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ORIGINAL ARTICLE

Weather: driving force behind the transmission of severe acute respiratory syndrome in China?

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Abstract

Background: The association between weather and severe acute respiratory syndrome (SARS) transmission in Beijing and Hong Kong in the 2003 epidemic was studied to examine the effect of weather on SARS transmission.
Methods: Pearson's correlation analyses and negative binomial regression analyses were used to quantify the correlations between the daily newly reported number of SARS cases and weather variables, using daily disease notification data and meteorological data from the two locations.
Results: The results indicate that there were inverse association between the number of daily cases and maximum and/or minimum temperatures whereas air pressure was found to be positively associated with SARS transmission.
Conclusion: The study suggests that weather might be a contributory factor in the 2003 SARS epidemic, in particular in the transmission among the community members.

Introduction

Severe acute respiratory syndrome (SARS) appears to be spread most commonly by close person-to-person contact through exposure to infectious droplets and aerosols and possibly by direct contact with infected body fluid.[1–4] As a respiratory virus infection, the transmission of the *SARS coronavirus* could be affected by environmental factors, including meteorological variables, such as air pressure, relative humidity and temperature. Such weather factors may be possible elements in the prediction of infectious disease transmission, including mosquito and rodent-borne diseases, respiratory infections,[5–9] and more recently, SARS transmission.[10–13] In developing emergency plans to contain the spread, transmission and resurgence as well as to prevent further international spread of new communicable diseases including SARS, it is important to set up early warning systems, using practical indices as markers for infectious disease transmission dynamics. These indices include pathogen infectivity, contact degree and frequency, population immunity and environmental factors. The use of weather variables may provide an additional potential tool for such projection. Given the need to remain vigilant about SARS worldwide, and the resurgence of the disease in late May 2003 in Toronto[14]and 2004 in Beijing,[15] the study of the association of weather to SARS transmission is timely. This paper quantifies the relationship between weather variables and the number of cases of SARS occurring on a daily basis in the epidemic of 2003 in Beijing and Hong Kong.

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Methods

Background information

The earliest SARS cases are now known to have occurred in mid-November 2002 in Guangdong Province of China. SARS has since spread rapidly around the world, with cases reported from 30 countries over five continents. From 1 November 2002 to 7 August 2003, there were 8422 reported cases, with 916 deaths. The countries and regions most seriously affected were China, Hong Kong, Taiwan, Singapore and Canada.[1] Hong Kong and Beijing were chosen as target cities in this study because they were the worst hit with the most SARS cases (1755 and 2521, respectively) occurring during the epidemic, but with different climatic conditions (subtropical and temperate).

Data collection

Target cases for this study were laboratory-confirmed cases from both Beijing and Hong Kong, and the World Health Organization (WHO) definition was followed. Daily 'probable' cases (clinical diagnosis only) in Beijing were analysed, but results were not included.

Data on the daily numbers of newly notified SARS cases from Beijing Municipality over the period from 21 April to 20 May 2003 were retrieved from the website of the Ministry of Health, China (http://www.moh.gov.cn, accessed on 15 August 2003). There were 2142 SARS cases over the period.

Data on daily SARS cases from Hong Kong (17 March to 31 May 2003) were obtained from the website of the Hong Kong Government (http://www.sars-expertcom.gov.hk/english/reports/reports/files/e-chp3_21.pdf, accessed on 10 September 2004). There were 1755 confirmed cases in Hong Kong over the study period.

The above study period was chosen for Beijing because, from 21 April to 20 May 2003, the Chinese government publicly opened its disease surveillance system, and the dataset over this period is believed to be more reliable than data collected outside these dates. The study period in Hong Kong covered the entire SARS epidemic period in 2003.

Daily weather data obtained from the World Meteorological Organization included daily maximum and minimum temperatures, rainfall, relative humidity and air pressure for the two cities. These indicators of weather condition were selected because they are known to be reported reliably, they are available mostly from international locations and they have been shown to be associated with communicable disease transmission from other studies.[5–8,11–13]

Data analysis

Pearson's correlation analyses were conducted between daily weather variables and daily numbers of newly notified SARS cases, respectively, in Beijing and Hong Kong over the study periods. The number of SARS cases was correlated to the weather variables on the same day, one day before, two days before, and so on until 10 days before; only the lagged day with the biggest correlation coefficient between the specific weather variable (e.g. minimum temperature) and daily notified SARS cases was chosen for regression analysis.

The analyses were carried out with SAS (9.0).[16] Negative binomial regression analyses (GEOMOD procedure) were used to quantify the relationships between daily SARS cases and weather variables . This method has been used in most of the environmental epidemiological studies, in particular, in the examination of short-term acute effects, for example, the effect of air pollution on daily hospitalizations.[17] This analytic method takes into account the effects of time trends, seasonal distribution and autocorrelation. For the consideration of multicollinearity, the weather variables with high correlations were put into different models (e.g. maximum and minimum temperatures).

Significance was determined using $\alpha = 0.05$ level.

Results

Correlation between weather and the transmission of SARS in Beijing and Hong Kong in the 2003 epidemic (Table 1)

The correlations between daily weather and SARS cases occurring were examined in both Beijing and Hong Kong over the study periods. Table 1 indicates that there were inverse correlations between weather (minimum temperatures and relative humidity) and the transmission of SARS in Beijing, with a 7-day lagged effect (indicated as the numbers in the brackets). In Hong Kong, the inverse correlations were higher for temperature (both maximum and minimum temperatures) and reported cases. A positive correlation was also found between air pressure and relative humidity and disease transmission in Hong Kong.

Association between weather and SARS transmission – regression analyses from Beijing and Hong Kong (Tables 2–4)

As there was considerable multicollinearity, highly correlated weather variables (coefficient greater than 0.6), for example, maximum and minimum temperatures were put into different regression models.

In Beijing, the combination of minimum temperature and relative humidity had a negative association with the occurrence of SARS. In Hong Kong, although temperatures (maximum and minimum) still had a negative association with the disease, the correlation between SARS

Table 1 Correlation coefficients of daily climatic variables and severe acute respiratory syndrome in Beijing and Hong Kong

Cases	Maximum temperature	Minimum temperature	Relative humidity	Air pressure
Beijing cases	NS	−0.41 (7)	−0.50 (4)	NS
Hong Kong cases	−0.79 (5)	−0.76 (5)	0.24 (7)	0.57 (2)

Numbers in brackets were lagged days. NS, not significant.

Table 2 Beijing: severe acute respiratory syndrome cases and weather

Parameter	d.f.	Estimate	Standard error	Wald 95% confidence limits		χ^2	*P*-value
Intercept	1	7.2581	0.5970	6.0881	8.4282	147.82	<0.0001
Minimum temperature	1	−0.1019	0.0267	−0.1542	−0.0496	14.57	0.0001
Relative humidity	1	−0.0315	0.0073	−0.0457	−0.0172	18.73	<0.0001

d.f., degrees of freedom.

transmission and air pressure was positive. Relative humidity was not significant in the regression model in Hong Kong, although it was significant in the correlation analysis.

Discussion

This systematic study indicates that the minimum and maximum temperatures had a negative association with SARS transmission in Beijing and Hong Kong in the 2003 epidemic, whereas the relative humidity was negatively associated with the daily number of reported SARS cases in Beijing.

Lower rainfall and therefore reduced relative humidity provide a good opportunity for the transmission of respiratory pathogen infections, including *SARS coronavirus*.[8] The inverse relationship between relative humidity and the transmission of SARS in Beijing suggests that a dry weather is suitable for SARS transmission. Such an association, however, was not found in Hong Kong. This may reflect the difference in the climatic zones between the two cities. With a subtropical climate, there is less variation in relative humidity in Hong Kong throughout the year.

Daily temperatures, especially daily minimum temperatures, have had a reverse association with SARS transmission in this study in both Beijing and Hong Kong. This indicates that lower temperatures may be important for SARS pathogen survival and transmission. Human behaviour may change on colder winter days with greater opportunity for disease transmission inside dwellings. Our results differ from those reported in a recent study, which showed a positive correlation between SARS cases and temperatures in Beijing.[12] This reflects the use of different study periods. In their study, Tan *et al.* used the daily number of SARS cases from early March to late May for their study time frame, whereas we chose 21 April to 20 May 2003 as the study period because we believe the data from this period were more reliable due to a change in policy about data transparency from the Chinese government from 21 April 2003.[15]

There was a reverse correlation between temperature and air pressure. The higher the temperature was, the lower was the air pressure and vice versa. Therefore, air pressure was positively associated with SARS transmission in Hong Kong as indicated in Tables 1, 3 and 4. However, this has not been detected in Beijing.

As the incubation period of SARS is estimated to range from 2 to 16 days, with a mean of 6.4 days, the lagged effect of 5–7 days in Hong Kong and Beijing identified empirically as being the most appropriate in this study fits the observed estimate.[3] This lagged effect could be very important in the disease transmission and the lagged-effect time should be taken into account seriously in SARS prevention and control as a prewarning period.

The meteorological factors selected for study were restricted to those that were readily available from international meteorological data reporting sites. Thus, although ultraviolet light might play a role in the transmission of SARS, we were not in a position to assess its impact.

Weather might influence the whole SARS transmission process, including any animal reservoirs, animal/human behaviour interaction and human-to-human behaviours. It should be pointed out that the weather factors may only be one influence behind the transmission of SARS and they may not be essential for transmission but may only play a part in the presence of other factors, such as an agent entering the seasonal epidemic cycle of a reservoir host species, contact with humans and lower population immunity.[11] Weather variables are a component of

Table 3 Weather and severe acute respiratory syndrome cases in Hong Kong: model 1

Parameter	d.f.	Estimate	Standard Error	Wald 95% confidence limits		χ^2	*P*-value
Intercept	1	−62.3058	21.2327	−103.921	−20.6905	8.61	0.0033
Maximum temperature	1	−0.1619	0.0233	−0.2076	−0.1161	48.17	<0.0001
Air pressure	1	0.0679	0.0208	0.0272	0.1086	10.69	0.0011
Relative humidity	1	0.0016	0.0108	−0.0195	0.0228	0.02	0.8800

d.f., degrees of freedom.

Table 4 Weather and severe acute respiratory syndrome cases in Hong Kong: model 2

Parameter	d.f.	Estimate	Standard error	Wald 95% confidence limits		χ^2	*P*-value
Intercept	1	−70.7053	21.6131	−113.066	−28.3443	10.70	0.0011
Minimum temperature	1	−0.1613	0.0257	−0.2118	−0.1109	39.30	<0.0001
Air pressure	1	0.0745	0.0212	0.0329	0.1161	12.33	0.0004
Relative humidity	1	0.0121	0.0113	−0.0101	0.0343	1.14	0.2848

d.f., degrees of freedom.

a causal constellation that are neither necessary nor sufficient by themselves for the transmission of SARS.[18]

A critical question for scientists investigating SARS transmission is whether the *SARS coronavirus* is transmitted through large droplets or on fomites, as that occurs with respiratory syncytial virus and *Mycoplasma*, or through aerosols, as occurs with measles and varicella. It is known that large droplets are the likely primary mode of transmission; however, in some circumstances, clusters of SARS cases suggest an aerosol transmission or direct contact. Therefore, transmission may be heterogeneous. Experience in Toronto,[19] Taiwan,[20] and elsewhere[21] also indicates that the primary mode of SARS transmission is through respiratory droplets and direct contact with patients and their contaminated environment. The cluster of SARS cases in Toronto health-care workers after the intubation of a patient,[22] as well as other reported super-spreader events, suggest the possibility of limited airborne transmission under certain circumstances.[23] These circumstances may be enhanced by weather conditions.

The transmission of SARS across the world in the 2003 epidemic had two phases. The first phase consisted of sporadic SARS cases without nosocomial transmission. In the second phase, when transmission within hospital led to a subsequent nosocomial outbreak, with health-care workers making up a large proportion of cases,accounting for 37–63% of the suspected cases in highly affected countries.[19] The role played by weather variables in the nosocomial stage for the SARS transmission is uncertain. However, weather may play an important role in SARS transmission as an environmental factor at the first stage, that is, transmission in the community. Therefore, it would be ideal to distinguish nosocomial infections from non-nosocomial infections and to study the correlations with weather and non-nosocomial infections alone. Unfortunately, such data were not readily available to these researchers and this is a limitation of this study.

In Hong Kong, the large number of cases from the Amoy Gardens outbreak may easily have distorted the estimates of the weather effect, although relative humidity could be a factor in the survival of infective droplets in the outbreak. Once again, in the disease notification system we are not able to distinguish these cases for separate analysis.

The transmission of respiratory virus infections including SARS is complex, and involves many factors, such as socioeconomic status, viral infectivity and pathogenicity, contact degree and frequency, population immunity, disease control and prevention measurements (which could be very important in SARS control in the 2003 epidemic) and other environmental factors. Obviously, weather variables may only be part of the potential risk factors and the relatively low R^2 in the regression models also indicated this. Therefore, more systematic studies on the influence of weather on host/reservoirs, patients and virus are necessary in future. Global vigilance on SARS for the winter of the next several years could be critical for observing how the virus behaves, whether the winter weather accelerates the transmission and how human beings handle that acceleration.

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