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Patterns of Transmission Dynamics of Severe Fever with Thrombocytopenia Syndrome Virus in Dalian: Roles of Systemic, Co-Feeding, and Transovarial Routes

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Abstract. Severe fever with thrombocytopenia syndrome (SFTS) is an emerging tick-borne zoonotic disease caused by severe fever with thrombocytopenia syndrome virus. In recent years, there has been an increasing number of human SFTS cases in central and northeast China. In the study region, Dalian, the number of human cases in years between 2011 and 2019 exhibited recurrent patterns in synchrony with the seasonal temperature variation. Here, we develop a transmission dynamics model to incorporate contact characteristics of animal and human hosts from published literature, and fit the model to historical temperature and human incidence data in our study region to analyze trends in human SFTS incidence and the time trends of SFTS prevalence within the natural tick-host cycle. Our analysis highlights the contributions of the systemic, co-feeding, and transovarial transmission routes, and provides insights for cost-effective public health interventions targeted to reducing transmission in these coexisting transmission pathways.

AMS subject classifications: 34C25, 92D25, 92D30
Key words: SFTS, dynamics model, basic reproduction number, sensitivity analysis.

1 Introduction

Severe fever with thrombocytopenia syndrome is an emerging tick-borne zoonotic disease caused by severe fever with thrombocytopenia syndrome virus (SFTSV). Most SFTS

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cases in China are distributed in rural areas of central and northeastern China, including Shandong, Hubei, Henan, Anhui, Liaoning, Zhejiang, and Jiangsu provinces. Since its first identification in the central provinces of Hubei and Henan [38] in 2009, SFTS has gradually spread to other regions of Asia, including Japan and South Korea. The primary clinical and laboratory characteristics of SFTS include fever, gastrointestinal and neurological symptoms, as well as thrombocytopenia and leukopenia, with fever being the most common symptoms. The incubation period is generally 6-14 days with an average of 9 days. The case-fatality rate ranges from 12% to 50% [13]. According to surveillance data from the China Disease Prevention and Control Information System, the incidence and prevalence of SFTS have been increasing annually [22].

Recent studies indicate that ticks are the main hosts of SFTS and play a key role in its transmission. Ticks, such as Haemaphysalis longicornis, Ixodes nipponensis, Dermacentor silvarum, and Rhipicephalus microplus, are susceptible to severe fever with thrombocytopenia syndrome virus, among which H. longicornis being the predominant tick species [14]. H. longicornis is also capable of transmitting Rickettsia japonica, Russian spring-summer encephalitis virus, and tick-borne encephalitis virus. The transmission pathways of SFTS via H. longicornis include tick bites, human-to-human contact (such as blood and bodily fluid contact), and inter-species co-feeding transmission [2,8,34]. Experimental evidence has shown that transovarial transmission is also a major source of infection in ticks [18]. The life cycle of H. longicornis consists of four stages: egg, larva, nymph, and adult, each post-egg stage requiring a different host to complete development. There are a great number of early works on stage-structured population dynamics models [3,20,32,35]. The main hosts for larvae and nymphs are rodents and birds, while adult ticks primarily feed on large mammals. In eastern China, domesticated animals H. longicornis ticks fed on include goats, cattle, pigs, deer, cats, dogs, and chickens [19]. The spread of SFTS is also influenced by environmental factors, such as climate change and land use patterns, which not only affect tick survival and activity, but also influence host behavior and distribution, thus altering the risk of transmission of SFTSV.

Early works on SFTS dynamics research mainly focused on time series forecasting. For example, Deng *et al.* [5] used a generalized additive model to study the impact of meteorological factors and tick density on SFTS transmission in Jiangsu Province, finding that temperature, wind speed, and duration of sunlight significantly increased incidence. Wang *et al.* [31] employed SARIMA, XGBoost, and LSTM models to predict the incidence trend in Hubei Province, showing that XGBoost performed well in predicting seasonal trends and monthly incidence rates. In addition, much attention is also paid to the clinical diagnosis and treatment of SFTS. Li *et al.* [15] designed a clinical scoring model, combining age and neurological symptoms with laboratory variables, including abnormal lactate dehydrogenase concentrations, aspartate aminotransferase, blood urea nitrogen, and abnormal neutrophil percentage. They further suggested the best time for the application of ribavirin. Based on hospital data collected from Henan and Shandong between 2011 and 2020, Ge *et al.* [9] compared clinical progress for patients with SFTS and acute hyperglycemia and concluded that acute hyperglycemia is responsible for SFTS-related