Ian Y. Y. Tsou, FRCR
Jeffrey S. K. Goh, FRCR
Gregory J. L. Kaw, FRCR
Thomas S. G. Chee, FRCR

Index terms:
Pneumonia
Radiology and radiologists, How I Do It
Severe acute respiratory syndrome

Published online before print
10.1148/radiol.2291030789
Radiology 2003; 229:21–26

Abbreviations:
PACS = picture archiving and communication system
SARS = severe acute respiratory syndrome

[1] From the Department of Diagnostic Radiology, Tan Tock Seng Hospital, 11 Jalan Tan Tock Seng, Singapore 308433, Republic of Singapore. Received May 19, 2003; revision requested June 13; revision received June 17; accepted June 18. **Address correspondence to** J.S.K.G. (e-mail: *jeffrey_goh@ttsh.com.sg*).

Severe Acute Respiratory Syndrome: Management and Reconfiguration of a Radiology Department in an Infectious Disease Situation[1]

Severe acute respiratory syndrome, or SARS, is a new infectious disease pandemic with important public health concerns. The high infectivity rate by means of droplet transmission places health care workers at substantial risk of contracting the disease. Radiology departments are particularly affected, since imaging plays a vital role in both diagnosis and follow-up of this disease. The authors outline their experience in infection control and isolation procedures during this outbreak. Barrier precautions, reconfiguration of the department, separation of imaging equipment, cleaning procedures, personal protective equipment, and staff safety are discussed.

Severe acute respiratory syndrome (SARS) is the first worldwide infectious disease outbreak of the 21st century. So far, more than 7,700 patients in three countries have been affected in a short span of 6 months, with most cases within East Asia (1). The mode of transmission has been droplet spread through close personal contact, and the causative organism has been identified as a coronavirus (2).

Imaging has a major role in both diagnosis and categorization of SARS on the basis of case definitions issued by the World Health Organization and the Centers for Disease Control and Prevention. According to these case definitions, a suspected case is classified as a probable case when there are radiographic findings of pneumonia. Laboratory tests such as polymerase chain reaction assays or seroconversion have also been developed and are being verified. In view of the infectious nature of this disease, health care workers form a substantial proportion of those infected with SARS—45% of patients infected from one of three index patients in Singapore are health care workers (3). Isolation and barrier procedures are necessary to protect both health care workers and other patients in the hospital. We describe our experience in the setup of our diagnostic radiology department for an infectious disease situation such as SARS. We also describe the actual reconfiguration and management of our department during the outbreak.

BACKGROUND AND CURRENT SITUATION

Tan Tock Seng Hospital was established in Singapore in 1844. Planning and design of the current hospital building started in 1993, and the building was operational in June 1999, with 1,200 beds. Since it was the tertiary referral center for treatment of tuberculosis and was located at the same site as the Singapore Communicable Disease Centre, there was a need to be able to image patients with infectious disease.

On March 14, 2003, the World Health Organization issued an unprecedented worldwide alert regarding a large number of cases of atypical pneumonia seen in southern China and Hong Kong (4). Prior to this alert, the first three index cases returned to Singapore from Hong Kong on February 25, 2003, after coming into contact with an infected person in a hotel (5). One of these index patients was admitted to Tan Tock Seng Hospital on March 1, 2003, and there was extensive spread of this disease to family members, other patients, visitors, and health care workers in the ward before the patient was isolated. In addition,

some of the other patients had comorbidities, such as chronic obstructive pulmonary disease or congestive cardiac failure, which masked symptoms and made detection of SARS difficult.

The initial response started on March 16, 2003, after a Singapore Ministry of Health notification on March 15, 2003. Tan Tock Seng Hospital was designated as the hospital in Singapore for care of patients with SARS. The measures taken by the hospital as a whole included implementation of barrier precautions for all infected persons, placement of patients in single-bed rooms for isolation, provision of personal protective equipment for health care workers, and erection of an outdoor tent for screening of cases in the emergency department. The next elevation in the alert level took place 1 week later, on March 24, when the hospital was closed, and only patients suspected of having SARS were admitted. Patients with other medical conditions that required hospitalization were transferred to other acute-care hospitals.

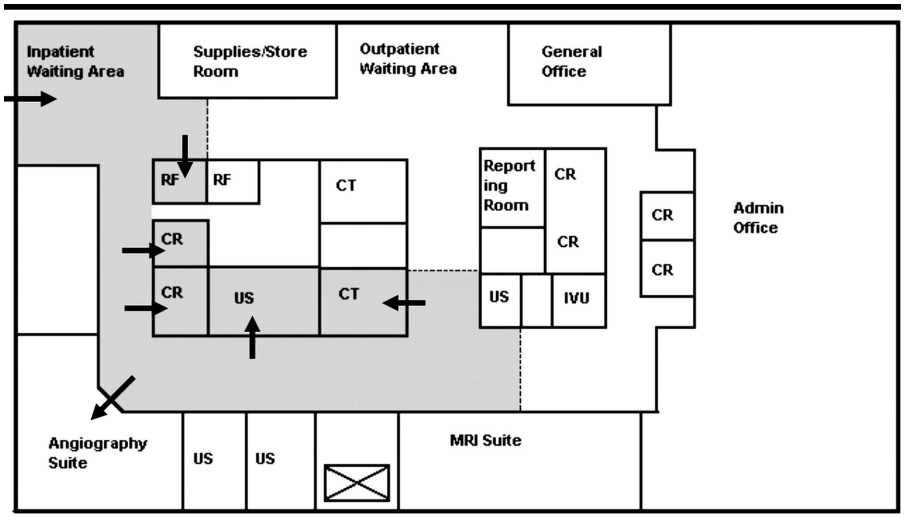

Figure 1. Diagram of the layout of our radiology department (not to scale) shows barriers that limit the movement of inpatients and patients suspected of having SARS to the imaging rooms and areas shaded in gray. Imaging rooms in white were left unused. Arrows indicate the positions of entrances into the department and the various examination rooms. *Admin* = administrative, *CR* = computed radiography, *RF* = radiographic fluoroscopy suite, *IVU* = intravenous urography suite.

BARRIER PRECAUTIONS AND RECONFIGURATION OF THE RADIOLOGY DEPARTMENT

The diagnostic radiology department took additional measures in addition to those implemented throughout the hospital. The department already had separate inpatient and outpatient entrances, so the waiting areas for inpatients and outpatients were also separated to minimize contact between these two groups of patients. Barriers were also placed to cordon off the area reserved for inpatients, and these served as a visual reference for staff to differentiate the two areas (Fig 1). Directional signs were put up to guide outpatients and nursing and portering staff who accompanied inpatients.

Screening measures were implemented at the outpatient entrance. A reception area was set up to screen all incoming patients, and this was staffed by a nurse and a nursing aide. Personal information and contact telephone numbers for each patient or visitor who entered the department were recorded. This was done to facilitate contact tracing if needed. A series of recommended questions was asked, including whether they had fever, cough, or difficulty breathing; whether they had traveled to certain countries afflicted with SARS, as listed by the World Health Organization; and whether they had close contact with anyone suspected of having SARS. Patient temperatures were also recorded with an ear thermometer, which was able to give a reading quickly, within 3 seconds. If the answers to all questions were negative and the person was afebrile, the patient was allowed to proceed into the department for imaging investigation. Accompanying persons were not allowed into the department, unless their assistance was needed if the patient had difficulty ambulating (eg, if the patient was in a wheelchair). In such instances, the accompanying person was similarly required to answer the questionnaire and submit to a temperature check.

Staff from other clinical and administrative departments were also stopped at the door, and the radiology staff met them at the barrier. Radiographic consultations were conducted by means of telephone and the picture archiving and communication system (PACS), with a small number of consultations conducted in the reception area for assessment of radiographs from outside institutions. Reports were written for all screening chest radiographs in the PACS within 2 hours of imaging to reduce the number of requests for reports. This was necessary because our radiologic information system, or RIS, had not been installed yet, and the hard-copy radiology reports still needed to be dispatched to the wards.

The emergency department was reconfigured to receive patients suspected of having SARS for screening. The floor area of the outdoor tent was increased and extended into an open-air space (parking lot) to cater to a larger number of persons in attendance. It was kept in the open to allow better ventilation and reduce the risk of contamination of the building and the air-conditioning systems. A designated decontamination area was identified for the very ill and high-risk patients after triage. Three bedside x-ray units were set up at one end of the tent, with appropriate lead shields placed around them to reduce radiation exposure.

A form was designed for inpatient screening for SARS (Fig 2) to allow segregation of patients according to their perceived risk. This screening form was completed by the ward physician and was submitted with the request form for imaging. Pertinent clinical details, such as presence of fever, white blood cell count, and contact history were assessed by the radiologist on duty, who decided whether to accept the imaging request, and if so, where imaging was to be performed. This was applied to all inpatient requests for ultrasonography (US), computed tomography (CT), fluoroscopy, angiography, and interventional procedures.

Inpatients categorized as not having SARS according to the infectious disease physician were allowed entry to the radiology department. These patients were brought into an inpatient holding area while their case records and temperature charts were checked and verified by a radiologist to ensure that they were not classified as having SARS and were afebrile. Only then were they transported

Diagnostic Radiology - Checklist for Special Radiological Investigations

Name: _____

NRIC: _____

Patient's Sticky Label (if available)

Ward/Bed No: _____ **Name of Requesting Doctor:** _____

Contact Number: _____

Date & Time of Request: _____

Investigation: _____

SARS Status: Probable ☐ Suspect ☐ Observe ☐ Unknown ☐

Fever: No ☐ Yes ☐ No of Days _____ Current Temp _____

White cell count _____ Platelets _____

Latest CXR: Normal ☐ Abnormal ☐

For CT Scan with contrast, creatinine level _____

Any other relevant information _____

For clarifications or in doubt, please call duty radiologist at ext 8131

For Radiology Dept use only

Outcome: To be done Date / Time: _____

Dept ☐ B3 CT ☐ Portable ☐ NNI Portable CT ☐

Postponed to _____

Vetted by: Radiologist _____

Date _____

Figure 2. Screening form for all inpatient imaging requests to assess probability of SARS. *CXR* = chest radiography.

into the procedure room in the department.

SEPARATION OF IMAGING EQUIPMENT AND CLEANING PROCEDURES

Imaging examinations were performed outside the department as often as possible. The bedside x-ray units in the emergency department were divided, with one placed in the decontamination and/or high-risk area and the other two placed in the low-risk area. Inpatient radiography was also performed with bedside units in the ward. At the peak of the outbreak in mid-April, our bedside radiography teams performed an average of 550 radiographic examinations in the emergency department and in the wards. All computed radiography plates that were used for conventional radiography were enclosed in a plastic sheet, and these sheets were disposed of after every use. The cassette surfaces were wiped with a disinfectant (70% alcohol wipes). We encountered no problems with the plastic wrapper causing artifacts that led to degradation of image quality.

For modalities for which we had more than one imaging unit (CT, US, fluoroscopy), we also divided the use such that each room was dedicated to imaging of either inpatients or outpatients only. We already had separate radiography rooms in different areas for the inpatients and outpatients.

US in patients with SARS and those suspected of having SARS was performed in the ward. Indications for US varied. During this outbreak, we noticed a higher incidence of deep venous thrombosis in our nonambulant patients with SARS (unpublished data, 2003). As part of the illness, there also is frequently elevation of liver enzyme levels, and our clinicians sometimes required us to exclude a liver abscess as the cause. Our more elderly patients also had other comorbidities that required further evaluation. A dedicated US machine was used (Sonosite; Sonosite, Bothell, Wash), and the machine was wrapped in clear plastic with a plastic sheath over the probe. The US radiologist and sonographer operated as a team to expedite both preparation for US and verification of findings in real time. This was done to minimize the length of exposure of the team to the patient. Full personal protection measures (N95 mask, gown, gloves, and goggles) were used, with powered air-purifier respirator hoods whenever appropriate. These hoods have a ventilation fan that filters surrounding air for breathing. The patient was also given a surgical mask to wear during the US examination. Another high-end US machine (ATL 5000; Philips Medical Systems, Andover, Mass), which was permanently located in the intensive care unit, was used to scan critically ill patients.

For all CT requests, patients were stratified according to suspicion of SARS infection. On the basis of this classification, patients were assigned to CT scanners that were physically separate within the hospital. This was done to reduce cross infection with other patients who required CT. In addition, the scanning order was stratified, with patients considered at the least risk for SARS undergoing CT first. The facility and equipment were cleansed thoroughly between patients.

The CT unit (Tomoscan M; Philips Medical Systems) routinely used in the neuroradiology department for intraoperative head scanning was used for all probable cases of SARS or cases in which SARS was highly suspected. This single–detector row spiral CT scanner was located in an empty ward on the same level as the intensive care unit. Movable lead shields were placed along the walls that

faced the inside of the building. A power injector was used for intravenous contrast material administration. The protocol for each case was determined by the radiologist prior to the examination, and the images acquired were sent via the hospital network to the PACS.

The multisection CT scanner (Aquilon; Toshiba America Medical Systems, Tustin, Calif) from the radiation therapy department was also used three afternoons a week. Patients scanned with this unit were under observation or were febrile and were classified as not having SARS or as mildly suspected of having SARS. These examinations were the last to be performed each day. Images were transferred by means of magnetic optical disks to the Toshiba CT scanner within the department and from there to the PACS. A similar Toshiba multisection CT unit within the diagnostic radiology department was used to scan outpatients who were screened and deemed to be of the same minimal risk as were well members of the public, with no risk factors for SARS.

All SARS-related imaging that required fluoroscopy or angiography was performed with the fluoroscopy unit (Opescope WHA50 C-arm; Shimadzu Medical Systems, Torrance, Calif) in the coronary care unit, which is usually used during cardiac pacing. This unit was suitable for real-time imaging; however, the quality of digital subtraction angiographic images was not adequate to depict fine details. During this period, this unit was used mostly for nonvascular procedures, such as drainage of pleural effusions or intraabdominal fluid collections.

Only one magnetic resonance (MR) imaging unit was available in the department. Since it was not possible to segregate cases by location, we used an arbitrary interval of at least 1 hour between patients after room decontamination. There was little demand for MR imaging of patients with SARS, however, mainly because it would likely add little to what can be seen at CT regarding pulmonary disease.

All surfaces that were in contact with the patient and all horizontal surfaces within the room were wiped with a disinfectant solution (description of composition to follow) after the patient left the room. The CT and MR imaging gantries were also cleaned, even though there was no direct patient contact. Table and couch surfaces were covered with a disposable sheet that was changed after every patient. All rooms designated for imaging of patients with SARS were disinfected after every patient and were left for at least 30 minutes to air out. The disinfectant used was 1:40 diluted bleach, 1 per 1,000 ppm sodium hypochlorite, and 70% alcohol for metallic surfaces. The cleaning schedule was stepped up—general areas such as corridors were cleaned every 3–4 hours instead of daily. Vacuuming and mechanical buffing within the department were temporarily halted to reduce risk of aerosolization of potentially infectious material. Manual sweeping with a broom and mopping were implemented instead. Biohazard disposal bags were also placed in every room. Since the radiology department is located on a basement level, ventilation involved use of the air-conditioning system. This system had already been configured such that the circulation was kept separate between the inpatient, outpatient, and administration areas.

PERSONAL PROTECTIVE EQUIPMENT AND STAFF SAFETY

Universal precautions were implemented for all staff who dealt with patients with SARS or patients in whom SARS status was unknown. These precautions included hand hygiene, contact, and airborne precautions: Staff were required to wear a mask, cap, gown, and gloves during direct patient contact, and the gown and gloves were changed between contact with each patient. Instructions were given to wash hands before putting on the mask and to mold the nasal ridge of the mask to ensure a good seal. The N95 respirators and filtration masks were fitted individually at one of many mask-fitting and training sessions. Qualitative fit was also tested with a chemical spray; if the mask fitted well, no chemical taste could be detected. Goggles were used if the patient was coughing, if contact with the patient's body fluids was expected, or if an invasive procedure was being performed. Powered air-purifier respirator hoods were also worn if the procedure was anticipated to be long or if there was risk of aerosolization or fluid splatter.

These personal protective measures were used in the diagnostic radiology department and throughout the hospital and were particularly emphasized to personnel at higher risk, including sonographers and US radiologists, who were in prolonged close contact with patients when performing US. Another area of increased risk is the angiography and interventional suite, where there is prolonged contact with the patient, as well as contact with secretions, blood, or bodily fluid.

The radiographers and technicians in the department who had direct patient contact were organized into different teams to deal with inpatients and outpatients. The inpatient team was further divided into three teams: one in the radiology department, one in the emergency department, and one in the wards for bedside radiography. These groups of radiographers were also placed on fixed rotating shifts for 2 weeks. All this served to reduce mingling and contact between the staff. All radiology staff with direct patient contact in the inpatient and emergency areas were provided with hospital clothing or scrubs that they changed into during their shift. At the end of the shift, they could shower and change into their own clothes before leaving the hospital.

All radiology staff took and recorded their own temperatures at the beginning, in the middle, and at the end of their shifts. Those with a temperature higher than 37.5°C were sent to the emergency department for screening and given medical leave or isolated as necessary. A supervisor was appointed to every grade of staff to oversee that the thrice-daily temperature recordings were obtained punctually. The head of the department was alerted immediately to any staff member with fever and ensured compliance with the follow-up action according to hospital guidelines. Separate rest areas were designated for staff with direct patient contact to reduce mingling of different groups of staff. Handwashing procedures were reinforced, antiseptic hand wash solutions were placed at every sink, and alcohol hand-rubs were placed at reception counters and common areas.

Compliance with these new and admittedly restrictive policies was surprisingly easy. This was because we were all working in a climate of fear.

Radiologists and senior radiographers attended daily briefings to keep updated on events, and input was sought on management of workflow and any problems that arose from such changes. Probable SARS cases were reviewed at the readout session each morning, so that everyone was familiar with the spectrum of radiologic findings. The rest of the department attended a second briefing at the end of each working day for further education and discussion.

At the time of writing this article, plans were underway to make use of an unoccupied building from an adjacent com-

munity hospital. Renovations are being proposed for this six-story building to provide isolation rooms with incorporation of appropriate radiologic modalities. We have a national register of patients seen at the emergency department of Tan Tock Seng Hospital for possible SARS and all patients admitted with a final diagnosis of SARS at discharge. This registry is Web-based and is open to those who are duly licensed to access its information, which consists of confidential medical data.

Our department and hospital have not reverted back to normal operations yet, mainly because of a fear of a "relapse." What we have realized is that the way we practice will have to change drastically and permanently. A team has already been set up by our department to look into revision of all our operating procedures, again with input from our infectious disease experts.

DISCUSSION

The speed and extent to which SARS has spread in 2 months is unprecedented in recent times, and this has been aided by its contagious nature and the prevalence of airborne travel. When compared with other infectious diseases in modern history, there are two main factors that contribute to its rapid spread. The droplet mode of transmission means that a person can be infected easily by means of casual contact or even fomites on contaminated environmental surfaces. The presence of local transmission with human-to-human spread is the other factor, as compared with some biological terror agents such as inhalational anthrax, where the disease is not contagious from an infected person to an uninfected one.

The degree of response by the radiology department and the hospital as a whole to any infectious disease outbreak is determined primarily by the estimated risk of cross infection to staff and other patients. If this risk is low, then appropriate precautions taken only by staff in direct contact with the patient may be adequate. If the risk is high, then proportionally tighter measures need to be implemented to limit spread of the disease, particularly among health care workers. Some of these measures that can be implemented immediately include reinforcement of personal hygiene, especially hand hygiene. Protective equipment such as gowns, gloves, and masks must be made readily available, and staff must be trained in the correct use of these items.

Hospitals play an important role in the chain of medical care in any infectious disease outbreak, in cases of both natural transmission and bioterrorism events. The West Nile virus outbreak in New York City, NY, in 1999 and the anthrax episodes in 2001 served as wake-up calls to the medical community. A recent survey of 30 hospitals revealed that only 30% had preparedness plans for a biological terror attack in their hospital disaster plans (6).

Victims of biological terror are likely to report to emergency departments of hospitals, and at the beginning, these will be isolated incidents or will occur in small numbers. Patients exposed to infectious agents spread by means of inhalation will present with respiratory symptoms, and chest radiography is an important factor in helping to confirm the presence of disease and to distinguish between different diseases (7,8).

One of the main factors in management of any infectious disease situation is whether it is contagious or noncontagious. If a potentially contagious patient is brought into the department, then the department and the radiology staff will be inadvertently contaminated. The department may then have to close for decontamination, and the staff may be quarantined. Radiology support to the hospital will be hampered. To prevent this scenario from happening, all potential patients should be sent to areas outside the department that are already considered "contaminated" to undergo imaging. To reduce the risk of contamination at our hospital as much as possible, most imaging is being performed at the bedside.

Once a contagious infectious disease situation has been identified, the radiology senior management have to consider four main areas of response: data gathering, collaboration, needs assessment, and expert advice (9). Data gathering includes dissemination of up-to-date case definitions and confirmatory tests to all staff with direct patient contact to allow appropriate barrier precautions to be taken. All typical and atypical imaging features of the disease should be made known to all radiologists to assist in recognition of the disease at imaging and to allow accurate reporting of these findings. We stored images of all probable cases of SARS in a designated folder in the PACS so that these images were readily available for any radiologist to review, and comparison with images from previous imaging studies was also facilitated.

Collaboration with the radiology departments of other hospitals is crucial, since the initial patients may present to different centers, depending on geographic location and travel distance. These patients may be few in number at a single hospital, but if combined, a more accurate overall picture develops in terms of both imaging features and epidemiology. Dissemination of this information to all health care facilities will also lead to early recognition of the disease, and appropriate isolation measures may be instituted.

The support our department received from other hospitals and equipment vendors was a key factor in enabling us to adapt quickly to the new system and still service our hospital. All available bedside x-ray machines from every hospital in our country were loaned to us. Our equipment vendors also diverted bedside units to us that were scheduled to be delivered to other destinations.

A specific needs assessment has to be made quickly, with deployment of equipment to designated areas. The number of units required for each modality has to be evaluated. For example, bedside x-ray units were placed in the open-air area rather than within the building to allow better ventilation. A smaller and more portable US machine was borrowed from another department to perform bedside US, in place of the more bulky unit that we usually use. We also borrowed bedside x-ray units from other centers not affected by the outbreak to supplement our capability for bedside radiography.

It is important to obtain expert advice to refine procedures that have been implemented. The infectious disease team should review the practices in the radiology department, where there is direct patient contact, to help reinforce proper infection control techniques and close any loopholes. Input from the chest physician, intensivist, microbiologist, and pathologist regarding the disease process and complications is useful to the radiologist during image assessment. A "town hall" meeting involving all clinical disciplines may be an effective way of spreading important information effectively.

The Internet has been used for distribution of medical information, and the almost-instantaneous exchange of information regarding infectious disease outbreaks makes it an indispensable tool for the physician. Within 1 year of the posting of information on infectious diseases by the Centers for Disease Control and Prevention on the World Wide Web, 50% of requests for information were handled over the Internet. The Internet also allows for case definitions and guide-

lines to be posted in a timely manner and enables uniformity in case reporting. Links to other Web sites as hypertext within a Web page also provide more information from other sources, although the credibility of each Web site must be evaluated on an individual basis. Surveillance data on an infectious disease outbreak can also be rapidly communicated back to a central coordinating body by means of the Internet or e-mail.

Since our hospital received the first patients with SARS in Singapore and local transmission occurred before isolation procedures were implemented, our center was one of the first in the world to handle a large number of SARS cases. Once the previously described measures were implemented, there were no health care workers in either the radiology department or the entire hospital who subsequently contracted SARS. We believe that our experience in management and reconfiguration of our radiology department and workflow changes implemented in the current SARS situation is useful for other radiology units in preparation for dealing with imaging of patients with SARS.

Acknowledgments: We acknowledge the assistance provided by the Department of Neuroradiology, National Neuroscience Institute, Singapore, for use of the bedside CT scanner, and the Department of Emergency Medicine, Tan Tock Seng Hospital, Singapore, for use of the portable US machine during this period.

References

1. World Health Organization. Cumulative number of reported probable cases of severe acute respiratory syndrome (SARS). Available at: *www.who.int/csr/sars/country/2003_05_17/en/*. Accessed May 17, 2003.
2. Peiris JS, Lai ST, Poon LL, et al. Coronavirus as a possible cause of severe acute respiratory syndrome. Lancet 2003; 361: 1319–1325.
3. Hsu LY, Lee CC, Green JA, et al. Severe acute respiratory syndrome (SARS) in Singapore: clinical features of index patient and initial contacts. Emerg Infect Dis [serial online]. June 2003. Available at: *www.cdc.gov/ncidod/EID/vol9no6/03-0264.htm*. Accessed May 2, 2003.
4. World Health Organization. Outbreak news: acute respiratory syndrome. Weekly Epid Rec 2003; 78:73–80.
5. Centers for Disease Control and Prevention. Severe acute respiratory syndrome: Singapore, 2003. MMWR Morb Mortal Wkly Rep 2003; 52:405–410.
6. Treat KN, Williams JM, Furbee PM, et al. Hospital preparedness for weapons of mass destruction incidents: an initial assessment. Ann Emerg Med 2001; 38:562–565.
7. Ketai L, Alrahji AA, Hart B, Enria D, Mettler F. Radiologic manifestations of potential bioterrorist agents of infection. AJR Am J Roentgenol 2003; 180:565–575.
8. Cunha BA. Anthrax, tularemia, plague, ebola or smallpox as agents of bioterrorism: recognition in the emergency room. Clin Microbiol Infect 2002; 8:489–503.
9. Katona P. Bioterrorism preparedness: a generic blueprint for health departments, hospitals and physicians. Infect Dis Clin Pract 2002; 11:115–122.
10. Manangan LP. The infection control information system of the Hospital Infections Program, Centers for Disease Control and Prevention. Am J Infect Control 1996; 24:463–467.