EVIDENCE BASED PUBLIC HEALTH POLICY AND PRACTICE

Monitoring the severe acute respiratory syndrome epidemic and assessing effectiveness of interventions in Hong Kong Special Administrative Region

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Objective: To estimate the infection curve of severe acute respiratory syndrome (SARS) using the back projection method and to assess the effectiveness of interventions.
Design: Statistical method.
Data: The daily reported number of SARS and interventions taken by Hong Kong Special Administrative Region (HKSAR) up to 24 June 2003 are used.
Method: To use a back projection technique to construct the infection curve of SARS in Hong Kong. The estimated epidemic curve is studied to identify the major events and to assess the effectiveness of interventions over the course of the epidemic.
Results: The SARS infection curve in Hong Kong is constructed for the period 1 March 2003 to 24 June 2003. Some interventions seem to be effective while others apparently have little or no effect. The infections among the medical and health workers are high.
Conclusions: Quarantine of the close contacts of confirmed and suspected SARS cases seems to be the most effective intervention against spread of SARS in the community. Thorough disinfection of the infected area against environmental hazards is helpful. Infections within hospitals can be reduced by better isolation measures and protective equipments.

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The severe acute respiratory syndrome (SARS) epidemic poses one of the most serious global health threats since AIDS because of its infectiousness and its potential to spread through air travel. The contagiousness and lethality of SARS is of great concern. Hong Kong Special Administrative Region (HKSAR) as at 24 June 2003 has had 1755 infected cases with 296 fatalities. This has posed a serious threat to the existing health care system and has serious implications to future infectious disease control. During the course of the epidemic, the HKSAR government has implemented various preventive measures and interventions to fight against the epidemic outbreak. In this paper, ''preventive measures'' and ''interventions'' are used interchangeably to refer to actions taken to curb the spread of the epidemic either in the general population or in some specific groups.

There seems to be lack of a quantitative method to justify the effectiveness on a population level of preventive measures and interventions taken. Monitoring changes in the number of infections over the course of the epidemic provides some insight on the effectiveness. However, the number of infections is unobservable, while the available information on the number of reported cases, because of the disease incubation period, is not sensitive enough to reflect the immediate effect of the preventive measures. It requires very prompt and decisive actions to be taken in monitoring a new emerging epidemic. There is need to construct the infection curve in assisting to evaluate the effectiveness of intervention measures. We propose the use of the back projection method to construct the SARS infection curve instead of tracing the patients' contact history as in Chan-Yeung and Yu.[1] The case study method is helpful, but it is not efficient because detailed individual contact histories are usually unavailable and/or unreliable. In addition, the infection curve estimated by case study method subjects to individual fluctuations. The estimated infection curve from the back projection method smoothes these fluctuations so that the infection waves can be clearly identified over the course of the epidemic.

The back projection technique[2] is widely used in modelling the spread of HIV/AIDS. As SARS involves progression from infection, incubation, and to onset of symptoms, the back projection technique also can be applied to this epidemic. In HIV/AIDS epidemic, the estimated total number of infections is valuable as it gives information on how many unobserved infected people are circulating in the community. Though the incubation time is relatively much shorter in SARS epidemic, the estimated unobserved daily number of infections over the course of the epidemic provides useful information on the effectiveness of any interventions and preventive measures.

METHOD

Data

The daily reported number of SARS cases is obtained from the Department of Health of the HKSAR.[3] There have been 1755 cases up to 24 June 2003. The data for 10 April 2003 and 11 April 2003 show an abnormal pattern with 28 and 61 reported cases, respectively. It is suggested that a reporting delay occurred in the previous day, and some of the cases reported on 11 April 2003 should be counted as the cases on 10 April 2003.[4] For this reason, an average of the two days are used in the analysis, 44 and 45 cases for the two days respectively.

The back projection method

Daily reported cases are used. Let $t = 1, 2, \ldots, \tau$ be the time units (that is, days) for the data. It is assumed that before 1 March 2003, the epidemic had not yet appeared, this is denoted as $t = 1$. Although there might be sparse cases

Abbreviations: SARS, severe acute respiratory syndrome; HKSAR, Hong Kong Special Administrative Region infected before this date, the current data do not provide any information on the early cases. Therefore, 1 March 2003 is assumed to be the start of the epidemic. The latest time when data are available for analysis is 24 June 2003, and thus τ is set to 116. The daily mean number of reported cases of SARS (μ_t) can be expressed in terms of the daily mean number of SARS infection (λ_s, $s = 1, \ldots, t$) by the convolution equation.

$$\mu_t = \sum_{s=1}^{t} \lambda_s f_{t-s,s} \quad (1)$$

where $f_{d,s}$ is the probability that an infected individual is admitted to hospital (reported) after a period of length d starting from time s. As suggested in Donnelly *et al*,[5] an infected person will go through two periods: from infection to onset of clinical symptoms and from onset of clinical symptoms to admission to hospital. The infection to onset time is assumed to follow a γ distribution with a mean 6.37 (SD = 4.09). The onset to admission time is assumed to follow a γ distribution with mean (SD) 4.85 (3.49), 3.83 (2.45) and 3.67 (3.27) for different time periods over the course of the epidemic. Hence, $f_{d,s}$ can be expressed as:

$$f_{d,s} = \sum_{i=0}^{d} g_i \cdot h_{d-i,s+i} \quad (2)$$

where g_d is the distribution of the infection to onset time (assumed independent to the starting time) and $h_{d,t}$ is the onset to admission time starting in time t. Estimates of the daily number of infection can be obtained using the EMS algorithm: for details of the method see Becker *et al*[6] and Chau *et al*.[7] For each time point, a point wise 95% confidence interval for the incidence is constructed by bootstrap procedure.[8]

RESULTS

Figure 1 gives the estimated mean number of SARS infections for each day from 1 March 2003 to 24 June 2003 and its point wise 95% confidence intervals. The cumulative number of SARS infections over this period is estimated to be 1755. All the infected cases have been diagnosed and known. It appears that there are four major infection waves over the course of the epidemic outbreak. The size of the second wave is the largest. After the fourth wave, it seems that the epidemic has been contained. Only residual effects were detected in the remaining of the period. Zero infections have been estimated for the period after 30 May 2003.

The back projection method usually gives imprecise estimates for the recent past. However, the estimates for the recent past for SARS outbreak are precise as the end of the epidemic has been reached. The numbers in the later part of the input series are all zero, granting higher precision and stability for estimates in the recent past.

Figure 2 gives the observed and fitted daily number of SARS reported cases from 1 March 2003 to 24 June 2003. The associated 95% confidence intervals based on the estimates from the back projection are also presented. Except for a few outliers, the fitted daily numbers of SARS cases agree well with the observed ones.

FINDINGS

The estimated SARS infection curve is examined closely in relating to the major events, preventive measures and interventions implemented by HKSAR government[3] over the course of the epidemic (see fig 1). The pattern of the infection curve is in line with the outbreak occurring in different subgroups of the population. The first infection wave, which started around 4 March 2003, was due to the outbreak in one of the large regional hospitals, Prince of Wales Hospital, which was initiated by the index SARS patient. He was admitted to the hospital's ward 8A on 5 March 2003. Subsequently, infections were found in the area of Shatin District, where the Prince of Wales Hospital is located, as the virus was not contained in the hospital and got out into the community. The number of infections decreased after 10 March 2003, probably because internal preventive measures were taken in the hospital. It seemed that the intervention taken within the hospital was effective, as the incidence continued to fall down until 16 March 2003.

After that, a second wave started at around 16 March 2003 in Amoy Garden, a large residential estate made up of many individual blocks. This was initiated by a patient who was treated for chronic renal failure but had been infected by SARS at Prince of Wales Hospital. He visited Amoy Garden on 14 and 19 March 2003 and used the toilet of his brother's flat. It was suspected that this outbreak was caused by environmental hazard—the sewage system. The peak of this outbreak was reached around 22 March 2003. By 30 March 2003, more than 120 confirmed cases in Amoy Garden were reported, the government then introduced a mandatory quarantine and isolation policy for the Amoy Garden residents at home on 31 March 2003 and 1 April 2003. After the evacuation, the area was disinfected completely. However, these measures were implemented nearly at the end of this outbreak. Before the implementation of the quarantine policy, many residents from Amoy Garden left their estate because of the fear of SARS infection and probably had introduced the virus into the community. Those residents who moved to the nearby Lower Ngau Tau Kok Estate II to live with their relatives caused more than 30 people in that estate to be infected. The whole district had then become seriously affected by the epidemic.

After the second wave, the epidemic had spread throughout Hong Kong. In the third wave, there were cluster infections in various hospitals. Two regional hospitals, the United Christian Hospital and the Princess Margaret Hospital, which started admitting SARS patients resulting from the second outbreak around 26 March 2003, both reported local outbreaks in the hospitals. It was suggested that the causes were sudden increase in workload of these hospitals, inadequate protective measures and equipment for medical and health care workers. A few days later, another regional hospital, Alice Ho Miu Ling Nethersole Hospital, reported a local outbreak among the healthcare workers. It was suspected the outbreak was caused by a SARS patient, without any symptom, being treated at the hospital. It is unfortunate that nearly all hospitals that treated SARS patients had infections among the healthcare workers and patients. To date, 386 of 1755 infections are medical and healthcare workers.

On 10 April 2003, home quarantine was implemented for all households with contacts of confirmed SARS patients. This preventive measure was implemented before the fourth wave whose peak was around 17 April 2003. The appearance of the fourth wave implied that this quarantine measure was not effective enough in stopping the spread. The failure might be explained by the fact that there was time lag in confirming the SARS cases. Those close contacts of these suspected cases could still spread the virus during the window period because of the time lag. In the fourth wave, there were probably cluster infections in various residential buildings, including in the Shatin District. It was suspected that the cause of infections was attributable to environmental hazard. Fortunately, with the experience of the Amoy Garden, the government responded quickly to disinfect the area and to monitor the situation closely. These minor outbreaks were

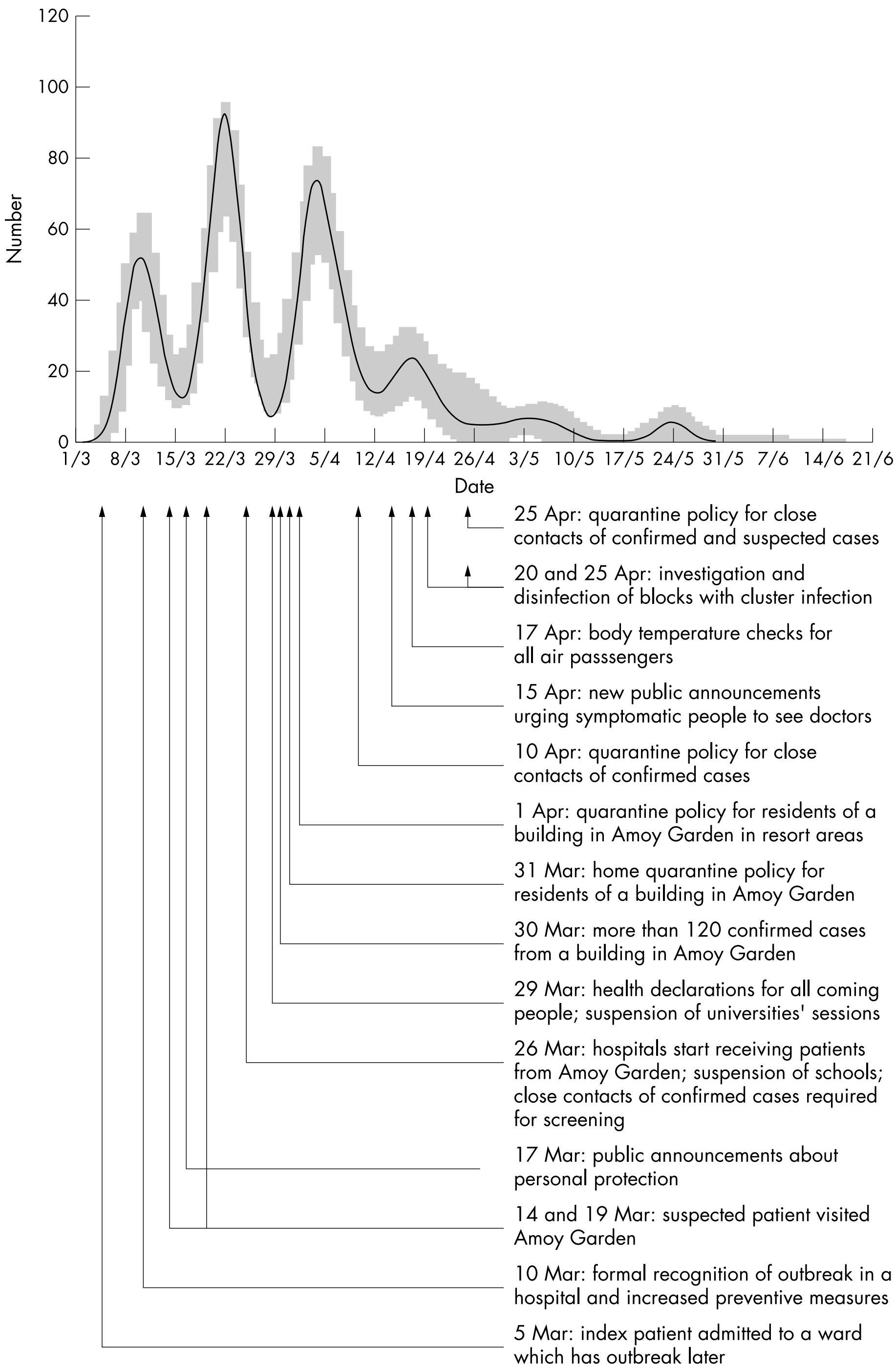

Figure 1 Estimated daily number of infection of severe acute respiratory syndrome and point wise 95% confidence intervals in Hong Kong Special Administrative Region; events[3 5] are marked in sequence of time.

not allowed to develop like the one in Amoy Garden. The main component of the fourth outbreak was the infection within Tai Po District, where the Alice Ho Miu Ling Nethersole Hospital is located. Unlike the second wave that took place in Kwun Tong District, over 70% of the outbreak in Tai Po District spread can be traced back as hospital related. These included medical and health workers, patients, and visitors.

From 25 April 2003, the government had extended the home confinement policy to households with contacts of suspected SARS patients. In other words, not only those close contacts with confirmed cases needed to be quarantined, but also those with suspected cases. This remedies the shortcomings of the previous practice. Except those residual effects of the dying down process of the epidemic, there was not any new infection wave after the fourth one. Zero infections have been estimated for the period after 30 May 2003. It seems that this preventive measure is very effective in preventing the spread in the community. However, it should be noted that the later reported cases included healthcare workers and patients who worked or stayed in non-high risk wards of the hospitals. It is probably attributable to the presence of asymptomic SARS patients as well as the cross infection between the suspected SARS and the genuine SARS patients in the large observation wards. Though the government has advised people to seek medical service in the presence of possible symptoms, hospitalisation might actually increase the risk to be infected because of the non-isolation arrangement for SARS suspected inpatients.

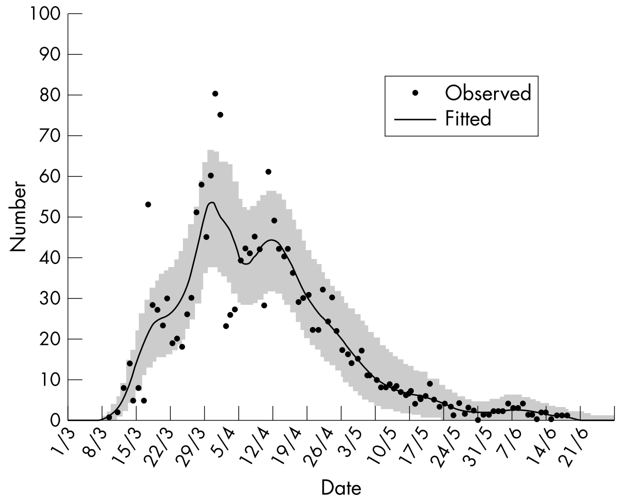

Figure 2 Observed and fitted number of SARS cases in Hong Kong Special Administrative Region.

Other preventive measures, like suspension of schools (since 26 March) and health declaration policy for all coming people (since 29 March), were taken during the period which might have contributed to the reduction of the fourth wave. These preventive measures were helpful in preventing the spread of the virus in the community to a certain extent, but they might not be aggressive enough to stop the outbreak in specific groups.

LIMITATIONS

There may exist reporting delay problem in the reported series. All cases reported after the cut off time are counted as cases for the next day. However, there was a change of cut off time between 1 pm and 3 pm, which may introduce some inconsistency in the data series. In addition, the department of health admitted the reporting delay of the number of cases.[4] Any similar delay may also introduce bias in the estimation. As reporting delay will affect the result of the back projection method,[9] the problem should be reassessed whenever sufficient new information becomes available.

The estimate of the infection curve is affected by the chosen incubation period distribution. As discussed in Donnelly *et al*,[5] the infection to onset period distribution might also contain bias because of the limited number of observations. In addition, we assumed the number of reported cases as the number of hospitalisation as the input series. Actually, we should improve the analysis by using the number of hospitalisation as it is better matched with the estimated onset to admission period. However, such data are not available, only the number of reported cases is available. Also, another factor—the warm weather that begun in April, may be contributing to controlling SARS outbreak. However, this effect is not addressed in this paper.

CONCLUSION

Quarantine of close contacts of confirmed SARS cases seems to be insufficient as there was time lag for confirmation. The virus can still be spread in this time lag. The extension of the quarantine policy to close contacts of both the confirmed and suspected SARS cases seems to be the most effective intervention against the spread of the virus in the community. The outbreak in hospitals could be contained by better isolation measures and better protection equipment. As there are SARS patients admitted to hospitals' non-high risk wards without symptoms, the preventive measures should therefore be implemented in both high risk and non-high risk areas of the hospitals over the course of the epidemic. Preventing infections among the medical and health workers is important in controlling the spread of the epidemic. In case there is environmental hazard, besides the quarantine policy, the most effective way to stop the spread is complete disinfection of the area and the environmental hazard must be removed.

It is difficult to contain the epidemic once it gets into the community. It would be most effective to contain SARS at the beginning by closing down Prince of Wales Hospital to stop the outbreak to get into community. This outbreak showed the consequence of failure to implement adequate quarantine measures in a timely manner. It is a very costly lesson for Hong Kong Special Administrative Region and other countries. The economic loss for Hong Kong is estimated to be around HK$ 8 to 10 billions and on top of this, nearly 300 lives. Hong Kong should continue to remove environmental hazards and promote personal hygiene to minimise the possible return of SARS in the future.

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