The 2003 SARS Outbreak In Singapore: Epidemiological and Clinical Features, Containment Measures, and Lessons Learned

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The Evolution of the SARS Outbreak in Singapore

The Beginning of the Outbreak at Tan Tock Seng Hospital

On 6 March 2003, the Singapore Ministry of Health was notified of a cluster of atypical pneumonia in three patients with a history of travel to Hong Kong (Hsu et al., 2003). These three female travelers had stayed at the Metropole Hotel on the same floor as a Chinese physician later diagnosed with severe acute respiratory syndrome (SARS) (Hsu et al., 2003; Peiris et al., 2003). After returning to Singapore, one of the travelers (index A) who developed fever on February 25 was hospitalized at Tan Tock Seng Hospital on March 1, and was managed initially for straightforward community-acquired pneumonia. The other two travelers were also admitted with similar symptoms. Shortly thereafter, clusters of cases emerged in three separate wards, all traceable to the first imported case. By the time index A was isolated on March 6, she had already infected 22 persons, comprising ten health care workers, two inpatients, seven visitors, and three family members. One of the infected health care workers (index case B), with onset of symptoms on March 7 and a provisional diagnosis of dengue fever, was later admitted on March 10 to Ward 8A. At the ward she in turn infected 21 persons, including an inpatient with ischemic heart disease and diabetes mellitus, before she was isolated on March 13 (Wilder-Smith et al., 2004b). The inpatient (index case C) had been admitted on March 10 with fever, community-acquired pneumonia, and gram-negative bacteremia. When she developed heart failure on March 12, she was transferred to Ward 6A (the coronary care unit) and mechanically ventilated. However, she was isolated only on March 20 when SARS was suspected. By that time, 21 health care workers and 5 family members had become infected (Wilder-Smith et al., 2004b). A total of 109 cases were epidemiologically linked to index A. Intra-hospital transmission at Tan Tock Seng Hospital was interrupted by April 12, the date of onset of the hospital's last case. Despite the institution of very rigorous infection control measures at Tan Tock Seng Hospital, SARS spread to four other health care institutions (Singapore General Hospital, National University Hospital, Changi General Hospital, and Orange Nursing Home – the last two are
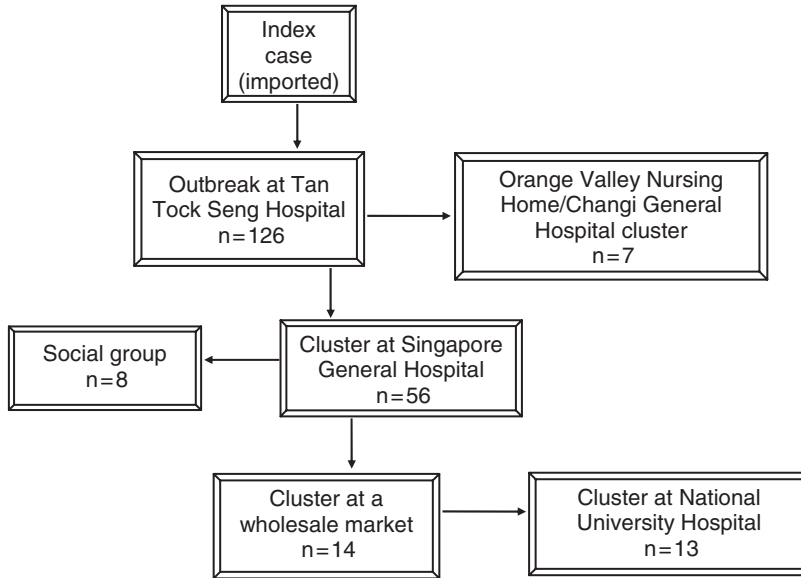
Fig. 1 Inter-hospital and community spread of the SARS outbreak in Singapore in 2003

grouped together in Fig. 1 and a vegetable wholesale market (Gopalakrishna et al., 2004) (Fig. 1).

Spread to Singapore General Hospital

Index case D was a 60-year-old ex-patient of Tan Tock Seng Hospital with multiple medical problems, including ischemic heart disease and diabetes mellitus with kidney damage. He was admitted on March 5 to Tan Tock Seng Ward 5A (the same ward as index case A) and discharged on March 20 with no clinical manifestations of SARS. He was later admitted to an open ward (Ward 57) at Singapore General Hospital on March 24 for steroid-induced gastrointestinal bleeding and a diabetic foot ulcer (Chow et al., 2004). Although he had a low-grade fever on March 26, four consecutive chest X-rays were normal. His blood culture grew *E. coli* (Tan et al., 2004). He was transferred to another open ward (Ward 58) where he stayed from March 29 to April 2. On April 4, a cluster of 13 febrile health care workers from the two wards he had occupied was identified. It was only on April 5 when chest X-ray showed evidence of pneumonia that he was clinically diagnosed as a probable SARS case. A total 40 cases were directly linked to him, with the date of onset of the last probable case on April 17. All the exposed health care workers and inpatients were transferred to Tan Tock Seng Hospital, where eight subsequently developed probable SARS.

Outbreak at National University Hospital

Index case E at National University Hospital was a 63-year-old man with a history of hypertension, ischemic heart disease, and chronic atrial fibrillation. He was infected with SARS when he visited his brother, index case D, at Singapore General Hospital on March 31. He developed a fever on April 5, was seen at the National University Hospital Accident and Emergency Department on April 8, and was admitted 4 h later to an open ward for cardiac failure (Fisher et al., 2003b; Ooi and Tambyah, 2004). When his condition deteriorated rapidly over the next 8 h, he was isolated in the intensive care unit (ICU). As soon as SARS was suspected, the patient was immediately transferred to Tan Tock Seng Hospital where he died on April 12. A total of 13 SARS cases at National University Hospital were epidemiologically linked to him, with the date of onset of the last case on April 25.

Outbreak at Orange Valley Nursing Home/Changi General Hospital

A 90-year-old woman (index case F) with pneumonia and a urinary tract infection who had been warded next to a SARS patient in Ward 7D at Tan Tock Seng Hospital from March 16–17 was discharged to a private nursing home (Orange Valley Nursing Home) and then admitted to Changi General Hospital on March 25 when she fell ill again with breathing difficulty (Tee et al., 2004). This led to a small cluster of seven cases linked to the nursing home and Changi General Hospital. The dates of onset of the last cases at the nursing home and Changi General Hospital were April 2 and April 4, respectively.

Community Outbreaks

Index case E at National University Hospital worked as a vegetable seller at the Pasir Panjang wholesale market. He worked there for a few hours each day on April 5, 7, and 8. It was only on April 19 that two additional SARS cases (a taxi driver who transported index E to work and another worker at the market) were epidemiologically linked to the market. Index E started a cluster of 14 cases, including eight in a family linked to the market. Another cluster of eight cases in the community was started by a febrile health care worker (index case G) at Singapore General Hospital who was given medical leave to stay at home. Transmission occurred through social contact in a Chinese card game.

There were two local cases whose sources of infection could not be determined despite intensive epidemiological investigations. Three of 32 probable cases retrospectively diagnosed to have SARS could not be linked to any of the clusters.

Summary of Epidemiological Features

The SARS outbreak in Singapore was mainly perpetuated in seven clusters related
to five index cases, with a fireworks-like pattern of spread (Fig. 2). A total of 206
probable SARS cases, including eight imported cases, with illness onset dates
between 25 February and 11 May 2003 were reported. Of these, 58 cases were
detected among 12,194 persons that had previously been on home quarantine
(7,863) or telephone surveillance (4,331). Of 600 clinically suspected cases who
were admitted to Tan Tock Seng Hospital and had laboratory tests conducted during
the post-outbreak period, an additional 32 probable cases were picked up, for a final
figure of 238 probable cases, including 33 deaths. None of the 700 patients admitted
for observation tested positive.

   The demographic characteristics of the reported cases and deaths are shown in
Table 1. The majority (79.4%) were Singaporeans, and 67.6% were females. About
half (46.6%) of the cases were in the 25–44-year-old age group. The ethnic distribu-
tion among the Singaporean cases was proportionate to that of the population of
Singapore. Health care workers constituted 40.8%; family members, friends, social
contacts, and visitors, 37.4%; and inpatients, 13%. Transmission within health care
and household settings accounted for over 90% of the cases.

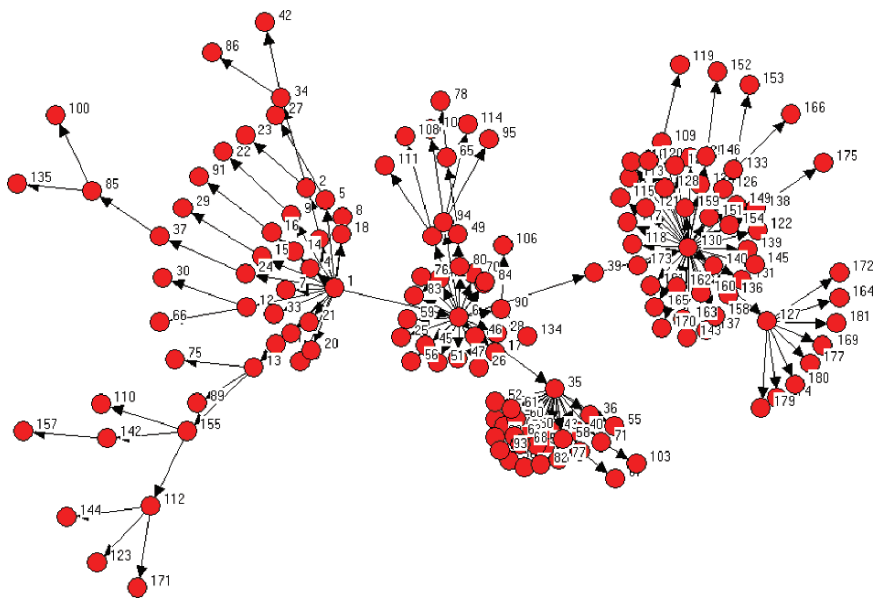   The epidemic curve of the SARS outbreak is shown in Fig. 3.

Fig. 2 The "fireworks effect" of several clusters related to five index cases in Singapore (Centers
for Disease Control and Prevention, 2003)

Table 1 Demographic characteristics of the 238 SARS cases in Singapore, March–May 2003

| Characteristics | Number of Cases (Deaths) | | | |
	Male	Female	Total	%
Age group (yrs)				
0–4	2 (0)	3 (0)	5 (0)	2.1
5–14	0 (0)	5 (0)	5 (0)	2.1
15–24	8 (1)	29 (0)	37 (1)	15.5
25–34	13 (2)	53 (2)	66 (4)	27.7
35–44	21 (4)	24 (1)	45 (5)	18.9
45–54	11 (2)	22 (5)	33 (7)	13.9
55–64	11 (4)	14 (2)	25 (6)	10.5
65+	11 (6)	11 (4)	22 (10)	9.2
Nationality				
Singaporean	66 (14)	123 (17)	189 (31)	79.4
Filipino	5 (0)	17 (1)	22 (1)	9.2
Chinese	3 (0)	7 (0)	10 (0)	4.2
Indonesian	1 (0)	6 (0)	7 (0)	2.9
Malaysian	1 (0)	4 (0)	5 (0)	2.1
Indian	1 (0)	3 (0)	4 (0)	1.7
Sri Lankan	0 (0)	1 (0)	1 (0)	0.4
Ethnic group (among 189 Singaporeans)				
Chinese	53 (9)	85 (15)	138 (24)	73.0
Malay	21 (0)	4 (3)	25 (3)	13.2
Indian	14 (2)	8 (2)	22 (4)	11.6
Other	3 (0)	1 (0)	4 (0)	2.1
Occupational group				
Health care workers	13 (3)	84 (2)	97 (5)	40.8
Nonhealth care workers[a]	64 (16)	77 (12)	141 (28)	59.2
Source of infection				
Imported	1 (0)	7 (1)	8 (1)	3.4
Healthcare institution	50 (16)	125 (8)	175 (24)	73.5
Household	17 (1)	24 (5)	41 (6)	17.2
Community/Workplace[b]	6 (2)	2 (0)	8 (2)	3.4
Undefined	3 (0)	3 (0)	6 (0)	2.5
Total	77 (14)	161 (19)	238 (33)	238 (33)

[a] Family members, friends or visitors (37.4%), inpatients (13%), others (8.8%)
[b] wholesale market (3), taxi (3), and airplane (1)

The last probable SARS patient, whose illness began on May 5, was isolated at Tan Tock Seng Hospital on May 11. The World Health Organization (WHO) removed Singapore from its list of areas with local SARS transmission on May 31. However, intensive case-finding efforts continued, particularly among patients with chronic medical conditions and with atypical clinical presentation. They were repeatedly tested for SARS-associated coronavirus (SARS-CoV) prior to discharge from the hospital. In view of the improved situation globally and locally, SARS prevention and control measures were progressively stepped down beginning in mid-July 2003. Unfortunately, a laboratory-acquired case of SARS was diagnosed at Singapore General Hospital on 8 September 2003 (Lim et al., 2004).
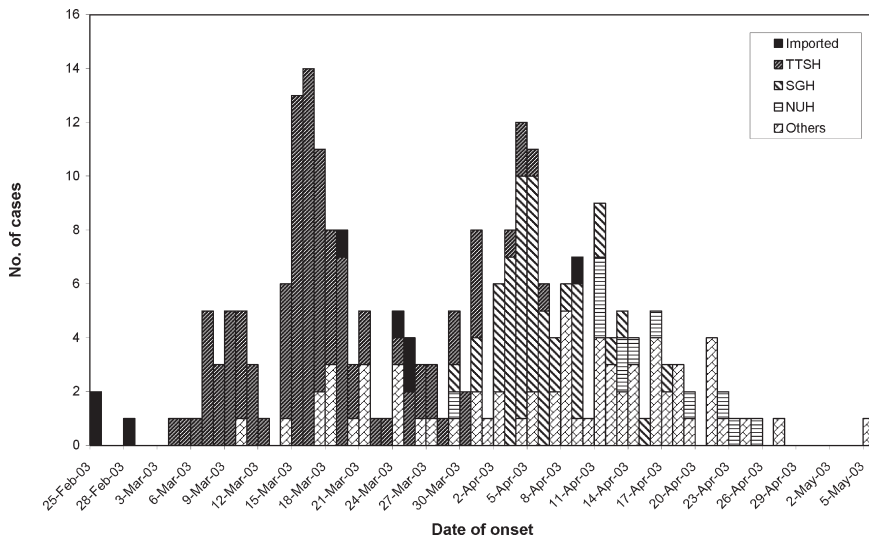
Fig. 3 Epidemic Curve of the SARS outbreak in Singapore in 2003

Laboratory-Acquired SARS Case

The patient with laboratory-acquired SARS was a 27-year-old Chinese Singaporean in his third year of a doctoral program in microbiology at the National University of Singapore. He was working on the West Nile virus at a University microbiology laboratory. He also did some work at the Environmental Health Institute (EHI) laboratory of the National Environment Agency; he last visited this laboratory on August 23. He had no history of travel to SARS-affected areas and no known contact with SARS patients. The date of onset of his illness was August 26. When he was admitted to Singapore General Hospital on September 3, he complained of fever, muscle aches, and joint pains, but he did not have any significant respiratory symptoms. He developed a dry cough after admission, but his fever resolved 2 days later. Three serial chest X-rays done at Singapore General Hospital were all normal. On September 8, his stool and sputum specimens tested positive for SARS-CoV by reverse-transcriptase polymerase chain reaction (RT-PCR). Three serial serological tests done on September 3, 4, and 8 showed a rising titer of SARS-CoV antibodies. He was immediately transferred to the Communicable Disease Centre at Tan Tock Seng Hospital for further management.

A repeat of his PCR tests in two other laboratories in Singapore on September 9 confirmed positive results. Blood samples also tested positive for antibodies to SARS-CoV in another laboratory in Singapore. Results from the Centers for Disease Control, Atlanta, corroborated Singapore's PCR and serological results.

Subsequent investigations of the chest on September 13 showed that he had radiological evidence of pneumonic changes in his left lung. Tests for a whole range of other pathogens, including two human coronaviruses (OC 43 and 229 E), were negative. The patient was discharged on September 16 and placed on a 14-day home quarantine.

Investigations by an 11-member review panel, comprising local and international experts, revealed that the patient worked in the EHI laboratory 3.5 days prior to the onset of his illness. Although the patient reported only working with West Nile virus, the laboratory was doing live SARS-CoV work around that time. Poor record keeping made it difficult to ascertain whether there was live SARS-CoV in the laboratory on the day of his visit, but it was there 2 days before. The frozen specimen that the patient worked with on August 23 was positive by RT-PCR for the SARS-CoV and West Nile virus, suggesting contamination. As the laboratory had only worked on one strain of the SARS-CoV, the laboratory strain and the patient strain were sequenced for comparison. Approximately 91% of the genome was sequenced from the patient's strain and found to be most closely related to the sequence of the laboratory strain. Minor differences were likely the result of natural mutations of the virus (Lim et al., 2004).

Clinical Features of SARS

The clinical and radiological manifestations of SARS in Singapore were consistent with those reported elsewhere (Hsu et al., 2003; Lee et al., 2003; Poutanen et al., 2003). The median incubation period was determined based on the records of 50 SARS cases who, prior to onset of illness, had a single and specific close contact history with another person who had been diagnosed with probable SARS. Of the 50 cases reviewed, 15 were hospital visitors, 20 were health care workers, and 15 were family and social contacts. The median age of the cases was 42 years (range 22–84 years) and 56% were females. The mean (standard deviation) and median incubation periods were estimated to be 5.1 (2.2) and 5 days, respectively. The 95th percentile for the incubation period was 9 days. None of the 50 cases studied had an incubation period longer than 10 days. (Kuk and Ma, 2005).

In the Singapore cohort, the case-fatality rate increased with age from 2.7% in the 15–24-year age group to 45.5% in those 65 years and older. The overall case-fatality rate was 13.9% (33/238). The median days from symptom onset to ICU admission was 8 days (range 6–10); the median length of hospital stay was 23.5 days (range 15–36); and the median length of stay in the ICU was 14.5 days (range 7–22) (Tai et al., 2003). Among SARS patients, 20.2% required ICU care. Predictors for ICU admission were comorbidities (especially diabetes mellitus and heart disease), advanced age, peaked lactate dehydrogenase, and high absolute neutrophil counts (Tai et al., 2003).

The WHO case definition for SARS was revised on 1 May 2003 after laboratory tests for SARS-CoV became available. Locally validated assays for SARS-CoV by

RT-PCR (available as of the first week of April) and serology (available as of the first week of May) were used for all suspected and probable cases as well as for cases under observation in whom SARS could not be excluded.

We conducted a seroepidemiological cohort study amongst 80 health care workers exposed to SARS patients prior to the implementation of infection control measures (Wilder-Smith et al., 2005). Of these, 45 (56%) were SARS-positive by serology. Of these 45, 37 (82%) were classified as having pneumonic SARS, 2 (4%) as subclinical SARS, and 6 (13%) as having asymptomatic SARS-CoV infection. The overall incidence of asymptomatic SARS-CoV infection was 7.5% (6 out of 80), and was higher than that reported elsewhere. This was most likely due to the fact that this cohort had unprotected exposure. The median titer of SARS antibodies was 1:6,400 (range 1:1,600–1:6,400) for pneumonic SARS, 1:4,000 (range 1:1,600–1:6,400) for subclinical SARS cases, and 1:4,000 (range 1:400–1:6,400) for asymptomatic cases. In univariate analysis, none of the variables for gender, age, use of gloves, hand-washing, index case, distance to index case, or contact time were associated with asymptomatic SARS. However, a higher proportion of those who had asymptomatic SARS (50%) had used masks compared to those who developed pneumonic SARS (8%) ($p = 0.025$). Although the extent to which cases with asymptomatic SARS-CoV infection contributed to the ongoing transmission during the outbreak is unknown, our data from Singapore suggest that they did not constitute a major source of transmission.

The diagnosis of SARS is difficult early in the illness as presentation and laboratory features resemble other nonspecific viral fevers, such as dengue. Dengue fever is endemic in Singapore. One of the index cases was misdiagnosed as having dengue and therefore not isolated, which led to subsequent SARS transmissions. We did a study to identify simple laboratory features to differentiate SARS from dengue (Wilder-Smith et al., 2004a). Multivariate analysis identified three laboratory features that together are highly predictive of a diagnosis of dengue and able to rule out the possibility of SARS: platelet count $<140 \times 10^9$ L^{-1}, white-blood-cell count $<5 \times 10^9$ L^{-1}, and aspartate aminotransferase >34 IU L^{-1} (Wilder-Smith et al., 2004a). The application of the combination of these parameters can identify dengue 75% of the time and rule out SARS 100% of the time. This approach can help to rationalize the use of isolation rooms for patients presenting with nonspecific fever. Dengue PCR is helpful in the early diagnosis of dengue and was used during the SARS outbreak in Singapore.

Containment Measures

Following the WHO's global alert on 12 March 2003, all health care institutions were advised to notify their Health Ministries of every patient who met the WHO's case definition of a suspected or probable case of SARS. Health care institutions were also directed to notify contacts of suspected and probable cases. Prevention and control measures were initiated by the Singapore Ministry of Health (MOH)

SARS Task Force, which was formed on 15 March 2003 and chaired by the Director of Medical Services. Its members included the chief executive officers of all hospitals, chairmen of medical boards, infectious disease physicians, epidemiologists, and virologists. Strategies to contain the rapid nosocomial transmission were discussed, formulated, and effectively implemented across all health care institutions through the Infectious Diseases Act and Private Hospitals and Medical Clinics Act. The Ministerial Committee on SARS (chaired by the Minister for Home Affairs) was established on April 7 to provide political guidance and quickly make strategic decisions to minimize the socioeconomic impacts of SARS. The Executive Group, comprising permanent secretaries of the relevant ministries, was responsible for the overall coordination and implementation of strategies to address multi-agency issues outside the health care setting, while an Inter-Ministry SARS Operations Committee ensured that cross-ministry operational issues on SARS were well coordinated. A Ministerial SARS Combat Unit was also appointed on April 20. This Unit worked closely with public and private hospitals and other health care institutions to prevent and control SARS transmission in these facilities. Key measures implemented in Singapore were directed at the prevention and control of SARS in health care institutions, in the community, and at borders.

Containment of SARS in Health Care Institutions

SARS transmission was quickly established to occur mainly via droplets and contact (Seto et al., 2003). A case–control study done early in the outbreak found that N95 masks and hand washing after each patient contact were independently associated with a significantly decreased risk of infection, with adjusted odds ratios of 0.1 and 0.07, respectively (Teleman et al., 2004). Contact with a patient's nasal secretions before infection control measures were implemented was independently associated with a 22-fold increased risk of infection. Enhanced personal protective measures were progressively instituted in tandem with growing understanding of this novel disease. From March 6, health care workers were employing N95 masks for personal protection when nursing the first index case and her contacts. By the end of week 2, personal protective equipment (PPE) against contact, droplet, and respiratory transmissions had been adopted by health care workers attending to patients in areas involved in SARS screening or treatment (ICU, emergency department, and communicable disease wards). On March 22, Singapore's second largest general hospital, Tan Tock Seng, was designated as the central referral, screening, and treatment center for SARS. The Communicable Disease Centre (which is part of Tan Tock Seng Hospital) is a specialist facility with a national role, staffed by experts in clinical infectious diseases, hospital infection control, and public health. By March 22, N95 masks were required when treating any patient in the hospital. On April 6, the wearing of gloves, gowns, and N95 masks was enforced during contact with all patients in the hospital, with visitors additionally advised for procedures with a risk of splashing. On April 25, goggles were made mandatory

for all patient contact. Later, powered air purifying respirators for high-risk or aerosol-generating procedures were also required. With all of these measures in place, no further intra-hospital transmission to health care workers at Tan Tock Seng occurred after March 22. However, with the new outbreak at Singapore General Hospital, health care workers were affected again. Prompt institution of strict measures in all hospitals nationwide curbed in-hospital transmissions, and the last such case occurred on April 13.

Triage and Surveillance

At the first point of contact with health care facilities (accident and emergency departments and specialist outpatient clinics), triage was carried out to separate febrile patients. To widen the surveillance net, the WHO's definition for suspected and probable SARS was expanded to include any health care worker with fever and/or respiratory symptoms (particularly in a cluster of three or more febrile cases), inpatients (>16 years old) with atypical pneumonia under investigation, sudden unexplained deaths with respiratory symptoms, and inpatients with unexplained fever (>38°C) of more than 72 h who also had relevant travel history. Case-finding was further intensified with the introduction of thrice daily temperature surveillance of all health care workers in every institution and active surveillance for clusters of febrile patients and for staff working in the areas occupied by these patients. Special attention was paid to immunocompromised patients who tended to have atypical clinical presentations. Health care workers' sick leave was centrally monitored. Audits were periodically conducted to ensure that the directives and guidelines issued by MOH were strictly enforced.

Three separate hospital containment strategies were implemented. Tan Tock Seng Hospital was designated as a SARS hospital and non-SARS patients were diverted to other hospitals (Gopalakrishna et al., 2004). The strategy at Singapore General Hospital was ring fencing and transfer of the exposed group (patients and health care workers) to Tan Tock Seng Hospital. At National University Hospital, the strategy was management of the exposed cohort in situ. These containment strategies were supported by strict enforcement of the proper use of PPE (test-fitted N95 masks, gowns, gloves, and goggles/protective eye gear if managing suspicious cases, and powered air purifying respirator for high-risk procedures such as intubation), control of visitors, restriction of movements of health care workers (including being confined to practice at one institution) and patients (readmission to the same hospital if within 21 days after discharge), and close monitoring of discharged patients from SARS-affected wards. In view of the risk posed by atypical SARS cases, all inpatients at Tan Tock Seng and Singapore General Hospitals with chronic medical conditions were placed on home quarantine for 10 days upon discharge.

The Infectious Diseases Act was amended to ensure that all necessary measures were taken to control the outbreak, e.g., handling and disposing of bodies within 24 h after SARS-related death.

Containment of SARS in the Community

Isolation, Contact Tracing, and Quarantine

There was a significant correlation between the length of time taken to isolate a case and the number of secondary cases that arose. A total of 159 cases who did not transmit had a mean time to isolation of 3 days, compared with those with who were isolated after 4–10 days and infected 15–40 secondary cases each. For the prevention and control of SARS within the community in Singapore, the key strategy was to detect persons with suspected or probable SARS as early as possible and isolate them at Tan Tock Seng Hospital. Early identification of SARS cases was achieved in several ways, including active tracing of all contacts within 24 h of notification of a case, mandatory home quarantine enforced through the use of electronic cameras, and intensive education of health care professionals and the public. The effectiveness of these strategies was reflected in the progressive reduction in the time to isolation of cases over the course of the outbreak. During the week of March 3, the average interval between the onset of symptoms and isolation in the hospital was 6.8 days. This interval was reduced to 2.9 days by the week of March 31 and 1.3 days by the week of April 21. Reducing the time to isolation of cases was one of the main contributing factors for interrupting transmission and curbing the outbreak in Singapore.

Contact tracing, initiated within 24 h of notification of a case, was carried out by trained medical and health officers in hospitals, nursing homes and other health care institutions, and the community, including residential homes, places of work or school, hostels, food centers, markets, places of worship, and factories. Following the spread of infection to a wholesale market in April, 200 staff members from the Peoples' Association were mobilized and trained on the spot to trace the large number of contacts. On April 23, 250 army personnel were deployed to the MOH for 2 months to strengthen its operational capability, especially the development of the IT system to support epidemiological investigations, contact tracing, and quarantine operations. Contacts included health care workers who did not wear personal protective gear while attending to a case of SARS, family members, visitors to health care institutions, school teachers, classmates, workplace colleagues, and commuters in close proximity to a SARS case in the public transport system (taxi, bus, train, ship, aeroplane). These contacts were assessed for the likelihood of exposure to SARS. Those who were febrile were immediately transported by a delegated ambulance service to Tan Tock Seng Hospital. Contacts who were apparently well were quarantined for 10 days either at home or at a specific quarantine center where their temperatures were monitored twice daily for early signs of SARS. Any person who developed a fever (>38°C) during the quarantine period was isolated at Tan Tock Seng Hospital for further investigations. As a precautionary measure, contacts assessed to have a low risk of developing SARS (e.g., inpatients with no chronic comorbid conditions discharged from Tan Tock Seng Hospital) were not quarantined but put on daily telephone surveillance for SARS symptoms for 21 days by a team of 100 health staff.

Secondary household transmission of SARS was studied in 114 households involving 417 contacts. The attack rate was low (6.2%) (Goh et al., 2004).

The Pasir Panjang wholesale market was closed for 15 days from April 19, and a total of 2,007 workers and regular visitors to the market from April 5–19 were put on mandatory home quarantine. Teams of nurses visited all those under quarantine to check their temperatures and to ensure that they were well. The infection did not spread to other wet markets.

To allay the concerns of parents, all preschools, primary, and secondary schools were closed for 2–3 weeks from the end of March to early-mid-April 2003.

Containment of SARS at Border Checkpoints

International travel was responsible for the rapid intercontinental spread of SARS. The outbreak in Singapore can be traced to the first imported case. To prevent further importation of SARS, a number of measures were taken at the air- and sea-ports and road entry points into Singapore. As of 30 March 2003, Health Alert Notices were issued to air passengers arriving from affected areas. On March 31 visual screening was instituted for all passengers arriving from SARS affected areas; this measure was replaced by temperature screening a few days later. Passengers who appeared to be unwell or had a temperature of >37.5°C were sent by a special ambulance to Tan Tock Seng Hospital, which had been singly designated to perform SARS screening. From April 7 onward, passengers arriving from SARS-affected countries were asked to complete health declaration cards. The information collected on these cards included recent travel, contact history, and symptoms suggestive of SARS, as well as address in Singapore and flight seat numbers to facilitate contact tracing. On April 23, thermal scanners were installed at Changi Airport and at the road entry points to check temperatures for all departing and arriving passengers. Temperature checks were introduced to all of the Singapore's ferry terminals on April 28. SARS screening was progressively extended to all arriving flights from April 29 onwards.

Of the seven imported cases, which all occurred before screening measures were implemented at the airport, only the first resulted in extensive secondary transmission (Wilder-Smith and Paton, 2003). None of the imported cases resulted in in-flight transmission. Of 442,973 air passengers screened after measures were implemented, 136 were sent to Tan Tock Seng Hospital for further SARS screening; none were diagnosed with SARS (Wilder-Smith and Paton, 2003). After implementation of screening methods, no further importation of patients with SARS occurred (March 31–May 31). The absence of transmission from the other six imported cases was likely a result of their relatively prompt identification and isolation together with a low potential for transmission. New imported SARS cases therefore need not lead to major outbreaks if systems are in place to identify and isolate them early. Screening at entry points is costly, has a low yield, and is not sufficient as a single containment strategy, but may be justified in light of the major economic, social,

and international impact that even a single imported SARS case may have (Wilder-Smith and Paton, 2003).

Between 25 February and 31 May 2003, nine passengers who were later diagnosed as suffering from probable SARS (based on the WHO criteria) arrived in Singapore on seven flights: three were from Hong Kong (with five cases of SARS), one from Beijing, one from New York, one from East Malaysia, and one from Indonesia. Six of the nine travelers imported SARS to Singapore (from Hong Kong and Beijing) and three had acquired SARS in Singapore and were returning to Singapore (from New York, East Malaysia, and Indonesia) (Wilder-Smith et al., 2003b). However, only three of the airplanes (carrying four of the passengers with probable SARS) had symptomatic cases of SARS on board; the passengers of the other flights developed symptoms within the first 2 days after arrival in Singapore (Wilder-Smith et al., 2003b). In-flight transmission occurred in only one of the three airplanes with symptomatic SARS patients on board. This transmission was to only one person, a stewardess who had served and cleaned the tray of the passenger with SARS on the flight from New York to Singapore via Frankfurt (March 14) (Wilder-Smith et al., 2003a). The passenger was a doctor who had treated the first admitted case of SARS in Singapore at a time when the new disease had not yet been identified and no infection control measures were in place. At disembarkation, the passengers were briefed on the symptoms of SARS and advised to seek prompt health care should they develop symptoms. None of the 82 passengers who disembarked in Frankfurt, or the 28 who disembarked in Singapore developed SARS. Very stringent steps were taken to minimize the possibility of exporting cases to other countries. These measures included rapid containment of outbreaks in Singapore, and mandatory temperature screening of all outgoing travelers from Singapore. In addition, special bilateral arrangements on the exchange of information necessary to conduct contact tracing and quarantine was set up with both Malaysia and Indonesia. Singapore also initiated a similar multilateral agreement among the ten member countries of the Association of Southeast Asian Nations plus China, Japan, and the Republic of Korea (ASEAN + 3) in view of the possible spread of infection by travelers.

SARS and the Public

During the outbreak of SARS in Singapore from 1 March to 11 May 2003, various measures were undertaken at the national level to control and eliminate the transmission of the infection. During the initial period of the epidemic, communication with the public was achieved through press releases and media coverage of the epidemic. About a month into the epidemic, a public education campaign was mounted to educate Singaporeans on SARS and the adoption of appropriate social behavior to prevent the spread of the disease. Rigorous preventive measures were implemented by various ministries. For example, the Ministry of Education issued a personal thermometer to every student, taught students about SARS and how to

check their temperatures, and required students and staff to declare their travel history. Standard operating procedures for screening children at child-care centers and kindergartens were implemented. The Ministry of Defense conducted daily screening of all recruits and national servicemen who were undergoing in-camp training, and issued personal thermometers to all personnel, including the Singapore Armed Forces. The Ministry of Environment checked sewerage systems and required environmental workers and market stallholders to take their temperatures twice a day. The government of Singapore disseminated information on SARS and encouraged the general public to adopt good health practices, such as measuring body temperature and restraining "socially irresponsible habits," such as spitting in public. During the SARS outbreak in Singapore, "fighting SARS" as a "shared responsibility" was a central message. Prime Minister Goh's open letter in the front page of the Singapore main newspaper (Straits Times) urged all Singaporeans to practice social responsibility and civic consciousness in order to be "good citizens." Singaporeans were also urged to give health care workers on the front line battling SARS their utmost support and not ostracize them. Contributions to the SARS Courage Fund, in aid of health care workers and victims of SARS exceeded US$10 million by the end of May 2003. A survey was conducted in late April 2003 to assess Singaporeans' knowledge of SARS and infection control measures, and their concerns and anxiety in relation to the outbreak (Deurenberg-Yap et al., 2005). The survey also sought to assess their confidence in the ability of various institutions to deal with SARS and their opinion on the seemingly tough measures enforced. The study involved 853 adults selected from a telephone-sampling frame. Stratified sampling was used to ensure adequate representation from major ethnic groups and age groups. The study showed that the overall knowledge of SARS and control measures undertaken was low (mean score of 24.5% ± 8.9%). While 82% of respondents expressed confidence in measures undertaken by Tan Tock Seng Hospital (the hospital designated to manage SARS), only 36% had confidence in nursing homes. However, >80% of the public agreed that the preventive and control measures instituted were appropriate. Despite the low knowledge score, the score for overall mean satisfaction with the government's response to SARS was 4.47 (out of a possible highest score of 5.00), with >93% of adult Singaporeans indicating that they were satisfied or very satisfied with the government's response to SARS. Generally, Singaporeans had a high level of public trust (satisfaction with the government, confidence in institutions, and agreement that government measures were appropriate), scoring 11.4 out of a possible maximum of 14. The disparity between low scores for knowledge and high scores for confidence and trust in the government's actions suggests that Singaporeans do not require high levels of knowledge to be confident in measures undertaken by the government to control the SARS crisis (Deurenberg-Yap et al., 2005).

A cross-sectional telephone survey of 1,201 Singaporean adults and 705 adults from Hong Kong compared the public's knowledge and perception of SARS and the extent to which various precautionary measures were adopted (Leung et al., 2004). The results showed that respondents from Hong Kong had significantly more anxiety about SARS than Singaporean respondents [State Trait Anxiety

Inventory (STAI) score, 2.06 vs. 1.77; $p < 0.001$]. The former group also reported more frequent headaches, difficulty in breathing, dizziness, rhinorrhea, and sore throat. More than 90% of respondents in both places were willing to be quarantined if they had close contact with a SARS case, and 70% or more would comply with quarantine following a social contact. Most respondents (86.7% in Hong Kong vs. 71.4% in Singapore; $p < 0.001$) knew that SARS could be transmitted via respiratory droplets, although fewer (75.8% in Hong Kong vs. 62.1% in Singapore; $p < 0.001$) knew that fomites were also a possible transmission source. Twenty-three percent of respondents in Hong Kong and 11.9% of those in Singapore believed that they were "very likely" or "somewhat likely" to contract SARS during the outbreak ($p < 0.001$). There were large differences between respondents in Hong Kong and Singapore in the adoption of personal precautionary measures. Respondents with higher levels of anxiety, better knowledge of SARS, and greater risk perceptions were more likely to take comprehensive precautionary measures against the infection, as were older, female, and more educated individuals (Leung et al., 2004).

Lessons Learned from the SARS Outbreak in Singapore

The SARS outbreak in Singapore can be traced to the first imported index case that was imported from Hong Kong before this new disease had been identified and before appropriate measures had been put in place to prevent transmission. Progressive understanding of the clinical manifestations and modes of transmission led to the progressive implementation of infection control and public health measures and the successful containment of the outbreak, even without an early diagnostic test for this novel viral agent. Because of the rapid institution of measures to quickly identify and isolate SARS cases, more than 80% of the cases did not transmit the infection to their contacts. Unrecognized cases of SARS in Singapore were rare, but were the main cause of perpetuation of the national outbreak because they were not isolated early enough. Unrecognized cases were either due to atypical presentations in patients with comorbidities (Fisher et al., 2003b) or to concomitant infection (Wilder-Smith et al., 2004b). The WHO definition for probable SARS states: "A case should be excluded if an alternative diagnosis can fully explain their illness" (definition from 2003 before sensitive and specific diagnostic tests were available). Whilst this definition is reasonable for epidemiological surveillance purposes, our cases show that it should not be the basis on which infection control measures are implemented during an outbreak (Wilder-Smith et al., 2004b). Discharged patients from a hospital with known SARS cases should be kept under surveillance for at least 14 days after discharge, and readmitted to the original hospital should medical problems arise within this time-frame. All patients with fever, even when there is another known etiology, should be isolated in times of a hospital-related SARS outbreak. In response to the experience of the index cases in Singapore, these policies were implemented and contributed to the successful containment of the outbreak. Nationwide enforcement

of infection control measures for the care of any patients (SARS or non-SARS) combined with temperature surveillance of all health care workers are thought to be the other major factors that interrupted the chain of transmission in Singapore. Although there were further imported cases of SARS to Singapore, none of them led to secondary transmission due to early identification and isolation. New imported cases need not lead to major outbreaks if systems are in place to identify and isolate them efficiently (Wilder-Smith and Paton, 2003). Although screening at entry points may be justified in the light of the severe socioeconomic and public health consequences of a single imported case, strengthening screening and infection control capacities at points of entry into the health care system should be prioritized over investing in airport screening measures to detect a rare infectious disease (St. John et al. 2005).

The rapid containment of the outbreak in Singapore was due to a combination of strong political leadership, effective control and coordination at all levels, prompt and coordinated inter-agency responses, good communication with the public (Menon and Goh, 2005), and collaboration with international agencies such as the WHO and US Centers for Disease Control.

Post SARS Surveillance and Preparedness

Based on the lessons learned, Singapore has further strengthened its operational readiness and laboratory safety measures to respond to SARS. A center has been established to undertake community contact tracing as well as coordinate and assist with contact tracing efforts undertaken by hospitals and government agencies. All matters related to quarantine operations, e.g., the issue and enforcement of home quarantine orders (HQOs), phone surveillance, ambulance services, allowances, and alternate housing facilities for those on HQOs, will be centrally managed. New SARS Information Technology infrastructure has been developed and consolidated to support the surveillance and management of SARS. It provides MOH and other agencies with the ability to access integrated information about all SARS cases in Singapore in a timely fashion. For medical surveillance, there is the Infectious Disease Alert and Clinical Database System, which integrates critical clinical, laboratory, and contact tracing information on SARS. In addition, the Health Check System enables health care professionals in hospitals and clinics to identify patients who may have been exposed to SARS. For contact tracing and quarantine operations, the Contact Tracing System is in place to capture SARS cases, contact history, and HQO status. This will facilitate speedier generation of HQO reports, contact listings, and listings for external agencies automatically. An e-Quarantine Management System has also been developed for better management in the processing and enforcement of HQOs by a Singapore security agency.

The MOH was reorganized with the incorporation of an Operations Group, which serves as the main operational linkage between the MOH and all health care providers. This group is responsible for the prevention and control of outbreaks of

major infectious diseases, including bioterrorism events, planning for crisis management and coordination of health services and operations during peacetime, and command and control of all medical resources during a crisis. A three-pronged strategy comprising the establishment of a disease outbreak and response system, the strengthening of the public health system, and the development of national biosafety standards was formulated. As a result, Singapore's surveillance and analysis capacity has been enhanced, a command and communication network has been put in place, contingency plans for all health care institutions and agencies have been developed and coordinated, preparedness exercises and audits are periodically conducted, and emergency procurement and stockpiling of critical medical supplies such as PPE for up to 6 months has been undertaken. Professional manpower has been reviewed and additional isolation facilities in all hospitals, including Tan Tock Seng Hospital's Communicable Disease Centre 2 with 39 isolation and 18 intensive care beds, have been built. A national center for infectious diseases and emergency preparedness is being reviewed. Legislative framework for biosafety, including licensing for Biosafety Level 3 laboratories, has been finalized.

A SARS response framework with three levels corresponding to local SARS transmission levels and the severity of threat to the public's health has been formalized. This framework serves as a platform for coordinating the responses of various agencies. There are three color-coded alert levels, which are also adopted by the hospitals: yellow (no cases or sporadic imported cases with no local transmission); orange (local transmission confined to close contacts in health care settings or households); and red (outbreak in the community where local transmission is no longer confined to close contacts in health care settings or households).

At the yellow SARS alert level, the main focus is to prevent imported cases and detect any SARS cases that do occur early. Active surveillance and enhanced protection at high-risk areas in health care settings underpin the prevention strategy. Temperature screening of inbound visitors will be instituted at all border entry points. Within the health care setting, active surveillance for atypical pneumonia as well as fever clusters will be carried out. For prevention, health care workers in high-risk areas such as accident and emergency departments, isolation facilities, ICUs, and triaging areas will be required to don full PPE. Workflow changes to separate febrile and non-febrile patients at hospitals and health care institutions will be enforced. To reduce the prevalence of acute respiratory viral infections due to influenza, health care workers and those traveling to temperate countries are encouraged to receive influenza vaccination. Influenza vaccination is mandatory for long-term patients in nursing homes.

At the orange alert level, the focus is on containment. Additional measures will be introduced to contain the spread of SARS in Singapore as well as to prevent the export of cases. Infection control measures in health care institutions will be enhanced to break the chain of transmission. This will include the restriction of hospital visitation and the movement of health care workers and patients between health care institutions. Contact tracing and quarantine efforts will be stepped up. Community surveillance through daily temperature-taking at workplaces and schools will also be instituted. Outbound screening and "not-to-depart" restrictions

will be implemented at the border checkpoints to prevent the export of cases. Health declaration cards will also be required for inbound travelers.

At the red alert level, the strategy is to suppress the outbreak. More stringent measures will be added to gain control of community spread in Singapore and prevent the export of cases. Such measures could include the selective closure of schools, foreign workers' dormitories, factories, and places of mass gatherings, and the suspension of selected public events. Contact tracing and quarantine measures will be strictly enforced.

The robustness of the response system was demonstrated in the early detection, isolation, and contact tracing of all contacts in the workplace, health care setting, and the community when the laboratory-acquired SARS case was diagnosed in September 2003.

Singapore is now better prepared to respond to the reemergence of SARS and other emerging infectious diseases spread by the respiratory route. An avian influenza/influenza pandemic preparedness plan was developed based on the SARS response framework to prevent and control an impending health emergency.

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