Introduction

Severe acute respiratory syndrome (SARS) is clinically severe with a high proportion of cases, approximately 20%, requiring intensive care unit (ICU) admission. The provision of organ support in the ICU therefore plays a potentially important role in reducing mortality, which may be as high as 10% for younger patients and 50% for patients older than 60 years. Radiological imaging of the chest is important because of the overriding importance of respiratory failure in determining the management and outcome of SARS. At the time of writing there were little published data detailing the ICU management and outcome of SARS, and much the information that follows is based on observational data derived from our institution.

ICU Admission

Patients generally present to the hospital with fever, chills, rigors, myalgia, headache and a non-productive cough. Common laboratory features include an elevated serum lactate dehydrogenase concentration, lymphopenia, hypocalcaemia and moderate thrombocytopaenia. SARS is a slowly progressive disease and the average interval from the onset of symptoms to requirement for ICU admission is approximately 10 days. Clinical deterioration of cases admitted to the ward is manifested by progressive hypoxia and dyspnoea, and is accompanied by progression of pulmonary infiltrates on chest radiograph. Close monitoring of disease progress in the general wards is therefore important to detect deterioration in those patients who will be admitted to ICU. Because clinical deterioration appears to be closely mirrored by the development of progressively worsening radiographic opacity, chest radiographs may serve to be a useful objective predictor of disease progression.

Key Points

- Severe SARS patients usually develop progressive dyspnoea and hypoxia over about 10 days prior to ICU admission.

Admission to ICU is invariably a consequence of progressive, severe respiratory failure unresponsive to administration of moderate concentrations of inspired oxygen. In general patients were admitted following

1. failure to maintain an arterial oxygen saturation of at least 90% while receiving
supplemental oxygen of 50%, and/or
2. respiratory rate greater than 35 breaths per minute.

Although chest radiograph features of bilateral, diffuse consolidation and/or ground glass opacification were present in all but one patient admitted to the ICU, radiograph appearance by itself was not sufficient to warrant ICU admission in the absence of the patient meeting the above pathophysiologic criteria. Typical radiological features seen on admission are areas of consolidation with ill-defined borders, mostly affecting the mid and lower zones. These tend to be bilateral in distribution. There is no evidence of hilar or mediastinal lymphadenopathy, cardiomegaly (unless pre-existing), pleural effusion, cavitation or calcification. The radiographic appearances are non-specific on their own and simulate severe cases of other types of pneumonia, especially bronchopneumonia (Figure 1). Surprisingly, some patients were noted to develop spontaneous pneumothorax and/or pneumomediastinum prior to mechanical ventilation, some even prior to ICU admission (Figure 2). The reasons for this observation are unclear.
Key Points
- Admission to ICU is precipitated by respiratory failure, which is usually the only organ failure present.
- Bilateral diffuse infiltrates are typically seen on chest radiographs.

The demographic profile of patients admitted to ICU is as follows. The average age of ICU admissions with SARS is approximately 50 years (range 23 to 81 years), with an approximately equal number of males and females admitted. All patients admitted to our ICU had severe respiratory failure and most meet the basic criteria for acute respiratory distress syndrome (ARDS). A typical admission APACHE II score is a moderate 10-12, indicating a relative lack of associated deranged physiology.

Key Points
- ICU patient demographics
  - average age of 50 years
  - approximately equal number of males and females
  - all patients admitted had severe respiratory failure
  - most meet the basic criteria ARDS
  - typical admission APACHE II score is 10-12

ICU Management and progress
Medical therapy for SARS is evolving and is an extension of the protocol utilized in the general ward. Currently this includes the use of broad-spectrum antibiotics (to treat common causes of atypical pneumonia), ribavirin and low dose corticosteroids. In addition, Methylprednisolone 500 mg to 1g daily for two to three days is used in an attempt to dampen the inflammatory response in those patients who continue to deteriorate. Deterioration is generally manifested by worsening hypoxia, respiratory distress, and radiological evidence of pulmonary deterioration. High-dose Methylprednisolone may be repeated to a total dosage of up to 5g in the most severe cases. Some of these cases may also receive convalescent plasma donated by patients who had recovered from SARS and/or IgM enriched immunoglobulin. Broad-spectrum antibiotics to cover typical nosocomial organisms are administered at the time of institution of high dose pulse methylprednisolone therapy, but are withdrawn in the absence of obvious clinical sepsis in the first 3 to 5 days.
following high-dose methylprednisolone therapy. Suspected infection is treated early with empirical broad spectrum antibiotics and if necessary, anti-fungal agents. The antibiotic regimen is modified according to the results of bacterial culture of sputum, tracheal aspirate and blood.

**Key Points**

- High dose pulse methylprednisolone is administered to try to suppress the immuno-inflammatory process that apparently affects the lungs in the later, severe stages of the disease.

Supportive management in the ICU focuses on oxygen supplementation and, when absolutely necessary, mechanical ventilation. Oxygen supplementation is provided by the use of nasal cannulae, and where necessary Hudson type masks. The use of entrainment or Venturi-type masks is avoided as the high gas flows generated might encourage dispersal of contaminated droplets during coughing or sneezing. Non-invasive positive pressure ventilation is also avoided because of the risk of viral transmission potentially resulting from mask leakage and high gas-flow compensation, possibly causing wide dispersion of contaminated aerosol.

**Key Points**

- Avoid devices that produce high gas flows

Although radiological changes mirror clinical deterioration in the majority of cases, as with the criteria for ICU admission, the decision to initiate intubation and mechanical ventilation is primarily a clinical one. Criteria for intubation and positive pressure ventilation are:

1. persistent failure to achieve arterial oxygen saturation of 90% while receiving 100% oxygen via a non-rebreathing mask and/or
2. onset of respiratory muscle fatigue as evidenced by an increase in arterial carbon dioxide tension (PaCO₂), sweating, tachycardia and/or a subjective feeling of exhaustion.

While these indications lead to intubation relatively later than might be usually expected, mechanical ventilation is required in 50-60% of patients admitted to the ICU.
Key Points

Criteria intubation and positive pressure ventilation:
1. persistent failure to achieve arterial oxygen saturation of 90% while receiving 100% oxygen via a non-rebreathing mask and/or
2. onset of respiratory muscle fatigue

Usually, mechanical ventilation with synchronized intermittent mandatory ventilation (SIMV), or pressure control ventilation is instituted. Positive end expiratory pressure (PEEP) and inspired oxygen concentration is titrated to achieve an arterial saturation of 90-95%. Tidal volume is maintained at 6-8 ml/kg estimated body weight and plateau pressure maintained at 30 cmH$_2$O or less. PaCO$_2$ was allowed to rise provided the pH was greater than 7.15. A small number of patients unable to meet the above parameters were ventilated in the prone position.

Key Points

- Controlled mechanical ventilation with low tidal volumes and pressures to protect the patient from barotrauma is required in the most severe, progressive cases

Fluid intake and losses are strictly controlled to maintain an intake/output balance of approximately nil. Vasopressors at small to moderate doses are used to maintain adequate blood pressure in preference to the use of bolus fluid infusion. Patients are otherwise managed according to standard ICU organ support protocols.

Key Points

- Excess fluid administration is avoided to prevent pulmonary venous hypertension and potential fluid leakage into the lung

The vast majority of patients admitted with SARS meet the criteria for acute respiratory distress syndrome (ARDS) during the ICU stay. The plain radiograph features of established SARS in the ICU are indistinguishable from those of ARDS (Figure 3). The typical features of ARDS include bilateral widespread, confluent opacification, with the lung periphery
being denser or more extensively involved than the perihilar regions. A “bat’s wing” appearance, where the perihilar regions are more densely opacified, is not a feature of ARDS in SARS but more commonly seen in cardiogenic (left heart failure) pulmonary oedema or that due to renal disease. There is no cardiomegaly, upper lobe pulmonary venous dilatation, peribronchial cuffing, septal lines or pleural effusion. The findings are non-specific for SARS but resemble ARDS from most other non-cardiac causes. It is possible that the pathogenesis of SARS related ARDS results in specific morphological changes that might be demonstrated on CT scan, as typical changes have been described in ALI/ARDS from different etiologies. There are also known to be changes in CT findings over time, particularly related to the duration of mechanical ventilation and the natural evolution of ARDS. Unfortunately no CT images were available for patients in the early acute stage of ARDS, however post mortem histology obtained from patients who died in the early stages of ARDS demonstrated changes consistent with the early and organizing phase of diffuse alveolar damage. The early phase is characterized by pulmonary oedema with hyaline membrane formation suggestive of the acute stage of ARDS and cellular fibromyxoid organizing exudates in the air spaces indicates an organizing phase that follows alveolar damage. Multinucleated pneumocytes are common. SARS is also associated with epithelial-cell proliferation and an increase in macrophages in the alveoli and the interstitium of the lung.

**Figure 3**
Chest radiograph of a 44-year-old male on day 9 after admission to ICU, 14 days after the onset of symptoms. He was receiving mechanical ventilation by pressure control mode, with an inspired oxygen concentration of 60%, a peak pressure of 34 cmH₂O, a tidal volume of 360 ml and PEEP of 15 cmH₂O. There are bilateral almost symmetrical areas of consolidative opacification. This gives an appearance similar to ARDS. A right jugular central venous catheter is present.
Key Points

X-ray features
- indistinguishable from those of ARDS
- bilateral widespread, confluent opacification, with the lung periphery being denser or more extensively involved than the perihilar regions
- “bat’s wing” appearance not a feature
- No cardiomegaly, upper lobe pulmonary venous dilatation, peribronchial cuffing, septal lines or pleural effusion

Key Points

SARS with ARDS:
- Clinical features, chest radiograph, histological and CT findings are similar to those seen in ARDS from other other causes

Despite relatively late intubation and mechanical ventilation and the close attention to limitation of excess pressure and volume during mechanical ventilation, the incidence of barotrauma appears to be high. So far the pneumothorax rate in ventilated patients is approximately 20%. This is substantially higher than that reported previously in ventilated patients with ARDS. At present we have no explanation for this observation, but the relatively high rate of pneumothorax in mechanically ventilated cases, coupled with the occurrence of barotrauma in non-ventilated cases suggests that care needs to be taken to avoid circumstances that might exacerbate the risk of barotrauma. Avoiding mechanical ventilation as much as possible and if required, utilizing low-volume, low-pressure ventilation would seem prudent. Routine daily chest radiographs are recommended to assist early detection of barotrauma and avoid progression to complications such as tension pneumothorax, particularly in mechanically ventilated patients.

Key Points
- Barotrauma appears to be frequent, despite attempts to reduce the incidence
ICU outcome

It is not yet clear what the mortality rate of patients admitted to the ICU will be, but based on outcomes achieved in our cohort so far, is expected to be about 30-35%. The average length of stay in the ICU is about 10 days. A remarkable feature of ICU patients with SARS is the apparent limitation of organ failure to the respiratory system. The median maximal multiple organ dysfunction (MOD) score during the ICU stay in our patients is a moderate to low score of five, with the majority of the score being made up of the respiratory component, again indicating the relative lack of organ failure outside the respiratory system. Nosocomial infection rates appear unusually high. Common organisms include Staphylococcus aureus, Stenotrophomonas maltophilia and Candida albicans. Common sites of infection were the lungs and urinary tract. The high incidence of nosocomial infection may be caused by the use of high-dose steroid therapy, or may be a consequence of the immunosuppressive effects of the disease itself. The ultimate cause of death is usually the result of oxygenation failure, organ failure as a consequence of nosocomial sepsis, or complications of pre-existing comorbid disease.

Key Points

- The mortality of patients admitted to ICU is about 30%. Nosocomial infection, particularly pneumonia, is common

Those patients who require mechanical ventilation remain in the ICU much longer than those who do not, and the average duration of ventilation is currently about two weeks. A large number of mechanically ventilated patients therefore progress beyond the acute stage and into the chronic stages of ARDS. In general, the CT features of late stage ARDS caused by SARS are similar to those seen in late stage ARDS from other causes. CT scans of a number of patients with late stage ARDS were performed (Figures 4 and 5). Patients had bilateral segmental or subsegmental areas of ground glass opacification, which involved most of the lung segments. Consolidative changes were generally of small volume and only a minority of the lesions were segmental. Segmental lesions tended to be in dependent regions. Septal thickening was evident. Irregular interfaces, parenchymal bands and traction bronchiectasis indicated fibrosis in these patients. Patients with fibrosis also demonstrated irregular septal thickening. Small, thick walled pulmonary cysts (less than one centimeter in diameter), were commonly seen. Larger cysts, also thick walled and somewhat distorted in shape, were less commonly seen. Both types of cysts were found in
the dependent and non-dependent segments and in areas of architectural distortion suggesting fibrosis. Interestingly, the duration of mechanical ventilation does not appear to have a major impact on disease progression as measured by CT findings. Severe CT changes of late stage ARDS may be present even in patients not mechanically ventilated (Figure 6). At this stage the outcome of patients with late stage ARDS from SARS is unknown.

**Figure 4**
HRCT of a 33-year-old man 38 days after ICU admission and 46 days after onset of symptoms. This patient had received high concentrations of oxygen and mechanical ventilation in the acute phase. Of special note is a 2cm thick walled cyst in the middle lobe. Multiple smaller, subpleural cysts are present in the right lower lobe anteriorly with thickened interlobular septae. There are architectural distortion, volume loss, bronchiectasis, parenchymal bands and irregularly thickened interlobular septae in the left lower lobe.

**Figure 5a**
HRCT of a 73-year-old man taken 29 days after the onset of symptoms and 23 days after ICU admission and mechanical ventilation. Mechanical ventilation was predominantly achieved by pressure control mode, with an inspired oxygen concentration 60%-100%, a average peak pressure of 28cmH₂O, an average tidal volume of 6.4ml/kg estimated lean body mass and a PEEP rang of 8-15 cmH₂O. There is consolidation in the dependent regions of both lungs. The non-dependent regions show mainly ground glass opacification and thickened interlobular septae. This distribution is typical for ARDS. There is a tiny right sided pneumothorax.

**Figure 5b**
HRCT showing features from the same patient as in Fig 6. Small emphysematous bullae are present in the medial aspect of the right upper lobe. The amount of inflation of the secondary lobules is variable giving rise to the cyst-like (hyperinflated) lobules mixed among lobules with ground glass opacification.
Figure 6
HRCT of the patient whose early chest radiograph is shown in Fig 1, performed 35 days after the onset of symptoms of SARS and in the late stage of ARDS. This patient received high concentrations of inspired oxygen (inspired oxygen concentration > 80%) for more than one week, and oxygen supplementation for more than one month, but was never mechanically ventilated. There is bilateral widespread ground glass opacification with thickened interlobular septae. There is clearing of the opacification in the subpleural 5mm of the lung. A loculated hydro pneumothorax is present in the left major fissure with a chest drain in situ.

**Key Points**

CT features of late stage ARDS caused by SARS:
- **similar to those seen in late stage ARDS from other causes**
- **Ground glass opacification: bilateral segmental or subsegmental, involving most of the lung segments**
- **Consolidative changes: usual subsegmental, larger in dependent regions**
- **Septal thickening**
- **Irregular interfaces, parenchymal bands and traction bronchiectasis**
- **Cysts with thick walls**

**Infection control**

SARS is readily transmissible and high viral RNA concentrations have been detected in respiratory secretions and faeces. Spread probably occurs most frequently via droplets and aerosols, which may be enhanced by the use of nebulizers or similar devices. The virus is stable on surfaces for days after shedding and so contact with infected surfaces could also be a possible source of contamination. In ICUs, where patients with SARS may be clustered together, the concentration of virus in the environment can be expected to be particularly high.
In high-risk environments like the ICU, strict adherence to infection control procedure is critical to prevent transmission. Details of infection control procedures used in the ICU can be obtained online, but some of the most important issues are summarized here.

The ICU should only be accessible to staff directly involved in patient care to prevent unnecessary exposure. Visitors should only be allowed under exceptional circumstances. Personal protective equipment such as N95 mask respirators, caps, goggles or full face shields, disposable gowns and gloves should be readily available to all staff (including visiting staff such as radiographers). All staff should undergo proper training and close supervision during preparation and when leaving the ICU in designated “gown-up” and “gown-down” areas. Initial, formal “fit-testing” with a commercially available kit should be performed to ensure adequate mask size and fit for each individual expected to enter the ICU environment.

**Key Points**

- **ICU should only be accessible to staff directly involved in patient care**
- **Personal protective equipment such as N95 mask respirators, caps, goggles or full face shields, disposable gowns and gloves should be readily available**
- **All staff should undergo proper training in putting on protective gear**

Infection control behavior in the ICU must be monitored and repeatedly enforced. Regular hand cleansing and glove changing between patient contacts is essential. This aspect of infection control is important for radiographers and assisting technicians from the radiology department to remember as they are frequently required to move from one patient to another while completing routine daily radiograph exposures. When exiting the ICU the “gown-down” area should also be regulated and monitored. Inanimate objects must either be placed in a protective covering or be properly cleansed when leaving high-risk area. All clinical areas and equipment (ultrasound or radiograph units) should be disinfected regularly and thoroughly with chlorine or hypochlorite solutions, especially prior to leaving a high-risk area.

Extra care needs to be taken if it is necessary to come into contact with patients receiving
high flow oxygen or nebulisation. Nebulization, oxygen delivery by Venturi masks and non-invasive positive pressure ventilation is avoided, if possible, to minimize dissemination of contaminated aerosols by these high flow and pressure-generating devices. Oxygen should be delivered by nasal catheters, Hudson mask or non-rebreathing mask, when possible. Infection control precautions must be maintained during transport of patients outside the ICU, for example in the radiology suite during specialized imaging procedures such as CT scan. For example, when transporting mechanically ventilated patients, a high efficiency heat and moisture exchanger filter at the circuit Y-piece and a viral filter at the ventilator expiratory port should be incorporated in the breathing circuit to minimize viral contamination of the environment. Of course, all ICU transport and receiving radiology suite staff should be attired in full personal protective clothing and equipment.

**Key Points**

- Infection control is essential to protect staff and other patients in high risk areas. Education of staff, availability of personal protective equipment and strict enforcement of infection control protocols are key goals.

**Conclusion**

SARS is a serious infection that causes predominantly severe respiratory failure, with little other organ failure. Admission rates to ICU are high and the morbidity and mortality are significant.

There appears to be a high incidence of barotrauma, particularly amongst those patients requiring mechanical ventilation.

Nosocomial infection rates appear high, and may be disease or therapy related.

Radiological imaging forms an important part of monitoring this condition and may have the ability to prevent complications and be predictive of clinical progress. Formal and detailed radiological imaging of the respiratory system in particular may increase our understanding of the pathological nature of this new condition.
References

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