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Transmission of SARS to healthcare workers. The experience of a Hong Kong ICU

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Abstract *Objective:* To describe the extent and temporal pattern of transmission of severe acute respiratory syndrome (SARS) to intensive care unit staff. *Design:* Retrospective observational cohort study. *Setting:* University hospital intensive care unit, caring solely for patients with SARS or suspected to have SARS. *Participants:* Thirty-five doctors and 152 nurses and healthcare assistants who worked in the ICU during the SARS epidemic. *Interventions:* Infection control measures designed to prevent transmission of disease to staff were implemented. *Measurements and results:* Sixty-seven patients with SARS were admitted to the intensive care unit. Four nurses and one healthcare assistant contracted SARS, with three of these developing symptoms within 10 days of admission of the first patient with SARS. Doctors were exposed to patients with SARS for a median (IQR) of 284 (97–376) h, while nurses and healthcare assistants were exposed for a median (IQR) of 119 (57–166) h. The ICU did not meet international standards for physical space or ventilation. *Conclusions:* In an ICU in which infection control procedures are rigorously applied, the risk to staff of contracting SARS from patients is low, despite long staff exposure times and a sub-standard physical environment.

Keywords Disease outbreaks · Infection control · Occupational health · Severe acute respiratory syndrome

Introduction

The global epidemic of severe acute respiratory syndrome (SARS) illustrated the risk to healthcare workers from this disease [1]. The risk may be particularly high amongst healthcare workers in intensive care units (ICU) [2], but there are only limited data from which to estimate this risk. Previous studies have reported selected cases or outbreaks and may therefore give an overestimate of the risk to ICU staff [2, 3, 4]. This is important, because the perceived risk of infection may affect the willingness of staff to work in the ICU in any future epidemic.

We describe our experience of infection of healthcare workers in our ICU, which was entirely dedicated to the care of patients suspected to have SARS for 4 months. Outcome data from the first 54 patients admitted to our ICU

have previously been published [5]. Some of these data have previously been published in abstract form [6].

Methods

The study was carried out with the approval of the Clinical Research Ethics Committee of The Chinese University of Hong Kong. It was a retrospective audit of the outcome of measures to prevent SARS infection amongst ICU staff.

The study period was from 13 March (the day after admission of the first patient with SARS) to 31 May. By the end of the period, all patients remaining in the ICU had been in the ICU for at least 2 weeks, and there were no further admissions with SARS. During the study period, only patients with SARS or suspected to have SARS were admitted to our ICU. The layout of the ICU is shown in Fig. 1. The ICU is normally a 22-bed adult multidisciplinary facility, but for 2 days during the first week of the epidemic, the capacity was increased to 24 beds by converting one of the four-bed cubicles into a six-bed cubicle. The number of air changes per hour was 15.6 in open patient areas, 16.9 in isolation rooms and 16.1 in offices. Seventy percent of exhaust air was recycled, except in isolation rooms, where 76% was recycled. Recycled air was filtered prior to recirculation. The quoted efficiency of the filters was 95% of 0.3 μm saline particles. Isolation rooms were either not used for isolation or were used for protective isolation of patients in whom the diagnosis of SARS was unclear. The nurse-to-patient ratio was 1:1. The following data were collected from patient notes and charts by a trained research nurse: patient demographic data and factors that might affect the rate of transmission of SARS—duration of invasive mechanical ventilation, place of intubation, ICU length of stay, number of days with diarrhoea and days from symptom onset to ICU admission. Diarrhoea was defined as two or more loose bowel motions in a calendar day. Duration of exposure to SARS patients was obtained from nursing and medical rosters. Only staff on the roster solely to work in the ICU were included in the study. Time for rest periods was taken into account when calculating number of exposure hours. The exposure hours therefore reflect time spent in contaminated areas of the ICU. All staff who became infected were questioned shortly after becoming infected, to obtain the data presented in Table 1. All other staff who worked in the ICU during the study period were asked, after the end of the study period, to give a sample of blood to test for SARS seroconversion, to detect asymptomatic infection. Written informed consent was obtained from all staff who agreed to testing.

Infection control procedures are given in detail in the electronic supplementary material. The procedures evolved during the first few weeks of the epidemic. The

Fig. 1 Floor plan of the ICU. The on-call rooms (*On call rm*) were not used by resident medical staff during the SARS outbreak (*PPE* personal protective equipment)
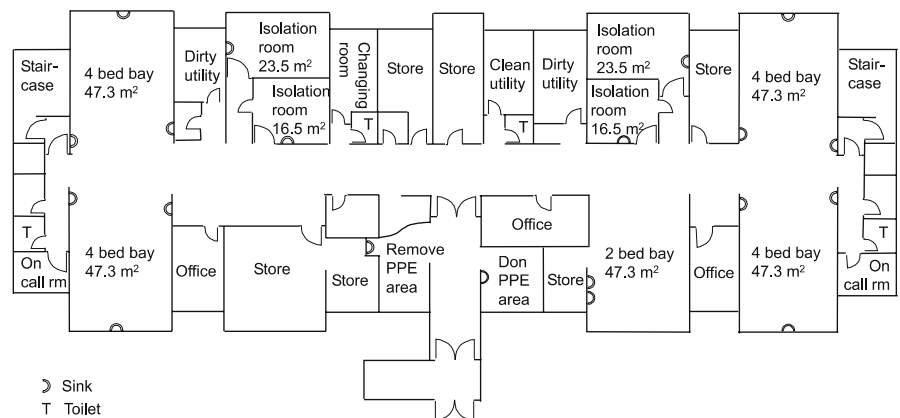

Table 1 Details of the five healthcare workers who contracted SARS

Job	Study day of symptom onset	Event believed to have led to infectious exposure	Breach of infection control guidelines	Type of patients cared for at presumed time of exposure
Volunteer ICU nurse	10	Feeding a patient who was spitting and coughing	None recalled	Non-intubated, non-confused
Full-time ICU nurse	9	Coughing, spitting patient with urinary incontinence	Scratched nose	Non-intubated
Full-time ICU nurse	17	No specific event	None recalled	Both intubated and uncooperative non-intubated patients
Healthcare assistant	8	No specific event	None recalled	Intubated
Full-time ICU nurse	45	Soiling of clothes during bed bath	None recalled	Non-intubated

Fig. 2 Time of introduction and discontinuation of various infection control measures. (*NIPPV* non-invasive positive-pressure ventilation, *N95* use of negative-pressure respirator of N95 standard or higher)
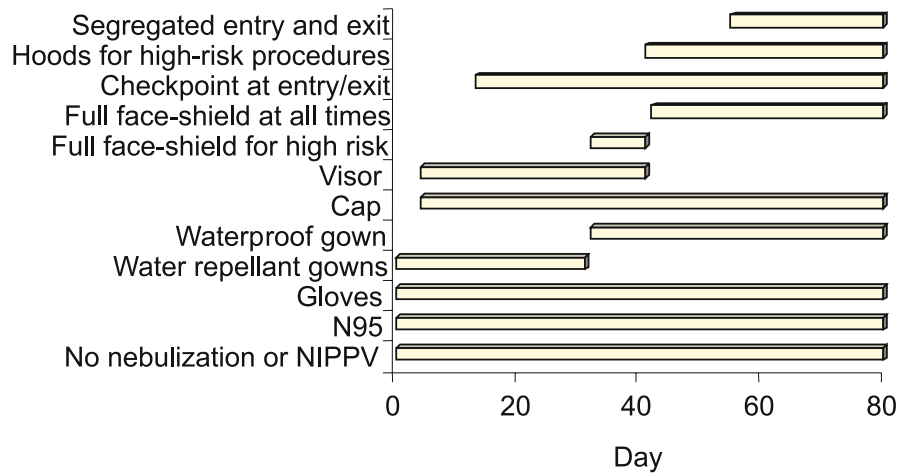
Fig. 3 Temporal distribution of admissions
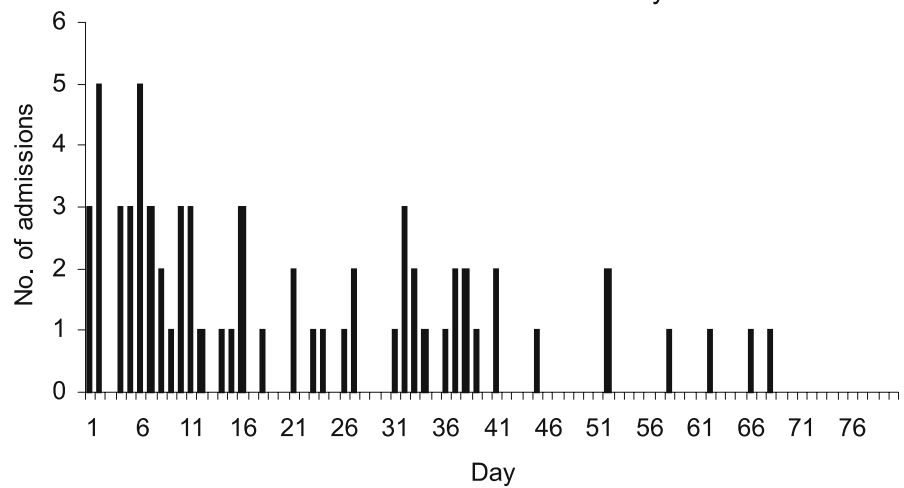
time of introduction of the major components of the protocol is illustrated in Fig. 2. In brief, the final protocol consisted of the following: All staff entering the ICU were required to clean their hands and don a waterproof gown, gloves, cap, full-face shield and fit-tested N95 or N100 mask. Initial fit testing involved a qualitative fit test, with a subsequent quantitative test for those who failed the qualitative test. Staff for whom an adequate fit could not be achieved with a N95 or N100 mask were issued powered air-purifying respirators. A nurse was stationed at the entrance of the ICU to ensure compliance, and staff were encouraged to ensure each other's safety by pointing out protocol errors. Entry and exit from the ICU were segregated. Hoods were the only additional personal protective equipment used for high-risk procedures, such as intubation. Patients were given oxygen at flow rates of up to 15 l/min via simple and reservoir face masks. Venturi-type masks were not used.

Statistics

Descriptive statistics were calculated using Excel 2000 (Microsoft, Redmond, WA, USA) and Hutchon's confi-

dence interval calculator (http://www.hutchon.freeserve. co.uk/Wilsons.htm).

Results

During the study period, 67 patients who met the US Centers for Disease Control and Prevention (CDC) criteria for SARS were admitted, with eight patients being admitted twice. All had subsequent laboratory confirmation by serological examination for SARS coronavirus. The level of SARS coronavirus IgG antibody was measured by an immunofluorescence assay. Paired serum samples were tested. The tests were regarded as positive if a sero-conversion or fourfold rise in antibody titre was detected. The time distribution of admissions and the number of SARS patients physically present in the ICU on any given day are given in Figs. 3 and 4. Median (interquartile range (IQR) length of ICU stay was 13 (6–24) days. Mean (SD) number of days between symptom onset and ICU admission was 9.5 (4.7) days. Median (IQR) age was 47 (36–59) years and median (IQR) APACHE II score 10 (8–13). The temporal distribution of admissions of patients and the number of patients in the ICU on any

Fig. 4 Number of patients in the ICU on any given day. The number is the total number of patients who were present in the ICU at any time on the given day and therefore may exceed the bed capacity of the ICU
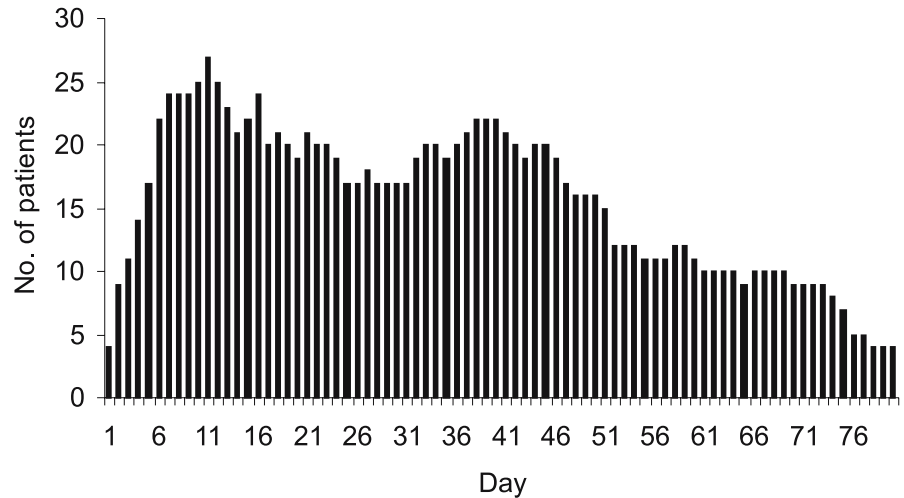
given day are shown in Figs. 3 and 4. Thirty-two patients were ventilated for a median (IQR) of 14.5 (7–25) days. Total number of ventilated patient days was 525. No patients received non-invasive ventilation. All patients who were ventilated were intubated by ICU doctors, 28 in the ICU and four in other areas of the hospital. Diarrhoea occurred in 55% of patients. Thirty-five doctors worked in the ICU for a median (IQR) of 284 (97–376) h. One hundred fifty-two nurses and healthcare assistants worked for a median (IQR) of 119 (57–166) h. The difference in working hours between doctors and nurses and healthcare assistants was statistically significant ($p < 0.001$).

Five ICU healthcare workers developed SARS (2.67%, 95% confidence intervals 1.15–6.11). Details are given in Table 1. None were involved in intubation at the time of likely exposure (based on incubation period of 6–10 days). None of the 37 ICU staff who underwent testing for asymptomatic infection tested positive. This included one nurse who suffered a needle-stick injury with a hollow needle contaminated with blood.

Discussion

The incidence of SARS amongst healthcare workers in our ICU was low despite a prolonged period of exposure to patients with SARS and a physical environment which was poor in terms of space and ventilation. The bed spaces in our ICU are considerably smaller (Fig. 1) than current minimum standards [8], and, although the air changes in our ICU exceed the recommendation for isolation rooms, a very high proportion of the air is re-circulated. CDC guidelines recommend not re-circulating exhaust air [9]. Furthermore, the re-circulated air should be filtered through a HEPA filter, which filters 99.97% of 0.3 μm saline particles, whereas our filtration system filters only 95%. In an intensive care unit that meets current international recommendations for space and ventilation, it might be expected that the risk to staff would be lower.

It is likely that the patients were maximally infectious during their ICU stay. The patients were admitted a median of 9.5 days after symptom onset, and maximal virus shedding occurs at around 10 days [7].

The majority of cases of healthcare worker infection occurred early in the outbreak (Table 1), with three of five cases becoming symptomatic within 10 days of admission of the first patient with SARS. The average incubation period of SARS is 6 days, with a range of 2–16 days [1, 10]. This strongly suggests that the three healthcare workers who became symptomatic within 10 days of admission of the first patient with SARS were infected in the first few days of exposure, when the protective strategies were being developed and vigilance in the correct use of protective equipment was probably lowest. Thereafter, only two members of staff became infected. None of the staff who agreed to testing showed evidence of asymptomatic infection. Our data suggest that, with adequate infection control measures, the risk to healthcare workers in ICU may not be as high as earlier reports suggested [2, 3, 4]. Although significant asymptomatic infection amongst untested staff remains a possibility, this is unlikely, as other data suggest subclinical infection is rare [11, 12].

We believe that the personal protective procedures adopted in our ICU were effective when rigorously applied and that this was responsible for the relatively low infection rate amongst our staff. A zero infection rate has been reported by a Singapore ICU that admitted 39 patients with SARS following strict imposition of infection control procedures [13, 14]. This unit used an even higher level of protection, using negative-pressure isolation rooms for each patient and powered air-purifying respirators. In contrast, data from a Toronto hospital, in which personal protective equipment was only inconsistently used by a substantial proportion of staff, showed that eight out of

32 critical care nurses exposed to three patients developed SARS. This occurred despite relatively short exposure times (40–935 min) [3].

One of the difficulties in determining the effectiveness of infection control measures in SARS is the bimodal nature of spread with the existence of "super-spreading" incidents, whereby, one individual infects many others, while many individuals do not infect any others [15, 16]. Different rates of infection may simply reflect the presence or absence of "super-spreading" events and may be unrelated to infection control measures. Data from a hospital in Vietnam which treated 33 patients over a 6-week period revealed that no staff became infected despite lax infection control measures during the first week of exposure [17]. It is therefore possible that our low infection rate merely reflects an absence of exposure to super-spreading events. However, we believe this unlikely. Firstly, excluding super-spreading events, SARS is moderately transmissible, with an estimated 2.7 secondary infections per case at the start of the epidemic [15]. Secondly, as discussed above, our patients were likely to be maximally infectious during their ICU admission. Thirdly, many of the individual components of our infection control measures (e.g., use of gloves, gowns, caps and masks) are associated with a decreased SARS infection risk [18, 19]. Fourthly, super-spreading events appear to be associated with older patient age, more severe illness, and larger number of close contacts [16]. Although our patients were relatively young, they were severely ill and, as hospitalised patients, had a large number of close staff contacts.

If our protective measures were effective when fully developed and rigorously applied, then the logical conclusion is that intensive care units should have strategies in place to prevent infection of healthcare workers; all staff should be fully aware of the procedures and be fully trained in the use of protective equipment. Strategies to enforce infection control procedures should also be devised [20]. This need for preparation is given greater urgency by the threat of an avian influenza pandemic.

All the staff who were infected were nurses or healthcare assistants, although the exposure time was greater for doctors. We speculate that the difference relates to the type of exposure. It is likely that the nurses, in particular, spent a greater proportion of their exposure time in close proximity to the patients, and both nurses and healthcare assistants are likely to have had greater exposure to the patients' faeces.

The study period did not correspond to the entire period during which there were patients with SARS in our ICU, as we felt that it was unlikely that the staff was significantly exposed to SARS virus beyond the end of our study period. The last patient was discharged from the ICU 61 days after the end of the study period. No staff were infected during this time.

In summary, our data indicate that, with infection control measures, the risk to ICU healthcare workers of acquiring SARS is low, despite prolonged exposure to patients with SARS. The timing of staff infections suggests that it is important that infection control procedures are applied rigorously from the start of the epidemic.

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