การพลวัตของโรคติดเชื้อที่มีต้นกำเนิดจากสุกรและการแพร่เชื้อไปสู่ประชากรมนุษย์: การศึกษาเกี่ยวกับสถานการณ์ในเอเชียตะวันออกเฉียงใต้

Transmission Dynamics of Zoonotic Pathogens from Swine to Human Populations: A Study of the Situation in Southeast Asia

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บทคัดย่อ

เชื้อโรคที่สุกรเป็นพาหะในภูมิภาคเอเชียตะวันออกเฉียงใต้ เป็นปัญหาด้านสาธารณสุขที่มีความซับซ้อนและเร่งด่วนมาก โดยเชื้อโรคจำนวนมากที่เกิดจากสัตว์ถือได้ว่าเป็นตัวการสำคัญในสถานการณ์การแพร่เชื้อนี้ เชื้อโรคเหล่านี้สามารถแพร่เชื้อสู่มนุษย์ได้หลากหลายวิธี ทั้งการสัมผัสโดยตรง การบริโภคผลิตภัณฑ์ที่ปนเปื้อนเชื้อ และการสัมผัสสิ่งแวดล้อมที่มีเชื้ออยู่ ผลกระทบจากเชื้อโรคจากสุกรต่อสุขภาพมนุษย์มีผลค่อนข้างมาก โดยสามารถแสดงอาการออกมาได้หลากหลายและมีความรุนแรงที่แตกต่างกันไป บทความนี้สำรวจสถานการณ์ของการแพร่เชื้อโรคจากสุกรสู่มนุษย์ การศึกษานี้จะเน้นไปที่ภูมิภาคเอเชียตะวันออกเฉียงใต้เป็นพิเศษ โดยศึกษาจากเอกสารและงานวิชาการที่เกี่ยวข้อง รายงานจากทางราชการ และการศึกษาวิจัยที่ผ่านมาจากฐานข้อมูล วารสารวิชาการที่เกี่ยวข้อง จากผลการศึกษา โรคติดเชื้อจากสุกรศัตรูสามารถเป็นอันตรายต่อสุขภาพมนุษย์ได้อย่างมีนัยสำคัญ การแพร่เชื้อจากสุกรไปสู่มนุษย์มีความซับซ้อนและมีหลายปัจจัยที่เกี่ยวข้อง

ปัจจัยเสี่ยงการติดเชื้อโรคจากสุกร เช่น มีสัมผัสใกล้ชิดกับสุกร การมีสุขอนามัยที่ไม่ดี และการบริโภคเนื้อสุกรที่ไม่ผ่านการปรุงให้สุก ผลกระทบของการติดเชื้อโรคจากสุกรมีตั้งแต่มีอาการเบาไปจนถึงรุนแรง ปัญหาในการรักษาโรคติดเชื้อจากสุกรยังเป็นปัจจัยที่น่ากังวล รูปแบบการแพร่ระบาดของโรคติดเชื้อจากสุกรมีความหลากหลายขึ้นอยู่กับชนิดของเชื้อโรค และตำแหน่งทางภูมิศาสตร์ การควบคุมโรคติดเชื้อจากสุกรเน้นไปที่วิธี One Health ที่เน้นการร่วมมือเพื่อป้องกัน ซึ่งเป็นการรับรู้และเข้าใจถึงความเชื่อมโยงระหว่างสุขภาพมนุษย์ สัตว์ และสิ่งแวดล้อม การใช้วิธีการร่วมมือจากบุคลากรหลาย ๆ อาชีพที่มีความเกี่ยวข้องมาทำงานร่วมกันเพื่อหาแนวทางในการแก้ไขปัญหา เพื่อลดการแพร่เชื้อและป้องกันการติดเชื้อทั้งในมนุษย์และสัตว์

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Abstract

Zoonotic pathogens harboured by swine in Southeast Asia present a complex and pressing public health challenge. These pathogens exhibit diverse mechanisms of transmission, encompassing direct contact, consumption of contaminated products, and environmental exposure. The impact of swine-associated zoonotic pathogens on human health is profound, manifesting in a spectrum of clinical consequences and varying severity of illnesses. This comprehensive review explores the transmission dynamics of zoonotic pathogens from swine to human populations, focusing on the unique context of Southeast Asia. A multitude of zoonotic microorganisms emerge as critical players in this transmission nexus, based on the study of documents and academic works, reports from government sources, and research studies from relevant databases, the related academic journals that have been published within the last 5 years. As a result, zoonotic diseases from swine pose a significant threat to human health. Transmission dynamics are complex, involving various mechanisms, with impacts ranging from mild to severe illnesses. Risk factors include close contact with pigs, poor hygiene, and undercooked pork consumption. Treatment challenges linked to swine exposure are a concern. Epidemiological patterns vary based on pathogen species and geographical location. Control strategies involve the One Health approach, emphasizing collaboration for prevention. Continued research and surveillance are crucial for understanding transmission dynamics and developing effective prevention strategies against zoonotic pathogens associated with swine.

Keywords: Zoonotics, Swines, Southeast Asia, Transmission, Diseases

Introduction

The intricate interplay between zoonotic pathogens harboured by swine and their potential transmission to human populations is a critical concern in Southeast Asia. For the purposes of this paper, we define southeast Asia as the ten member countries of the Association of Southeast Asian Nations (ASEAN), a region with growing geololitical influence in view of Asia's global economic ascendancy. The ASEAN countries are Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. In this region, the prevalence of zoonotic pathogens in swine populations presents a multifaceted challenge. Understanding the mechanisms of transmission from swine to humans is vital to assess the risks and implications for public health. These zoonotic pathogens can have a profound impact on human health, resulting in clinical consequences, varying levels of illness severity, and treatment challenges, particularly in the context of swine exposure in Southeast Asia.

The epidemiological patterns of swine zoonotic infections in Southeast Asia reveal distinct characteristics shaped by regional factors. Identifying risk factors associated with these infections is paramount for devising effective control and prevention strategies. One such approach, the One Health framework, recognizes the interconnectedness of human, animal, and environmental health, providing a holistic perspective for addressing zoonotic diseases associated with swine in Southeast Asia.

This comprehensive review will delve into various categories of zoonotic pathogens associated with swine, including bacteria, viruses, parasites, and fungi, and explore their respective diseases. It will encompass a thorough examination of the transmission dynamics, clinical implications, severity of illnesses, and treatment challenges associated with these pathogens in the context of swine exposure in Southeast Asia. Furthermore, we will dissect the epidemiological patterns, risk factors, discuss control and prevention strategies, and emphasize the imperative role of the One Health approach in safeguarding both human and animal populations.

Material and methods

In our comprehensive systematic review on the transmission dynamics from pigs to humans in South East Asia, we extensively explored scholarly sources like MEDLINE®, Springer, ACS Publications, Google Scholar, and ScienceDirect. Our search, conducted in English, spanned various timelines. We crafted a precise

search strategy using keywords and MeSH terms such as 'zoonotic transmission,' 'pig-associated pathogens,' 'South East Asia,' 'human health risks,' and 'disease transmission dynamics.' Meticulously scrutinizing reference lists and abstracts from international congresses, our review aims to provide a thorough understanding of transmission pathways and public health implications in this region.

Zoonotic Pathogens in South East Asian Swine Populations

Zoonotic pathogens in Southeast Asian swine pose a considerable public health risk with their potential transmission to humans. Various bacterial, viral, parasitic, and fungal pathogens have been identified in these populations, and their prevalence and diversity vary across regions due to complex interactions of environmental, socio-economic, and cultural factors. Categorizing these pathogens based on geographic regions reveals distinct challenges and highlights the need for tailored strategies to mitigate risks. It can categorized according to geographic region as below:

Mainland Southeast Asia: Swine farming is a prevalent livelihood in countries like Thailand, Vietnam, Cambodia, Laos, and Myanmar. Vietnam, with over 50% of its population engaged in rural areas and small-scale animal breeding,[1] faces elevated risks of zoonotic diseases. Notably, *Streptococcus suis* infections linked to swine contact have been reported,[2] along with Japanese Encephalitis Virus (JEV) outbreaks in both pigs and humans. Malaysia, a part of this region,[3] witnessed the emergence of Nipah Virus (NiV) in swine farms, leading to subsequent spillover to humans.[4]

Maritime Southeast Asia: Countries like Indonesia and the Philippines, with their isolated swine populations due to islands, face unique challenges. Swine Flu (Influenza A H1N1) outbreaks emphasize the necessity for surveillance and vaccination programs.[5] Schistosomiasis, caused by *Schistosoma japonicum*, poses a threat through waterborne transmission.[6]

Peninsular Malaysia and Singapore: Intensive swine farming and trade characterize these regions. The NiV outbreak in the late 1990s highlighted severe consequences of zoonotic diseases originating from swine.[4] Additionally, urbanization and a high density of pig farms contribute to the transmission of *Leptospira* spp., causing leptospirosis.[7]

The Mekong Delta: This region, spanning Cambodia and Vietnam, features rice paddy agriculture where swine play an integral role. High seroprevalence rates of

Hepatitis E Virus (HEV) in swine populations pose a significant foodborne risk.[8] Moreover, the unique *Schistosoma mekongi* causes human infections through contact with infested waters.[9]

Mechanisms of Transmission from Swine to Humans

The transmission of zoonotic pathogens from swine to humans in Southeast Asia involves intricate mechanisms with various routes playing a pivotal role in shaping the epidemiology of associated diseases. Key transmission routes include direct contact, foodborne transmission, environmental contamination, and swine acting as reservoir hosts.

Direct Contact Transmission: Direct contact with infected swine, through physical interaction, bites, or scratches, poses a significant transmission risk. Both symptomatic and asymptomatic swine can shed zoonotic pathogens through bodily fluids, secretions, and excretions. Occupational exposure in pig farming and slaughterhouses amplifies transmission risk, as seen in cases such as *Streptococcus suis*, where direct contact during slaughtering can lead to zoonotic transmission.[10-11]

Foodborne Transmission: Consumption of contaminated swine products, particularly pork, presents a substantial risk for zoonotic infections. Pathogens such as *Salmonella* spp., *Campylobacter* spp., and *Brucella* spp. can contaminate pork, leading to foodborne illnesses.[12] Heightened risk arises from inadequate cooking practices and unregulated food supply chains,[13] exemplified by Hepatitis E Virus transmission via the fecal-oral route.[14]

Environmental Contamination: Swine excreta, carrying pathogens like *Escherichia coli* and *Leptospira* spp., can contaminate water sources for irrigation and drinking, establishing an environmental transmission route. Human exposure to contaminated water sources can result in infection,[15] highlighting the critical role of environmental contamination in zoonotic transmission.[16]

Swine as Reservoir Hosts: Swine play a crucial role as reservoir hosts for notable diseases in Southeast Asia, including Japanese Encephalitis Virus (JEV), *Leptospira* spp., and *Schistosoma spp*. For JEV, swine act as amplifying hosts, transmitting the virus to humans through mosquito bites or the consumption of unpasteurized swine products.[17-18] Similarly, *Schistosoma*

japonicum transmission involves swine shedding schistosome eggs into water sources, leading to human infection through skin penetration by cercariae during agricultural and domestic water activities.[19]

A brief overview of selected newly emerging infectious diseases in southeast Asia

Nipah virus: In 1998-1999, Nipah virus caused severe febrile encephalitis in peninsular Malaysia and Singapore, resulting in over 100 deaths (40% case fatality rate).[8] The outbreak, linked to close contact between pigs and humans, led to a mass cull of over a million pigs. Subsequently, a related virus emerged in Bangladesh and India.

H5N1 influenza: Simultaneously with the SARS outbreak, H5N1 influenza spread across Southeast Asia in 1998. Despite high mortality in poultry (approaching 100%),[16] human infections raised greater concern, with a human case fatality rate of just under 70%.[5] While fears of a pandemic persist, sustained human-to-human transmission has not occurred.[17-19]

Determinants of Emerging Infectious Diseases in Southeast Asia

Driving forces in southeast Asia: Southeast Asia serves as a hotspot for emerging infectious diseases due to population growth, mobility, urbanization, and environmental changes. These driving forces contribute at three levels: a region containing diverse pathogens, a hub for transmission due to human-animal proximity, and an area with ecological factors promoting rapid pathogen mutation and host adaptation.

Livestock production: Intensive livestock production, notably poultry and pig farming, is increasing across Southeast Asia. Poultry density has doubled or tripled in some countries, correlating with the cumulative number of H5N1 cases. Intensive production systems may reduce cross-species infection but pose risks during large-scale outbreaks. Economic imperatives in marketplaces can override biosecurity concerns.

Climate: Climate change strongly influences vector-borne and waterborne diseases. El Niño strength predicts dengue outbreaks in Thailand and Vietnam. Arthropod vectors thrive in high temperatures, and water scarcity during droughts contributes to poor sanitation, driving the spread of diseases in Southeast Asia.

Impact of Zoonotic Pathogens on Human Health: Clinical Consequences, Severity of Illnesses, and Treatment Challenges Linked to Swine Exposure in South East Asia.

Pigs are a prevalent source of zoonotic pathogens, and human exposure can result in a spectrum of clinical consequences, influenced by factors like the specific pathogen, individual immune status, and transmission route. The clinical outcomes of zoonotic infections linked to pig exposure encompass various diseases, each posing unique challenges:

Zoonotic bacteria associated swine

Meningitis related *Streptococcus suis*: *Streptococcus suis*, commonly found in pigs, is a zoonotic pathogen causing severe, potentially fatal infections in humans, including meningitis, septicemia, and endocarditis in humans, often leading to neurological complications with a high untreated mortality rate. Primarily affects piglets with insidious onset and rapid progression. While it primarily affects pigs, early antibiotic treatment with doxycycline or penicillin is effective but faces concerns of antibiotic resistance. Timely diagnosis is vital due to high untreated mortality rate.[20]

Tuberculosis (*Mycobacterium tuberculosis*) is a bacterial infection affecting lungs (pulmonary TB) or other organs (extrapulmonary TB). Symptoms include cough, fever, weight loss, and fatigue, with potential severity and life-threatening consequences if treatment is delayed. Manifestations in various organ systems necessitate prompt diagnosis and treatment. Challenges include prolonged antibiotic courses and drug resistance, requiring multidrug therapy. Antibiotics like Isoniazid, Rifampicin, Ethambutol, and Pyrazinamide are effective in treating TB. Diagnosis involves tuberculin skin test, chest x-ray, and examination of sputum samples.[21]

Campylobacteriosis: Zoonotic pathogens that cause campylobacteriosis is *Campylobacter* spp., transmitted through contact with animals, contaminated food, and water. Symptoms include diarrhea, abdominal pain, and fever. Although the severity of the disease is generally not life-threatening, it can be significant, particularly in vulnerable populations such as the elderly and immunocompromised individuals. Campylobacteriosis usually resolves without antibiotics, but severe cases may require treatment; however, severe cases may necessitate treatment, raising concerns about antibiotic resistance.[22]

Brucellosis is an infectious disease caused by *Brucella* spp., transmitted to humans through unpasteurized dairy and meat consumption, or skin penetration of those in contact with livestock. Clinical consequences include undulant fever and chronic complications affecting various organs leading to serious complications. Treatment challenges include requiring prolonged antibiotic treatment, and recurrence is possible if not treated adequately.[23]

Anthrax is an infectious disease caused by *Bacillus anthracis* which naturally occurs in soils and affects many wild animals. Anthrax can manifest as cutaneous, inhalation, or gastrointestinal anthrax. Treatment challenges including prompt antimicrobial therapy is required, but inhalation anthrax is challenging to diagnose and treat. Cutaneous anthrax can be treated with appropriate antibiotics, and it is seldom fatal.[24]

Salmonellosis is a zoonotic infection caused by *Salmonella* spp. which leads to gastrointestinal symptoms like diarrhea, nausea, and vomiting. The infection usually resolves without antibiotics, but severe cases may necessitate antibiotic treatment, raising concerns about antibiotic resistance. Severity varies, with infants, elderly, and immunocompromised individuals at higher risk. The mortality rate associated with *S. enteritidis* infection outbreaks in the United States from 1985-1991 was 0.4%. Regarding treatment challenges, supportive care suffices for mild cases, but severe cases may necessitate antibiotics, raising concerns about antibiotic resistance.[25]

Gastrointestinal illness related *Escherichia coli* ; ***E. coli*** : *E. coli* is a bacterium commonly found in the gut of humans and warm-blooded animals. However, certain strains, such as *E. coli* O157:H7 can cause severe gastrointestinal illness characterized by bloody diarrhea. Young children and the elderly have risk of hemolytic uremic syndrome (HUS). Supportive care is crucial while antibiotics are generally not recommended due to the risk of exacerbating HUS.[26]

Leptospirosis is caused by *Leptospira* spp. that infects humans and animals, mostly they affect the kidney and can cause symptoms ranging from mild to severe, and organ failure. Prompting antibiotic treatment (doxycycline, penicillin) is crucial to prevent complications. Leptospirosis is a zoonotic disease that can be spread from animals to humans, and dogs are most commonly affected. Infection in humans can cause flu-like symptoms and can cause liver or kidney disease. The disease is prevalent worldwide, with preventive measures focused on protective equipment and rodent control.[27]

Zoonotic virus associated swine

Swine Flu (Influenza A H1N1): Swine flu, caused by the Influenza A H1N1 virus, is a highly contagious respiratory disease in pigs that can be transmitted to humans through contact with infected pigs or contaminated environments. Clinical consequences mirror seasonal influenza, ranging from mild symptoms to severe cases, especially in vulnerable populations. Early administration of antiviral medications like oseltamivir can be effective, but antiviral resistance is a concern. Vaccination against seasonal flu viruses, including H1N1, is a preventive measure.[28]

Foot and Mouth Disease (FMD) caused by coxsackievirus, is a highly contagious viral disease affecting cloven-hoofed livestock. Human cases are rare, resulting in mild flu-like symptoms. Severity is typically mild, with economic impact on the livestock industry being the main concern. No specific treatment for FMD in humans is available, and outbreaks can disrupt livestock production and trade, leading to significant economic losses.[29]

Hepatitis E Virus (HEV) is a liver disease causing a range of clinical consequences in humans, from asymptomatic to acute hepatitis with symptoms like jaundice and abdominal pain. Supportive care is often sufficient, but severe cases may require antiviral treatment. The disease is more prevalent in Asia and Africa, transmitted through the fecal-oral route. Vaccine availability varies by region.[30]

Japanese Encephalitis Virus (JEV) is a flavivirus transmitted by mosquitoes. JEV is a leading cause of viral encephalitis in Asia, maintained in pigs and wading birds.[31] Clinical consequences include encephalitis with symptoms like fever and neurological deficits. Severe cases can be fatal, with survivors facing long-term neurological sequelae. Supportive care is crucial, and a vaccine is available for preventive measures.[32]

Nipah virus (NiV): is a zoonotic virus primarily transmitted by fruit bats, causes severe respiratory and neurological symptoms, including encephalitis. Prevention involves avoiding exposure to sick pigs and bats, and not consuming raw date palm sap. Standard infection control practices help prevent person-to-person spread. No specific treatment for NiV exists, and supportive care is the mainstay. Vaccine availability varies by region.[33]

Zoonotic parasites associated swine

Trichinellosis: a parasitic infection caused by roundworms from *Trichinella spiralis,* results from consuming raw or undercooked

pork. Clinical consequences range from mild to severe, including muscle pain, diarrhea, fever, and facial swelling. Severe cases may lead to heart and respiratory issues. Early diagnosis is crucial for effective treatment, involving anthelminthic medications like albendazole.[34]

Cysticercosis caused by *Taenia solium,* cysticercosis follows the ingestion of undercooked pork. Symptoms vary based on affected organs, with severe cases impacting the central nervous system leading to epilepsy. Treatment involves surgery, antiparasitic drugs, or anti-inflammatory medications. Global variation underscores the need for tailored intervention strategies.[35]

Ascariasis caused by *Ascaris lumbricoides*, resulting from ingesting undercooked pork. Clinical consequences include abdominal pain, malnutrition, and bowel obstruction. Treatment includes anthelminthic medications, but challenges persist in preventing reinfection in endemic areas. Ascariasis is the most common global helminthic infection, prevalent in tropical regions.[36]

Toxoplasmosis caused by *Toxoplasma gondii*, stems from undercooked pork or contact with infected swine. Clinical consequences vary from flu-like symptoms to severe infections affecting multiple organs. Treatment challenges exist, and preventing infection during pregnancy is critical. Toxoplasmosis is considered a neglected parasitic infection, targeted for public health action.[37]

Balantidium coli: a relatively uncommon zoonotic parasite from swine, is transmitted through contaminated food or water. Clinical consequences include balantidiasis, affecting the large intestine. While typically non-lethal, severe cases can occur, especially in immunocompromised individuals. Treatment involves antiprotozoal medications, and hospitalization may be necessary in severe instances.[38]

Schistosomiasis: it is a zoonotic disease, and swine can act as a reservoir host for *Schistosoma japonicum*, which is found in Asia.[39] In swine, schistosomiasis can lead to a range of clinical consequences, including liver and intestinal damage. Microscopic eggs laid by adult worms trigger granulomatous reactions in the liver and intestines, potentially leading to fibrosis, portal hypertension, and gastrointestinal bleeding.[40] In humans, symptoms range from mild to severe complications such as liver damage and bladder cancer, and death.[40-42] The severity of illness depends on the

intensity and duration of infection, as well as the host's immune response.[40-41] Praziquantel is the primary treatment, but drug resistance is a concern. Ongoing vaccine development shows promise in clinical trials.[40,43]

Zoonotic fungi associated swine

***Aspergillus* spp.** notably *A. fumigatus, A. terreus,* and *A. flavus*, ubiquitous filamentous fungi, pose a risk of respiratory infections, especially in immunocompromised and pulmonary-compromised individuals. Termed invasive aspergillosis, symptoms include fever, cough, and chest pain. This infection can be severe, causing lung damage and presenting a life-threatening risk, particularly for those with weakened immune systems. Treatment involves antifungals such as voriconazole or amphotericin B. Challenges include the imperative for early diagnosis and the risk of antifungal resistance due to the angioinvasive nature, leading to vessel thrombosis and dissemination.[44]

***Candida* spp.** including the multidrug-resistant *Candida auris*, are fungi capable of causing candidiasis with varying symptoms depending on the infection site. Symptoms range from mild, localized infections to severe, life-threatening bloodstream infections, especially in critically ill patients. Treatment poses significant challenges, underscoring the importance of early detection and the risk of antifungal resistance. Strategies vary by infection site and severity, involving antifungals like fluconazole or echinocandins.[45]

The epidemiological patterns of swine zoonotic infections in Southeast Asia

The epidemiological patterns of swine zoonotic infections in Southeast Asia are complex and vary depending on the pathogen, the host, and the environment. Key zoonotic pathogens associated with swine in the region include *Streptococcus suis*, tuberculosis, campylobacteriosis, salmonellosis, and leptospirosis. Factors such as the intensity of pig production, proximity of humans to pigs, and the use of antibiotics in pig farming contribute to the prevalence of these diseases. *Streptococcus suis*-related meningitis is a significant zoonotic infection in Southeast Asia, primarily associated with swine. The incidence varies by region and season, with the highest incidence reported during the rainy season.[20] The incidence among abattoir workers and pig breeders is estimated at 3.0 cases per 100,000 population, while the risk is lower for butchers, at 1.2 cases. The prevalence of *S. suis* infection in swine is high in Southeast

Asia, with up to 90% of pigs carrying the bacterium. The high rates of *S. suis* meningitis in Vietnam are likely related to the country's substantial swine industry, which was documented to produce more than 26 million pigs in 2018.[46] The estimated annual incidence rate of *S. suis* human disease between 2011 and 2014 ranged between 0.249 and 0.324 per 100,000 population.[47] The prevalence of *S. suis* infection in swine and the high incidence of *S. suis*-related meningitis in humans underscore the significance of this zoonotic disease in Southeast Asia. Environmental factors and rural areas' habit of close contact with animals may also promote bacterial survival. Effective prevention and control measures are necessary to reduce the risk of transmission to humans. While the incidence of tuberculosis in Southeast Asia is high, with the highest incidence reported in Vietnam, followed by the Philippines and Indonesia. The WHO South-East Asia Region has nearly 4.3 million people falling ill with TB and estimated 700,000 deaths (Including HIV with TB mortality) because of the disease in 2020.[48] Factors such as population density, healthcare infrastructure, and socioeconomic conditions influence the epidemiological patterns of TB in Southeast Asia. The prevalence of tuberculosis in swine is low, but the risk of transmission to humans is high.[49]

The incidence of campylobacteriosis in Southeast Asia is high, with the highest incidence reported in Thailand, followed by Vietnam and Indonesia.[50-51] The prevalence of Campylobacter in swine is high, with up to 100% of pigs carrying the bacterium. The prevalence of campylobacteriosis can be influenced by cultural practices related to food preparation and hygiene in Southeast Asia, resulting in a relatively high prevalence and seasonal variations related to monsoon seasons. Increased rainfall and flooding during the monsoons can contribute to the contamination of water sources, leading to an uptick in campylobacteriosis cases.[50] Salmonellosis is a zoonotic bacterial disease that can be transmitted from pigs to humans. According to a review of findings from the Lao People's Democratic Republic, pork was implicated in 94.3% of human trichinellosis cases nationwide. However, only 31 epidemiological studies have been undertaken on these diseases in the past 25 years, indicating a need for greater understanding of the prevalence of zoonotic diseases in Southeast Asia.[14] A study on the prevalence and antibiogram of Salmonella and *Staphylococcus aureus* in poultry meat found that resistance genes were responsible for almost 78% of the *Salmonella enteri-*

ca isolates from poultry and pig meat.[52] A genome-based analysis of infrequent Salmonella serotypes through the Thai pork production chain found that swine and pork are implicated as important sources of salmonellosis in humans.[53] Leptospirosis is a zoonotic bacterial disease found in South and Southeast Asia, with a high prevalence in temperate or tropical climate regions.[54] In Vietnam, it is a notifiable disease in humans, with few reported cases to the Ministry of Health.[55] A study in Vietnam found that leptospirosis is considered endemic, and in pigs, it can result in reproductive problems, leading to economic loss and presenting a public health risk.[56] The prevalence of leptospirosis associated with swine varies by region and climate conditions.[57]

Zoonotic virus associated swine

Swine are a primary source for several zoonotic viruses, including Influenza A H1N1, Foot and Mouth Disease (FMD), Hepatitis E Virus (HEV), Japanese Encephalitis Virus (JEV), and Nipah virus (NiV). The G4 EA H1N1 virus has been found in many provinces of China since 2016 and has become predominant in swine populations. FMD is endemic in the majority of Southeast Asia, and the disease is estimated to circulate in 77% of the global livestock population. The seroprevalence of HEV in Southeast Asia ranges from 2% to 77.7%[58] and the prevalent genotypes across Southeast Asia are likely 1, 3, and 4, but not 2 as no cases have been reported. [59-60]JEV prevalence in swine ranges from 5% to 15% in various regions of Thailand[61] and Vietnam experienced sporadic outbreaks with an average of 30 to 50 human cases annually. [62-66] NiV outbreaks in Southeast Asia are sporadic and have high mortality in humans are characterised by their sporadic nature and varying case numbers. The virus has high mortality in humans, making it a significant public health concern. NiV prevalence in swine are sporadic cases in swine have been documented in Bangladesh and India.[67-68] However, India experienced sporadic NiV outbreaks in Kerala, resulting in 23 human cases with a 43% mortality rate,[69] while Bangladesh had an outbreak in 2004 with 45 human cases and a 75% mortality rate.[70]

Zoonotic parasites associated swine

Swine are a primary source for several zoonotic parasites, including Trichinellosis, Cysticercosis, and Schistosomiasis. Trichinellosis is prevalent among pigs in Southeast Asia, and a large outbreak of human trichinellosis occurred in Cambodia in 2017 after consumption of raw wild pig meat infected with Trichinella papuae.[71-72]

Cysticercosis is also prevalent among pigs in Southeast Asia, and the prevalence of human cysticercosis in Southeast Asia varies by region, with rates ranging from 0.80% in Indonesia to 41.8% in Thailand.[73-74] Schistosomiasis is endemic in Southeast Asia, particularly along the Mekong River, with rates ranging from 5% to 30% in Thailand,[75] exceeding 20% in Vietnam,[76] 10% to 30% in Cambodia, and up to 40% in Laos.[77-78] These zoonotic parasites pose a significant risk to public health and can be transmitted to humans through the consumption of undercooked pork or contact with infected animals.

Zoonotic fungi associated swine:

Due to the limited zoonotic significance of Aspergillus and Candida infections from swine and the rarity of documented cases, there may not be extensive prevalence data or case reports available for this specific scenario in Southeast Asia or other regions. Additionally, these infections are usually sporadic and not as well-documented as other zoonotic diseases.

Risk Factors, Control, and Prevention Strategy for Zoonotic diseases associated swine

Swines are in close proximity to humans, increasing the chances of zoonotic infection. Two-thirds of known diseases have an animal origin,[79] with swine being a primary source for several zoonotic pathogens. Identifying risk factors for zoonotic transmission from swine to humans is crucial for developing effective control and prevention strategies.

Key risk factors:

Proximity to swine: Individuals in close contact with swine, such as farmers and slaughterhouse workers, face a higher risk of zoonotic transmission due to increased exposure.[80]

Inadequate biosecurity: Poor biosecurity practices on farms, including lax hygiene and inadequate waste management, create favorable conditions for pathogen transmission.[81]

Pathogen diversity: The diversity of zoonotic pathogens in swine populations and their ability to evolve can increase the risk of spillover to humans.[79,82]

Antibiotic resistance: Prolonged and indiscriminate antibiotic use in pig farming increases the risk of antimicrobial resistance among bacteria in swine populations, potentially favoring the amplification of zoonotic pathogens and increasing the risk of transmission to humans.[83-85]

Consumption of raw pig meat: Public health campaigns should emphasize the importance of proper cooking techniques and discourage the consumption of raw or undercooked pig meat.[79,82]

Control and Prevention Measures:

Preventive measures for zoonotic transmission of swine-related diseases include personal sanitation, protective equipment, vaccination, biosecurity implementation, and regulatory compliance. Washing hands and wearing protective equipment are basic prevention measures for humans,[86] while farmers should wear protective gear and clean equipment and areas of exposure. Vaccination can significantly be lower the risk of diseases like swine flu and Japanese Encephalitis Virus (JEV) transmission,[87-88] but vaccinating swine can be challenging due to maternal antibodies reducing vaccine efficacy.[89] Biosecurity measures such as restricted access, regular disinfection, and proper waste disposal can minimize the risk of pathogen transmission.[90-91] Regulatory controls and monitoring compliance are also vital for reducing zoonotic infections. Shortening swine exhibitions to <72 hours can reduce the risk of zoonotic transmission of Influenza A Virus. Preventive measures such as vaccination and increasing surveillance and genomic studies of swine IAV can reduce the circulation of the virus in the field.[86, 92-93]

One Health Approach swine Zoonotic diseases associated swine in South East Asia

The One Health approach, which recognizes the interconnectedness of human, animal, and environmental health, offers a comprehensive strategy to combat these complex challenges. Additionally, it highlights exemplary collaborative endeavors and successful case studies from Southeast Asia that exemplify the efficacy of this approach.

The Crucial Role of a One Health Approach

Holistic Understanding of Zoonotic Diseases: Diverse experts collaborate to comprehend the complexity of swine-related zoonotic diseases, covering pathogens, host interactions, environmental influences, and human behaviour.

Early Detection and Surveillance: A multidisciplinary approach is underscored for early detection and surveillance of swine-related zoonotic diseases, mitigating risks through integrated efforts.

Vaccine Development and Immunization: Collaboration between immunologists and medical scientists results in the development of vaccines benefiting both swine and humans, reducing disease burdens in both populations.

Effective Control Strategies: Collaboration contributes significantly by devising effective control measures against parasitic infections in swine, reducing transmission risks to humans.

Environmental Considerations: Recognition of the significant impact of environmental factors on zoonotic disease transmission is crucial. Collaboration with environmental scientists facilitates a better understanding of the ecological elements influencing disease dynamics.

Collaborative Efforts and Exemplary Case Studies

A One Health approach has been pivotal in addressing various disease outbreaks. In Southeast Asia, collaborative efforts among microbiologists, epidemiologists, and veterinarians have been crucial in tracking and managing avian influenza (H5N1) in swine, thereby reducing human exposure to this deadly virus.[94] Similarly, in Malaysia, collaboration among pathologists, medical scientists, and epidemiologists identified the source of Nipah virus outbreaks in pigs, leading to the implementation of control measures that prevented further spillover to humans.[95] In Vietnam, the collaboration of immunologists and epidemiologists resulted in the establishment of vaccination programs for swine, significantly reducing the incidence of Japanese encephalitis in both pigs and humans.[96] Furthermore, in Cambodia, parasitologists and medical scientists worked together to implement control measures, effectively mitigating the risk of human infection from schistosomiasis in swine.[97-98] These collaborative efforts demonstrate the effectiveness of a One Health approach in addressing and controlling various zoonotic diseases.

Conclusion

In conclusion, zoonotic diseases associated with swine pose a significant threat to human health in Southeast Asia. The transmission dynamics of zoonotic pathogens from swine to human populations are complex and multifactorial, involving various mechanisms of transmission. The impact of zoonotic pathogens on human health can range from mild symptoms to severe illnesses,

and treatment challenges linked to swine exposure in Southeast Asia are a concern. The epidemiological patterns of swine zoonotic infections in Southeast Asia vary depending on the species of the pathogen and the geographical location. Risk factors for zoonotic diseases associated with swine exposure in Southeast Asia include close contact with pigs, poor hygiene, and consumption of undercooked pork. Control and prevention strategies for zoonotic diseases associated with swine include the One Health approach, which involves collaboration among different sectors. The review of zoonotic bacteria, viruses, parasites, and fungi associated with swine highlights the need for continued research and surveillance to better understand the transmission dynamics of these pathogens and to develop effective control and prevention strategies.

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