the hospital delayed discharges to ILTC facilities until after two incubation periods. In Containment Ring 6, MOH conducted community-based testing of 10,000 individuals who had visited the hospital during the probable transmission period.

SEGREGATION STRATEGY

The hospital campus was zoned to reduce staff and patient movement and avoid mixing among groups of staff and patients. For patient care, the hospital operated in four zones — isolation zone, ward zone, emergency department (ED) zone and specialist outpatient clinic (SOC) zone (Figure 2).

NCID and the isolation zone catered to the isolation of confirmed cases and hospital quarantine of inpatients who were close contacts. The ward zone saw the strictest segregation within and confinement from other zones. The hospital operated

Figure 2: Hospital segregated zones.

four categories of wards for patient cohorting and titration of containment measures — hot, cold, transit and clean. In the ward zone, infection control measures were enhanced and environmental cleaning intensified. Terminal cleaning with enhanced disinfection using hydrogen peroxide vapour or ultraviolet light were performed where confirmed cases were detected.

Hot wards were part of Containment Ring 2 with strict policies to limit any transfer out except for escalation to high dependency or intensive care. Cold wards accommodated low-risk patients who were in-flight during the period of transmission but who had no known exposure to any reported cases or had not been in a ward with confirmed cases detected. The cold wards were part of Containment Ring 3. A category of transit wards was created for patients coming out of intensive care unit or high-dependency rooms during the period of possible transmission; these patients were transferred to transit wards once their conditions had stabilised to minimise the risk of acquiring COVID-19 in the general wards.

Clean wards were set up for new admissions during this period. The ED remained accessible for walk-in patients, and those who required admission were cohorted in clean wards within the ED zone that were previously used as short-stay wards. Non-urgent electives and clinic appointments were rescheduled, and the SOC zone saw to urgent appointments with a segregated clinical team during this period.

RESET STRATEGY

The reset strategy sets up a logical and staged approach to resume and normalise ward operations. A colour-coded framework, aligned with the demarcation of ward zones, illustrates the transitions from the onset of the hospital cluster to the elimination of SARS-CoV-2 transmission (Figure 3).

The hospital reset was conducted over three phases, and 14-day periods were used to frame the transitions. This was based on the known maximum incubation period of COVID-19 infections.[15–17] To transit between phases, there had to be no new

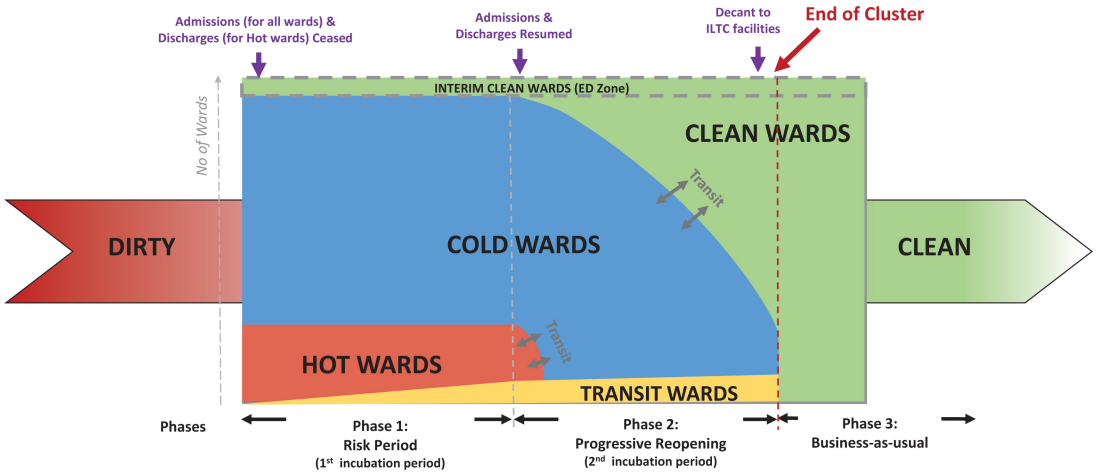

Figure 3: Reset the hospital to reopen safely and progressively.

COVID-19 cases in the wards, all patients' nasal and throat swabs had to be tested negative in these 14 days and environmental deep cleaning had to be completed.

Phase 1 denoted the 14-day risk period from the last known case with exposure in the wards, that is the case was not already isolated or quarantined. During Phase 1, there was a mix of hot, cold and transit wards. Admission to the ward zone was stopped. ED short-stay wards were converted to interim clean wards for inpatient admission for a few walk-in patients through ED. At the end of Phase 1, all hot wards transited to cold wards after one incubation period, with no new cases detected on daily swabs and after deep cleaning.

Phase 2 signified the progressive reopening of the wards and preparation on the resumption of ambulance conveyance and therefore an increase in admissions. Cold wards safely transited to clean wards. Window exhaust fans and portable high-efficiency particulate air filter (HEPA) filters were installed during this phase to improve air ventilation in the wards. Manpower constraints had to be balanced as a substantial number of staff were placed on quarantine in this hospital cluster. Transit wards were discussed earlier.

To avoid transmission to the community, discharge algorithms were remodelled to include extended quarantine with active case detection through swabs. Owing to the cessation of discharges to ILTC facilities, there were patients who stayed in the hospital for an extended period. These long stayers were kept within the hospital for at least two full incubation periods to eliminate any concerns of potential transmission.

Tight measures from the earlier containment and segregation strategies have effectively prevented the hospital cluster from uncontrollable spread. This resulted in the smooth transition to Phase 3, where business-as-usual services were resumed in about a month since the discovery of the hospital cluster.

IMPORTANT INSIGHTS FROM THE HOSPITAL CLUSTER

Singapore continued to experience an increase in community COVID-19 cases as the hospital emerged from the cluster. As a learning organisation, a review process was embarked on, which yielded two important insights to prevent and to prepare for future occurrences as described next.

STRENGTHENING THE HOSPITAL'S LINES OF DEFENCE TO PREVENT ANY REPEAT HOSPITAL CLUSTERS

It was important that lines of defence be strengthened to prevent a cluster forming from within while a strong hospital outbreak response plan was maintained. These post-cluster measures were adopted from the response strategies and classified into three principles —test, monitor and protect.

Test

Active case detection for staff and patients is stepped up. Rostered routine testing (RRT) using nasal and throat swabs for staff will be conducted fortnightly. Newly admitted patients will be swabbed on admission, on Day 4 of admission and subsequently at regular weekly intervals. These added defences reduce the risk of unknown cases who may still be in incubation or are asymptomatic.

Monitor

As part of enhanced surveillance, inpatients and staff with fever or ARI symptoms will be swabbed. The early reporting by staff allowed prompt diagnosis in this cluster. This showed that enhanced syndromic surveillance was critical. When two or more patients within the same cubicle develop ARI symptoms, they will be flagged up for investigation by the infection control and epidemiology teams. Similarly, investigations will be promptly conducted if there are three or more staff from the same working area who are symptomatic within a period of four days.

Protect

Protection of all staff, patients and visitors remains the chief priority. About 85 per cent of TTSH staff have been vaccinated and continuous efforts are ongoing to encourage the remaining staff to do so. Infection control measures will remain augmented post-hospital cluster as staff previously on surgical masks continue to use N95 respirators and eye protection for all clinical duties during Singapore's heightened alert period and given the emergence of new variants.

There had been published reports on the role of aerosols in SARS-CoV-2 transmission.[18,19] An airflow study conducted in a TTSH general ward has shown that aerosol-based transmission was a contributory factor in an indoor environment (unpublished data). As longer-term studies are under way, ward ventilation has been improved in the interim as described previously.

PREPAREDNESS TO RESPOND FAST AND EFFECTIVELY

Despite the strengthened lines of defence, the hospital must be prepared if defences are breached by SARS-CoV-2. TTSH coordinates response measures through an integrated outbreak coordinating platform with collective leadership across the hospital and real-time data for important decision-making and coordination. The hospital's preparedness protocol can be categorised into 3Cs: contingency, communications and care.

Contingency

The hospital's outbreak contingency plan has been refined to strengthen the containment strategy. A hot ward activation protocol will be developed so that it can be activated in short notice to contain any COVID-19 cases detected among inpatients or staff. This will quickly eliminate onward transmission to other areas. The rings of containment strategies would then be built as additional layers of containment, followed by the full segregation plans restricting patient and staff movement across the hospital's settings.

Maintaining quality of care remains a priority. Coupled with the existing robust quality framework, resources such as manpower and bed occupancy rate, when regularly tracked, serve as important indicators to activate load balancing to prevent compromised care. As part of the contingency plan, three such approaches were taken by the hospital. Diversion of ambulances to other hospitals, shift in modality towards telemedicine and triaging of selected patients with stable conditions to community hospitals and nursing homes. Strong collaborations with downstream partners enabled a smooth flow of patients and seamless care despite the hectic changes that were required.

Communication

Clear, transparent and timely communication to staff and patients is important in the hospital's response. Updates should be regular and timely, even though there may be incomplete information. All essential updates and policies are hosted on the hospital's intranet as a single source of truth, preventing circulation of outdated and misinformation. During this hospital cluster, regular staff bulletins were disseminated via email and social media platforms. Senior management held engagement sessions through virtual town hall sessions to address concerns and clarifications. A COVID-19 chat bot was deployed to address common staff queries.

Care

Caring for the health and well-being of inflight patients and staff enabled responses to be sustained during this COVID-19 hospital cluster. Daily updates through posters and dedicated video calls helped family members and loved ones remain connected to patients. Each patient also received an activity planner to encourage them to focus on the events throughout the day.

For hospital staff, mindfulness lunch sessions and exercise classes were conducted online for self-care. Special arrangements with e-services were established for transport and essential needs. Welfare officers were in place in each department to support morale. This was complemented by a chatbot for staff mental well-being and a staff-support-staff programme.

CONCLUSION

The response strategies in managing a hospital cluster during the COVID-19 pandemic is, in essence, managing a crisis within a crisis. It is akin to fighting the enemy from within and from the community simultaneously. Implementing strategies of early detection and containment of COVID-19 cases remains challenging in fighting a viral epidemic that has a variable range of incubation periods, asymptomatic transmission, atypical presentations as well as new variants emerging. Hence, the hospital strengthened lines of defence to test regularly, monitor continuously and protect always. Despite the best defence, hospitals must be prepared to respond if a case is detected from within. The strategies deployed and lessons learned through this cluster have reinforced the hospital's preparedness and resilience. While these strategies were largely contextualised to Singapore, the broad concepts remain relevant to any acute hospital managing an outbreak cluster from within as it seeks to emerge safely and progressively.

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References

1. WHO. (2021) 'WHO Coronavirus (COVID-19) dashboard with vaccination data', available at: https://covid19.who.int/ (accessed 23rd September, 2021).
2. Hu, B., Guo, H., Zhou, P., et al. (2021) 'Characteristics of SARS-CoV-2 and COVID-19', *Nature Reviews Microbiology*, Vol. 19, pp. 141–154.
3. Oran, D. P., Topol, E. J. (2021) 'The proportion of SARS-CoV-2 infections that are asymptomatic: A systematic review', *Annals of Internal Medicine*, Vol. 174, No. 5, pp. 655–662.
4. Wei, W. E., Li, Z., Chiew, C. J., et al. (2020) 'Presymptomatic transmission of SARS-CoV-2 — Singapore, January 23–March 16, 2020', *MMWR Morbidity and Mortality Weekly Report,* Vol. 69, No. 14, pp. 411–415. https://www.cdc.gov/mmwr/volumes/69/wr/mm6914e1.htm (accessed 12th May, 2021).
5. WHO. (2021) 'Tracking SARS-CoV-2 variants', available at: https://www.who.int/en/activities/tracking-SARS-CoV-2-variants/ (accessed 11th June, 2021).
6. Ng, Y., Li, Z., Chua, Y. X., Chaw, W. L., et.al. (2020) 'Evaluation of the effectiveness of surveillance and containment measures for the first 100 patients with COVID-19 in Singapore — January 2–February 29, 2020', *MMWR Morbidity and Mortality Weekly Report,* Vol. 69, No. 11, pp. 307–311. https://www.cdc.gov/mmwr/volumes/69/wr /mm6911e1.htm (assessed 17th June, 2021).
7. Team TraceTogether. (2021) 'How does Trace Together work?', available at: https://support.tracetogether.gov.sg/hc/en-sg/articles/360043543473-How-does-TraceTogether-work (accessed 12th May, 2021).
8. Abdullah, W. J., Kim, S. (2020) 'Singapore's responses to the COVID-19 outbreak: A critical assessment', *American Review of Public Administration*, Vol. 50, No. 6–7, pp. 770–776. https://doi.org/10.1177/0275074020942454 (accessed 18th May, 2021).
9. Ministry of Health. (2021) 'Update on local COVID-19 situation and vaccination progress (30th August 2021)', available at: https://www.moh.gov.sg/news-highlights/details/update-on-local-COVID-19-situation-and-vaccination-progress-(30-august-2021) (accessed 25th October, 2021).
10. Ministry of Health. (n.d.) 'Health facilities', available at: https://www.moh.gov.sg/resources-statistics/singapore-health-facts/health-facilities (accessed 19th October, 2021).
11. Ministry of Health. (n.d.) 'Hospital services', available at: https://www.moh.gov.sg/home/our-healthcare-system/healthcare-services-and-facilities/hospital-services (accessed 19th October, 2021).
12. Ministry of Health. (n.d.) 'Admissions and outpatient attendances', available at: https://www.moh.gov.sg/resources-statistics/singapore-health-facts/admissions-and-outpatient-attendances (accessed 19th October, 2021).
13. Htun, H. L., Lim, D. W., Kyaw, W. M., et.al. (2020) 'Responding to the COVID-19 outbreak in Singapore: Staff protection and staff temperature and sickness surveillance systems', *Clinical Infectious Diseases*, Vol. 71, No. 8, pp. 1947–1952. https://pubmed.ncbi.nlm.nih.gov/32315026/ (accessed 18th May, 2021).
14. *Ibid.,* ref. 13 above.
15. Elias, C., Sekri, A., Leblanc, P., et.al. (2021) 'The incubation period of COVID-19: A meta-analysis', *International Journal of Infectious Diseases*, Vol. 104, pp. 708–710.
16. Center for Disease Control and Prevention. (2021) 'Interim clinical guidance for management of patients with confirmed coronavirus disease (COVID-19)', available at: https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-guidance-management-patients.html (accessed 20th May, 2021).
17. WHO. (2020) 'Transmission of SARS-CoV-2: Implications for infection prevention precautions', available at: https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions (accessed 12th May, 2021).
18. CDC. (2021) 'Scientific brief: SARS-CoV-2 transmission', available at: https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/sars-cov-2-transmission.html (accessed 10th June, 2021).
19. Tang, J. W., Marr, L. C., Li, Y., et al. (2021) 'COVID-19 has redefined airborne transmission', *BMJ*, Vol. 373, p. n913.