Anesthesiology 2004; 100:1394–8

Infection Control Measures for Operative Procedures in Severe Acute Respiratory Syndrome–related Patients

Victor Wei Ter Chee, M.Med., Mark Li-Chung Khoo, F.R.C.S.,† Sow Fong Lee, B.Sc.,‡ Yeow Choy Lai, M.Med.,§ Ngek Mien Chin, M.Med.‖*

Background: **Singapore reported its first case of Severe Acute Respiratory Syndrome (SARS) in early March 2003 and was placed on the World Health Organization's list of SARS-affected countries on March 15, 2003. During the outbreak, Tan Tock Seng Hospital was designated as the national SARS hospital in Singapore to manage all known SARS patients. Stringent infection control measures were introduced to protect healthcare workers and control intrahospital transmission of SARS. Workflow processes for surgery were extensively modified.**

Methods: **The authors describe the development of infection control measures, the conduct of surgical procedures, and the management of high-risk procedures during the SARS outbreak.**

Results: **Forty-one operative procedures, including 15 high-risk procedures (surgical tracheostomy), were performed on SARS-related patients. One hundred twenty-four healthcare workers had direct contact with SARS patients during these procedures. There was no transmission of SARS within the operating room complex.**

Conclusions: **Staff personal protection, patient risk categorization, and reorganization of operating room workflow processes formed the key elements for the containment of SARS transmission. Lessons learned during this outbreak will help in the planning and execution of infection control measures, should another outbreak occur.**

SEVERE acute respiratory syndrome (SARS) is a newly identified infectious disease that manifests as a severe atypical pneumonia. It is caused by a new strain of coronavirus.[1–4] From March 12, 2003, to July 5, 2003,[5,6] infections were reported in 29 countries, with more than 8,400 cases and more than 900 case fatalities.#

Severe acute respiratory syndrome transmission is thought to occur mainly *via* respiratory droplets and close human contact; transmission through fecal–oral spread and contact with contaminated surfaces can also occur, and the risk of airborne transmission exists.**

Singapore recorded its first case of SARS on March 1, 2003, 11 days before the World Health Organization (Geneva, Switzerland) issued its global alert on SARS on March 12, 2003.

This first wave of infections was largely due to intrahospital transmission, and 42% (84) of the initial cases were healthcare workers.[7] This high percentage of healthcare worker infection mirrored that observed in other major centers of outbreak, such as Toronto, Ontario, Canada (51%),[8] Hong Kong, China (62%),[9] and Taiwan, China (33%).[10] All cases of infected healthcare workers in Tan Tock Seng Hospital, Singapore, occurred within two "estimated incubation periods" (15.7 days)[11] from the date in which standard protective equipment use was implemented (fig. 1).

A key element of the national strategy to contain SARS in Singapore was to centralize the treatment of all suspected and probable SARS cases in one healthcare facility. Tan Tock Seng Hospital, a 1,200-bed acute care hospital where the national Communicable Disease Centre is colocated, was designated by the Ministry of Health of Singapore on March 22, 2003, for the management of all suspected and probable SARS cases. This enabled the hospital to wind down all non-SARS admissions. Infection control measures in the operating room (OR) were implemented progressively over a 25-day period.

During the SARS outbreak in Singapore, 238 people were infected, of whom 33 died (14%). Forty-one surgical procedures were performed on SARS-related patients. These ranged from minor operations under local anesthesia to major operations requiring general anesthesia for several hours. Twenty-four patients required tracheal intubation and anesthetic airway management, and 15 patients required tracheostomy.

A total of 124 OR healthcare workers (55 doctors, 58 nurses, and 11 healthcare attendants) were directly involved in the management of these patients. None contracted the illness.

We outline the implementation of the new infection control measures during the SARS outbreak with regard to staff protection, patient categorization, and OR reorganization. The management of high-risk procedures in SARS-related patients is also described.

Development of SARS Infection Control Measures

Before the SARS outbreak, infection control protocols against known infectious diseases such as tuberculosis, hepatitis B, and human immune deficiency virus were practiced within the OR. However, because of the difference in mode of transmission and infectivity, they were unlikely to be adequate for managing SARS-related patients safely.

* Registrar, ‡ Operations Manager, § Consultant, ‖ Senior Consultant, Department of Anaesthesiology, † Consultant, Department of Otorhinolaryngology.

Received from the Departments of Anaesthesiology and Otorhinolaryngology, Tan Tock Seng Hospital, Singapore. Submitted for publication June 30, 2003. Accepted for publication January 12, 2004. Support was provided solely from institutional and/or departmental sources.

Address reprint requests to Dr. Chee: Department of Anaesthesiology, Tan Tock Seng Hospital, 11, Jalan Tan Tock Seng, Singapore 308433. Address electronic mail to: victor_chee@ttsh.com.sg. Individual article reprints may be purchased through the Journal Web site, www.anesthesiology.org.

World Health Organization: Summary table of SARS cases by country, 1 November 2002-7 August 2003. Available at: http://www.who.int/csr/sars/country/2003_08_15/en/. Accessed September 1, 2003.

** Centers for Disease Control and Prevention: Severe acute respiratory syndrome: Fact sheet; basic information about SARS, August 19, 2003. Available at: http://www.cdc.gov/ncidod/sars/factsheet.htm. Accessed September 1, 2003.

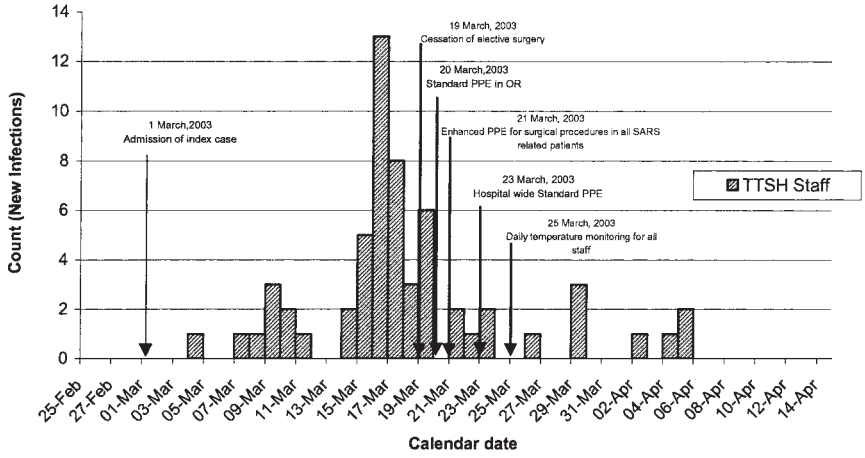

Fig. 1. Epidemic curve of Tan Tock Seng Hospital (TTSH) staff (n = 59) who were infected by severe acute respiratory syndrome (SARS) coronavirus. Admission of index case occurred on March 1, 2003. Use of standard personal protective equipment (PPE) was implemented on March 20, 2003, in the operating room (OR) complex. Hospital-wide use of standard PPE was implemented on March 23, 2003. Last infected healthcare worker in TTSH presented on April 5, 2003.

The strategy for infection control against SARS was targeted at three key areas: (1) staff personal protection, (2) categorization of patients to stratify risk of SARS transmission, and (3) reorganization of the OR.

Staff Personal Protection

Staff protection focused on three levels. First, personal protective equipment (PPE) was introduced for all patient contact throughout the hospital. Fitted N95 masks were worn by all personnel whenever they were in patient care areas. Standard PPE, which comprised an N95 mask, a surgical cap, eye protection (goggles or face shield), a gown, and gloves, was mandatory for all patient contact. In addition, enhanced PPE, which comprised standard PPE, plus the use of shoe covers and a positive air–powered respirator, was required for all high-risk procedures in all patients and procedures in all high-risk patients. PPE was disposed of after each patient contact, except for the positive air–powered respirator, which was disinfected.

These empirical measures prevented the transmission of SARS even during high-risk procedures such as tracheal intubation and tracheostomy.

Second, staff education was continually emphasized. Because compulsory use of PPE was time-consuming and uncomfortable, it was important to explain to every healthcare worker the rationale for the use of PPE. All staff were taught the method of donning PPE and its proper sequential removal during the decontamination process. Formal mask-fitting sessions were arranged for all staff in the hospital. Frequent hand hygiene and avoidance of touching the mask and face with unwashed hands were emphasized.

Third, the hospital conducted frequent audits of infection control measures. Staff were constantly reminded to look out for each other and to report breaches in infection control. This identified weaknesses in the system and allowed necessary improvements to be made. Infection control nurses supervised the audit process.

Categorization of Patients to Stratify Risk of SARS Transmission

The case definition of SARS evolved over time. All inpatients were categorized into five main groups. Patients in the "probable," "suspect," "observation," and "unknown with contact history" categories were treated as high-risk, requiring healthcare workers to use enhanced PPE during operative procedures. Observation and unknown with contact history category patients were managed as high-risk to cast a wider net for patients who might present with atypical SARS. Patients in the unknown without contact history category were managed as low-risk patients requiring enhanced PPE only during high-risk procedures.

Reorganization of the OR

Seven key areas were addressed in the reorganization of the OR to minimize the transmission of SARS.

Limit Traffic in the OR. All elective surgery was initially ceased, and efforts were directed at treating the SARS patients and a minority of non-SARS inpatients. This measure ensured that patients in the community who were well were not exposed to the SARS virus during surgery. As the clinical picture and mode of transmission of SARS became understood, urgent operative procedures in non-SARS patients were progressively restarted.

Limit Patient Movement within the OR. Patient entry into the OR was strictly controlled and supervised. Surgical procedures that could be performed by the bedside were performed in the intensive care unit rather than the OR.

Geographic Segregation within the OR Complex. Geographic segregation within the OR complex was necessary to minimize contamination by SARS-related patients. Specific routes and dedicated elevators were used for patient transport. These were clearly signposted. Probable, suspect, observation, and unknown with contact history cases had surgery performed in designated SARS ORs.

After recovery from anesthesia within the OR, patients were sent directly back to the ward by the same dedicated anesthesiology team. This process differed from the pre-SARS practice, in which patients were transported by a common porter pool, transited in the OR complex reception area, checked by reception staff before surgery, and observed in an open PACU after surgery.

Strict Screening for All OR Staff. Temperature monitoring was mandatory for all hospital staff. Staff with temperatures above 38°C or staff with respiratory symptoms were taken off duty immediately and sent for SARS screening. This involved screening for a possible cause of fever; evaluation of known SARS symptoms such as cough, myalgia, or diarrhea; a chest x-ray if clinically indicated; and epidemiologic contact tracing. Within the OR complex, all contact episodes between staff and patients were recorded so that in the event a staff member should develop SARS, contact tracing and isolation measures could be implemented quickly.

Reorganization of Staff Deployment within the OR. For each surgical procedure, the surgical team was divided into two groups, a "contaminated surgery" group (with enhanced PPE), in direct contact with the patient, and a "clean surgery" group (with standard PPE), providing support to deliver equipment and instruments to the contaminated surgery group should the need arise. A dedicated infection control nurse ensured that all infection control measures were strictly adhered to in the OR. She supervised proper application of PPE and decontamination of personnel, equipment, and the OR. She also maintained a complete list of all staff involved in the case.

Physical Modification of ORs. Modification of SARS-designated ORs was done early on in consultation with the hospital's facilities management service. Three ORs were selected; each had a separate air-conditioning and humidification unit with individual atmospheric air inlet and exhaust systems.

These ORs had a conventional plenum-type ventilation system that operated under positive pressure and allowed 25 air changes per hour. Fresh air was supplied to the OR without recycling, and the outflow to the atmosphere occurred *via* overhead exhaust vents located in the adjoining scrub and anesthetic induction rooms.

Modifications were made to minimize the outflow of contaminated air from the OR into the rest of the OR complex. All doors into the OR except that from the anesthetic induction room were locked and sealed with tape. Entry and exit was possible only *via* the anesthetic induction room. The existing pressure-relief valves opening from the OR into the corridors and adjacent rooms were sealed. With this arrangement, the anesthetic induction room, with its double doors, functioned as an anteroom and air lock, minimizing the flow of contaminated air from the SARS designated ORs into the rest of the OR complex.

After each surgical procedure, the OR was thoroughly decontaminated and allowed to air for 1 h. This mandatory 1-h interval between cases allowed for further dilution of airborne contaminants to 0.0000002% of their former levels.[12]

Safe Handling and Decontamination of Surgical Equipment. Disposable equipment was used whenever possible. For reusable equipment, a scrub nurse wearing enhanced PPE performed general cleaning within the OR disposal room. Instruments were placed in a biodegradable bag and then into another biohazard bag for transport to the central sterilizing and supply depot. There, staff handled the equipment with standard PPE, removing the outer bag and placing the biodegradable bag into an automated cleaning processor. Instruments were subsequently packed and sterilized again. Special equipment such as gastroduodenoscopes used during the SARS outbreak were manually washed thoroughly after each procedure by staff wearing enhanced PPE. Disinfection of the instruments was performed according to manufacturer recommendations.

Management of High-risk Procedures

High-risk procedures were defined as those that would present healthcare workers with a high aerosolized viral load. During the SARS epidemic, procedures such as tracheal intubation, extubation, bronchoscopy, thoracotomy, and tracheostomy were categorized as high-risk procedures.

Tracheostomy constituted the majority of procedures in SARS-related patients. Multiple disconnection and reconnection of the breathing circuit during patient transport and the surgical procedure can lead to aerosolization of airway secretions and contamination of the environment. Loss of positive end-expiratory pressure during circuit disconnection would also significantly impair oxygenation in these patients with acute respiratory distress syndrome.[13] These considerations, together with those mentioned earlier and the limited capabilities of transport ventilators, favored open surgical tracheostomy to be performed by the bedside in the intensive care unit. The individual intensive care unit rooms, equipped with independent air conditioning units and exhaust systems and capable of negative pressure ventilation, were ideal for isolating SARS patients.

Open tracheostomy was selected over percutaneous tracheostomy because it entailed a lower risk of aerosolization of airway secretions.

Satellite surgical teams, comprising a contaminated surgery group and a clean surgery group, were formed to perform these tracheostomies. These groups functioned in a similar manner as in the SARS-designated OR, except with fewer members in each group because of space considerations. Multiple rehearsals were conducted until

the team was well versed. Meticulous planning ensured that all necessary equipment was packed into a single sterile pack to simplify transport and preparation of equipment within the isolation room. Protocols and checklists were developed to aid the safe conduct of these procedures.

The other high-risk procedure frequently performed was tracheal intubation. Within the OR, tracheal intubation was performed by senior anesthesiologists with the help of an assistant. Rapid sequence intubation was preferred to minimize the need for mask ventilation. Enhanced PPE was used for all intubations, regardless of SARS status.

During the SARS outbreak, a dedicated emergency airway management team continued to provide service throughout the hospital. Staff anesthesiologists attending to such service activations performed all procedures with enhanced PPE.

Discussion

The SARS outbreak showed the importance of infection control measures for highly infectious diseases. Successful implementation of infection control required strict adherence to protocols and exercise of individual discipline in tolerating the inconveniences of daily temperature monitoring, repeated hand washing, proper mask fitting at all times during patient exposure, and donning of standard and enhanced PPE whenever required.

Patient safety has always been a tenet in the practice of medicine. The SARS outbreak led to a dramatic reevaluation of healthcare workers' protection. This became a major priority overnight. Coordination and collaboration at all levels was essential to ensure that all patients and healthcare workers were adequately protected.

During the initial period of uncertainty over the precise mode of transmission, there was overwhelming use of the positive air–powered respirators. Such equipment was in limited supply, and time was needed for it to be cleaned and for the batteries to be recharged after use. Consequently, situations arose when the positive air–powered respirators were not available when it was critically required. Equipment use therefore needed to be rationalized appropriately so as to allow the limited resources to be channeled to the necessary high-risk areas of work. Processes were regularly reviewed and modified, and priorities were realigned accordingly.

The successful use of infection control measures at our hospital suggest that they may also be effective for infective agents that have similar modes of transmission as the SARS virus. This would be useful for future outbreaks.

The practice of anesthesia was significantly affected by the implementation of infection control strategies during the SARS outbreak. In the OR, the practical conduct of anesthesia, such as airway instrumentation, was generally performed by staff or experienced anesthesiologists. There was a low tolerance for failed attempts and retries. Procedural training for junior residents took a backstage role; the aim was to make a good, clean attempt in the shortest possible time, without compromising the safety of the patient or the healthcare worker.

Staff designated to the SARS-designated OR consisted of the minimum required for efficient functioning. Relief exchange protocols for the anesthesiologist were not practical and were not practiced unless absolutely necessary: There were limitations on the supply of positive air–powered respirators; staff exposed were to be minimized; and the entire "gowning" and equipping session was in itself a laborious exercise. Although staff fatigue was inevitable, it in fact emphasized the importance of adhering to the new practice techniques.

Psychosocial support was important for all staff involved in the care of SARS patients. There was a sense of fear, dread, and isolation. Psychological support helped each individual to cope with this period of uncertainty.

Surgery was more difficult as a result of the cumbersome enhanced PPE, the limited field of vision, and impaired communication within the surgical team. In the intensive care unit, this difficulty was aggravated by the following factors: (1) positioning was suboptimal; (2) many patients were on anticoagulation before surgery, making surgical hemostasis important; and (3) critically ill patients could not tolerate long periods of apnea and loss of positive end-expiratory pressure. An experienced surgeon was therefore required to reduce the risk of complications and to perform the procedure quickly.

One of the key national strategies was to have a designated hospital for the treatment of all SARS cases. This required the transfer of all SARS-related patients and fever clusters of unknown origin to the designated hospital. It is likely that this designation of a specific hospital to manage SARS was one of the reasons for the fewer case fatalities observed in Singapore as compared with the other major cities that had significant infections.# Although this concentration of services helped to heighten awareness within the hospital, it also led to the cessation of elective surgery at our hospital. Locally, there were anecdotal reports of tumor progression and metastasis in cancer patients who had surgery postponed. In Singapore, planning for a standalone facility to manage SARS and similar disease outbreaks started in April 2003. This facility is now operational, with a screening center, isolation rooms, an intensive care unit, and an OR. With this facility, the need for cessation of elective and semiurgent surgery may not be necessary in future SARS outbreaks.

In terms of personal protection, staff members should treat all contact areas, including their own hands, as contaminated and avoid contact with mucosal mem-

branes (eyes, nose, mouth) without immediate previous washing or decontamination. This perspective toward personal protection may perhaps be more important than the physical protection provided by PPE, and failure to embrace this concept may explain breakthrough infection despite use of PPE.[14,15]

With strict adherence to protocols and guidelines described, there was no transmission of SARS to other persons with clinical disease within the OR.

Evidence from the global containment of the SARS epidemic indicates that these measures are adequate to break the chain of SARS transmission. It is important to note that all these measures are targeted toward prevention by respiratory droplet and contact transmission. If the contagion were truly airborne, it is unlikely that these measures alone would be totally effective.

In summary, a continued high level of vigilance (personal, institutional, and national) is required. Successful containment of another SARS outbreak would require rapid identification of the disease and communication.[16]

References

1. World Health Organization Multicentre Collaborative Network for Severe Acute Respiratory Syndrome (SARS) diagnosis: A multicentre collaboration to investigate the cause of severe acute respiratory syndrome. Lancet 2003; 361: 1730–3

2. Peiris JSM, Lai ST, Poon LLM, Guan Y, Yam LYC, Lim W, Nicholls J, Yee WKS, Yan WW, Cheung MT, Cheng VCC, Chan KH, Tsang DNC, Yung RWH, Ng TK, Yuen KY, members of the SARS Study Group: Coronavirus as a possible cause of severe acute respiratory syndrome. Lancet 2003; 361:1319–25

3. Drosten C, Günther S, Preiser W, van der Werf S, Brodt H-R, Becker S, Rabenau H, Panning M, Kolesnikova L, Fouchier RAM, Berger A, Burguière A-M, Cinatl J, Eickmann M, Escriou N, Grywna K, Kramme S, Manuguerra J-C, Müller S, Rickerts V, Stürmer M, Vieth S, Klenk H-D, Osterhaus ADME, Schmitz H, Doerr HW: Identification of a novel coronavirus in patients with severe acute respiratory syndrome. N Engl J Med 2003; 348:1967–76

4. Ksiazek TG, Erdman D, Goldsmith CS, Zaki SR, Peret T, Emery S, Tong S, Urbani C, Comer JA, Lim W, Rollin PE, Dowell SF, Ling A-E, Humphrey CD, Shieh W-J, Guarner J, Paddock CD, Rota P, Fields B, DeRisi J, Yang J-Y, Cox N, Hughes JM, LeDuc JW, Bellini WJ, Anderson LJ, the SARS Working Group: A novel coronavirus associated with severe acute respiratory syndrome. N Engl J Med 2003; 348:1953–66

5. From the Centers for Disease Control and Prevention: Outbreak of severe acute respiratory syndrome—worldwide, 2003. JAMA 2003; 289:1775–6

6. From the Centers for Disease Control and Prevention: Update: Severe Acute Respiratory Syndrome—worldwide and United States, 2003. JAMA 2003; 290: 1022–3

7. From the Centers for Disease Control and Prevention: Severe Acute Respiratory Syndrome—Singapore, 2003. JAMA 2003; 289:3231–4

8. Booth CM, Matukas LM, Tomlinson GA, Rachlis AR, Rose DB, Dwosh HA, Walmsley SL, Mazzulli T, Avendano M, Derkach P, Ephtimios IE, Kitai I, Mederski BD, Shadowitz SB, Gold WL, Hawryluck LA, Rea E, Chenkin JS, Cescon DW, Poutanen SM, Detsky AS: Clinical features and short-term outcomes of 144 patients with SARS in the greater Toronto area. JAMA 2003; 289:2801–9

9. Lee N, Hui D, Wu A, Chan P, Cameron P, Joynt GM, Ahuja A, Yung MY, Leung CB, To KF, Lui SF, Szeto CC, Chung S, Sung JJ: A major outbreak of severe acute respiratory syndrome in Hong Kong. N Engl J Med 2003; 348:1986–94

10. From the Centers for Disease Control and Prevention: Severe Acute Respiratory Syndrome—Taiwan, 2003. JAMA 2003; 289:2930–2

11. Donnelly CA, Ghani AC, Leung GM, Hedley AJ, Fraser C, Riley S, Abu-Raddad LJ, Ho LM, Thach TQ, Chau P, Chan KP, Lam TH, Tse LY, Tsang T, Liu SH, Kong JHB, Lau EMC, Ferguson NM, Anderson RM: Epidemiological determinants of spread of causal agent of severe acute respiratory syndrome in Hong Kong. Lancet 2003; 361:1761–6

12. Hoffman PN, Williams J, Stacey A, Bennett AM, Ridgway GL, Dobson C, Fraser I, and Humphreys H: Microbiological commissioning and monitoring of operating theatre suites: A report of a working party of the Hospital Infection Society. J Hosp Infect 2002; 52:1–28

13. Lew TWK, Kwek TK, Tai D, Earnest A, Loo S, Singh K, Kwan KM, Chan Y, Yim CF, Bek SL, Kor AC, Yap WS, Chelliah R, Lai YC, Goh SK: Acute respiratory distress syndrome in critically ill patients with SARS. JAMA 2003; 290:374–80

14. From the Centers for Disease Control and Prevention: Cluster of severe acute respiratory syndrome cases among protected health-care workers—Toronto, Canada, April 2003. JAMA 2003; 289:2788–9

15. Sing TTL, Buckley TA, Yap FHY, Sung JJY, Joynt GM: Severe acute respiratory syndrome (SARS): Infection control (letter). Lancet 2003; 361:1386

16. Vastag B: CDC unveils SARS plan; emphasizes rapid identification and communication. JAMA 2003; 290:2533–4