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ORIGINAL RESEARCH

Early Stage Risk Identification and Governance of Major Emerging Infectious Diseases: A Double-Case Study Based on the Chinese Context

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Purpose: Based on the Chinese context, this study uses severe acute respiratory syndrome (SARS) and coronavirus disease 2019 (COVID-19) outbreaks as examples to identify the risk factors that lead to the major emerging infectious diseases outbreak, and put forward risk governance strategies to improve China's biosecurity risk prevention and control capabilities.

Material and Methods: This study combines grounded theory and WSR methodology, and utilizes the NVivo 12.0 qualitative analysis software to identify the risk factors that led to the major emerging infectious diseases outbreak. The research data was sourced from 168 publicly available official documents, which are highly authoritative and reliable.

Results: This study identified 10 categories of Wuli risk factors, 6 categories of logical Shili risk factors, and 8 categories of human Renli risk factors that contributed to the outbreak of major emerging infectious diseases. These risk factors were distributed across the early stages of the outbreak, and have different mechanisms of action at the macro and micro levels.

Conclusion: This study identified the risk factors that lead to the outbreak of major emerging infectious disease, and discovered the mechanism of the outbreak at the macro and micro levels. At the macro level, Wuli risk factors are the forefront antecedents that lead to the outbreak of the crisis, Renli factors are the intermediate regulatory factors, and Shili risk factors are the back-end posterior factors. At the micro level, there are risk coupling, risk superposition, and risk resonance interactions among various risk factors, leading to the outbreak of the crisis. Based on these interactive relationships, this study proposes risk governance strategies that are helpful for policymakers in dealing with similar crises in the future.

Keywords: major emerging infectious diseases, risk factors, SARS, COVID-19, grounded theory, WSR methodology

Introduction

Major emerging infectious diseases refers to the infectious diseases that emerge for the first time in China or those that have been eliminated and recur, or occur suddenly, which cause or have the potential to cause serious damage to public health, causing social panic and affecting social stability.[1] It is a major risk challenge related to national security and development.[2] The SARS and COVID-19 outbreaks in China in the 21st century fall under this definition. After the SARS and COVID-19 outbreaks, the spread of the epidemic was controlled in a relatively short period of time with the concerted efforts of the Party Central Committee, the government and the people of the country, and the national epidemic situation improved rapidly. However, "If a nation cannot turn disaster into wealth, it is a real misfortune".[3] We should take the rare opportunity brought by the SARS and COVID-19 outbreaks to improve China's public health emergency management, gain experience, and correct errors in the country's current public health governance system, in order to help the country to avoid the same errors in the future.

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By tracing back to the SARS outbreak and COVID-19 outbreak, it is not difficult to find that most of the problems in the emergency management are focused on the early stages of the epidemic formation and prevention and control. In the early stages of the epidemic, as the new virus was still highly unknown, various social groups failed to effectively identify and avoid the risk of the outbreak, leading to the escalation of the crisis and the eventual catastrophe. On February 14, 2020, General Secretary Xi, while presiding over the 12th meeting of the Central Committee for Comprehensively Deepening Reform, pointed out that

> It is necessary to strengthen risk awareness and improve the collaborative mechanism for research, assessment, decision-making, prevention and control of major public health risks, and improve the national public health emergency management system and raise the level of capacity to respond to major public health emergencies.[4]

On May 24, 2020, General Secretary Xi stressed again at the third session of the 13th National People's Congress that

> Preventing and resolving major epidemics and sudden public health risks is a matter of national security and development, as well as the stability of the general social and political situation.[5]

However, strengthening public health emergency management and capacity building is a systematic and complex project, and it is necessary to use system engineering thinking to deal with and constantly evaluate changing or unpredictable public health risks, and quantify the effect of prevention and early warning, so as to establish a robust national emergency management system and enhance the capacity for public health governance.

Major emerging infectious disease events have strong characteristics of early confusion, multiple causes, and widespread transmission. Modern medicine strictly adheres to the "evidence-based principle" and relies on clinical data to determine the etiology and pathogenic attributes of the disease, which is a universally recognized scientific practice. However, constrained by the biological characteristics of pathogens and the level of modern medicine, the time it takes to arrive at scientific conclusions is beyond human control. Rigorous scientific conclusions require a significant investment of time and effort, but this will inevitably lead to a delay in societal protective behaviors in responding to serious pandemic crises. In addition, there are numerous risk factors that contribute to the outbreak of major emerging infectious diseases. Devoting a great deal of time and effort to adhere to the "evidence-based principle" may result in the inability to consider the interactions among other risk factors, leading to irreparable consequences.

The most critical step in emergency management is to draw lessons from crises, identify and eliminate risks, enhance risk prevention and control capabilities, and further improve policies in order to enhance immunity to new crises. Therefore, this study takes the SARS outbreak and the COVID-19 outbreak as examples, combines grounded theory and WSR system methodology to systematically identify risk factors that are critical drivers of major emerging infectious disease outbreaks, explore the outbreak mechanisms, and propose targeted risk management strategies to provide reference for China's public health emergency management system and capacity building.

Literature Review

WSR Methodology and Application

Wuli-Shili-Renli system methodology (WSR methodology) is an oriental system methodology proposed by researcher Jifa Gu and Dr. Zhichang Zhu in 1994.[6] This methodology uses the systems of Wuli, Shili and Renli to solve problems comprehensively and effectively.[7] The term "Wuli" refers to the general laws involving material motion and technological actions, used to describe the objective existence of matter or facts. "Shili" refers to the rationale of doing things, mainly addressing how to arrange all the equipment, materials, and personnel, usually using the knowledge of operations research and management science to answer the "how to do it", in order to improve the effectiveness and efficiency of human practical activities. "Renli" refers to the rationale of being a human being, which usually uses the knowledge of humanities and social sciences to answer the questions of "how should we do" and "how best to do it", by combining the multidisciplinary knowledge of psychology, sociology and behavioral sciences to study human psychology, behavior, purpose and value orientation.[8]

At present, WSR methodology has been widely applied to solve complex problems in various fields, and the research achievements are related to risk management, emergency management, engineering practice, theoretical analysis, system evaluation and other fields.[9] In the field of risk management and emergency management, the research outcomes focus on the theoretical constructs and practical applications. For example, in terms of theoretical research, Denis Caro combines the research paradigm of WSR methodology with the grounded theory method, and puts forward a new theory that transcends the transformational emergency leadership.[10] Xu and other scholars used WSR methodology to build a comprehensive integrated framework for post Wenchuan earthquake recovery and reconstruction.[11] At the practical applications, Zhou built a WSR model for the risk management of port hazardous chemicals logistics based on the in-depth analysis of Wuli, Shili and Renli, and carried out risk assessment on 10 important hazardous chemicals handling ports in China.[12] Chen and other researchers developed a conceptual model of construction safety for assembled buildings using the WSR approach and identified key risk carriers for construction risk transmission in each workspace of assembled buildings.[13]

From the research results of the WSR methodology in the field of emergency management, it can be observed that major accidents and natural disasters are the primary focus of study, while research findings related to public health emergencies are rare. To construct an effective public health emergency management system, guidance from a systematic approach is necessary. Therefore, applying the WSR methodology to the field of public health can help rapidly improve China's ability to manage and govern public health emergency situations.

Study of Risk Factors for Major Emerging Infectious Diseases Outbreaks

In epidemiology, risk factors are defined as variables that are associated with an increased risk of disease or infection.[14] As one of the few "catastrophic risks" facing humanity in the 21st century, related research involves ecology, epidemiology, public health, sociocultural, medicine, molecular biology and sociology.[15,16]

Firstly, there is a close relationship between infectious disease outbreaks and environmental changes.[17] The virus transmission across species depends on the interconnection between the host and the pathogenic environment.[18] For example, climate change can increase the chance of virus-host contact, leading to cross-species transmission of virus.[19,20] Secondly, viruses do not have geopolitical borders, increasing international cooperation can increase the risk of infectious disease epidemics emergence.[21,22] In a globalized trade environment, pathogens can travel across spatial and temporal boundaries, causing the spread of epidemics.[23] In nature, many infectious diseases are zoonotic, and animal hosts are an important source of viruses. Direct contact between humans and animals is a common route of virus transmission, such as through the consumption of infected wildlife or livestock.[24,25] In addition to this, for the microorganisms themselves, their resistance to antimicrobial drugs has led to the re-emergence of many outbreaks.[26] The adaptation and mutation of microorganisms can allow pathogens to bypass the human immune system, infect human cells and spread disease. For doctors, prescribing the wrong antimicrobial drugs and the wrong dose also contributes to the growth and spread of microbial resistance, driving outbreaks of infectious disease.[27,28]

From existing research, it can be observed that scholars usually investigate the impact or mechanism of one or several risk factors on the spread of infectious diseases, rather than comprehensively exploring the role of these risk factors and their interactions from a management perspective during disease outbreaks. From a systems perspective, the outbreak of infectious diseases is actually a transient imbalance in the social system. When multiple risk factors interact with each other in the social system, it may cause various subsystems to lose stability, thereby making the entire system unable to function normally. Therefore, this study will use systems thinking to comprehensively identify the risk factors that affect the outbreak of major emerging infectious diseases, and analyze their interactions to obtain the mechanism of the major emerging infectious diseases outbreak, then find effective strategies to respond to such events.

Materials and Methods

Sample Selection

This article takes the SARS and COVID-19 outbreaks that occurred in China in the 21st century as research samples for three main reasons. Firstly, both SARS and COVID-19 outbreaks occurred in China, which was also the first country to take preventive measures against both outbreaks.[29,30] Secondly, in terms of outbreak time, both SARS and COVID-19 outbreaks occurred in winter, near the Chinese New Year, and China's unique "Spring Festival travel rush" culture facilitated the outbreaks. Finally, in terms of the biological characteristics of the pathogens and the transmission mechanism, both SARS and COVID-19 outbreaks were caused by coronaviruses that can cause pneumonia and can infect others through direct transmission, contact transmission, as well as airborne transmission through aerosols and the air during medical procedures.[31] Therefore, the two also share similar pathogenic mechanisms and epidemiological characteristics.

Data Collection

This study takes the SARS outbreak and COVID-19 outbreak as the research objects, focusing on describing the official authoritative reports before the outbreaks. Detailed data sources include the local news website, industry media, central news organization, government announcement platform, as well as some relevant academic papers and officially published works. The data contains a large amount of highly valuable academic materials, including text records of press conferences, interviews with authoritative experts, on-site interviews by journalists, and interviews with medical workers. In addition to published works, all text data are obtained from the latest "List of Sources of Internet News Information" released by the Cyberspace Administration of China to ensure the authority and reliability of the research data.[32]

For the SARS outbreak, the data sources for this study mainly focused on information describing the period between November 16, 2002 and February 11, 2003. For COVID-19 outbreak, the data sources for this study mainly focused on information relevant to the period between December 1, 2019 and January 20, 2020. The reasons for the time range selection are as follows:

According to the epidemiological investigation of early patients by experts, the onset date of the first confirmed SARS case in China can be traced back to November 16, 2002 at the earliest, and the onset date of the first confirmed COVID-19 case in China can be traced back to December 1, 2019 at the earliest, so these two dates can be used as the starting date of the data collection.[33,34]

On February 11, 2003, the first official announcement of the SARS outbreak was made to the public. On January 20, 2020, Zhong Nanshan, a famous Chinese respiratory disease expert, confirmed the "human-to-human" transmission characteristic of COVID-19 at the national level. These two announcements were public, authoritative, and early warning, and quickly attracted the attention of the whole society, thus these two dates can be used as the end date of the data collection.[35,36]

The time frame chosen for the above two outbreaks was a critical period of rapid virus spread, widespread infection and hidden progression of the epidemic. During this period, various social groups lacked timely, scientific and accurate knowledge of the unknown new virus, and various risk factors were most concentrated during this period, which are most conducive to the study.

During the data collection process, this study searched text data on critical news media websites and academic paper platforms based on key words related to SARS and COVID-19. In the search process, three authors first read the text content roughly, judged whether the text data is closely related to this study, and retained the closely related text data; For repeated reports from multiple media outlets, only one copy was retained, and the rest was discarded. This is also true for the text collection process of academic papers and public works. After precise screening, 168 pieces of text data were collected. Then 130 text data were randomly selected for analysis, and the remaining 38 were used for saturation test. The statistical results of data collection are shown in Supplementary Figure 1, and the detailed list of data sources can be found in Supplementary Table 1.

Research Methods

WSR Methodology and Reasons for Selection

The WSR methodology is a powerful tool for solving complex problems. It considers the elements, events, and people in a social system as a dynamic and interactive whole, making it applicable to the analysis of complex systems at both macro and micro levels. This paper adopts the WSR methodology for the following reasons:

Firstly, the outbreak process of major emerging infectious diseases involves multiple risk factors, such as natural environment, medical resources, and information management. The various risk factors are highly correlated, and the use of WSR methodology is advantageous in exploring the mechanism of the occurrence of such crises from both macro and micro perspectives.

Secondly, compared with hard system approaches such as system analysis and operations research, WSR methodology places great emphasis on the people-oriented nature of Eastern culture. Societal risks are in fact closely linked to various human decisions.[37] Human risk factors play a prominent role in major emerging infectious disease outbreaks, and the use of the WSR methodology facilitates a more in-depth analysis of these human risk factors.

Thirdly, the cases selected in this study occurred in a cultural context with strong Chinese characteristics. Compared with western systems engineering methods, WSR methodology is more in line with traditional Chinese philosophy, more suitable for analyzing Chinese situations, and the research conclusions are more enlightening to China.

Grounded Theory and Reasons for Selection

Grounded theory is a classic qualitative research strategy proposed by American scholars Glaser and Strauss. Instead of making theoretical assumptions before conducting the study, the researcher starts directly from actual observations and excavates, constructs or develops theories through systematic data collection, analysis, comparison, reflection and transformation.[38] Grounded theory is particularly applicable to the issues of factor identification. It allows researchers to discover several types of factors that influence a particular problem from vast amounts of basic data, explore causal relationships among these factors, and construct a new theory about the research problem.

When using grounded theory to conduct research, it is necessary to first identify the scientific problem, and then discuss and define the problems. After that, data collection and screening can be conducted according to scientific problems. For grounded theory, “all is data” is a fundamental principle.[39] After completing data collection, the analysis of the text data begins, and the analysis procedure consists of open coding, axial coding and selective coding. Following data analysis, researchers can develop a theoretical model based on the coding results and conduct theoretical saturation test. If the theory reaches saturation, the theoretical model can be further explained; if the theory does not reach saturation, additional data are needed to revise the theoretical model until the theory reaches saturation before the next step can be performed. The detailed flow chart of grounded theory research is shown in Supplementary Figure 2.

Grounded theory is a “bottom-up”, “micro-to-macro” analytical process that heavily relies on the amount of data and the researcher’s experience. In contrast, the WSR methodology first defines the problem in Wuli, Shili, and Renli dimensions, allowing the researcher to analyze the data “from top to bottom”. Combining grounded theory with WSR methodology to analyze the data can effectively correct directional bias that may arise during the use of grounded theory and enhance the accuracy of factor identification and categorization.

Definition of Risk Factors of Wuli, Shili and Renli in Major Emerging Infectious Diseases Outbreaks

When using WSR methodology for research, it is first necessary to define the scope of risk factors of Wuli, Shili and Renli in major emerging infectious diseases. Based on the basic meaning of Wuli, Shili and Renli in WSR methodology, this paper gives the following definitions of Wuli, Shili and Renli risk factors in major emerging infectious diseases outbreak:

Wuli risk factors refers to the risk factors that people face before outbreak, which are composed of objective facts and natural laws. For example, the risk factors related to virus characteristics, climate and environment, geographical location, etc. In addition, it also includes certain conditions that are not easy to change in a short time, such as medical resource reserves, individual physical factors, etc.

Shili risk factors refer to the mechanism of people’s intervention in the face of the objective facts and laws of the Wuli level. Such as the organizational and management risk factors related to disease diagnosis, information management, communication and coordination.

Renli risk factors refers to the interrelationships and changes between people in the process of outbreak. The scope of Renli risk factors here includes six key elements of relationship, emotion, habit, knowledge, interest and coordination proposed by researcher Gu. Any factor related to these six elements can be regarded as Renli risk factors in this study. For example, individual habits, individual cognition, individual emotion and so on.

Data Analysis

After the completion of data collection, this study will use NVivo 12.0, a qualitative data analysis software, for data analysis. NVivo 12.0 is considered the best software for managing the "coding" process in qualitative data analysis. Researchers can use this software to code textual data and explore the relationship between data categories and themes, thereby enhancing their understanding of a particular phenomenon.[40] The use of NVivo 12.0 software greatly improves the efficiency of qualitative data analysis, and produces more scientifically rigorous results, which can significantly enhance research quality.

To conduct data analysis using NVivo 12.0 software, the first step is to create a thematic project and import all text data into it. Next, three researchers carefully read each piece of text data to extract risk statements related to the outbreak of major emerging infectious disease. These statements were then preliminarily classified according to the definitions of Wuli risk factor", Shili risk factors, and Renli risk factors for coding purposes. Through careful reading, summarizing, and organizing of the text data, the three researchers obtained a total of 872 risk statements with research value. Among these, 700 statements were used for coding analysis, while the remaining 172 statements were used for theoretical saturation test.

In this study, the process of data analysis is essentially a process of coding risk statements. To increase the objectivity and accuracy of the coding results and avoid being influenced by researchers' individual understanding or bias, two researchers were first assigned to independently code 700 risk statements. Consistent coding results were kept, while statements with inconsistent coding results were discussed until a consensus was reached. If a consensus could not be reached, a third author was involved to mediate and the three researchers discussed the coding results repeatedly until they reached a consensus.

The process of data analysis strictly follows the grounded theory research paradigm, which consists three steps: open coding, axial coding, and selective coding. Among them, Open coding involves cutting and assigning concepts to words, phrases, sentences, paragraphs, and entire texts in the original data. This process includes not only the systematic categorization of the original data, but also the deep excavation of the hidden concepts behind the data in the context of the research, so as to achieve a deeper analysis of the research problems. To ensure the scientific validity of the research results, this study excluded risk statements with very low frequency and only extracted the initial categories from risk statements with a frequency of three or more, because in Chinese philosophical concepts, "three" implies "many". If a risk sentence is found three or more times, it is considered to have academic research value.[41] Axial coding is the process of the repeated comparing and analyzing of the categorized results from open coding, and further clustering them into main categories. The main task of this process is to discover and establish various connections between the initial categories, in order to demonstrate the organic relationships among various parts of the data. These relationships may include causal relationships, temporal relationships, semantic relationships, contextual relationships, similarity relationships, difference relationships, and so on. Selective coding is the process of re-clustering the main categories identified in the axial coding process to obtain the core categories. Compared to other categories, the core categories are overarching and can encompass most of the results of research within a relatively broad theoretical scope.

An example of the data analysis process is shown in Table 1. In this table, "OW" represents "Open coding results of Wuli risk factors", "AW" represents "Axial coding results of Wuli risk factors", and "SW" represents "Selective coding results of Wuli risk factors." The meanings of "OS", "AS", "SS", "OR", "AR", and "SR" can be similarly inferred.

Results

Coding Results

After analyzed 700 risk statements by using NVivo 12.0 software, statistical results of each coding process were obtained, as shown in Supplementary Figure 3. Based on this, the list of Wuli risk factors, Shili risk factors and Renli risk factors can be generated. The detailed results can be found in Supplementary Tables 2–4.

Table 1 An Example of the Data Analysis Process

Category	Typical Evidence	Open coding	Axial Coding	Selective Coding	Source
Wuli risk factors (W)	Coronaviruses are a type of RNA virus, which are extremely unstable and can easily mutate due to environmental influences.	(OW1) Easy mutation of novel virus	(AW1) Highly mutability of novel virus	(SW1) Novel virus characteristics	http://www.nhc.gov.cn/wjw/zcjd/201304/36622dfd8b574d13b30c8d02e024a360.shtml
	During the Spring Festival transportation in 2020, railways, highways and airlines in Wuhan are expected to send 15 million passengers, an increase of 0.5% over the previous year.	(OW33) Mass migration of people	(AW17) large flow of people	(SW8) People gathering and flowing	http://www.hubei.gov.cn/hbfb/rdgz/201912/t20191228_1801236.shtml
Shili risk factors (S)	After the SARS epidemic occurred in Guangdong, the epidemic information was not released to the public in a timely manner, which made it impossible for all sectors of society to understand the characteristics of the epidemic and the main routes of transmission as early as possible, and to prevent it scientifically in advance, thus causing the spread of the epidemic to a certain extent.	(OS9) Delayed information release	(AS4) Imperfect information release mechanism	(SS2) Imperfect information management mechanism	https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CPFD&dbname=CPFD9908&filename=ZHYF200311001018&uniplatform=NZKPT&v=chYOYxG2WwioEPlxa6sExHPpThp4Lrcp9ClnRHrdYvrZ-QyjNH8sk_gaw677g-EpNJPJWbfWK6g%3d
	To some extent, it can be said that it is the loopholes in the health and safety management order that provide the entrance to the virus infestation, and the epidemic becomes the terminal presentation of the failure of the governance order.	(OS16) Inadequate supervision on food hygiene	(AS7) Insufficient hygiene supervision	(SS3) Insufficient supervision	https://guancha.gmw.cn/2020-01/28/content_33510862.htm
Renli risk factors (R)	On March 24, the CDC announced that an as yet unrecognized novel coronavirus may be the cause of SARS.	(OR9) Limited awareness of viral biological characteristics	(AR7) Limited awareness of virus characteristics	(SR4) Limited awareness of virus	http://www.nhc.gov.cn/wjw/zcjd/201304/45d440d5bfab4f33886c2437a986b7f5.shtml
	Due to the indiscriminate consumption of wild animals, people who eat and come into contact with them may become "patient zero" of the epidemic, posing a potential risk of disease for those around them and the public.	(OR7) Indiscriminate wildlife eating habits	(AR11) Eating wildlife	(SR16) Individual eating habits	http://country.people.com.cn/n1/2020/0319/c419842-31639376.html

Open Coding Results

Through open coding process, a total of 97 initial categories representing risk factors were obtained, of which 51 were initial categories representing Wuli risk factors, 28 were initial categories representing Shili risk factors, and 18 were initial categories representing Renli risk factors.

Axial Coding Results

Through axial coding process, a total of 51 main categories representing risk factors were obtained, of which 25 were main categories representing Wuli risk factors, 13 were main categories representing Shili risk factors, and 13 were main categories representing Renli risk factors.

Selective Coding Results

Through selective coding process, a total of 24 core categories representing risk factors were obtained, of which 10 were core categories representing Wuli risk factors, 6 were core categories representing Shili risk factors, and 8 were core categories representing Renli risk factors.

Theoretical Saturation Test

The theoretical saturation test is used to verify data analysis results by selecting previously reserved data as the test object and recoding it to determine whether a new concept category emerges. If no new concept categories emerge, the theory is considered saturated. In this study, we utilized the NVivo 12.0 software to recode the 172 reserved risk sentences. No new concepts or categories were identified, and no new relationships were found between each category. This indicates that the coding results successfully passed the saturation test.

Macro Mechanism of Major Emerging Infectious Disease Outbreak

The evolution of any crisis involves multiple stages, and major outbreaks of new and highly infectious diseases are no exception. By analyzing the timelines of the SARS and COVID-19 outbreaks and summarizing the commonalities in the evolution of these two crises, we can identify four stages in the outbreak process of such infectious diseases.

In stage I, the virus completes cross-species transmission, generating the "Patient Zero". In stage II, "Patient Zero" begins to show clinical symptoms and gains the ability to transmit the virus. If "Patient Zero" is not treated during this stage, the outbreak will enter the third stage. In stage III, a large number of people are infected with the virus, overwhelming hospital capacity. During this stage, timely and effective measures may stop the crisis from escalating, but otherwise, it will rapidly enter stage IV. In stage IV, the number of people infected in the society rapidly increases, leading to a major outbreak of the disease. Summarizing the risk factors that appear in each stage leads to the results shown in Table 2. Statistical analysis of these risk factors at different stages yielded the results shown in Supplementary Figure 4.

By analyzing the distribution characteristics of these risk factors, it can be observed that Wuli risk factors are most prominent in both stage I and stage II. These factors constitute the necessary conditions for the occurrence of a crisis event and play a significant role in the breeding of viruses and the generation of "Patient Zero". They can be regarded as the forefront antecedents for the outbreak of major emerging and infectious diseases.

In both stage II and stage III, Renli risk factors are most prominent. The emotions, attitudes, knowledge, habits, and behaviors they exhibit in these stages play a crucial role in promoting and regulating the development of the situation. These factors force individual infections to turn into group infections and can be regarded as intermediate regulatory factors that affect the outbreak of major emerging and infectious diseases.

In both stage III and stage IV, Shili risk factors are most prominent. The lack of medical treatment systems and crisis response mechanisms catalyzed the outbreak of the epidemic, which can be regarded as the back-end posterior factors that affect the outbreak of major emerging and infectious diseases. Therefore, from a macroscopic perspective, the

Table 2 The Appearance of Risk Factors at Each Stage

Stage	Risk Factors
Stage I	Novel virus characteristics, Favorable climatic environment, Insufficient supervision, Poor environment hygiene, Individual factors of patients, Individual eating habits
Stage II	Individual factors of patients, Doctor underestimation and misdiagnosis, Limited medical capacity, Patient underestimation and concealment
Stage III	People gathering and flowing, Efficient and convenient transportation, Public panic and anxiety, Limited medical capacity, Non-standard isolation and protection, Doctor underestimation and misdiagnosis, Limited awareness of virus, Time-consuming for scientific research, Inaccurate expert prediction, Imperfect diagnosis and treatment mechanism
Stage IV	Imperfect laws and regulations, Imperfect information management mechanism

outbreak of major emerging and infectious diseases generally follows the pattern of "Wuli risk factors driving the crisis occurrence - Renli risk factors regulating the situation development - Shili risk factors catalyzing the crisis outbreak".

Micro Mechanism of Major Emerging Infectious Disease Outbreak

To prevent the evolution of major emerging infectious diseases, it is not enough to only analyze the mechanisms at a macro level. It is necessary to deeply analyze the risk factors of Wuli, Shili, and Renli at a micro level in order to formulate effective risk management strategies. During the data analysis process, multiple interactions between risk factors can be found. Different interactions can have different effects on the system. Some interactions can create new risks or consequences, some can accelerate the transmission rate of system risks, and some can cause a surge of system risks and break through the system's defense line. This study defines these three types of risk interactions as risk coupling, risk superposition, and risk resonance, respectively, and uses them to explain the micro mechanisms of major emerging infectious disease outbreaks.

Definitions of Risk Coupling, Risk Superposition and Risk Resonance

In physics, coupling is considered a phenomenon of interaction between multiple systems or motion forms. Risk coupling refers to the presence of explicit interactions and mutual drivers between multiple risks in a risk correlation chain. In this study, risk coupling is a phenomenon in which two intrinsically related risk factors interact to generate new risks or new consequences that cannot be generated by these two risks acting alone.

In addition to the coupling relationship between risk factors, there is also a risk superposition relationship. Public crises and disasters are often the result of multiple risk factors acting in combination, with the superposition of these risk factors leading to severe system disruptions that are difficult to recover from quickly, ultimately resulting in a public crisis. In this study, risk superposition refers to the phenomenon that the transmission rate and destructive power of system risks are accelerated due to the other risk factors in the transmission process of system risks.

In addition to the superposition and coupling effects between risk factors, risk resonance can also occur. The concept of resonance comes from circuit science. When resonance occurs in a circuit containing energy storage elements, the voltage can surge to tens or even hundreds of times of the supply voltage in a short time.[42] In this study, risk resonance refers to the phenomenon that in the process of risk transmission, the addition of some risk factors makes the system risk surge exponentially, so as to break through the risk defense line.

These three types of interactions will be further used in the micro mechanisms of major emerging infectious disease outbreaks.

Micro Mechanism of Each Stage

There is a close relationship between animals and emerging infectious diseases. According to existing scientific research, animal-borne diseases account for 75% of all newly emerging infectious diseases, with over 70% of them coming from wild species.[43,44] Most zoonotic diseases are due to increased contact between humans and animals. Currently, Extensive scientific research indicates that wild animals are highly likely to be the origin of the viruses responsible for the SARS and COVID-19 outbreaks, which may have been transmitted to humans through the transportation, slaughter, sale, and trade of wild animals. As a result, this study uses unknown viruses in wild animals as a starting point for analysis and, aided by the three risk interaction types previously defined, conducts a thorough analysis of the micro-mechanisms involved in each stage. The analysis results are presented below.

Stage I: Accelerated Proliferation of the Virus – Species Defense Line Breakthrough

Supplementary Figure 5 shows the stage I of the micro mechanism underlying the outbreak of major emerging infectious disease.

People inhabit the planet of viruses, and wild animals serve as reservoirs for these viruses. As a special life form in the ecosystem, viruses do not possess the ability to reproduce on their own and must parasitize various hosts to survive, with wild animals being their most likely hosts. In addition to their parasitic nature, the survival and reproduction of viruses also depend on certain natural conditions and environments. Specific climate factors act as a driving force behind the increase in virus populations. When the suitable climate and environment coincide with the biological characteristics of the virus, it can lead to a risk coupling phenomenon, resulting in a rapid increase in the virus population within a short period of time.

Some viruses have a broad range of hosts, but these hosts may be geographically separated due to regional or lifestyle factors. However, illegal wildlife trade can potentially break down these geographical barriers, allowing different species of wild animals to come together and provide an opportunity for viruses to find new hosts. In reality, at least three regulatory departments are involved in the process of capturing, transporting, and selling wild animals: the wildlife conservation department, the animal quarantine department, and the market management department. If any of these departments fail to adequately supervise, it can lead to a risk superposition effect, allowing wild animals to enter the trade market. The gathering of different species of wild animals in cramped, dirty and unsanitary spaces will greatly increase the risk of viral transmission between different animals.[45]

Cross-animal transmission of viruses does not result in direct serious consequences, as long as infected animals do not come into contact with humans, the systemic risk can still be controlled. However, the trading places of wild animals are often hidden in wet markets with dense populations and high mobility. Some ineffective law enforcement by health regulatory agencies has resulted in poor ventilation, pungent odors, and damp and cold conditions inside the wet markets, making them a "fermenting pot" for viruses. These viruses, along with sewage and waste, have caused pollution in the surrounding areas.

Therefore, when humans enter the wet market, they are exposed to a viral environment. In this case, people should take protective measures to avoid infection. However, some diners, driven by their appetites and vanity, frequently enter wet markets to purchase wild animals. When they frequently come into contact with and consume wild animals, the risk resonance phenomenon is generated, which can increase their risk of infection by tens or even hundreds of times compared to others. The increased systemic risk breaks through the species barrier, giving the virus the opportunity to directly confront humans. At this point, the human immune system becomes a new barrier to defense against viral invasion. For known viruses, the immune system may be effective in eliminating the viruses; however, for highly unknown new viruses, the population is generally susceptible. Especially for those with weak immune systems and multiple underlying diseases, they are more susceptible to the virus breaking through the line of defense and becoming the "Patient Zero".

Stage II: "Patient Zero" Appears – Initial Treatment Failure

Supplementary Figure 6 shows the stage II of the micro mechanism underlying the outbreak of major emerging infectious disease.

After being infected with the virus, "Patient zero" often first conducts "self-diagnosis and treatment" according to their own symptoms, medical philosophy, and economic situation. Especially for atypical and common clinical symptoms such as fever, cough, and fatigue, self-medication is usually the common practice for patients in the early stages of infection. For individuals with strong immune function, self-medication may improve their condition; but for those with weak immune function, self-medication may delays the optimal treatment time and can worsen their condition. When this happens, "Patient Zero" is forced to consider seeking professional treatment at a hospital.

In reality, "Patient zero" typically seeks medical treatment at smaller private hospitals or community clinics rather than larger public hospitals or specialized infectious disease hospitals. In China, primary medical institutions generally have limited capacity for specialized treatment and lack experience in dealing with emerging infectious diseases, making it difficult to diagnose the cause of illness in "Patient zero". At the same time, if the patient's early clinical symptoms are mild and atypical, doctors are more likely to underestimate and misdiagnose emerging infectious diseases, and prescribe incorrect treatment plans. If the patient's symptoms are severe, these primary medical institutions may not have the ability to cure the patient. In this process, some doctors may detect abnormalities due to professional sensitivity and provide some advice to the patients, but patients often reject it due to individual factors such as underestimating their condition, illness awareness, and economic considerations.

It can be observed that in the stage II, there is a risk coupling phenomenon between the patient, the doctor, and the medical institution. If the patient's immune function and self-protection awareness are strong, or the doctor has rich treatment experience, or the hospital has strong treatment capabilities, it is possible to treat the "Patient Zero" in a timely manner, thus interrupting the risk of virus transmission. However, if these risk factors are not eliminated in a timely manner, they will continue to couple and resulting in the failure of "Patient Zero" treatment.

Stage III: Initial Treatment Failure – Infected People Cannot Get Treatment

Supplementary Figure 7 shows the stage III of the micro mechanism underlying the outbreak of major emerging infectious disease.

The initial treatment failure of the "Patient zero" resulted in the virus not being promptly eliminated, which led to the event progressing to stage III. Certain specific regional environments or situations are more likely to trigger sudden events, and by following specific pathways of risk transmission and coupling forms, the situation of the event can escalate and expand. For major emerging infectious disease outbreaks, convenient and efficient transportation and the growing demand for population mobility will be coupled to form a well-connected transportation network. If it coincides with a holiday, the flow of people will surge in a short period of time, providing favorable conditions for the virus to spread. Therefore, when "Patient zero" enters places with dense populations and high mobility, the system will experience a risk resonance phenomenon once again, quickly causing the infection to escalate.

Many people infected by the "Patient zero" initially adopt the "self-medication" approach before seeking hospital treatment if it proves ineffective. While some infected individuals may choose to seek treatment from high-level public hospitals. At this point, some experienced doctors suspect that a new infectious disease has emerged and suggest isolating the patients. However, due to inadequate hardware conditions in hospitals and the reluctance of some infected individuals, it is difficult to implement effective hospital isolation measures. Due to professional ethics and a sense of responsibility, some doctors may suggest home isolation for infected individuals. However, improper implementation of home isolation measures can actually lead to more household infections. In addition, during the diagnosis process, some doctors may neglect to take sufficient protective measures and are infected by patients. The continuous increase in the number of infected individuals, worsening patient conditions, and a surge in outpatient volume at hospitals have raised public concern and panic. However, due to the temporary absence of official authoritative information, rumors and hearsay have spread, prompting experts in relevant fields to conduct investigations.

Experts' investigations have temporarily eased public panic, but the public urgently needs to know the investigation findings. However, the conclusion of the investigation depends on the progress of scientific research, and the time frame cannot be determined. For a new virus, there is a high degree of unknowns in its biological characteristics, host source, and outbreak pattern. Only through continuous research can the unknown be turned into the known, which cannot be achieved overnight. Due to the urgent time constraints, the worsening conditions of infected individuals, limited scientific research conclusions, and incomplete information, it is difficult for experts to make accurate judgments on the pathogenic causes of infected individuals, the transmission of pathogens, and the degree of harm in a short period of time, and to develop effective treatment plans. In the early stages of the epidemic, the timeliness and accuracy of treatment plans will objectively affect the effectiveness of treatment for infected individuals, but it may also cause some infected individuals to be left stranded in society due to the inability to meet diagnostic criteria, resulting in the acceleration of crisis evolution.

Stage IV: Patients Return to Society – Crisis Outbreak

Supplementary Figure 8 shows the stage IV of the micro mechanism underlying the outbreak of major emerging infectious disease.

Infectors who failed to meet admission criteria are left in the community, exacerbating social infection and panic, and the situation enters stage IV. At this stage, a large number of doctors have realized the severity of the situation and attempted to report it through official channels. However, the imperfect information management mechanisms and legal regulations once again work together to impede efficient information transmission, thereby delaying the society's emergency response.

After the SARS outbreak, China established the "Infectious - Diseases and Public Health Emergencies Reporting System" in order to report emerging infectious diseases earlier. However, the "infectious diseases" referred to by this system mainly refers to statutory infectious diseases with clear causes, rather than emerging infectious diseases. In response to this situation, China also established the "Surveillance System for Pneumonia of Unknown Etiology". However, the process of using this system is complicated and cumbersome, and whether doctors use the system to report "Pneumonia of Unknown Etiology" mainly depends on voluntary participation. In reality, if a doctor suspects that a patient is infected with "Pneumonia of Unknown Etiology", he will usually report it orally to the department first, and then the department will report it to the hospital for diagnosis. If the hospital is unable to determine the cause of the disease, experts will be invited to assist in the diagnosis. Based on the diagnosis, a decision will be made on whether to report it within the "Surveillance System for Pneumonia of Unknown Etiology". This complex reporting process inevitably leads to delayed warning and response to emerging infectious diseases. The process before reporting has been time-consuming and labor-intensive. Even if the experts have made preliminary conclusion on the cause of the disease, the reporting procedure involves a series of registrations, form-fillings, and investigations, which will greatly distract the doctors' energy. Faced with patients whose conditions are getting worse, doctors often prioritize treating patients and have no time to consider the reporting procedure. In addition, in recent years, the situation of infectious diseases in China has been relatively stable, which has led to a lack of professional training for doctors in some hospitals. Many doctors do not know how to use the reporting system, and some do not even know the existence of the system.

Although there are some shortcomings and vulnerabilities in the information reporting mechanism, if the information is communicated smoothly between departments, it will also be conducive to the rapid communication of key information. However, the reality is that although most hospitals in China have basically achieved information operation in recent years, the information construction of each hospital is independent and lacks a unified and smooth communication platform, which makes it difficult for departments to communicate information timely, comprehensively, and accurately when a crisis arises, forming a closed "information island".

Apart from the imperfection of the information reporting and information communication mechanisms, imperfect information release mechanisms are also an extremely critical part of the information management mechanism. For information on infectious diseases related to the health of the public, the government is the subject of information disclosure and must inform the public of key information in a timely manner.[46] However, information release must also comply with laws and regulations. If the laws and regulations are not perfect, the government will fall into a decision-making dilemma. According to the relevant laws, in the face of a possible emerging infectious disease, local disease prevention and control agencies are required to first report the relevant information to the local health administration department, which in turn reports to the local people's government as well as other higher authorities. At this point, the higher authorities will organize experts to make a rigorous scientific judgment on the infectious disease. After the scientific judgment, if the government believes that the rate of transmission and the degree of harm of the infectious disease are comparable to the legal threshold of infectious diseases in the "Law of the People's Republic of China on Prevention and Treatment of Infectious Diseases", it will request the State Council to approve the establishment of the infectious disease as a legal infectious disease and take appropriate preventive and control measures. Finally, the State Council authorizes lower-level departments to make information disclosure. However, in this process, there are many imperfections in laws and regulations, such as conflicting legal provisions, inconsistent information disclosure authorities, and unclear key concepts. These legal risk factors are coupled with risk factors in the information management mechanism, delaying the process of information disclosure of emerging infectious diseases, so that the most valuable response time is missed.

Even with perfect laws and regulations in place, the government's release of information on infectious diseases is never simply a matter of making relevant information available to the public. Information released by the government is an official source of information that can greatly influence the public's health actions. Before the information disclosure, the government needs to anticipate the various consequences that may arise such as the public's reaction, the potential for mass panic, and the government's ability to mobilize resources for an emergency response. These considerations require risk tradeoffs. In order to maintain social stability, governments may be inclined to make conservative conclusions. However, conservative conclusions can lead to delays and inaccuracies in the official information release, and may contribute to the spread of unconfirmed rumors before a scientific conclusion is reached. Nowadays, the rapid development information and communication technologies have enabled official information to be disseminated instantaneously to every individual in society. This rapid spread of information can significantly influence the awareness and behavior of the population. If the official information released is conservative or not accurate enough, it may lead to the reoccurrence of risk resonance, allowing the already alert population to let down their guard and be exposed to high risks. If authorities fail to correct inaccurate information in a timely manner, the situation will rapidly spiral out of control until outbreak occurs.

For the entire stage, the set of risk factors consisting of contaminated environment and objects, insufficient development in disciplines, insufficient crisis awareness and common sense, shortage of medical resources, and poor literacy of emergency response can be called comprehensive risk factors. The formation of comprehensive risk factors is the result of accumulation over time and exists in the system for a long time. When an epidemic crisis starts to occur, the presence of comprehensive risk factor will have a risk superposition effect on each stage and accelerate crisis evolution.

Discussion on Risk Governance Strategies

Rome was not built in a day. The outbreak of major emerging infectious diseases is by no means as simple as the cross-species transmission of a novel virus. The root cause behind the virus being able to break the "defense barrier" layer by layer is the interaction effects of Wuli, Shili and Renli risk factors.

From a macro perspective, for the forefront antecedents represented by Wuli risk factors, such as the characteristics of new viruses, favorable climate and other risk factors, it may be impossible to avoid and control them due to limited human capabilities. However, for Wuli risk factors within the scope of human capabilities, such as people gathering and moving, poor sanitation and other risk factors, eliminating these risk factors is conducive to blocking virus transmission at the early stage of the epidemic. For the intermediate regulatory factors represented by Renli risk factors and the back-end posterior factors represented by Shili risk factors, they are risk factors that can be changed by human ability, mitigating these risk factors can effectively help to inhibit the crisis evolution. However, identifying the risk factors with the best avoidance effect needs to be determined by the micro mechanism. Therefore, based on the micro mechanism among risk factors, this study proposes the following risk management strategies.

Governance Strategies Based on Risk Coupling

Risk coupling emphasizes the creation of new risks or consequences under the interaction of multiple risk factors. For the coupling between Wuli risk factors in stage I and stage II, we cannot easily control it; however, for the coupling between Shili and Renli risk factors in stage III and stage IV, decision-makers can propose risk management strategies in the areas of legal construction, information reporting systems, and reporting mechanisms.

Revise Laws and Regulations in Time to Speed Up the Improvement of the Legal System

Rigorous and ideal laws are conducive to slowing down or even blocking the coupling between Wuli, Shili and Renli risk factors directly at the source. Since the founding of China, several laws and regulations related to the emergency management mechanism of infectious diseases have been introduced, such as laws represented by the "Law of The People's Republic of China on Prevention and Treatment of Infectious Diseases" and "Emergency Response Law of the People's Republic of China", administrative regulations represented by the "Regulation on the Urgent Handling of Public Health Emergencies", departmental regulations represented by the "Measures for the implementation of the Law of the People's Republic of China on Prevention and Treatment of Infectious Diseases", and normative documents issued by the State Council and local governments at all levels. On the whole, these laws, regulations and normative documents form a basic legal framework for responding to infectious disease outbreaks. However, practical applications of them still reveal gaps, weaknesses, and shortcomings.[47] For example, the different times, backgrounds, and main issues targeted by laws and regulations lead to inconsistencies in the design of certain legal concepts, procedures, and specific mechanisms, insufficient articulation of the system, and insufficient systematization.

For the legal system, this paper recommends firstly unifying the different concepts and provisions in the Infectious Disease Prevention and Control Law and other related laws and regulations by comparing provisions in various existing laws and regulations. This will avoid delayed decision-making due to unclear authority and responsibility when an infectious disease outbreak comes. Secondly, an important feature of emergency rule of law is to use experience to legislate, which is derived from practical experience. Therefore, it is suggested to re-examine the existing laws and regulations related to public health emergencies, timely update and improve the legal provisions that do not meet the needs of the times, and improve the frequency of law revisions, so as to promote the positive interaction between laws and events. Finally, for the new laws introduced in response to the needs of the times, such as the "Biosecurity Law of the People's Republic of China", the departments involved in the law need to refine the specific legal system and management laws according to their own characteristics, so as to promote the implementation of each effective measure.

Improve the Reporting System and Enhance the Efficiency of Information Reporting

The imperfect information reporting mechanism and the imperfect treatment mechanism are likely to produce a risk coupling effect, leading to a "snowball" type of systemic risk enhancement. At present, China has established the "Infectious - Diseases and Public Health Emergencies Reporting System", but the actual use of the system is not satisfactory. First of all, in the process of reporting information, problems such as non-standard reporting happen frequently, slow data information processing, and unskilled use of the operating system are also problems. Secondly, as the actual operators of the reporting system, some doctors are unwilling to fill in or have no time to fill in the reporting system. If other reporting methods are used, such as oral reporting, it is easy to cause information distortion in the process of communication, resulting in delayed decision-making.

To address aforementioned issues, this study recommends several actions. Firstly, the Chinese Center for Disease Control and Prevention should promptly optimize and improve the direct reporting system. It is suggested that a more efficient reporting channel for emerging infectious diseases should be redesigned, and a new direct reporting system with easy operation, simple processes, and rapid data processing capabilities should be established. Secondly, the government can also consider integrating the new direct reporting system with the "Electronic Medical Record" and use big data technology to evaluate the risk of an emerging infectious disease outbreak in real-time by analyzing space-time intersections and similar disease information between hospital patients. Thirdly, social individuals' support is crucial in timely blocking epidemics. The government can follow the "health code" mode and establish a joint system of "online direct reporting-health code". The public can report their daily health conditions to the system at any time, which will analyze the data to assess the risk of emerging infectious disease outbreaks.

Establish a Reporting Incentive and Fault-Tolerant Mechanisms to Encourage Social Groups to Report Information

The optimization of the information reporting system does not completely block the risk of major emerging infectious disease outbreaks, and the lack of reporting incentives and fault-tolerance mechanisms can make the direct reporting system ineffective. In the face of a possible crisis, the silence of social groups helps them to avoid the risk of uncertainty brought about by proactive actions, forcing them to pin their hopes on official news. However, official announcement may cause some delay due to legal and regulatory constraints, time-consuming scientific research and other factors, and cause the best time for epidemic prevention and control to be lost. Therefore, it is necessary to establish a set of reporting incentive and fault-tolerant mechanisms to encourage various groups or units in society to actively report through effective ways when they find a possible epidemic crisis. Although non-professional information from the general public may be proven to be inaccurate or even false in retrospect, which can cost the government a lot of effort and money, it is unrealistic and unscientific to require various social groups to make accurate judgments on crisis indicators in the early stages of a crisis, which would also go against the principle of risk prevention. At the same time, it is necessary to establish a "first reporter" incentive and fault-tolerant system, which offers rewards to the first person who reports accurate information, and provides some exemption from liability for the "first reporter" even if the information is not accurate. This not only greatly helps to save the public from major threats or crises in advance, but also supports and safeguards virtues such as courage, integrity, and honesty.

Governance Strategies Based on Risk Superposition

Risk superposition emphasizes that the addition of certain risk factors during the transmission process accelerates the speed of risk transmission in the system. The risk superposition effect occurs throughout all stages, among which the superposition effect produced by the risk factors related to medical resources in the comprehensive risk factors is the most obvious. The emergence of these risk factors is the result of long-term accumulation, and their governance also requires long-term planning. Therefore, this study proposes the following governance strategies to reduce the superposition effect.

Building a Resilient Medical Supplies System and Raising Awareness of People's Supplies Reserves

Adequate emergency supplies are the premise and foundation of epidemic prevention and control. However, the reality is that the medical materials reserved by the government and hospitals are often insufficient to meet the needs of all parties when an outbreak comes, which not only restricts the treatment of patients, but also threatens the health of the people. Therefore, this study suggests building a highly resilient medical material system to solve this practical problem. Building a highly resilient medical supplies system can never be accomplished by one person, but requires the joint participation of government, enterprises, the public and other groups. The construction of this system can be planned in five aspects: medical supply reserves, production, transportation, deployment and supervision.

Firstly, as the core force in responding to major emerging and sudden infectious disease outbreaks, the government must take the lead in raising awareness of risk prevention, increasing the proportion of financial spending on emergency medical supplies, and increasing the amount of emergency medical supplies in reserves to ensure a temporary and adequate supply at the moment of crisis. Additionally, the government should work with medical material manufacturers and transportation enterprises to develop a material reserve and production mechanism, create a medical material supply chain list, and ensure the stable supply of emergency medical materials when the outbreaks occur. Furthermore, the government should establish a medical materials information management platform to manage the reserve quantity, distribution and allocation of medical materials and the procurement plan in real-time. This will ensure the reasonable distribution, normal use, and rapid supply of materials. Finally, to avoid a run on medical supplies when major emerging infectious diseases occur, the government should increase public announcement efforts and improve residents' awareness of emergency medical supply reserves. The government should also advocate for residents to reserve a certain amount of emergency medical supplies such as masks, alcohol, disinfectant, etc.

Strengthen the Construction of Critical Care Emergency Medical Systems and Accelerate the Training of Professional Talents

In responding to major emerging infectious diseases, the strength of the emergency medical system is crucial to the successful treatment of severe patients. However, in China, there are currently several problems within the emergency medical system, including insufficient beds and wards, a shortage of medical staff, uneven distribution of critical medical resources, and an immature training system for critical medical personnel. These issues significantly hinder the development of the emergency medical system in China.

To strengthen China's emergency medical system, it is recommended to focus on three key areas. Firstly, by strengthening the construction of critical care medical centers with emergency critical care as the primary goal. These centers should be established in general hospitals with strong critical care medicine departments, equipped with the necessary diagnostic and treatment facilities, and staffed by experienced clinical specialists in critical care medicine. This will provide better support for the development of critical care medicine centers. Secondly, establish an online critical emergency medical system. At present, the distribution of severe-case medical resources in China is uneven, which is mainly reflected in severe-case medical materials and human resources. The shortage of severe medical materials can be quickly solved by increasing production capacity, but the shortage of human resources is not easy to quickly improve. Therefore, it is recommended to establish an online critical care emergency medical platform with the help of the internet, and to gather talents experienced in critical care in this platform to provide online guidance for critical care in each region in order to alleviate the shortage of critical care talents in some regions. Thirdly, there is a need to strengthen the mechanism for training talents in emergency critical care medicine. Currently, the training period for critical care medicine talents in China is lengthy and the work pressure is high, resulting in many doctors being directly employed without undergoing systematic and standardized specialized training in critical care medicine. To address this issue, it is recommended that the government and hospitals jointly establish a systematic mechanism for training talents in critical care medicine. This can start with the development of a professional curriculum for undergraduate programs and extend to the professional operation ability of practitioners. By enhancing the training of professionals in critical care medicine, China can improve the overall quality of emergency medical services and better cope with the challenges posed by emerging infectious diseases and other public health emergencies.

Governance Strategies Based on Risk Resonance

During the risk transmission process, risk resonance has the most obvious amplification effect on system risk. Each occurrence of risk resonance represents a breakthrough in the risk defense line. In stage I and stage II, risk resonance led to the cross-species transmission of the virus, resulting in "Patient zero"; in stage II and stage III, risk resonance caused the escalation of infection; in stage III and stage IV, risk resonance led to the outbreak of the epidemic. Therefore, the following risk governance strategies can be used to reduce the amplification effect of risk resonance.

Gathering Talents from Various Departments to Build a High-End Expert Think Tank System

When a crisis event arouses public concern, experts' insights are not only a key source of information for answering public questions but also a critical basis for policy-making. The outbreak mechanism of major emerging infectious disease involves multiple disciplinary fields. Even experienced experts may get trapped in a "decision-making black box" due to the limitations of their research field. Therefore, the more experts involved in the discussion and the broader the fields covered, the more conducive it is to making accurate judgments.

This study proposes the establishment of a high-end expert think tank system, which would include scientists, government decision-makers, and senior industry personnel, and be integrated into the "online direct reporting-health code" joint system. The system would be comprised of three subsystems. The first subsystem would consist of multidisciplinary experts in fields such as epidemiology, virology, clinical medicine, and public governance, among others. These experts would have real-time access to national health data, and if any anomalies are detected, they would provide immediate insights from their respective professional perspectives, and convey their final opinions to the second subsystem. The second subsystem consists of senior decision makers in various government departments, who tend to be more risk-aware and are timely, forward-looking and are able to make systematic responses to crisis events, which facilitates government departments to make quick decisions and avoid missed opportunities. The third subsystem comprises experienced personnel from high-risk areas, including international airports, customs, biosafety labs and son on. When staff members identify abnormal phenomena, such as groups of inbound passengers with a fever, collective staff leave-taking, or frequent interception of exotic species, they can immediately report them within the system for analysis by experts and decision-makers. This helps streamline the reporting process and prevent distortions or delays caused by vertical transmission of information.

Establish a News Information Verification Mechanism and Provide Legal Protection

The news media is the "lookout on the bow" and directly affects the public's judgment of the severity of a crisis based on the timeliness, accuracy, and clarity of information release. In the prevention and control of major emerging infectious diseases, the news media is an "amplifier" for expert conclusions and government policies. If the judgments of experts and decision-makers are accurate, then timely and accurate reporting by the news media will be beneficial to outbreak prevention and control. If the judgments of experts and decision-makers are inaccurate or even wrong, then the risk warning function of the news media will be reversed, accelerating the outbreak.

Therefore, it is recommended to establish an information verification mechanism for major emerging infectious diseases to compensate for possible reporting mistakes caused in the early stages of outbreak. When the news media receives authoritative sources from the government and experts, they should first inform the public of the information in a timely manner. At the same time, the news media should also uphold a skeptical attitude and verify the authenticity of reported events through field interviews and other means to verify the judgment of experts and the government, so as to avoid irreparable consequences caused by amplifying the inaccurate judgment of experts and decision-makers. Furthermore, it is recommended that the government update the current laws and regulations related to the dissemination of epidemic information. The government could grant early reporting rights to media with significant social influence within a certain scope and establish a fault-tolerant mechanism to provide legal protection for the media's verification of emerging infectious disease outbreaks.

Establish a Risk Culture Discipline System to Enhance the Risk Awareness of All People

In a risk society, risk awareness determines the presence of risk. If people have high risk awareness, they will refuse to eat wild animals in stage I, and then the risk of cross-species transmission of the virus will be greatly reduced. Even if the virus is contracted in stage II and stage III, the "patient zero" would be highly vigilant and take appropriate protective measures in time to avoid infecting others. However, shaping risk awareness requires a long-term process and cannot be accomplished by individual efforts alone. It requires the joint efforts of the government and the public. Therefore, it is recommended that the government take the lead in establishing various risk culture disciplines and incorporating them into compulsory education. Starting from the basic education stage, cultivating the level of risk awareness and the ability to respond to emergencies among the population will greatly contribute to the overall improvement of China's risk governance capacity and reduce the probability of emergencies.

Study Strengths and Limitations

Compared to existing research, this study also has many strengths, which can be reflected in three aspects. Firstly, unlike most scholars who use Western systems methodology to "validate" the Chinese context, this study uses a local Chinese systems methodology to conduct the study. This not only expands the application field of WSR, provides a direction for subsequent scholars to analyze major emerging infectious disease emergencies, but also helps China to export Chinese wisdom and contribute Chinese solutions to the world.

Secondly, previous studies have mainly focused on the role of specific or certain types of risk factors in the outbreaks, lacking the analysis of the interaction among various risk factors from the perspective of management. This study investigated the interaction and transmission mechanisms of Wuli, Shili, and Renli factors at both macro and micro levels, and proposed the concepts of risk coupling, risk superposition, and risk resonance to more accurately describe the interactions among early stage of emerging infectious diseases. The research results provide a theoretical basis for subsequent scholars to study outbreaks and also provide a basis for decision-makers to formulate relevant policies.

Thirdly, the results of this study are beneficial to the construction of China's biosecurity governance system. Many risk factors identified in this study exist uniquely in the cultural context of China. Currently, China is actively constructing a biosecurity risk prevention and control system, and direct reference to the experience of Western biosecurity systems may not be suitable for China. Therefore, the results of this study are more applicable to the Chinese context and are conducive to the development of China's biosecurity.

However, there are also some limitations to This study. Initially, although the data source for this study is reliable, it is derived from the internet rather than firsthand materials, such as interviews or surveys, to support the study. The primary challenge is the difficulty in locating infected individuals from the early stages of the epidemic for face-to-face interviews, as most are hesitant to participate due to privacy concerns. Consequently, this study can only rely on publicly available interview records on the internet as one of its data sources. Additionally, this study is focused on the Chinese context, so Chinese cases were selected as the sample, and the applicability of the study findings in the world needs to be verified by cases in other countries. Finally, the results of the study are only applicable to the analysis of major emerging infectious diseases caused by animal pathogens and cannot be applied to outbreaks of a different nature.

Conclusion

Based on the Chinese context, this study identifies the risk factors that have led to the outbreak of major emerging infectious diseases, using the SARS and COVID-19 outbreaks as research subjects, and analyzes the outbreak mechanism from both macro and micro perspectives. The specific conclusions are as follows.

There are many risk factors that can lead to the outbreak of major emerging infectious diseases. These risk factors can be summarized into 10 Wuli risk factors, 6 Shili risk factors, and 8 Renli risk factors based on the WSR methodology.

From a macro perspective, Wuli risk factors are the forefront antecedents of epidemic outbreaks, Renli risk factors are the intermediate regulatory factors, and Shili risk factors are the back-end posterior factors. The outbreak of major emerging infectious diseases generally evolves in the direction of "Wuli risk factors drive the crisis to occur - Renli risk factors adjust the crisis situation - Shili risk factors catalyze the crisis outbreak".

From a micro perspective, there are interactive relationships of risk coupling, risk superposition, and risk resonance Wuli physical risk factors, Shili risk factors, and Renli risk factors. Risk coupling promotes the generation of new risk factors or risk events, risk superposition accelerates the risk transmission rate, and risk resonance leads to the breakthrough of the system's risk defense line, resulting in a qualitative change in events. The outbreak of major emerging infectious diseases is the result of these three types of interactions.

The government can develop risk management strategies through various means, such as enacting laws and regulations, reporting information, allocating medical resources, establishing mechanisms, and providing education and training. These strategies aim to mitigate the effects of risk coupling, risk superposition, and risk resonance in the system, while also guiding the government in improving its capacity for public health emergency management.

Abbreviations

SARS, Severe acute respiratory syndrome; COVID-19, Coronavirus disease 2019; WSR methodology, Wuli-Shili-Renli system methodology.

Data Sharing Statement

All data analyzed in this study are published on the Internet and the detailed sources can be found in the Supplementary Information.

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Disclosure

The authors report no conflicts of interest in this work.

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