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The incidence of mumps in Taiwan and its association with the meteorological parameters

An observational study

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Abstract

Mumps is an acute and common childhood disease caused by paramyxovirus. It has been reported that the occurrence of mumps is influenced by seasonality. However, the role of meteorological variables in the incidence of mumps remains unclear. The purpose of this study was to explore the relationship between meteorological factors and the incidence of mumps infection. Poisson regression analysis was used to study the relationship between weather variability and the incidence of mumps in Taiwan. Between 2012 and 2018, 5459 cases of mumps cases were reported to the Centers for Disease Control, Taiwan (Taiwan CDC). The occurrence of mumps virus infections revealed significant seasonality in the spring and summer seasons in Taiwan. The incidence of mumps virus infections began to increase at temperatures of 15°C and started to decline if the temperature was higher than 29°C ($r^2=0.387$, $P=.008$). Similarly, the number of mumps cases began to increase at a relative humidity of 65% to 69% ($r^2=0.838$, $P<.029$). The number of mumps cases was positively associated with temperature and relative humidity during the period preceding the infection. This study showed that the occurrence of mumps is significantly associated with increasing temperature and relative humidity in Taiwan. Therefore, these factors could be regarded as early warning signals and indicate the need to strengthen the intervention and prevention of mumps.

Abbreviations: IRR = incidence rate ratio, NNDSS = National Notifiable Disease Surveillance System, Taiwan CDC = Centers for Disease Control, Taiwan.

Keywords: infectious disease, meteorological factors, mumps, seasonality

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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1. Introduction

Mumps is an acute but mild infectious disease caused by the mumps virus. The mumps virus is an envelope, single-stranded RNA virus of the paramyxovirus family.[1] Mumps is a highly contagious disease that involves susceptible people rapidly. The transmission of mumps mainly occurs by droplets, direct close contact, and contaminated fomites.[2–5] Infection can be localized to the mucosa of the respiratory tract.[2] The incubation period of mumps virus infection is 12 to 24 days, with a median of 19 days.[6] The clinical illness of mumps involves subclinical infection to severe infection of the central nervous system.[7] In the prevaccination era, the high-risk group included children aged 5 to 9 years and some adolescents who had a previous infection.[7,8] There was a reduction in mumps cases immediately after the implementation of the mumps vaccination program in Taiwan; the mean incidence fell from 10.4 (in 1992) to 2.4 (in 2018) per 100,000 population.[9] High proportions (up to 40%) of patients with mumps develop serious complications, including orchitis, oophoritis, aseptic meningitis, encephalitis, pancreatitis, or deafness.[9–11]

The morbidity of mumps virus infections presents a seasonal variation that has been well recognized in different regions. In temperate zones, the incidence of mumps exhibits obvious seasonality, with high rates in winter and spring.[12] A higher risk of mumps virus infections is observed during the summer months than during other seasons in Asia.[12–15] In addition, distinct seasonal variation has been detected in several countries.[17–20] Further investigation of the relationship between climatic factors and the occurrence of mumps could help improve both disease forecasting and preventive efforts.

Although the seasonality of mumps virus infections provides evidence that climatic factors might play an important role in the occurrence of mumps virus infection, these seasonal variations have not been well explained. Therefore, the aim of this ecological study was to assess the relationship between the occurrence of mumps and climatic factors in Taiwan.

2. Methods

2.1. Study area

Taiwan is located between 21° 45' N and 25° 56' N in Asia. The Tropic of Cancer (23.5°N) runs straight through Chiayi City, which is situated in southern Taiwan. Taiwan's population is approximately 23,400,000. Most of them (95%) live in the western part of Taiwan, which is divided into northern, central, and southern regions. Only 5% of the population lives in eastern Taiwan, where medical care is sub-standard and socioeconomic status is classified as low. The northern part of Taiwan belongs to the subtropical monsoon climate zone, whereas the southern part belongs to the tropical monsoon climate zone. Overall, the climate in Taiwan is relatively warm and moist throughout the year.

2.2. Data source

The study methods have been described previously.[13] Briefly, this study was based on data reported to the Centers for Disease Control, Taiwan (Taiwan CDC). Mumps has been a legally notifiable disease in Taiwan since 1999. All cases were reported by the National Notifiable Disease Surveillance System (NNDSS) to Taiwan CDC.[9] Until 2005, only the number of mumps cases was reported by the Taiwan CDC. Since 2008, mumps has been a reportable disease by law in Taiwan, and physicians are required to report all cases of mumps to the Taiwan CDC within 1 week of case confirmation.[9] The monthly mumps data in this study were obtained from the Taiwan CDC.

We collected a subset of data from the NNDSS database of the Taiwan CDC. All mump-related data were obtained from January 2012 to December 2018. The database contains the patient's age, sex, area of residence, and onset date for swelling of the parotid or other salivary glands. Serum samples were also collected from selected patients for serological confirmation of diagnosis. Serological testing was performed in the Taiwan CDC mumps virus laboratory. Serum specimens were tested for mumps IgM and/or IgG using a commercially available capture IgM and/or IgG enzyme immunoassay kit (Denka Seiken Co., Ltd., Niigata, Japan) according to the manufacturer's instructions.[9,21]

A clinical case of mumps was defined as a patient who was ill with an acute onset of unilateral or bilateral tenderness and self-limited swelling of the parotid or other salivary glands that lasted 2 or more days, without other apparent causes.[22] A confirmed case was defined as a patient who had a positive laboratory test (isolation of mumps virus or mumps RNA from a clinical specimen or presence of IgM antibodies and/or a four-fold increase in IgG antibodies) and was epidemiologically linked to a biologically confirmed case.[23,24]

This study was approved by the Institute Review Board of the Show Chwan Memorial Hospital, Taiwan (No. 1080101).

2.3. Meteorological data

Meteorological data were obtained from the Taiwan Central Weather Bureau database (http://www.cwb.gov.tw). The climate database contains daily temperature, relative humidity, vapor pressure, precipitation, and sunshine hours between January 2012 and December 2018. Because Taiwan is a relatively small island, we used the mean meteorological data value for each calendar week obtained from all 15 weather stations across the island, excluding stations on isolated islands and areas in the mountains.

2.4. Statistical analysis

We verified the data, examined for consistency, and removed missing data values after the data were collected. The annual incidence of mumps was calculated by dividing the number of reported mumps cases by the mid-year population of individuals of the same age, as reported between 2012 and 2018 in the Taiwan census data and displayed as the number of mumps cases per 100,000 individuals. Seasonal trends in the occurrence of mumps were determined using Poisson regression models that incorporated sine and cosine oscillators, with yearly terms:[25,26]

$E[Y_i(t)] = \exp[\alpha + \beta_{1i} \times \text{year}_i(t) + \beta_2[\cos(3 \times 2\pi \times \text{month}(t)/12)] + \beta_3[\sin(3 \times 2\pi \times \text{months }(t)/12)] + \beta_4[\text{temperature }(t)] + \beta_5[\text{relative humidity }(t)] + \beta_6[\text{vapor pressure i }(t)] + \beta_7[\text{cumulative precipitation i }(t)] + \beta_8[\text{precipitation time}_i(t)] + \beta_9[\text{cumulative sunshine hours}_i(t)] + \beta_{10}[\text{vaccination status (yes/no)}]]$

where $E[Yi(t)]$ is the expected number of cases at month t in year i, α is a constant value, each β term denotes a regression coefficient for a year or month, t indicates the months between January 2012 and December 2018, and i indicates the 7 years from 2012 to 2018. The function year$_i(t)$ denotes whether it is year i (1 = yes, 0 = no). The function month (t) indicates the month number (i.e., 1–12 for January to December). We used univariable and multivariable Poisson regression models to analyze the relationship between monthly mumps cases and climate factors. For smoothing to account for annual variations, the cubic spline method was used during the 6-year study period. Akaike's information criterion was used to optimize the knots within the spline model to avoid the pitfalls associated with both overfitting and underfitting.[27] In the multivariable analysis, a backwards-elimination algorithm was conducted, with covariates retained for $P \leq .2$.

To study the association between the occurrence of mumps virus infections and various temperatures and relative humidity levels, we calculated the mumps cases at different temperatures and relative humidity levels.[28] In this study, we assumed that the survival and transmission of the mumps virus would change as the temperature and relative humidity change,[4,14] and therefore, these factors might affect the infectivity of the mumps virus in a defined population. The average incidence of mumps (N_T) in various temperature domains (T to T+ΔT) was calculated using the following equation:[26,28]

$$N_T = \frac{\sum_i^n C_i f(t_i)}{\sum_i^n f(t_i)}$$

Here, i is an index from 0 to n, t_i denotes the mean temperature for the ith 7-day period, C_i is the total number of mumps cases for the $i+2$nd 7-day period, and $f(t_i)$ is a function as follows:

$$f(t_i) = \begin{cases} 1 \text{ when } & t < t_i \leq \mathrm{t} + \Delta t \\ 0 & \text{otherwise} \end{cases}$$

The numerator on the right side of the equation is the sum of all C_i including the 7-day mean temperatures (t_i) within the temperature domain of T to T+ΔT during the study period. The denominator is the total number of mumps with $T<t_i\leq T+\Delta T$ during the same study period.

Similarly, the mean mumps cases (N_h) in different relative humidity domains (h to h+Δh) were calculated using the following equation:

$$N_H = \frac{\sum_i^n C_i f(h_i)}{\sum_i^n f(h_i)}$$

Here, i is a sequence from 0 to n, h_i is the relative humidity for the ith 7-day period, C_i is the total number of mumps cases from the i + 2nd 7-day period, and $f(h_i)$ is an equation as follows:

$$f(h_i) = \begin{cases} 1 \text{ when } & h < h_i \leq h + \Delta h \\ 0 & \text{otherwise} \end{cases}$$

To investigate the interaction (effect modification) by the demographic characteristics of mumps cases, we conducted a multiplicative interaction analysis with a logistic regression model.[29] SAS Version 9.2 software (SAS Institute Inc., Cary, NC, USA) was used to conduct all statistical analyses. Statistical *significance was set at $P<.05$.*

3. Results

3.1. Demographic characteristics of mumps cases

Table 1 shows the demographic characteristics and the occurrence of mumps. Between January 2012 and December 2018, 5459 cases were reported to the Taiwan CDC. The annual incidence rate (cases per 100,000 person per year) of mumps was 3.36 (range: 2.65–4.85). More males were infected with mumps virus than females (3.94 vs 2.78). The incidence rates of mumps virus infection decreased as age increased, with a peak (23.71) at the ages of 5 to 9 years. The highest and lowest incidences of mumps were 4.53 and 2.72 in the eastern and central regions, respectively, in Taiwan. Compared with that in the winter (December, January, and February), the incidence of mumps increased in spring (incidence rate ratio [IRR]=1.408, 95% CI: 1.302–1.523), summer (IRR=1.366, 95% CI: 1.262–1.477), and fall (IRR=1.304, 95% CI: 1.205–1.412).

Table 1

Demographic characteristics of patients with mumps in Taiwan, 2012 to 2018.

Variables	Case number (%)	Annual incidence rate per 100,000
Total	5459	3.36
Gender		
Male	3192 (58.5)	3.94
Female	2267 (41.5)	2.78
Age groups (yrs)		
≦4	1026 (18.8)	14.61
5–9	1078 (30.7)	23.71
10-19	895 (16.4)	4.76
≧20	1860 (34.1)	1.44
Regions of residence		
Northern	2866 (52.5)	3.88
Central	1103 (20.2)	2.72
Southern	1314 (24.1)	2.98
Eastern	176 (3.2)	4.53
Seasons		
Spring	1514 (27.7)	0.93
Summer	1468 (26.9)	0.90
Autumn	1402 (25.7)	0.86
Winter (12–2)	1075 (19.7)	0.66

3.2. Seasonal variation and effects of meteorological variables

We used a Poisson regression model that incorporated terms for the calendar year and sine and cosine oscillators to determine the trends and seasonality of mumps virus infections. Additionally, we added the mean temperature, mean humidity, vapor pressure, precipitation, and sunshine hours into the model using a backward elimination algorithm for analysis. We found that mean temperature and relative humidity were the only factors found to be independently associated with mumps virus infection when oscillatory or cubic spline smoothers were incorporated into the model.

Figure 1 shows the trends of actual and predicted mumps cases in Taiwan. A seasonal trend of mumps infection was noted (for seasonal oscillation, $P<.001$), but no distinct annual patterns were found in this result. However, there were no significant differences between actual mumps cases and predicted mumps cases (Pearson Chi-Squared=49.76; $P>.05$). The trends of the predicted mumps cases fit the trend of actual mumps cases well.

The relationships between meteorological variables and the occurrence of mumps are shown in Table 2. Univariate analysis revealed several potential meteorological variables associated with the occurrence of mumps. All significant variables found in the univariate analysis were included in the multivariate analysis. In multivariate logistic regression analysis, after annual trends and cubic spline smoothers were incorporated into the models, only mean temperature and relative humidity were independently associated with the occurrence of mumps (Table 2). Vapor pressure, precipitation, and sunshine hours were not significantly associated with the occurrence of mumps (all $P>.05$). Age and sex did not affect the effects of temperature or relative humidity.

3.3. Temperature, relative humidity, and mumps

Figure 2 displays the mumps cases and the mean temperature. The occurrence of mumps is related to changes in temperature. The mumps cases started to rise at a temperature of 15°C and began to decline when the temperature was higher than 29°C ($r^2=0.387$, $P=.008$). The average proportion of mumps cases increased by 3.3% (95% CI: 1.8%–4.8%) for each 1°C increase in temperature.

Figure 3 shows the relationship between the case count of mumps and the different domains of relative humidity. The case count of mumps started to rise at a relative humidity of 65% to 69% ($r^2=0.838$, $P=.029$). An increase in the relative humidity with 5% was associated with an increase of 2.2% in mumps cases (95% CI: 1.3%–3.1%).

4. Discussion

Mumps are an important infectious disease worldwide.[30–32] In this study, the NNDSS database provides epidemiologic characteristics and associated meteorological risk factors for

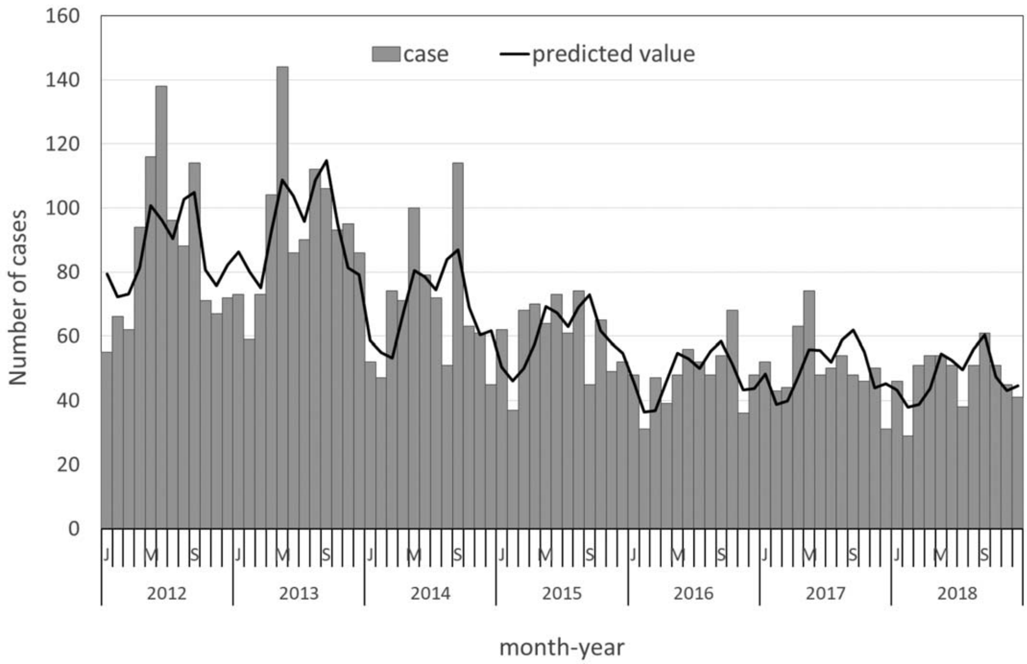

Figure 1. The actual and predicted mumps cases from 2012 to 2018 in Taiwan.

the occurrence of mumps in Taiwan. This study highlighted that the incidence of mumps was highest during the spring and summer months, but that incidence was positively correlated with an increased mean temperature and relative humidity. These findings are consistent with those of several previous studies conducted in Asia.[13–16]

There are various explanations for the seasonality of mumps virus infections. For example, fluctuations in human immune competence are mediated by seasonal factors, seasonality-related activity factors, and climatic factors.[12] However, human activity factors alone do not explain the correlation between the seasonal pattern observed and the occurrence of certain mumps cases. It has been indicated the occurrence of mumps is affected by the change of temperature and humidity.[32,31] Temperature and humidity may influence the living conditions and infectivity of pathogens, as well as the risks of exposure and vulnerability of susceptible populations.[15,16,32] Warm and humid weather are advantageous for viral replication and evolution. Increases in temperature and relative humidity prolong the virus survival time and activate its virulence in the environment,[5,13] which consequently increases the risk of hosts becoming victims of mumps infection. Additionally, in warm weather, children tend to have more outdoor activities, which may increase the risk of infection.[15,16]

In this study, the occurrence of mumps infection started to rise at 15°C and began to decline when the temperature was higher than 29°C. We also found that the mumps began to rise at a relative humidity of 65% to 69%. Mumps virus is transmitted through droplets, close contact, and contaminated fomites.[5,11,13] It has been shown that the mumps virus can survive at 4°C for several months; however, it cannot survive at temperatures above 55°C.[2] The role of temperature and relative humidity in the replication and infectivity of the mumps virus is still unclear. Further investigation is required. Although vaccination coverage rates have been over 90% in Taiwan in recent years, mumps cases have continued to occur every year. More studies are needed to explore whether climatic variation is a potential risk factor influencing the occurrence of mumps.[33]

Mumps virus infection presents seasonality in various reports. The role of seasonality in the occurrence of mumps is complex and can be related to various environmental factors, the

Table 2

Selected meteorological factors and the incidence of mumps virus infection in Taiwan, 2012 to 2018.

	Univariate models			Multivariable model		
	IRR	95% CI	*P* value	IRR	95% CI	*P* value
Mean temperature, mean, °C	1.02	1.02, 1.03	<.001	1.03	1.02, 1.03	<.001
Difference in temperature, mean, °C						
Mean Relative humidity, %	1.02	1.01, 1.03	<.001	1.01	1.00, 1.02	.044
Vapor pressure, mean, hPa						
Mean cumulative precipitation, mm	1.03	1.02, 1.03	<.001			
Precipitation time, hr						
Cumulative sunshine h, hr	1.03	1.01, 1.05	<.001			

Covariance including age, sex, and vaccination.

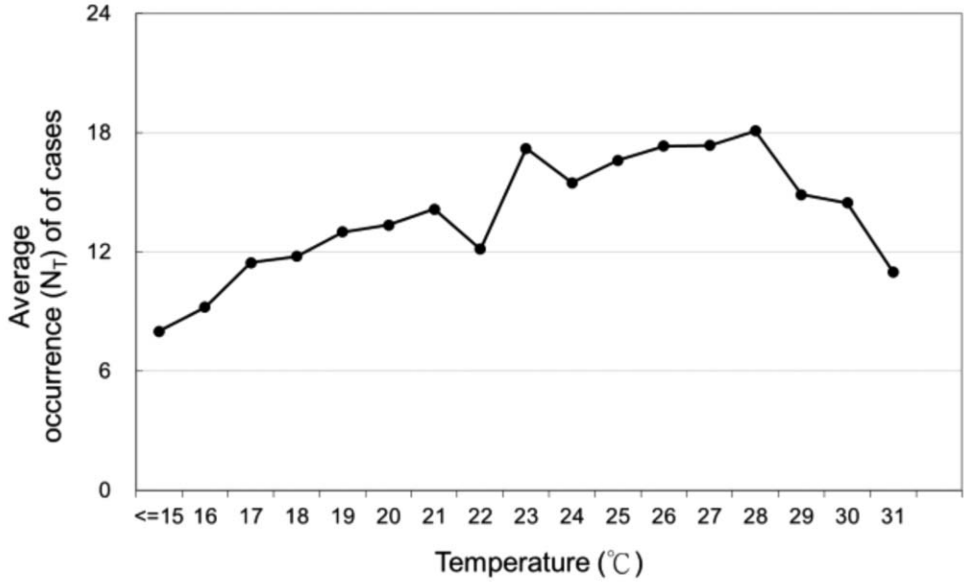

Figure 2. The case count of mumps at various temperatures.

circulation of the mumps virus, the infectivity of the mumps virus, or the lifestyle of the host.[32] Particularly, environmental conditions may be an important determinant of viral transmission.[34,35] Various patterns of mumps seasonality have been reported in different countries and territories. A seasonal pattern with significant peaks in April was observed in the USA.[17] In China, mumps cases are concentrated in the spring and summer.[4] In Ukraine, most cases of mumps occur in winter and spring.[36] Our results showed a seasonal pattern of mumps infection with a peak occurrence in the spring and summer months. Our findings were similar to those of previous studies in China,[37,38] but differed from those in Jordan.[19] The effects of varied seasonal exposure and mutual interactions between climatic factors in different areas may explain this discordance of findings.[13]

We found that the incidence of mumps was associated with the mean temperature and relative humidity in our study; this result was consistent with previous studies in Japan[13], Mexico,[39] China,[16] and Taiwan[14]; however, a study in the Czech Republic found that mumps was not associated with warmer and drier weather.[31] These inconsistent findings may be due to the different methodologies used in the studies or whether the interactive variables were controlled.

In our study, we found that the occurrence of mumps was higher in men than in women. This finding is consistent with that of previous studies.[4,22,40] In an epidemic of mumps in the United States,[22] females had a higher infection rate (64%) than males. In a mumps outbreak in Guam,[4] the ratio of male cases to female cases was 1:1. Physiological sex differences and discrepancies in behavioral patterns may explain this discrepancy.[40] In warm

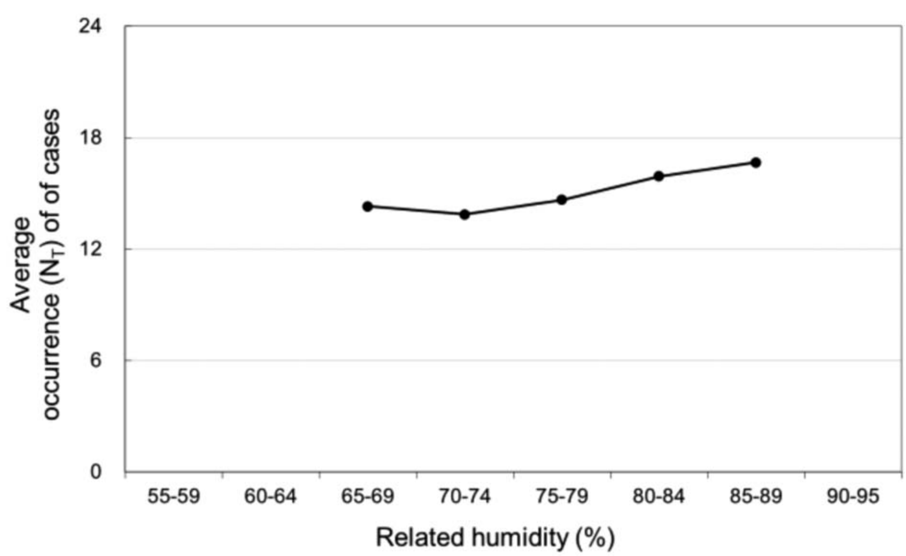

Figure 3. The mumps cases at various relative humidity values.

weather, males are more active outdoors and more likely to have close contact with friends, which will increase the chance of being infected with infectious diseases.

The northern region of Taiwan belongs to the subtropical monsoon climate zone, and the southern region belongs to the tropical monsoon climate zone. However, in this study, a high number of mumps cases (52.5%) occurred in the northern region of Taiwan, followed by the southern region (24.1%), central region (20.2%), and eastern region (3.2%). The northern region has a high socioeconomic status, and approximately 40% or more of the Taiwanese population lives in this area.[14] The high number of mumps cases that occurred in this region reflects the population density of this region. The low population density in the eastern region could explain the lower number of cases in the eastern region. In contrast, we found that the highest incidence of mumps occurred in the eastern region. The reason for this phenomenon remains unclear.

Developing and analyzing mathematical models is a key tool for the prevention and control of infectious diseases.[41] compartmental model is the basic mathematical framework used for estimating the dynamics of epidemics. Susceptible-Exposed-Infectious-Recovered (SEIR) is a semi-analytical method.[42] In the SEIR model, the fraction of the population that is susceptible (S) becomes infected at a rate of $\beta = R_0\gamma$, where R_0 is the basic reproductive number. R_0 is the expected number of cases directly generated by one case in a population in which all individuals are susceptible to infection. The effective reproductive number (R_E) is the new number of new infectious cases emerging from a single infectious case under the implementation of preventive measures.[41] If R_E is lower than 1.0, then the epidemic is unlikely to be sustained in the long term. If the R_E approach is higher than 1.0, then the epidemic is likely to occur in the long term.[41,42] Based on the estimate of transmission rate, previous studies indicate that the most efficient preventive measure for the control mumps epidemic is vaccination with 2 doses of the mumps vaccine.[43,44] However, urging people to popularize health knowledge and preserve good personal hygiene habits are still essential components to retrain the mumps spread among populations.[43]

A previous study indicated that psychosocial conditions, including depression, anxiety, feelings of loneliness, feeling stigmatized, social isolation, and poor quality of life (QoL), have been experienced among patients with infectious diseases.[45] To explore the severity of psychosocial problems among patients with infectious diseases is an important task in the future.

This study has several limitations. First, the data were obtained from the NNDSS of Taiwan CDC. This system is a passive reporting system. The data (e.g., mumps) may be under-reported.[46] Second, we cannot exclude the potential confounding factors, including host susceptibility and geographic factors, as presented in our study. However, we did not find that weather effects were correlated with the likelihood of disease reporting.[27] Finally, we did not consider air pollution, which has been recognized as a risk factor for mumps virus infection.[47]

5. Conclusions

In summary, we found that the seasonal pattern of mumps infection in Taiwan and meteorological variables, including the mean temperature and relative humidity, might contribute to the observed seasonality of mumps infection. Our findings demonstrate the importance of meteorological variables in determining mumps case occurrence and can help explain the notable seasonal pattern of mumps. Public health authorities should alert the variations of climate as a warning signal, and they could develop intervention measures before the seasonal time of mumps occurrence to mitigate the risk of mumps infection.

Author contributions

Conceptualization: Cheng-Yao Lin, Shih-Bin Su, Kow-Tong Chen.
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