Original Article

The Outbreak of SARS at Tan Tock Seng Hospital – Relating Epidemiology to Control

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Abstract

Introduction: The outbreak of severe acute respiratory syndrome (SARS) began after the index case was admitted on 1 March 2003. We profile the cases suspected to have acquired the infection in Tan Tock Seng Hospital (TTSH), focussing on major transmission foci, and also describe and discuss the impact of our outbreak control measures. Materials and Methods: Using the World Health Organization (WHO) case definitions for probable SARS adapted to the local context, we studied all cases documented to have passed through TTSH less than 10 days prior to the onset of fever. Key data were collected in liaison with clinicians and through a team of on-site epidemiologists. Results: There were 105 secondary cases in TTSH. Healthcare staff (57.1%) formed the majority, followed by visitors (30.5%) and inpatients (12.4%). The earliest case had onset of fever on 4 March 2003, and the last case, on 5 April 2003. Eighty-nine per cent had exposures to 7 wards which had cases of SARS that were not isolated on admission. In 3 of these wards, major outbreaks resulted, each with more than 20 secondary cases. Attack rates amongst ward-based staff ranged from 0% to 32.5%. Of 13 inpatients infected, only 4 (30.8%) had been in the same room or cubicle as the index case for the ward. Conclusions: The outbreak of SARS at TTSH showed the challenges of dealing with an emerging infectious disease with efficient nosocomial spread. Super-spreading events and initial delays in outbreak response led to widespread dissemination of the outbreak to multiple wards.

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Key words: Communicable diseases, Emerging; Cross infection; Patient isolation

Introduction

Severe acute respiratory syndrome (SARS) is an emerging infectious disease caused by a novel coronavirus.[1-3] Worldwide, the virus caused a total of 8098 reported infections and 774 deaths[4] before it was brought under control. Several publications have commented on the risk of transmission within hospitals.[5-9]

The epidemic in Singapore began after a 23-year-old female returned from a visit to Hong Kong and was admitted on 1 March 2003 to Tan Tock Seng Hospital (TTSH), a 1400-bed acute care hospital.[10] Primary, secondary and tertiary transmission of infection ensued shortly after her admission,[11] before infection control measures were instituted.

By the end of the outbreak on 31 May 2003, 206 cases had been diagnosed.[12] An additional 32 cases were identified following a review of laboratory and clinical information in July 2003.[13] The TTSH index is thought to have initiated the chain of transmission which infected all cases in Singapore, except for 6 other imported infections.

This paper reviews the outbreak at TTSH. It describes the profile of cases suspected to have acquired the infection in TTSH, focussing on the major areas where transmission occurred, and the epidemiological control measures implemented. It also discusses how those control measures contributed to the eventual control of the outbreak.

Materials and Methods

This study focuses on all cases of probable SARS who may have acquired the infection within TTSH. This was operationally defined as persons documented to have passed through TTSH less than 10 days prior to the onset of fever;

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the resulting number of cases based on this definition hence differ slightly from those reported elsewhere.[14] The case definitions for suspected and probable SARS were adapted from those issued by the World Health Organization (WHO),[15] and are given below.

Suspect Case

FEVER plus one of the following:

1. CLOSE CONTACT with a known case of SARS, OR
2. VISITED at-risk locations, in this case TTSH, OR
3. History of travel, to countries other than Singapore in which there were reported foci of transmission of SARS,

the above exposures having occurred less than 10 days prior to the onset of fever.

Probable Case

A SUSPECT case with:

1. radiographic findings of pneumonia or respiratory distress syndrome, OR
2. pathological features at autopsy that were consistent with SARS, OR
3. positive SARS coronavirus (SARS-CoV) on PCR testing on 2 specimens taken from 2 different sites, OR
4. positive serology for SARS-CoV.

Epidemiologic investigations at TTSH began on the evening of 14 March 2003, 13 days after the index case was admitted. All suspected and probable cases admitted to TTSH were notified to the team of on-site epidemiologists through a case-reporting form, who then collected the relevant epidemiological data and investigated possible epidemiological linkages. Data on cases not admitted to TTSH were obtained from the respective treating institutions and other previously published data.[6,16,17]

Data items included demographics, administrative data on dates of admission and isolation, and epidemiological information on dates of fever onset, possible dates and locations of exposure, type and degree of contact, and the suspected source of infection where ascertainable. Cases were considered infective from the day of onset of symptoms. Isolation was defined as being nursed in a special facility for SARS, where health staff worked under the protection of N95 masks, gowns and gloves, which were the standard for personal protective equipment (PPE) for staff.

Attack rates were computed for staff, using denominator information obtained from the TTSH human resource staff database; this analysis was attempted only for ward-based staff, as the requisite data for computing attack rates for non-ward-based staff (e.g., physiotherapists, radiographers) were not available. We also computed attack rates for exposed inpatients where possible. For wards with inpatient infections, cubicle attack rate was the number of secondary infections in patients divided by the number of patients whose stay in that cubicle overlapped with the index; an attack rate for all patients passing through the exposed ward up till the removal of the last infective case was also computed from contact tracing data.

All statistical analyses were performed using the software SPSS for Windows version 11.5.

Results

Start of the Outbreak

The outbreak began after the TTSH index case was admitted on 1 March 2003 to Ward X, a 38-bed facility with an isolation room (equipped to hold up to 2 beds) and six 6-bed cubicles separated by a low wall, and common bath areas. Clinical features of the index have been described in a previous publication.[10] She stayed in Ward X till 6 March 2003, when her clinical deterioration warranted transfer to the intensive care unit (ICU). There, she was nursed with respiratory precautions, on suspicion of possible "avian flu" following reports from Hong Kong,[18] which she had recently visited.

Descriptive Profile of Cases

In all, 105 cases fulfilled our criteria as possibly having acquired the infection in TTSH (Table 1). This included 91 cases diagnosed during the outbreak, and a further 14 cases retrospectively reclassified as probable SARS in July 2003, on the basis of positive serological results that only became available after the outbreak.

The majority of the secondary cases were healthcare staff (57.1%). Earlier cases (onset before 16 March 2003) consisted mostly of staff and visitors, whereas cases who acquired the disease as inpatients made up a sizeable proportion (29%) of the cases infected after 22 March 2003. While the average time from onset to isolation was longest amongst visitors, the highest proportion of those admitted to non-isolation facilities comprised cases acquiring the infection as patients, suggesting that these cases were the most likely to be missed at presentation. Of the patients infected, 10/13 (76.9%) developed symptoms from the disease only after being discharged from hospital (following recovery from the original reason for their admission).

Progression of the Outbreak

Figure 1a gives the time-profile of the entire outbreak. While the earliest secondary cases had begun to present by 4 March 2003, the outbreak was only detected on 13 March 2003 following the WHO global alert issued on 12 March 2003. By the time outbreak investigations were initiated, the first wave of infections had already occurred. The infection subsequently spread to other areas in the hospital (Fig. 2). Ninety-three cases (88.6%) had documented exposures in 7 wards where outbreaks were suspected to

Table 1. Key Features of Cases Infected in the TTSH Outbreak

Features	*Healthcare staff (n = 60)	Visitors (n = 32)	Patients (n = 13)	Total (n = 105)
†From retrospective reclassification – %	9 (15.0)	1 (3.1)	4 (30.8)	14 (13.3)
Median age (range) – y	29 (19-71)	38 (14-73)	59 (25-90)	31 (14-90)
Males – No. (%)	5 (8.3)	12 (37.5)	6 (46.2)	23 (21.9)
Ethnicity – No. (%)				
Chinese	28 (46.7)	24 (75.0)	10 (76.9)	62 (59.0)
Malay	7 (11.7)	6 (18.8)	1 (7.7)	14 (13.3)
Indian	10 (16.7)	0 (0.0)	2 (15.4)	12 (11.4)
Other	15 (25.0)	2 (6.3)	0 (0.0)	17 (16.2)
Date of onset – No. (%)				
Before 16/3/03	17 (28.3)	18 (56.3)	4 (30.8)	39 (37.1)
16/3/03 to 21/3/03	32 (53.3)	10 (31.3)	3 (23.1)	45 (42.9)
22/3/03 and later	11 (18.3)	4 (12.5)	6 (46.2)	21 (20.0)
Presence of comorbid disease – No. (%)	3 (5.0)	3 (9.4)	‡10 (76.9)	16 (15.2)
Admission to non-isolation facility after illness onset – No. (%)	2 (3.3)	4 (12.5)	8 (61.5)	14 (13.3)
Average time in days from onset to isolation – Median (Range)	3.8 (3.0, 0-12)	4.9 (5.5, 1-11)	§3.9 (3.0, 1-8)	4.2 (4.0, 0-12)

* Three (5.0%) allied health staff, 2 cleaners (3.3%), 10 doctors (16.7%), 4 health attendants/healthcare assistants (6.7%), 32 nurses (53.3%), 5 (8.3%) student nurses and 4 (6.7%) ward clerks.

† Reclassified as probable cases when serological results which only became available after the end of the outbreak were reviewed between June and July 2003. Twelve cases (9 healthcare staff, 1 visitor and 2 of the inpatients) had already been previously diagnosed as suspected cases; the remaining 2 inpatient cases were detected during a retrospective screening programme involving combined serological and PCR screening of 70+ long-staying patients of TTSH.

‡ Comorbid disease considered were those which could compromise immune function (e.g., diabetes mellitus, malignancies, autoimmune disease) or cause respiratory insufficiency (e.g., chronic obstructive lung disease, congestive cardiac failure).

§ Excludes 2 patients who were part of a ward quarantine cohort and not isolated.

PCR: polymerase chain reaction; TTSH: Tan Tock Seng Hospital

have occurred, including 3 major outbreaks in 2 general wards (X and Y) and in the Coronary Care Unit (CCU; henceforth referred to as Ward Z), as well as 4 minor outbreaks in the ward designated P, Q, R and S. We describe the various ward-based outbreaks below.

Ward X outbreak: The time-course of the Ward X outbreak is given in Figure 1b. The initial wave of infections (onset up to 11 March 2003) consisted largely of staff and visitors, all of whom reported direct contact with the original index case who was admitted to the ward on 1 March 2003 and was subsequently transferred out on 6 March 2003. Later cases involved mainly staff and inpatients, and may have been due to transmission by secondary cases remaining in the ward. Ward X produced the index cases that seeded Wards Y, P, Q, R and S, as well as the index case for the major outbreak in Singapore General Hospital (SGH; see Figure 2).[19]

Ward Y outbreak: The outbreak in Ward Y began when a nurse working in Ward X was admitted on 10 March 2003 with a febrile illness, which was initially suspected to be dengue fever. By the time she was isolated on 13 March 2003, she was suspected to have infected multiple secondary cases, including 12 staff, 8 visitors and 3 patients (Fig. 1c), although in retrospect, some of these cases could have also have been infected by the index case for Ward Z, who was an adjacent inpatient in the same room, and who developed symptoms on 12 March 2003 and then was transferred out on the same day to the CCU (Ward Z). The events in Ward Z will be described in greater detail below. Two visitors to Ward Y also subsequently caused minor incidents of transmission when admitted to National University Hospital (NUH) and Changi General Hospital (CGH).

Investigators only became aware of the outbreak in Ward Y after 15 March 2003, when staff from the ward began to present as cases of suspected and probable SARS.

CCU outbreak (Ward Z): The inpatient from Ward Y, who had shared the same room as the index case for that ward, had been admitted for an unrelated febrile illness on 10 March 2003. This patient, who had pre-existing ischaemic heart disease and diabetes, developed progressive shortness

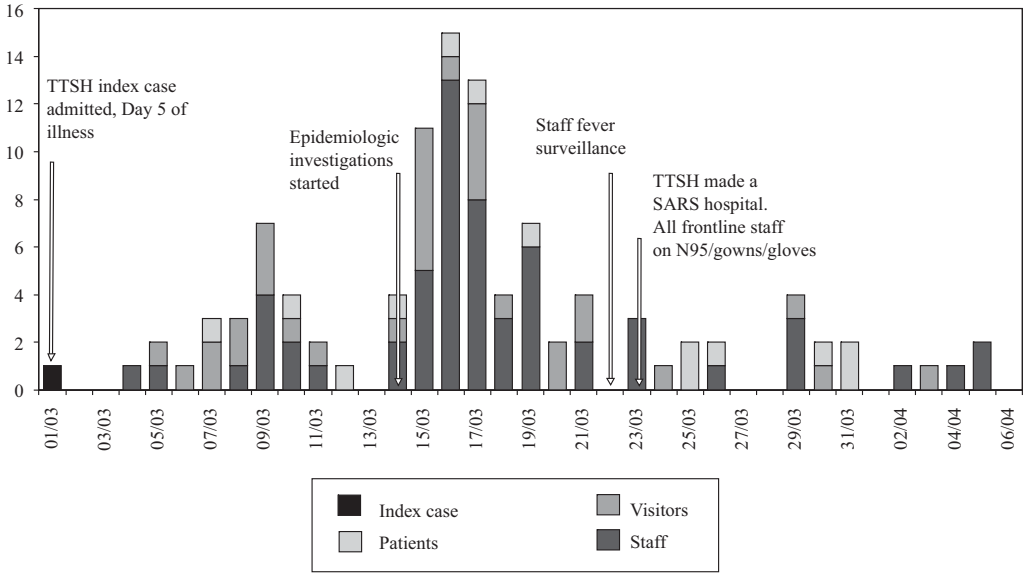


Fig. 1a. Overview of epidemic curve TTSH.

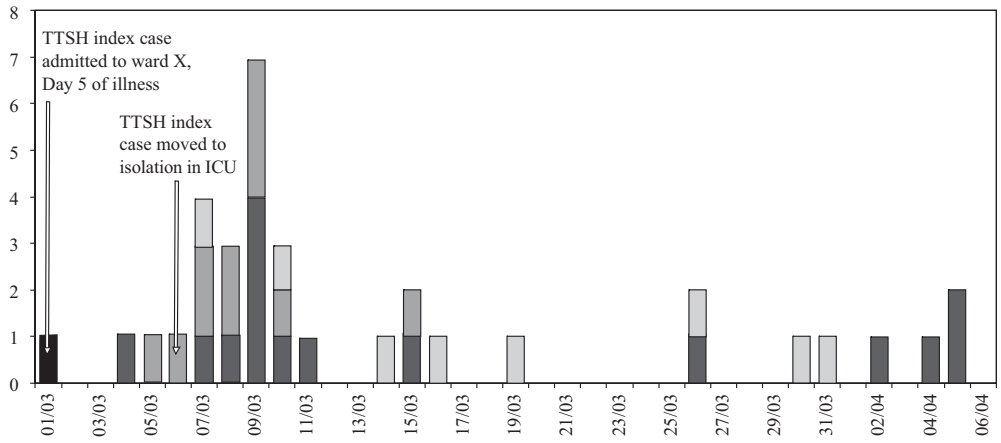


Fig. 1b. Epidemic curve in ward X.

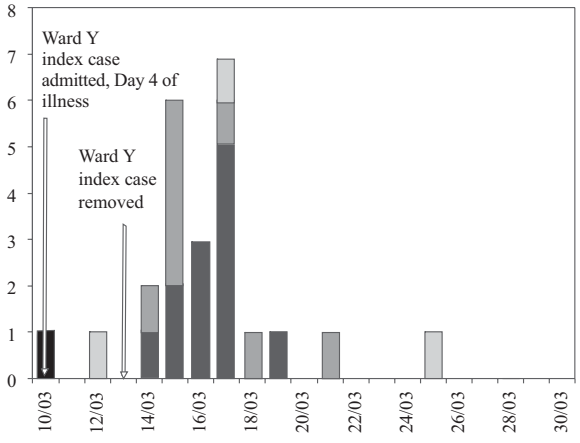


Fig. 1c. Epidemic curve in ward Y.

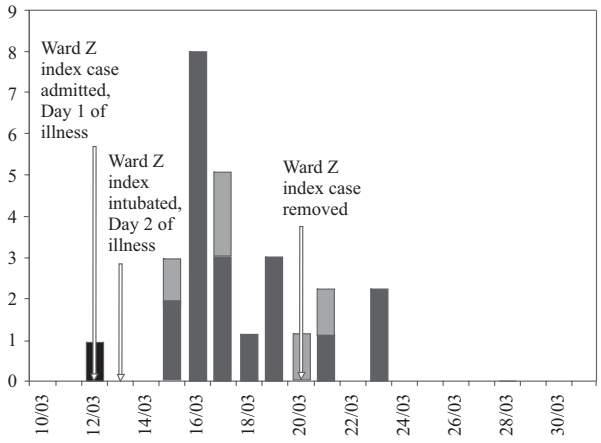
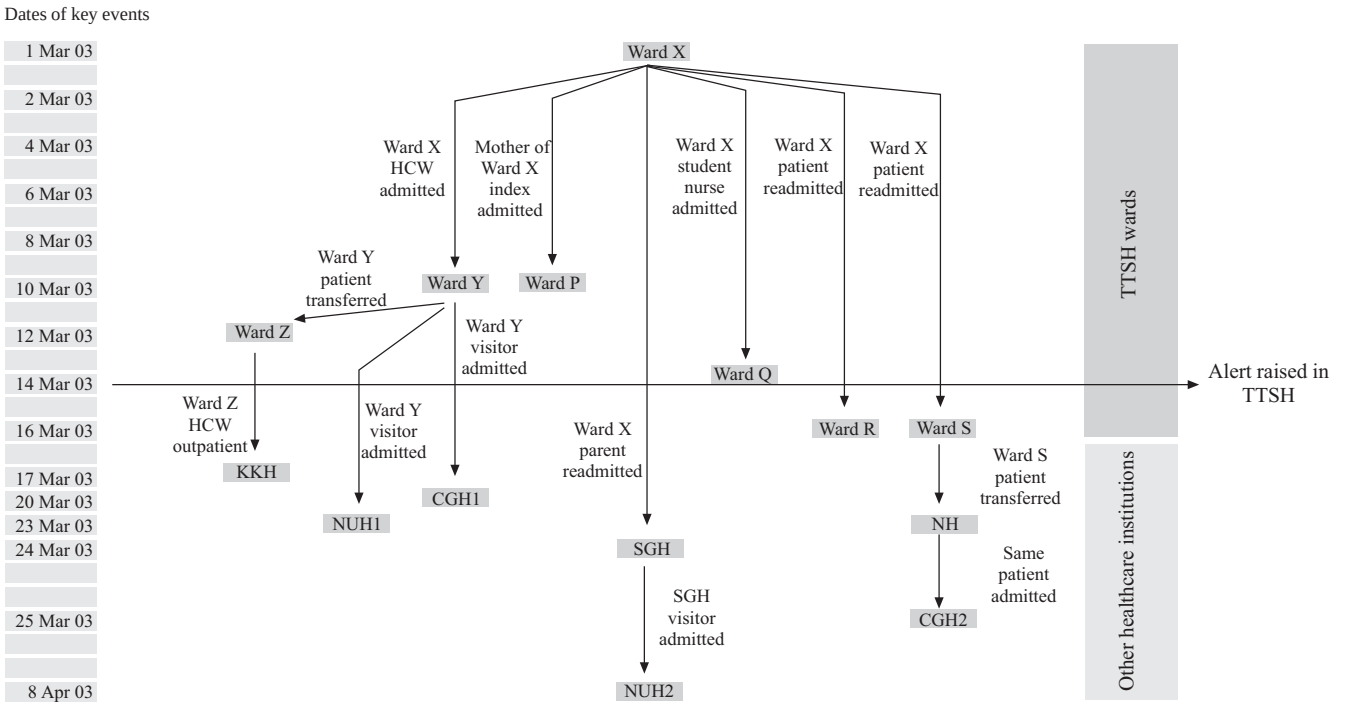


Fig. 1d. Epidemic curve in ward Z.



CGH1, CGH2:	Changi General Hospital, first and secound incidents
HCW:	Healthcare Worker
KKH:	KK Women's and Children's Hospital
NH:	Nursing Home
NUH1, NUH2:	National University Hospital, first and second incidents
SGH:	Singapore General Hospital
TTSH:	Tan Tock Seng Hospital

Fig. 2. Transmission of SARS within TTSH and seeding of other institutions.

of breath on 12 March 2003. There was no contact or travel history of relevance to SARS prior to hospitalisation, and blood cultures drawn on admission grew gram-negative bacilli. Due to her pre-existing ischaemic heart disease, the presumptive diagnosis was that of worsening cardiac failure secondary to sepsis, and she was transferred to the coronary care unit (Ward Z). In the CCU, she rapidly deteriorated, and had to be intubated on 13 March 2003.

The CCU outbreak (Fig. 1d) was discovered when a staff member was admitted with a pneumonia-like illness on the evening on 19 March 2003. Case-finding initiated that night eventually identified infections in a total of 20 nursing, medical and allied health staff working in the CCU. Five visitors to the index case of the CCU also contracted SARS. No other inpatients of the CCU were clinically diagnosed to have SARS, although we did not recall these patients for serological testing when these tests became available later in the outbreak. A healthcare worker (HCW) seeking obstetric care would subsequently cause 1 secondary case at Kandang Kerbau Women's and Children's Hospital.

Outbreaks in Wards P, Q, R and S: A staff member in Ward P, who had no other contact history of note, was suspected to be infected when the mother of the TTSH index case was admitted briefly to the ward for a period of less than 1 day. There were no subsequent incidents of transmission in that ward.

In Ward Q, a student nurse who had been infected in Ward X was admitted without precautions for 3 days. During this time, she was suspected to have infected 2 HCWs; however, no subsequent spread was traced to patients or staff from this ward.

The index cases for Wards R and S were 2 ex-patients of Ward X, both of whom had pre-existing end-stage renal failure. Both patients presented with pneumonia-like illness on 16 March 2003. While they were quickly isolated 1 day later on 17 March 2003, secondary spread had already occurred. In Ward R, there was a chain of transmission involving 3 HCWs, 1 patient, and 1 visitor, but again no subsequent spread to other wards or hospitals was traced to this ward. In Ward S, however, an elderly patient with multiple comorbid conditions was infected prior to her discharge. This patient would go on to infect a nurse aide in a nursing home, as well as cause a cluster of infections in CGH.[17]

Table 2 summarises the features of the 7 ward-based outbreaks in TTSH. Of note, super-spreading events, arbitrarily defined as an outbreak involving 10 or more secondary infections, occurred in 3 of the wards. The key difference between the major and minor ward outbreaks was the time the index case spent in those wards (median of 5 days versus 1 day respectively, $P = 0.042$, Mann-Whitney U test). HCWs were the first to fall ill in 5 out of 7 wards, and were affected in all but Ward S, where

Table 2. Wards with Documented Transmission due to Unisolated Cases of SARS

	X	Y	Z	P	Q	R	S
*Ward class	C	B1	CCU	C	C	C	C
Ward size	38 beds	30 beds	17 beds	38 beds	38 beds	38 beds	38 beds
Ward organisation	6-bed cubicles	4-bed rooms	single ICU and HD rooms	6-bed cubicles	6-bed cubicles	6-bed cubicles	6-bed cubicles
Air-conditioning	No	Yes	Yes	No	No	No	No
Super-spreading event	Yes	Yes	Yes	No	No	No	No
Date index case was admitted	1 Mar 03	10 Mar 03	12 Mar 03	10 Mar 03	14 Mar 03	16 Mar 03	16 Mar 03
Isolation of index case	6 Mar 03	13 Mar 03	20 Mar 03	11 Mar 03	17 Mar 03	17 Mar 03	17 Mar 03
Time that index case spent in ward	5 days	3 days	8 days	1 day	3 days	1 day	1 day
Onset of first secondary case	4 Mar 03	12 Mar 03	15 Mar 03	14 Mar 03	16 Mar 03	18 Mar 03	20 Mar 03
Interval from admission of 1° to onset of 2° case	3 days	2 days	3 days	4 days	2 days	2 days	4 days
First secondary case	Healthcare worker	Patient	Healthcare worker	Healthcare worker	Healthcare worker	Healthcare worker	Visitor
Number of generations in cluster	3	1	1	1	1	2	1
Number of HCWs infected	15	12	20	1	2	3	0
Number of patients infected	8	3	0	0	0	1	1
†Number of visitors infected	11	8	5	0	0	1	2
Total	34	23	25	1	2	5	3
Onset of last case	5 Apr 03	25 Mar 03	23 Mar 03	14 Mar 03	19 Mar 03	31 Mar 03	24 Mar 03
Attack rate for ‡ward-based staff	13/40 (32.5%)	6/36 (16.7%)	14/55 (25.5%)	1/39 (2.6%)	1/37 (2.7%)	2/37 (5.4%)	0/35 (0.0%)
Cubicle attack rate for inpatients	1/14 (7.1%)	2/6 (33.3%)	NA	NA	NA	0/6 (0.0%)	1/6 (16.7%)
§Ward attack rate for inpatients	8/115 (7.0%)	3/56 (5.4%)	NA	NA	NA	1/41 (2.4%)	1/70 (1.4%)

* C class wards are open wards with 5 or more beds, and are the most heavily subsidised by the government;
B1 class wards are organised into 4-bed rooms, with a 20% government subsidy; for further details see reference 20.
† Includes family and household members suspected to have acquired the infection in hospital.
‡ Includes nursing, administrative and ancillary staff whose work-area is restricted to one ward.
§ Includes cases counted under cubicle attack rate as well as cases in other cubicles.
CCU: coronary care unit; HCWs: healthcare workers; HD: high dependency unit; ICU: intensive care unit; NA: not applicable SARS; severe acute respiratory syndrome

secondary cases were restricted to 2 visiting family members and an adjacent inpatient.

Attack rates amongst ward-based staff varied widely, with the highest being 32.5% in ward X. Cubicle and ward attack rates for patients also varied widely, and of 13 inpatients infected, only 4 (30.8%) had been in the same room or cubicle as the index case for the ward.

Control Measures and Their Impact

The following interventions were rolled out in quick succession:

1. Isolation of infectious cases as and when discovered, and admission of any new suspected or probable cases to isolation facilities, from 13 March 2003.
2. Dissemination of information on contaminated areas and clinical features of SARS as and when they were discovered, beginning with infectious disease physicians on Friday evening, 14 March 2003, and subsequently to all physicians in an ad-hoc meeting on Monday morning 17 March 2003.
3. Contact tracing of discharged cases to recall symptomatic cases for screening, with subsequent daily telephone surveillance of asymptomatic cases till the maximum incubation period had elapsed; the programme started with known contaminated areas from 17 March 2003, and escalated to include all discharges from 20 March 2003.
4. Establishment of a staff surveillance system, comprising

strict temperature surveillance of staff (3x/day) from 22 March 2003, with sick leave to be certified only by our own emergency department.
5. Closure of TTSH as an acute hospital on 22 March 2003.
6. Use of N95 masks, gowns and gloves for all patient care throughout the hospital, operationally implemented on 23 March 2003.

The impact of the above measures played out as follows. Firstly, the index cases for wards Q, R and S were discovered and isolated on 17 March 2003. After 17 March 2003, no cases were admitted directly to general wards within TTSH. Unfortunately, 1 ex-patient from Ward X and another ex-patient from Ward S would be admitted to the general wards of SGH and CGH respectively, leading to outbreaks in those hospitals.

Secondly, staff protection measures dramatically reduced infection rates in staff. Although TTSH continued to accept SARS patients over the course of the outbreak, the number of staff infections decreased dramatically after universal PPE was introduced (Table 1). While 52 staff members had onset of disease prior to 23 March 2003 when universal PPE was implemented, only 8 staff members had onset of disease subsequent to that date. The above represented a 6-fold reduction in staff attack rate, in spite of the fact that the number of probable SARS patients managed in the hospital continued to increase (to a peak on 14 April 2003, unpublished data).

Lastly, the delay in isolation decreased over the course of the epidemic. While cases with onset before 16 March 2003 were, on the average, isolated 6 days after onset, those with onset after 22 March 2003 were isolated within a mean of 2 days.

End of the Outbreak in TTSH

Ten days after the institution of PPE for all patient care, a final cluster of infections amongst 4 staff from Ward X were flagged by the staff surveillance system.

A detailed investigation failed to confirm a single source, although initial suspicions focused on a confused patient, who would pull off protective equipment from staff during nursing procedures. This patient had subsequently left the hospital before any confirmatory investigations could be performed. However, contact tracing revealed that none of the family members of this patient reported being ill.

Due to concerns about possible undetected cases amongst long-staying inpatients with multiple comorbidities, we conducted combined serological and PCR screening of 70+ long-staying inpatients of TTSH who were still in hospital at the conclusion of the outbreak in June 2003, including ex-patients of Ward X as well as other wards.

In all, 4 additional cases were retrospectively identified amongst ex-inpatients from Ward X, but not amongst ex-patients of other wards. Two had already been readmitted to isolation rooms as cases of suspected SARS; 2 others had been undiagnosed but had remained quarantined within Ward X, which had been sealed off to new admissions.

After the final cluster of staff infections in Ward X, no further infections were traced to TTSH. The original outbreak in Ward X was the one that lasted the longest, with the last case having an onset of disease on 5 April 2003.

Discussion

Many lessons can be drawn from the TTSH experience. Firstly, the outbreak showed the consequences of late detection. By the time the alert was raised on 14 March 2003, 5 wards had been contaminated; contamination of 2 other wards followed during the weekend (on 16 March 2003), before measures could be taken to disseminate the relevant information to all parties. Delayed detection at the ward level was also associated with larger outbreaks. Moreover, our experience suggests that the pool of patients who were secondarily infected were not restricted to the cubicle or room of the index case, but were also from other cubicles, possibly due to mingling in common areas such as lobbies and baths, or other possible modes of transmission such as fomite spread or through infected staff. As such, delays, combined with the complexity of healthcare contacts, resulted in a long list of exposed contacts. With the lack of visitor records at the time, and the large number of wards and patients involved, failures in contact tracing were to be expected. In addition, there was evidence of undetermined interactions amongst infected and susceptible persons, mostly amongst cases infected as inpatients, who had infections that initially went unrecognised.

It has been suggested in the paper by Gopalakrishna et al,[14] that in retrospect, a decision should have been made to stop all admissions and discharges to TTSH. This, if implemented before 20 March 2003, could have averted the major outbreak at SGH, and transmission from Ward S to the nursing home and CGH (Fig. 2). This drastic option was not taken until 22 March 2003. The decision-making process was partially complicated by the unknown nature of the disease, and the fact that the full extent of the contamination would only become apparent in the week starting 17 March 2003, when the outbreaks in wards Q, R and S were discovered on the night of 17 March 2003, and the outbreak in CCU on the night of 19 March 2003.

Within the hospital, the main missed opportunities after 14 March 2003 was to mitigate the outbreak in Ward Z, and also the secondary outbreak among the staff of Ward X. Had all exposed cases been identified and quarantined, the source of infections in Ward Z could have been detected and isolated earlier; however, considering that the earlier

part of the epidemic curve for Ward Z resembles a point source outbreak, with 16/25 (64%) of the infected cases having developed symptoms by 17 March 2003. As such, most of the infections could not have been averted by 14 March 2003. The aim would hence have been to prevent a secondary generations of cases, which was partially achieved by the timely discovery of the source case on the night of 19 March 2003.

The outbreak in the CCU, and the secondary staff outbreak in Ward X, also illustrated the difficulty of recognising inpatients with SARS superimposed upon background medical conditions. Of the 14 cases that were retrospectively diagnosed as probable SARS, the HCWs and visitors had already been admitted as suspected SARS (Table 1), whereas 2 of the 4 cases infected as inpatients were only diagnosed due to a screening programme for long-staying inpatients, most of whom had multiple co-morbidities. In retrospect, while we cannot definitively arrive at an answer due to the lack of comprehensive test results and data from all patients discharged from that ward in that period, it could be that the secondary outbreak in Ward X was caused by one (or more) of these inpatients remaining in the ward with undiagnosed SARS. The difficulty of diagnosing such patients was not peculiar to our experience, and has been highlighted in numerous other publications.[16,17,19]

In terms of control measures, information dissemination after 17 March 2003 could be credited for the discovery of the 3 cases that had at the time been admitted to general wards, and in preventing further cases from being admitted without isolation. As for staff policies, staff surveillance, based on notifications of staff with pneumonia or clusters of febrile illness, could have detected 6 out of the 7 ward-based outbreaks had it been in place before the outbreak. Although it is uncertain if detection by such means would have been sufficiently timely, such a system is likely to be both sensitive and specific, as we have shown in another publication that pneumonia in staff, and clusters of febrile staff, are uncommon events.[21] In contrast, surveillance systems based on detecting clusters of fever in patients must overcome a high degree of background noise, and so would be highly non-specific. Moreover, it must be noted that the majority of infected patients (76.9%) only manifested their infections after their discharge from hospital, which would greatly reduce the sensitivity of any surveillance system based on detecting clusters of febrile disease in patients. While the team of epidemiologists instituted a post-discharge surveillance system to monitor all discharged patients for symptoms, the system was unable to detect and recall all cases prior to their admission to other institutions. Ultimately, what prevents ex-patients incubating SARS from being admitted without precautions are good clinical judgment, and timely information about the prior admission history of such cases. In addition, one way of facilitating the clinical diagnosis of such cases by front-line staff during an outbreak is to stipulate that discharged patients return to their original hospital for reassessment.

Our analysis of the outbreak at TTSH must be interpreted in the light of its limitations. Our investigation was based mostly on the documentation of known exposures; i.e., we assumed that the 93 cases who had documented exposures in the 7 ward-related outbreaks were infected in those wards, since their distribution of onset times were compatible with the putative exposures. However, we were unable to rule out the possibility that they may also have been transiently exposed in common areas (e.g., lifts and lift lobbies) and shared facilities such as radiology suites (which had been implicated in a cluster of transmission for the outbreak at SGH).[19] Of the remaining 12 cases, 1 case reported exposure in the MICU, and another in the staff clinic, while the location of infection for 5 staff and 5 visitors could not be confidently ascertained. These staff and visitors could have been infected in the common areas, but we are also unable to rule out smaller foci of transmission that remained undetected throughout the outbreak, since the retrospective screening programme did not cover all patients and visitors who passed through TTSH during the outbreak period. Another limitation of this study is that, while our study hints at the importance of the duration without isolation as a risk factor for causing larger outbreaks, we did not adjust for potential confounders such as disease severity in the index case[22] and other environmental variables which may have enhanced transmission, such as the use of high-flow oxygen,[23] both of which have been hypothesised to be important in the dissemination of the disease. A follow-up analysis looking at this issue could be attempted using a larger collection of cases, as many of the issues surrounding what facilitated the transmission of SARS remain unresolved.[24]

From the subsequent cases of SARS in Guangzhou in December 2003,[25] it is clear that an animal reservoir still exists, and future outbreaks are hence a distinct possibility. Should an outbreak of SARS return to a hospital setting, the measures found to be useful in this review of the TTSH outbreak are:

1. Early detection through a combination of surveillance methods, particularly institution-wide surveillance for sick leave in staff.
2. Centralised collation, coordination, processing and dissemination of relevant epidemiologic information to staff members, and sharing of that information with other healthcare institutions.
3. Contact tracing and telephone surveillance for discharged patients and visitors from exposed areas, treating each contaminated ward as a unit, and not just

the cubicle or room of the index case.
4. Quarantine or isolation of existing inpatients who have been exposed, with aggressive and repeated case-finding through clinical evaluation and laboratory tests on all patients who could possibly have been exposed.
5. Empirical isolation of exposed cases who have to be readmitted.
6. Institution-wide use of PPE once a case has been detected in the institution, until and unless outbreak investigations can confirm that exposures were localised to limited areas.
7. Closure of a hospital should an outbreak be discovered late after the introduction of an infectious case, unless outbreak investigations can determine that the infection has not become disseminated.

During the initial stages of the outbreak in TTSH, the aetiological agent, incubation period, mode of transmission and the effectiveness of protective equipment and control measures were unknown. Our experience with SARS in TTSH hence involved the real-time application of epidemiology – the constant gathering and processing of information, with quick dissemination to facilitate control by practising clinicians, the application of epidemiological principles in control, and the constant evaluation and re-evaluation of epidemiologic information to judge the impact of such control measures.

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