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Full Length Research Paper

Early warning CUSUM plans for surveillance of infectious diseases in Wuhan, China

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This study is in order to explore the effect of cumulative sum (CUSUM) in the early warning of infectious diseases. The infection percentile of chickenpox in 2005 to 2009 was set as baseline. Using CUSUM for the early warning of chickenpox infection in 2010, the CUSUM parameter was determined in Wuhan City. CUSUM showed high specificity for the warning of a special time point; its low sensitivity can be compensated by reducing baseline or t value. The percentile method can promote the effect of CUSUM on the early warning of prevalent diseases. In Wuhan, when Ci is less than 10, the disease is not considered prevalent, but when Ci is more than 20, the disease is likely to be prevalent. In combination with the percentile method, CUSUM has high sensitivity and specificity for the early warning of infectious diseases and is useful for the prediction of the prevalence of diseases.

Key words: Cumulative sum (CUSUM), chickenpox, percentile, Wuhan.

INTRODUCTION

Infectious diseases are still a great problem in the world. The 2009 H1N1 influenza pandemic is a good example. Although the exact number of infected cases could not be ascertained because of a lack of serological evidence of asymptomatic cases, there were approximately 50 million people who were infected in the United States in December, 2009. More importantly, the new pandemic strain of the influenza virus spread rapidly throughout the globe with different peaks and with more than one wave in different cities (Ross et al., 2010). As such, setting up an early warning plan to detect emerging diseases is necessary.

There are several traditional control charts that can be used on prospective automated surveillance of diseases and syndromes, including Shew-hart, exponentially weighted moving average (EwMA), and cumulative sum (CUSUM) (Tseng and Adams, 1994). CUSUM procedures were first proposed by Page in 1954. More recently, CUSUM charts have proven very useful in monitoring manufacturing processes, and are also being used for public health surveillance (Sparks et al., 2010). However, little is reported in China on the prediction of infectious diseases by CUSUM. In this study, we used chickenpox data in Wuhan in 2005 to 2009 to set up an early warning model and evaluated the effects of CUSUM on the infectious disease by analyzing chickenpox epidemic information in 2010.

MATERIALS AND METHODS

Data collection

From 2005 to 2010, personal information of infectious patients were collected from the National Disease Supervision Information Management System (NDSIMS), a system set up in 2004 for managing national infectious diseases by the China Disease Prevention and Control. In this study, we analyzed chickenpox infection as the study subject.

Data analysis

All data were stored and collated using Foxpro database, and then sorted by illness day for the subjects collected in 2005 to 2009, or by report date for those in 2010. Analysis of CUSUM test results

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Table 1. CUSUM warning under different effects of baseline (*t*=3.5).

Parameter		Positive number	Negative number	Sensitivity	Specificity
Gold standard	**P_{80}**	**217**	**148**		
Baseline 1	**P_{65}'**	64	133	0.29	0.90
Baseline 2	**P_{70}'**	49	138	0.23	0.93
Baseline 3	**P_{75}'**	36	144	0.17	0.97

was performed using the Tabular method, a method proven to be more advantageous than V mask by Montgomery (1996). Assume that X is a normal distribution parameter, N (μ_0, σ), then

$$C_i^+ = \max\{0, X_i - (\mu_0 + K) + C_{i-1}^+\} \quad (1)$$

$$C_i^- = \max\{0, (\mu_0 - K) - X_i + C_{i-1}^-\} \quad (2)$$

where C_i^+ is the upside accumulation, C_i^- is the downside accumulation, *k* is an allowing partial volume, and $C_0^+ = C_0^- = 0$ is the initial value for accumulation. When the mean value of samples increases from μ_0 to μ_0 + tσ, which corresponds to a timely alarm, and the value of *k* is half of tσ, an important value directly affects the detection efficiency of CUSUM control chart and is usually determined by experiments.

Chickenpox analysis

In this study, we analyzed chickenpox infection in Wuhan City from 2005 to 2010. All subjects' information was included in the Foxpro database. Based on experience, we sorted data based on onset date for subjects collected from 2005 through 2009, or based on report date for subjects collected in 2010. The number of cases reported daily was counted. According to the principles of an early warning model control chart (Zhang, 1995), cases reported in three days (before, during, and after) in 2005~2009 were set as the baseline, enabling us to calculate the specified percentile (Px), then move the series data at seven days' average, and get the data as specified percentile of the historical baseline (Px'), and the standard deviation (δ). Putting the data above to model (1), we can calculate the value of C_i^+, and then draw the control chart using Excel 2003.

Parameter setting

In this study, only single side cumulative (C_i^+) should be counted in the chickenpox analysis. As such, we set X_i as the number of cases reported daily in 2010, and percentile P_{75} as a historical baseline. Based on experience, we take P_{75}' for the mean value (μ) and 3.5 for the t value in model (1).

RESULTS

Comparison between CUSUM and percentile methods in early warning of chickenpox infection based on the data collected in 2005 to 2009, we compared CUSUM and the percentile method in the early warning of chickenpox in 2010. At first, we set the *t* value as 3.5 and P75 as the gold standard reported by Chen et al. (2009). When the baseline increased from P65' to P75', sensitivity of the CUSUM method decreased from 0.61 to 0.35, whereas specificity of the CUSUM method increased from 0.65 to 0.97 (Table 1). At the same baseline, specificity of the CUSUM method increased based on an increase in *t* value (Table 2). The use of CUSUM in early warning of chickenpox infection.

To identity the effects of CUSUM on early warning of chickenpox infection, we draw a control chart based on the C_i^+ value (Figure 1). Our results indicate that the value of C_i^+ is zero when the daily reported cases are less than a certain number, and increases with an increase in the number of daily reported cases. With more daily reported cases and longer lasting time, the value of C_i^+ becomes greater, which is significantly associated with epidemic disease situations (Figure 1).

We also determined the C_i^+ value at different baselines or *t* values, which showed negative association to the baseline and the *t* value (data not shown).

DISCUSSION

Statistical process control (SPC), including CUSUM, is the most popular and most widely used industrial control method in the world. Although Wallstrom et al. (2005) reported that CUSUM has higher specificity and sensitivity than EWMA in disease surveillance, little is known about CUSUM use in China. In this study, we explored the use of CUSUM in infectious disease surveillance.In previously conducted studies, the percentile method was the most popular method, which showed high sensitivity and low specificity. In contrast, our data indicate that CUSUM has high specificity for the warning of special time points, and its sensitivity can be significantly promoted by decreasing the baseline or the *t value*. As such, combining CUSUM and the percentile or other methods significantly increases warning ability. To reduce the effects of climate, we used a seven-day percentile as the mean value (μ) in a CUSUM model

Table 2. T-value of different levels CUSUM warning effect (P75 'baseline).

Parameter	Positive number	Negative number	Sensitivity	Specificity
Gold standard	217	148		
T = 3.0	54	137	0.25	0.93
T = 3.5	36	144	0.17	0.97
T = 4.0	24	147	0.11	0.99

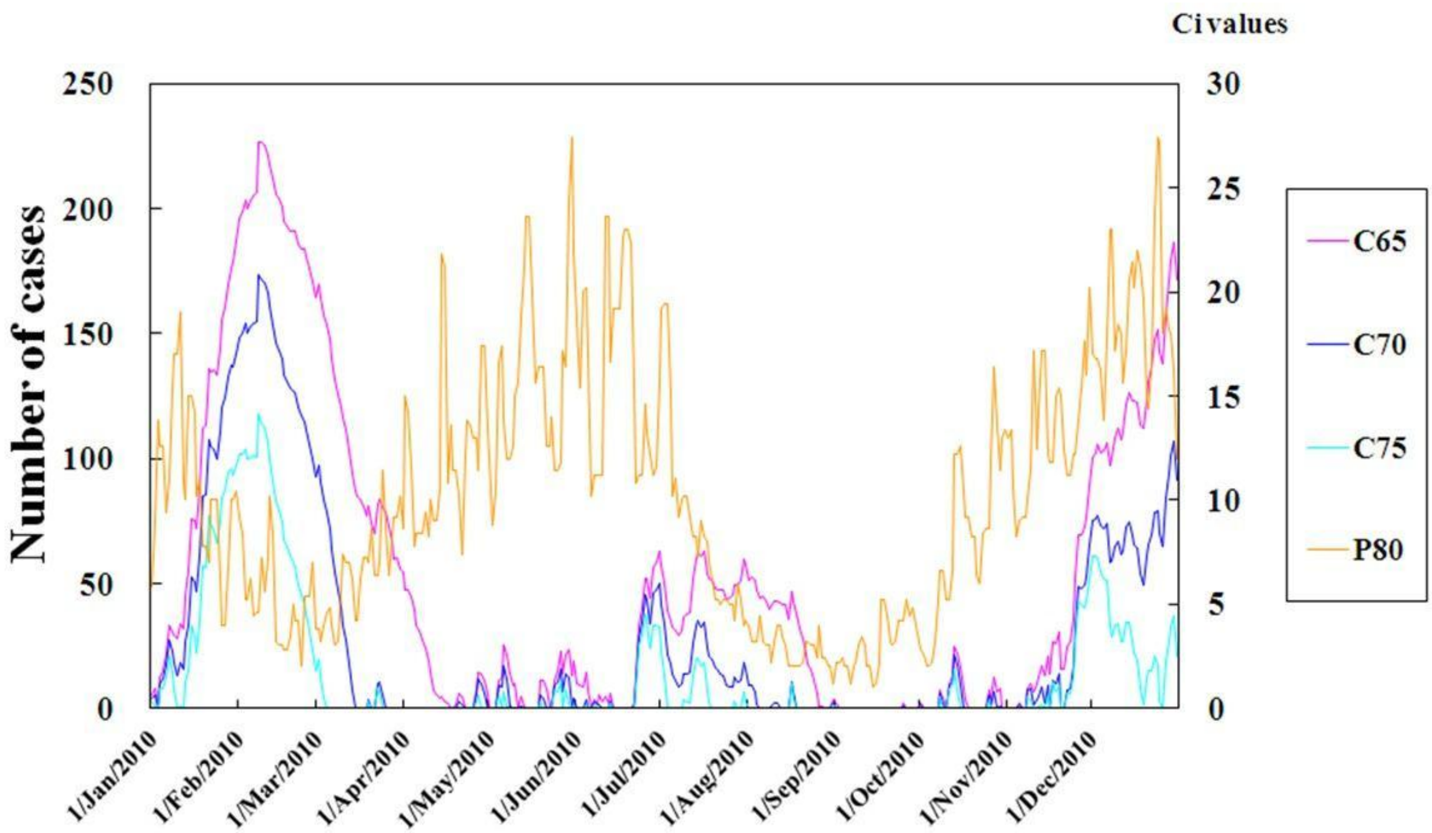

Figure 1. Control chart analyzed by CUSUM for early warning of chickenpox infection in 2010 in Wuhan, China. P80 showed the daily reported number of chickenpox infectious cases when analyzed by gold standard of 80 percentile baseline. C65, C70 and C75 indicated the Ci values calculated by CUSUM method at baseline of P65, P70 and P75, respectively, in which Ci values were significant associated with the daily reported cases.

for chickenpox infection analysis in 2005 to 2009. Our data indicate that the C_i value is associated with epidemic diseases. Percentile is 70 and *t* value is 3.5 if C_i is less than 10, which indicates that the disease may not become epidemic or may only become popular in part if C_i is more than 20, indicating that the disease may become prevalent. As such, CUSUM is a useful method for early warning of epidemic diseases, such as chickenpox, mumps, rubella, and others. Finally, because the baseline is difficult to define and the case information is not clear, CUSUM for early warning is not recommended in places with small population.

Conclusion

In conclusion, our data suggest that a combination of the percentile method and CUSUM produces high sensitivity and specificity for the early warning of infectious diseases and is useful for the prediction of prevalent diseases.

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