Modelling the Transmission Dynamics of Severe Fever With Thrombocytopenia Syndrome in Jiangsu Province

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Research

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Modelling the transmission dynamics of Severe Fever with Thrombocytopenia Syndrome in Jiangsu Province

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Abstract

Background: Severe fever with thrombocytopenia syndrome (SFTS) is an emerging infectious disease that is regionally distributed in Asia with high fatality. Constructing the transmissibility model of SFTS could help provide clues for the intervention of disease control and fill the gap in the research of the SFTS model.

Methods: Based on the Susceptible–Exposed–Infectious–Symptomatic–Recovered (SEIAR) model and combined with the epidemiological characteristics of SFTS in Jiangsu Province. An SFTS transmission dynamics model was built to evaluate the effect through cutting off the different transmission routes and taking different interventions, to offer clues for disease prevention and control, and filled the gap in research of the SFTS model.

Results: For the transmission model of SFTS, the fitting effect of case data and model is great. Meanwhile, cutting off the transmission routes of the environment have the greatest effect on the prevention and control of SFTS, but isolation and shorten the course of the disease did not gain more effect.

Conclusions: This study is determined that cutting off the transmission routes from the environment to humans had the greatest effect on SFTS prevention and control.

Keywords

Severe fever with thrombocytopenia syndrome; Bunyavirus; SEIAR model of SFTS; Environment; Ticks

Introduction

Severe fever with thrombocytopenia syndrome (SFTS) is an emerging infectious disease infected by a novel bunyavirus, which is called Severe Fever with Thrombocytopenia Syndrome Virus (SFTSV) [1]. The clinical manifestations of human infection have been characterized by high fever, a drastic reduction of platelets and leukocytes and hemorrhage[2, 3, 4, 5]. The clinical course is mainly divided into three stages: fever, multiple nerve dysfunction and recovery[1, 3, 4, 6, 7].

In addition, the circulating region of SFTS mainly covers the rural areas of central and northeast China, with a number of 500~1500 in 2011-2012 and a fatality rate of nearly 30%. However, the fatality rate has dropped to 10%~12% in recent years[8]. Besides, SFTS has also spread in South Korea and Japan. In South Korea, SFTS mainly occurred in tick-active months from May to September and infections reports continued until November, the fatality rate was above 35% among 2012-2013 and the incidence rate dropped to 11.52% in 2016 [9]. In Japan, the cases were mainly reported in the western part, with a case fatality rate slightly higher than that in China (23%) [10]. Currently, the SFTS fatality rate in Asia, seems to be decreasing but the incidence rate is increasing regionally, especially in China. According to the monitor data from China Information Network System of Disease Prevention and Control in 2010-2016, the incidence rate and prevalence of SFTS have increased year by year, SFTS cases have been found in 23 provinces in China[11]. Additionally, SFTS has not only brought the health burden, but also a certain amount of economic pressure. There was a study showing that patients and their families should pay nearly \$3,158.4 for their treatment, which is almost equal to the disposable income of rural residents in Anhui Province in 2017 [2]. Obviously, SFTS has become a significant threat to public health.

To fight against this emerging infectious disease, the domestic and foreign research of etiology and risk factors has made certain progress in recent years. According to the epidemiological characteristics of SFTS, some articles show that Henan Province, Hubei Province and Anhui Province are the mainly provinces, especially the border areas among these three provinces and the number of cases was largest[12]. The main infected population of SFTS is farmers who live in forested or hilly areas[13, 14, 15,

16] and the main onset age is 50 years old and above. Recent research suggested that the *Haemaphysalis longicornis*[1, 17, 18, 19] is the most likely vector. The SFTS cases were distributed from March to November, but the peak period of disease focused on August and September. The seasonal distribution of SFTS cases was closely related to the seasonal trend of tick density[20, 21].

For the natural routes of transmission of SFTS, there is some preliminary research that comes up with the process of host animal-tick-human[22]. However, there was few systematic and definite research on transmission routes among vector, host and population of SFTSV. Meanwhile, various problems occurred in the treatment of SFTS such as unclear pathogenesis, no vaccine for prevention and no specific antiviral therapy for SFTS. As a result, we cannot keep the fatality rate at a low level. By far, there is no research on the transmission dynamics model of SFTS and no clear evidence for some preventive methods could achieve optimal intervention effect. Finding out the cause of the disease should be the first step, which means effective interventions and specific treatments should be positively researched to decrease the morbidity of SFTS, thus contributing to reducing the fatality rate.

This study aims to construct the Susceptible–Exposed–Infectious–Asymptomatic–Recovered (SEIAR) model combination with the epidemiological characteristics of SFTS in Jiangsu Province and the transmission features of SFTS. In addition, the reported data of SFTS in Jiangsu Province from January 2001 to December 2019 was used to fit this model; the conditions were stimulated and the intervention effect of cutting different routes of transmission was assessed by setting the parameter of the model to obtain the best intervention plan, thus providing the clue to the intervention of disease control and filling the gap of the research of SFTS model.

Method

Study design

This study is divided into three sections. In section1, the transmission dynamics model of SFTS was established by searching scientific literature and analyzing data reported. In section 2, the data of reported cases was used to fit this model. In section 3, different conditions of cutting off transmission routes were stimulated and the effect of SFTS

incidence was evaluated by simulating different interventions, see [Figure 1](#).

Establishment of transmission dynamics model

According to the characteristics of epidemic and the route of transmission of SFTS in Jiangsu Province[23, 24, 25, 26], this study established SFTS transmissibility model in terms of days and based on the model of SEIAR. This model included four parts: human, tick, host animal and environment. Therefore, the human part is represented by subscript 1; The tick part is denoted by subscript 2; The host animal is represented by subscript 3; The environment is represented by subscript w, see [Figure 2](#). The SEIAR model used in this study is based on the following assumptions:

Human part of the SEIAR model

1) This model supposes that disease belongs to vertical transmission and that the newborn of all kinds of people are all susceptible. And we suppose that the total population is N , the birth rate is br , the natural mortality rate is dr . According to literature, the fatality rate of overt infections, f , is 16.1%[5]. In the meanwhile, in the SEIAR model of SFTS, the mortality rate of all kinds of people, excluding overt infections, is low and the mortality rate of population SFTS is lower so we take the population-wide mortality rate to approximately replace the mortality rate of excluding overt infections. But the mortality rate of overt infections will be set as the sum of the mortality rate of the whole population and the mortality rate of SFTS.

2) According to literature, the means of SFTS transmission are limited to “human to human” transmission[27, 28], which can infect by contacting the blood[29] of patient or aerosol[30]. At the same time, the infectious ability of overt infection and latent infection can be different. So, we set the transmissibility of latent infection relative to overt infection as the κ and the susceptible S_1 contact with two types of people as the incubation period E_1 that have some transmissibility and the infection rate coefficient is β_1 .

3) We suppose that there are certain percentage the incubation period $(1-p)E_1$ ($0 \leq p \leq 1$) can transform to overt infections I_1 and at the same time other part of the incubation period pE_1 will become the latent infections A_1 after an incubation period. So, at time t , the development speed of the E_1 to I_1 pathway is proportional to the number of people

in the incubation period, and the proportional coefficient is $(1-p)\omega_1$, the development speed of the E_1 to A_1 pathway is proportional to the number of people in the incubation period, and the proportional coefficient is $p\omega_1$.

4) The out speed of the population in the overt infections I_1 and latent infections A_1 are respectively proportional to their number of population and the ratio coefficients are respectively γ and γ' .

5) The infectors of SFTS will produce antibody after they are removed but this study supposes that this remover will never be infected and that set R_1 as the destination of the transmission route between people because the literature about the second infection in population was not found.

Environment part of the SEIAR model

1) There is no literature that can frankly prove that the environment is one of the transmission routes but there was evidence suggesting that in the environment, the possibility of infecting SFTS was higher than ticks[31, 32, 33, 34]. So, we assume that the environment has the ability to spread SFTS to humans and animals and we set it as β_w [35].

2) As reported, the blood and excreta of human or host animals may diffuse the SFTS. And commonly SFTS have highly occurred in the wild, so we suggest that the animals have the possibility to infected the environment by their blood or excreta. We set the propagation coefficient j as 10[36].

Tick part of the SEIAR model

1) According to literature, the SFTS as a natural focal disease, it mainly spread by ticks in nature and the *Haemaphysalis longicornis* Neumann is the dominant tick species[1, 17, 18, 19]. The infectious ticks can spread the virus in the body by biting the host animal and can spread the disease in the population by directly biting the people[37].

2) As the Long-term storage host, ticks that infected SFTSV can lastingly preserve the pathogen and can keep the infectious ability of pathogen and have no symptoms[37]. So, this study set the transmission route among ticks as the Susceptible-Exposed-Asymptomatic (SEA) model.

3) In the transmission among ticks, the infection rate coefficient is β_2 . Our study

considers that the SFTS was not diffused among ticks, so we set β_2 as 0. The susceptible S_2 has some transmission ability that can make some infected ticks become the incubation period E_2 and the proportion of this part is $\beta_2 S_2 A_2$.

4) This study supposes that after one incubation period all the incubation period will transform to latent infection A_2 , so, at time t , the number of the ticks that in the E_2 to A_2 route is $\omega_2 E_2$.

5) The ticks that in the state of latent infection can spread the SFTSV further in the body of animals by biting them. Because the coefficient of infection rate that the virus spread from ticks to host animal is β_{2-3} so the part of $\beta_{2-3} S_3 A_2$ host animal can obtain the virus by tick's bite. In addition, those ticks can spread the SFTS among people by directly biting humans. Because the coefficient of infection rate that the virus spread from ticks to humans is β_{2-1} , so the part of $\beta_{2-1} S_1 A_2$ people can save the virus by ticks directly bite.

Host animal part of the SEIAR model

1) According to the report, the main amplification hosts of arboviruses are small rodents which means after biting small rodents the arthropods can cause relative viremia; but the other uninfected arthropods can make the virus spread further by biting infected small rodents [38].

2) In SFTS, the ticks that infected SFTSV can cause viremia by biting host animals such as mice or domestic animals. Those uninfected ticks can be infected by biting infected host animal and the host animal has no symptoms after being infected with SFTSV[38, 39, 40, 41]. So, we still set the transmission progress of SFTSV as the SEA model in the part of host animal of transmission dynamics model.

3) Among the transmission of host animals, the infection rate coefficient is β_3 . The susceptible S_3 has some infectious ability that can make some infected host animal transform to the incubation period E_3 and this ratio is $\beta_3 S_3 A_3$.

4) This study supposes that all the incubation period E_3 will transform to latent infection A_3 after one incubation period. At the time t , the number of host animals in the E_3 to A_3 pathway was $\omega_3 E_3$.

5) The uninfected ticks can make the SFTSV spread further in the body of ticks after biting the host animal that is in the state of latent infection. The coefficient of host-to-

tick transmission of the virus is β_{3-2} , so ticks with a $\beta_{3-2}S_2A_3$ component acquire the virus by biting an infected host animal.

The differential equation

The above transmissibility model is expressed by differential equations as follows:

$$\frac{dS_1}{dt} = b_r N_1 - d_r S_1 - \beta_1 S_1 (I_1 + kA_1) - \beta_{21} S_1 A_2 - \beta_w S_1 I_w - \beta_{31} S_1 A_3$$

$$\frac{dE_1}{dt} = \beta_1 S_1 (I_1 + kA_1) + \beta_w S_1 I_w + \beta_{21} S_1 A_2 + \beta_{31} S_1 A_3 - d_r E_1 - p\omega_1 E_1$$

$$- (1 - p)\omega_1 E_1$$

$$\frac{dA_1}{dt} = p\omega_1 E_1 - d_r A_1 - \gamma' A_1$$

$$\frac{dI_1}{dt} = (1 - p)\omega_1 E_1 - \gamma I_1 - (d_r + f) I_1$$

$$\frac{dR_1}{dt} = \gamma' A_1 + \gamma I_1 - d_r R_1$$

$$\frac{dW}{dt} = jA_3$$

$$\frac{dS_2}{dt} = -\beta_2 S_2 A_2 - \beta_{32} S_2 A_3$$

$$\frac{dE_2}{dt} = \beta_2 S_2 A_2 + \beta_{32} S_2 A_3 - \omega_2 E_2$$

$$\frac{dA_2}{dt} = \omega_2 E_2$$

$$\frac{dS_3}{dt} = -\beta_w S_3 W - \beta_3 S_3 A_3 - \beta_{23} S_3 A_2$$

$$\frac{dE_3}{dt} = \beta_3 S_3 A_3 + \beta_{23} S_3 A_2 + \beta_w S_3 W - \omega_3 E_3$$

$$\frac{dA_3}{dt} = \omega_3 E_3$$

The left-hand side of the equation is respectively expressed as the instantaneous change velocity of S , E , I , A and R at time t .

Estimation of parameters

The value of parameters: $p, 1/\omega_1, 1/\gamma, 1/\gamma', f, 1/\omega_2, 1/\omega_3$ and j all according to relative literature. Among them, p of recessive infection ranged from 3.2% to 5.5%[42], and the mean was 4.3% in this study, i.e., $p = 0.043$. And $1/\omega_1$ of incubation period of SFTS in

population ranged from 9 days to 14 days[43, 44], and the median was 11 days in this study. The course of the disease $1/\gamma$ of overt infection was 2 weeks[45], i.e. 14 days. The research about the course of the disease $1/\gamma'$ of latent infection was not found, so using the same days with the course of the disease of overt infection, i.e., 14days. The fatality rate f ranged from 11.2% to 30%, and $f=0.16$ [5]. The incubation period after tick infection with SFTSV was $1/\omega_2$ weeks, i.e., 7 days. The incubation period of SFTSV infection in host animals $1/\omega_3$ was 12 days[40]. The coefficient of infection β_1 was generated by model fitting. No valid data or literature support was found for the relative transmissibility coefficient κ of recessive infected persons. In this study, $\kappa=1$ was selected for calculation. The birth rate (br) and the death rate (dr) were obtained from the statistical yearbook of Jiangsu Province, see [Table 1](#).

Evaluation of cutting off different transmission routes

In this study, the transmissibility coefficient in the model was used to reflect different transmission routes, including transmissibility of environment to humans or host animals (β_w), host animals to humans (β_{3-1}), ticks to humans (β_{2-1}), human to human (β_1), ticks to host animals (β_{2-3}), host animal to ticks (β_{3-2}) and host animals to host animals (β_3). Based on the established SFTS transmissibility model, using 2019 data, a scenario of cutting off various transmission routes is established by setting one of the above infection rates up to seven values to 0 at the time of simulation. We arranged the matrix between different transmission routes, as shown in [Table 2](#), to perform a more comprehensive resection of transmission routes. The above methods are used to obtain the intervention effect of cutting off different transmission routes of SFTS, and the indicators of intervention effect include: cumulative number of cases, total attack rate, peak incidence site and peak incidence, to provide guidance for the prevention and control of the occurrence of SFTS epidemic.

Evaluation of intervention effect

In this study, the patients of SFTS took two interventions, isolation and shortened the disease course, and the model was established as the [Figure 3](#). Among this, Q was the number of people isolated, R_Q was the recovery of isolation, was the isolation coefficient and the c were the coefficient of shorting disease course in the model. We

set the ϕ as the proportion of isolation which can be calculated by $\phi = \frac{R_Q}{R_1 + R_Q}$; Then we use γ to represent shortened disease courses. In our study, we set ϕ as 0.5%, 5% and 50%; and set γ as 1/14, 1/12, 1/10, 1/8, 1/6, 1/4. The two were combined in pairs to judge the intervention effect of SFTS under different intervention intensity. And then set ϕ as 98%, 90%, 80%, 70%, 60%, 50% to simulate the solo effect of different isolation ratio. The indicators of intervention effect also included: cumulative number of cases, incidence rate, peak position of incidence and peak size of incidence. Finally, the optimal way to intervene in the spread of SFTS and provide guidance for the prevention and control of the outbreak of SFTS.

Model simulation and statistical analysis

In this study, Excel was used for data summary and chart drawing, IBM SPSS Statistics (Version 21.0.0.0) was used for data statistical analysis, and Berkeley Madonna (Version 8.3.18) was used for fitting existing data and models, and epidemic prediction and evaluation were conducted for intervention effects under different transmission routes.

Result

Model fitting

The result of model fitting 2011-2019 SFTS incidence rate in Jiangsu Province was shown as [Figure 4](#). We discovered that the incidence rate of SFTS has strictly seasonal changed by analyzed every month and years SFTS incidence rate, which means in a year the incidence rate of high in summer and autumn, often appear two peaks, but no cases in winter. Just as the result of model fitting, the SFTS incidence rate of 2011-2019 in Jiangsu Province was periodically changed. And it is often at rest in winter, begins to increase in spring, and peaks by July-August, and the peak incidence rate of SFTS in Jiangsu Province has increased to some extent in recent years compared with 2011-2014. The R^2 and P values of the model fitting results for 2011 – 2019 were listed in [Table 3](#), and it can see that the model fitting results for all years were good and P was significant. ($P < 0.05$).

Model simulation

Cutting transmission routes

The simulation results of cutting off different transmission routes based on the 2019 SFTS transmission dynamics model in Jiangsu Province are shown in [Table 4](#). When the route of transmission between people is cut off, SFTS cannot spread in the population, so other combinations containing β_1 are not shown. It can be seen that when the transmissibility of environment (β_w) is cut off, the transmissibility of SFTS in the population is very weak, so its four evaluation indicators are low. In cutting off multiple transmission routes, it was found that the transmission of SFTS in the human population was lower when the transmission of the environment and animals was cut off at the same time. And as more transmission routes are cut off, SFTS becomes less transmissible in the population, see [Table 4](#).

Taking different interventions

It can be seen that both interventions, taking isolation and shortening the course of the disease, have not limited the spread of SFTS regardless of the combination of interventions. And no matter how many isolation ratios we applied, taken isolation also had little effect on the number of SFTS cases. There will only be a case reduction if the isolation is combined to shorten the course of disease, but the cumulative number of cases has fallen by only one. There was no difference in the incidence rate of SFTS between different degrees of isolation or shortening the course of the disease, see [Table 5, 6](#).

Discussion

SFTS is an emerging infectious disease caused by a novel bunyavirus, which was termed severe fever with thrombocytopenia syndrome virus (SFTSV). Since it was first discovered in China in 2009, the incidence rate has been increasing year by year, and the coverage of the epidemic area has expanded. Data from the Chinese CDC information system from 2010 to 2016 showed that Jiangsu Province is one of the provinces with the highest incidence of SFTS. Since the first confirmed case of SFTS discovered in 2010, Jiangsu Province has conducted stringenter SFTS monitoring. Therefore, based on the SFTS monitoring data of Jiangsu Province from 2011 to 2019, the SFTS transmission dynamics model was established to use the model to simulate

the change of incidence rate by cutting different transmission routes and taking interventions. We assessed the effect of those interventions and its effects are of great significance for preventing and controlling the occurrence of SFTS.

The effect of cutting different transmission routes

Previous studies have shown that the number of SFTS patients infected by the environment were more than those who were infected by ticks[17, 31, 32, 33, 34]. But most studies only use the density of ticks in the environment and the anti-body of SFTSV in ticks to evaluate the hazardous situation of environment[46, 47, 48, 49], so they do not consider the environment as one of the transmission routes. As we all know, several factors such as the number of ticks, the dominant phase of ticks, outdoor activities and the change of weather can affect the occurrence of SFTS[50]. There was one study collected SFTSV from the inanimate things in the room of SFTS patients, which can consider the environment could be one of the transmission routes of SFTS, although the test result of the air sample was negative[51]. Therefore, we established a SFTS transmissibility model and used the coefficient of transmissibility to reflect the different ways of transmission. Based on the literature and the data of SFTS incidents in Jiangsu province, 2019. We simulated cutting different transmission ways to show the different effects of interventions. The result of this study showed that in all the combination of cutting different transmission routes, the cumulative number of SFTS cases and other indicators could be significantly reduced when the transmission route containing the environment was cutoff. Moreover, the intervention effect is more obvious when the combination of environmental and host animal transmission routes is cut simultaneously. Those results indicated that the environment is an important route for the transmission of SFTS, this was consistent with previous research. Besides, this also provides a direction that can be explained. The reason may be that people were not exposed to wild environment, and the chance of contacting ticks or animal excreta, blood, etc., decreases, which leads to the low incidence rate of SFTS. In addition, some literature has shown that SFTS was an environment-tick-host animal-tick cycle and that humans were infected by accidental participation in one of the progress. Therefore, the more transmission ways we cut off, the smaller the impact of SFTS was. Interestingly,

the effect of cutting off the environment and the transmission route of ticks on SFTS was less than that of cutting off the environment and host animals simultaneously. This might be the main way for people to be infected with SFTS except for tick bites. In previous studies, there was also literature showing that those infected with SFTS with a clear history of tick bites only accounted for a small proportion (about 22%-29%[6, 34, 52]) of all infected individuals. The study also suggested that humans might be infected with SFTS after exposure to animal blood[6]. Although the transmission of SFTS was initiated by ticks, it may be that the two transmission routes of animal and environment are more important for human beings.

The effect of taking interventions

For infectious diseases, there are three links and two factors. Three links include the source of infection, transmission routes, the population; two factors include natural factors and social factors. Common measures to control infectious diseases include controlling the source of infection, cutting off the route of transmission and protecting the population. Therefore, after cutting off the route of transmission and protecting the population, we also need to control the source of infection, and here we choose to take interventions including taking isolation and shortening the course of the disease. Besides, we added the effects of taking isolation and shortening the course of the disease according to the established SFTS transmissibility model. Based on the data of SFTS in 2019 , the results of the simulation were used to evaluate the effect of the two interventions on SFTS. The results showed that whether taking isolation alone or shortening the course of the disease, or combining the two interventions, the effect of interventions mentioned above on the incidence of SFTS was limited. And the different isolation ratio has little effect on the cases. The reason for this may be that the incidence of SFTS is low, and most of the patients are farmers, or field workers[17, 33, 34, 50]. For people living in cities, they are less likely to be infected with SFTSV. And even human-to-human transmission, the greatest chance of occurrence was only the population who contact its blood, such as nurses or family members[53]. In addition, secondary SFTS infection leads to milder clinical manifestations compared with primary SFTS. Therefore, secondary patients only experience sudden fever,

thrombocytopenia, leukopenia, and gastrointestinal symptoms and recover more quickly[27].

In summary, taking isolation and shortening the course of the disease have little impact on SFTS, which may suggest that prevention and control of the development of SFTS should focus on cutting off the direction of transmission routes. Therefore, according to the results of cutting off the transmission route earlier, the possibility of traveling to the wild environment should first be avoided in order to prevent and control the transmission of SFTS. For the population living in rural areas or taking exercise in the wild, self-protection should be done well, such as wearing protective clothing and regularly cleaning the animal feces around the residence. What's more, in order to reduce the possibility of infection from domestic animals, livestock should be placed in certain places as far as possible to prevent its contact with the field environment.

Limitation

There are some limitations in our study. First, the data of SFTS cases collected by the National Disease Surveillance Information Reporting Management System, which the capability and availability of this system is finite. Second, this study failed to separate the effects of ticks and host animals on humans in the environment. Third, some perimeters of our model are collected from literature that may be a certain error in its timeliness.

Conclusion

In this study, the transmission dynamics model of SFTS was constructed based on the epidemiological characteristics of SFTS in Jiangsu Province, the effect of cutting off different transmission routes and taking isolation and shortening course of disease on SFTS control was evaluated. Finally, it was determined that cutting off the transmission route from environment to human had the greatest effect on SFTS prevention and control.

Abbreviations

SFTS: Severe fever with thrombocytopenia syndrome; SFTSV: Severe Fever with Thrombocytopenia Syndrome Virus; SEIAR: Susceptible–Exposed–Infectious–Asymptomatic–Recovered; SEA: Susceptible-Exposed-Asymptomatic; CDC: Center for Disease Control and Prevention;

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Ethics approval and consent to participate

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Consent for publication

Not applicable.

Availability of data and material

Data supporting the conclusions of this article are included within the article.

Competing interests

The authors declare that they have no competing interests.

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Authors’ contributions

TMC, JR and BD designed research; NZ, JR, BD, CL, JFH, ZYL, WKL, LL, PHL, TLY and XQC analyzed data, TMC, JR, BD, LXQ, ZYZ, SNL, MY, YZZ, YW, JWX, JFH, ZYL, ZFL, SYL and JLH conducted the research and analyzed the results; TMC, JLH, NZ, JR and BD wrote the manuscript. All authors read and approved the final manuscript.

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649 Figure legends

650 Figure 1 Study design map

651 Figure 2 SFTS without intervention model

652 Figure 3 SFTS with intervention model

653 Figure 4 Model fitting result of incidence of 2011-2019 in Jiangsu Province

654

656 Table 1 Definition and value of parameters

para	mete	definition	value	unite	method
	r				
		Person-to-person transmissibility coefficient	-	(person*day) ⁻¹	model fitting
		Relative transmissibility coefficient of inapparent infection	1	1	-
	p	Proportion of latent infection	0.043	1	Ref.[42]
Person	1/ ω_1	Incubation period	11	day	Ref.[43]
		Infectious period of dominant infection	14	day	Ref.[45] ¹
	1/ γ'	Latent infection period	14	day	-
	f	Fatality rate	0.16	1	Ref.[5]
	br	Birth rate	0.009481	1	statistical Yearbook of Jiangsu Province
	dr	Mortality rate	0.007003	1	statistical Yearbook of Jiangsu Province

Ticks	β_2	Coefficient of transmissibility between ticks	0	$(\text{pieces} \cdot \text{day})^{-1}$	-
	β_{2-1}	Coefficient of tick-to-human transmissibility	$8\beta_1$	$(\text{person} \cdot \text{day})^{-1}$	Ref. [35]
	β_{2-3}	Coefficient of tick-to-host infection	$8\beta_1$	$(\text{pieces} \cdot \text{day})^{-1}$	Ref.[35]
	$1/\omega_2$	Incubation period of ticks	7	day	Ref. [26]
Host animal	β_3	Coefficient of transmissibility between host animal	$2\beta_1$	$(\text{pieces} \cdot \text{day})^{-1}$	Ref.[35]
	β_{3-1}	Coefficient of transmissibility rate of host animal to human	$2\beta_1$	$(\text{pieces} \cdot \text{day})^{-1}$	Ref.[35]
	β_{3-2}	Coefficient of host animal infection to ticks	$8\beta_1$	$(\text{person} \cdot \text{day})^{-1}$	Ref.[35]
	$1/\omega_3$	Host animal incubation period	12	day	Ref.[40]
	j	Rate of host animal	10	-	Ref.[36]

discharge to the
environment

Enviro nment	β_w	Coefficient of transmissibility rate of the environment to humans and host animals	$9\beta_1$	(human/animal * day) -1	Ref.[35]	
	W	Environmental tick density	0.0474 94291	One · km2/pers on (flag · hour)	Jiangsu Province	surveillance data

657

658

659 Table 2 Combined transmissibility matrix

	β_1	β_3	β_w	β_{21}	β_{31}	β_{32}	β_{23}
β_1	1	$2\beta_1$	$9\beta_1$	$8\beta_1$	$2\beta_1$	$8\beta_1$	$8\beta_1$
β_3	$1/2\beta_3$	1	$9/2\beta_3$	$4\beta_3$	$1\beta_3$	$4\beta_3$	$4\beta_3$
β_w	$1/9\beta_w$	$2/9\beta_w$	1	$8/9\beta_w$	$2/9\beta_w$	$8/9\beta_w$	$8/9\beta_w$
β_{21}	$1/8\beta_{21}$	$1/4\beta_{21}$	$9/8\beta_{21}$	1	$1/4\beta_{21}$	$1\beta_{21}$	$1\beta_{21}$
β_{31}	$1/2\beta_{31}$	$1\beta_{31}$	$9/2\beta_{31}$	$4\beta_{31}$	1	$4\beta_{31}$	$4\beta_{31}$
β_{32}	$1/8\beta_{32}$	$1/4\beta_{32}$	$9/8\beta_{32}$	$1\beta_{32}$	$1/4\beta_{32}$	1	$1\beta_{32}$
β_{23}	$1/8\beta_{23}$	$1/4\beta_{23}$	$9/8\beta_{23}$	$1\beta_{23}$	$1/4\beta_{23}$	$1\beta_{23}$	1

660

661

662 Table 3 Model fitting effects 2011-2019

Year	R^2	P
2011	0.573878	<0.05
2012	0.29952	<0.05
2013	0.482155	<0.05
2014	0.764983	<0.05
2015	0.408163	<0.05
2016	0.767604	<0.05
2017	0.776788	<0.05
2018	0.801787	<0.05
2019	0.758567	<0.05

663

664

665 Table 4 Interventional effect of cutting off different transmission routes on SFTS

Transmission route	Cumulative number of cases	Total attack rate	Peak time	Peak attack rate
β_1	0	0	0	0
β_3	671	0	205	0
β_w	0	0	198	0
β_{21}	671	0	205	0
β_{31}	671	0	205	0
β_{23}	671	0	205	0
β_{32}	671	0	205	0
$\beta_3\beta_w$	0	0	198	0
$\beta_3\beta_{21}$	671	0	205	0
$\beta_3\beta_{31}$	671	0	205	0
$\beta_3\beta_{23}$	671	0	205	0
$\beta_3\beta_{32}$	671	0	205	0
$\beta_w\beta_{21}$	0	0	198	0
$\beta_w\beta_{31}$	0	0	10	0
$\beta_w\beta_{23}$	0	0	198	0
$\beta_w\beta_{32}$	0	0	198	0
$\beta_{21}\beta_{23}$	671	0	205	0
$\beta_{21}\beta_{31}$	671	0	205	0
$\beta_{21}\beta_{32}$	671	0	205	0
$\beta_{31}\beta_{23}$	671	0	205	0
$\beta_{31}\beta_{32}$	671	0	205	0
$\beta_{23}\beta_{32}$	671	0	205	0
$\beta_3\beta_w\beta_{21}$	0	0	198	0
$\beta_3\beta_w\beta_{31}$	0	0	10	0
$\beta_3\beta_w\beta_{23}$	0	0	198	0
$\beta_3\beta_w\beta_{32}$	0	0	198	0

$\beta_3\beta_{21}\beta_{31}$	671	0	205	0
$\beta_3\beta_{21}\beta_{32}$	671	0	205	0
$\beta_3\beta_{21}\beta_{23}$	671	0	205	0
$\beta_3\beta_{31}\beta_{23}$	671	0	205	0
$\beta_3\beta_{31}\beta_{32}$	671	0	205	0
$\beta_3\beta_{23}\beta_{32}$	671	0	205	0
$\beta_w\beta_{21}\beta_{31}$	0	0	10	0
$\beta_w\beta_{21}\beta_{23}$	0	0	198	0
$\beta_w\beta_{31}\beta_{23}$	0	0	10	0
$\beta_w\beta_{21}\beta_{32}$	0	0	198	0
$\beta_w\beta_{31}\beta_{32}$	0	0	10	0
$\beta_w\beta_{23}\beta_{32}$	0	0	198	0
$\beta_{21}\beta_{31}\beta_{23}$	671	0	205	0
$\beta_{21}\beta_{31}\beta_{32}$	671	0	205	0
$\beta_{21}\beta_{23}\beta_{32}$	671	0	205	0
$\beta_{31}\beta_{23}\beta_{32}$	671	0	205	0
<hr/>				
$\beta_3\beta_w\beta_{21}\beta_{31}$	0	0	7	0
$\beta_3\beta_w\beta_{21}\beta_{23}$	0	0	198	0
$\beta_3\beta_w\beta_{21}\beta_{32}$	0	0	198	0
$\beta_3\beta_w\beta_{23}\beta_{32}$	0	0	198	0
$\beta_3\beta_w\beta_{31}\beta_{23}$	0	0	10	0
$\beta_3\beta_w\beta_{31}\beta_{32}$	0	0	10	0
$\beta_3\beta_{21}\beta_{31}\beta_{23}$	671	0	205	0
$\beta_3\beta_{21}\beta_{23}\beta_{32}$	671	0	205	0
$\beta_3\beta_{21}\beta_{31}\beta_{32}$	671	0	205	0
$\beta_3\beta_{31}\beta_{23}\beta_{32}$	671	0	205	0
$\beta_w\beta_{21}\beta_{31}\beta_{23}$	0	0	10	0
$\beta_w\beta_{21}\beta_{31}\beta_{32}$	0	0	10	0
$\beta_w\beta_{21}\beta_{23}\beta_{32}$	0	0	198	0

$\beta_w\beta_{31}\beta_{23}\beta_{32}$	0	0	10	0
$\beta_{21}\beta_{31}\beta_{23}\beta_{32}$	671	0	205	0
$\beta_3\beta_w\beta_{21}\beta_{31}\beta_{23}$	0	0	10	0
$\beta_3\beta_w\beta_{21}\beta_{31}\beta_{32}$	0	0	10	0
$\beta_3\beta_w\beta_{21}\beta_{23}\beta_{32}$	0	0	198	0
$\beta_3\beta_w\beta_{31}\beta_{23}\beta_{32}$	0	0	10	0
$\beta_3\beta_{21}\beta_{31}\beta_{23}\beta_{32}$	671	0	205	0
$\beta_w\beta_{21}\beta_{31}\beta_{23}\beta_{32}$	0	0	10	0
$\beta_3\beta_w\beta_{21}\beta_{31}\beta_{23}\beta_{32}$	0	0	10	0

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Intervention	Cumulative of cases	number	Total		Peak rate	attack
			attack rate	Peak time		
$\gamma=1/14 \phi=0$	530		0.00	197	0	
$\gamma=1/14 \phi=0.5\%$	531		0.00	197	0	
$\gamma=1/14 \phi=5\%$	530		0.00	197	0	
$\gamma=1/14 \phi=50\%$	530		0.00	197	0	
$\gamma=1/12 \phi=0$	531		0.00	197	0	
$\gamma=1/12 \phi=0.5\%$	531		0.00	197	0	
$\gamma=1/12 \phi=5\%$	531		0.00	197	0	
$\gamma=1/12 \phi=50\%$	531		0.00	197	0	
$\gamma=1/10 \phi=0$	531		0.00	197	0	
$\gamma=1/10 \phi=0.5\%$	531		0.00	197	0	
$\gamma=1/10 \phi=5\%$	531		0.00	197	0	
$\gamma=1/10 \phi=50\%$	531		0.00	197	0	
$\gamma=1/8 \phi=0$	531		0.00	197	0	
$\gamma=1/8 \phi=0.5\%$	531		0.00	197	0	
$\gamma=1/8 \phi=5\%$	531		0.00	197	0	
$\gamma=1/8 \phi=50\%$	531		0.00	197	0	
$\gamma=1/6 \phi=0$	531		0.00	197	0	
$\gamma=1/6 \phi=0.5\%$	531		0.00	197	0	
$\gamma=1/6 \phi=5\%$	531		0.00	197	0	
$\gamma=1/6 \phi=50\%$	531		0.00	197	0	
$\gamma=1/4 \phi=0$	531		0.00	197	0	
$\gamma=1/4 \phi=0.5\%$	531		0.00	197	0	
$\gamma=1/4 \phi=5\%$	531		0.00	197	0	
$\gamma=1/4 \phi=50\%$	531		0.00	197	0	

670 Table 6 Interventional effect of taking different r

Isolation ratio	Cumulative number of cases	Cumulative attack rate	Peak time	Peak rate	attack
50%	530	0.00	201	0.00	
60%	530	0.00	201	0.00	
70%	530	0.00	201	0.00	
80%	530	0.00	201	0.00	
90%	530	0.00	201	0.00	
98%	530	0.00	201	0.00	

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Figures

Figure 1

Study design map

Figure 2

SFTS without intervention model

Figure 3

SFTS with intervention model

Figure 4

Model fitting result of incidence of 2011-2019 in Jiangsu Province

Supplementary Files

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- [GraphicalAbstract.jpg](#)