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A mumps model with seasonality in China

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ABSTRACT

Background: Mumps, an infectious viral disease, classically manifested by inflammation of salivary glands and is best known as a common childhood viral disease with no specific treatment. Although it can be protected by vaccine, there are more than 100,000 reported mumps cases according to the Chinese Center for Disease Control and Prevention. However, the factors and mechanisms behind the persistence and prevalence of mumps have not been well understood.

Methods: A mumps model with seasonal fluctuation is formulated and investigated. We evaluate the basic reproduction number $\mathscr{R}_0$ and analyze the dynamical behavior of the model. We also use the model to simulate the monthly data of mumps cases and carry out some sensitivity analysis of $\mathscr{R}_0$ in terms of various model parameters.

Results: It is shown that there exists only disease-free solution which is globally asymptotically stable if $\mathscr{R}_0 < 1$, and there exists a positive periodic solution if $\mathscr{R}_0 > 1$. $\mathscr{R}_0$ is a threshold parameter, and its magnitude determines the extinction or persistence of the disease.

Conclusion: Our analysis shows that vaccination rate and invalid vaccination rate play important roles in the spread of mumps. Hence, Our study suggests to increase the vaccine coverage and make two doses of MMR (Measles, mumps and rubella vaccine) vaccine freely available in China.

1. Background

Mumps, also known as epidemic parotitis, is a viral disease caused by the mumps virus, classically manifested by inflammation of salivary glands and fever (Ennis & Jackson, 1968; Latner & Hickman, 2015). This disease is best known as a common childhood viral disease (Richardson, Elliman, Maguire, Simpson, & Nicoll, 2001). Initial signs and symptoms often include fever, muscle pain, headache, and feeling tired, and there is no specific treatment (Mühlemann, 2004). It is usually followed by painful swelling of one or both parotid glands (Wharton, Chaudhry, & French, 2006). Symptoms in adults are often more severe than in children. Aseptic, meningitis, encephalitis, orchitis and oophoritis are common complications of mumps, which can arise in adult men and women (Latner & Hickman, 2015). About a third of people have mild or no

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symptoms (Unal et al., 1998). Complications may include infections of the covering of the brain (15 percent), pancreatitis (4 percent), permanent deafness, and painful testicular swelling which uncommonly results in infertility (Hviid, Rubin, & Mühlemann, 2008).

In general, many infectious diseases fluctuate over time and show seasonal patterns in the incident rate, such as measles, whooping cough, polio, influenza, chickenpox, mumps, etc (Bjϕrnstad, Finkenstädt, & Grenfell, 2002; Dowell, 2001; London & Yorke, 1973). We consider the periodic transmission attribute to the following three facts (Ma & Ma, 2006): (1) In winter most children stay at home because the cold weather and while in summer and fall, people especially children have more frequent outdoor activities which increase chances of contact. (ii) Meanwhile, in summer the warm climate contribute to the growth of virus and the spread of disease. (iii) From April to June children usually go to school and study together, and during July and August most schools are closed for summer vacation thus many children play together without supervision of their parents. All these cause the disease spread easily and form a seasonal pattern. Mumps is highly contagious and spreads rapidly among people living in close quarters. The virus is transmitted by respiratory droplets or direct contact with an infected person (Gupta, Best, & Macmahon, 2005). Only humans get and spread the disease. A person infected with mumps is contagious from approximately seven days before the onset of symptoms until about eight days after symptoms start. The incubation period can be 12–26 days, but is typically 16–18 days. 20–40 percent of persons infected with the mumps virus do not show symptoms, so it is possible to be infected and spread the virus without knowing it (Kutty et al., 2010). After an infection a person is typically immune for life. Reinfection is possible but tends to be mild (Senanayake, 2008). Larger outbreaks of disease would typically occur every two to five years. Children between the ages of five and nine were most commonly affected. Among immunized population often those in their early 20s are affected. Around the equator it often occurs all year round while in the more northerly and southerly regions of the world it is more common in the winter and spring (Wharton et al., 2006). About one per ten thousand people who are infected die.

The most common preventative measure against mumps is a vaccination with 2 doses of the mumps vaccine, invented by American microbiologist Maurice Hilleman at Merck (Buynak, Weibel, Whitman, Stokes, & Hilleman, 1969). Before the introduction of a vaccine, mumps was a common childhood disease worldwide. Widespread vaccination has resulted in a more than 90 percent decline in rates of disease. Most of the developed world includes it in their immunization programs, often in combination with measles and rubella vaccine (MMR). Hospitalization may be required if meningitis or pancreatitis develops (Gupta et al., 2005; Senanayake, 2008). The vaccine may be given separately or as part of the MMR immunization vaccine that also protects against measles and rubella. In the US, MMR is now being supplanted by MMRV, which adds protection against chickenpox (varicella, HHV3). The WHO (World Health Organization) recommends the use of mumps vaccines in all countries with well-functioning childhood vaccination programmes. In the United Kingdom it is routinely given to children at age 13 months with a booster at 3–5 years (preschool). This confers lifelong immunity. The American Academy of Pediatrics recommends the routine administration of MMR vaccine at ages 12–15 months and at 4–6 years (Center for Disease Control and Prevention, 2012). In some locations, the vaccine is given again between four and six years of age, or between 11 and 12 years of age if not previously given. The efficacy of the vaccine depends on the strain of the vaccine, but is usually around 80 percent (Schlegel, Osterwalder, Galeazzi, & Vernazza, 1999). Because of the outbreaks within college and university settings, many governments have established vaccination programs to prevent large-scale outbreaks. In Canada, provincial governments and the Public Health Agency of Canada have all participated in awareness campaigns to encourage students ranging from grade one to college and university to get vaccinated.

Not only did it greatly reduce the incidence of mumps but also decreased significantly in patients with encephalitis and meningitis. Mumps vaccination is almost universally used in developed countries nowadays (Guy et al., 2004; Latner & Hickman, 2015). In Beijing, starting from 2000, under the disease immunization program: with Children should get 2 doses of MMR vaccine, a year and a half after the first immunization, the children need to be vaccinated at the age of 6 (Beijing vaccine). But for most of the cities and provinces in China, according to the National Immunization Program by Chinese Center for Disease Control and Prevention (National Immunization Program Chinese Center for Disease Control and Prevention), children just get vaccinated one dose. We also note that there have been outbreaks in vaccinated populations. An outbreak of mumps occurred unexpectedly in May 2005 in Nova Scotia, Canada, followed later by an outbreak in Quebec, Canada (Watson-Creed et al., 2006), and in September 2005, by an outbreak in Iowa (Centers for Disease Control and Prevention, 2006). In 2006 the United States experienced the largest nationwide mumps epidemic in 20 years (Barskey, Glasser, Lebaron, & Charles, 2009).

The organization of this paper is as follows. In the next section, an epidemic model for mumps with seasonal fluctuation is proposed to understand the infectious dynamics. Then we study the global asymptotic stability of the disease-free equilibrium and the existence of positive periodic solutions. Simulations of the model and sensitivity analysis of the basic reproduction number are performed in Section 3. We end this article with model-based suggestion of intervention improvement to control the mumps.