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Investigating Foodborne Transmission of *Salmonella Typhi* and Contamination Sources

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ABSTRACT

Salmonella enterica serovar Typhi (*S. Typhi*), the etiological agent of typhoid fever, is predominantly transmitted through the fecal-oral route, with contaminated food and water being major vehicles. While waterborne transmission has been well-documented, increasing evidence points to foodborne pathways playing a significant role in endemic and epidemic outbreaks, especially in low- and middle-income countries (LMICs). This review explores the mechanisms of foodborne *S. Typhi* transmission, identifies critical contamination points across the food supply chain, and evaluates epidemiological data from outbreaks. Key contamination sources include poor sanitation in food production, unhygienic food handling, improper storage, and cross-contamination in households and street food settings. Surveillance studies, molecular typing methods, and whole-genome sequencing have enhanced understanding of *S. Typhi* transmission dynamics, aiding in outbreak detection and source attribution. The review highlights the need for integrated food safety strategies, improved hygiene practices, and regulatory interventions to curb foodborne typhoid transmission and protect public health.

Keywords: *Salmonella Typhi*, typhoid fever, foodborne transmission, contamination sources, food safety, epidemiology, sanitation, street food

INTRODUCTION

Salmonella enterica serovar Typhi (S. Typhi) is a highly specialized, Gram-negative, facultative intracellular pathogen that exclusively infects humans, causing typhoid fever, a potentially life-threatening systemic illness [1]. Unlike non-typhoidal Salmonella species, which have a broad host range, S. Typhi is uniquely human-restricted and has evolved complex mechanisms to evade host immune responses and persist in both acute and chronic infections. The global burden of typhoid fever remains substantial, particularly in low- and middle-income countries where water and sanitation infrastructure is often inadequate. According to the World Health Organization (WHO), typhoid fever is responsible for an estimated 9 to 12 million new infections and over 110,000 deaths annually, with the highest morbidity and mortality rates occurring in South Asia and sub-Saharan Africa [2]. In sub-Saharan Africa, typhoid fever remains a significant public health threat. Urbanization, climate variability, poverty, and weak public health infrastructure have compounded the challenges associated with the prevention and control of S. Typhi transmission [3]. Although clean water supply and improved sanitation are crucial, they remain inaccessible to a large portion of the population. This creates a favorable environment for the bacterium to spread rapidly, especially in densely populated urban slums and peri-urban areas. Historically, the transmission of S. Typhi has been closely associated with contaminated drinking water. However, recent epidemiological data have revealed a significant and often underappreciated role of foodborne transmission [4]. Street foods, raw vegetables irrigated with untreated wastewater, improperly handled meat, and asymptomatic food handlers have emerged as critical contributors to the spread of S. Typhi. These alternative routes of transmission are increasingly relevant in settings where food safety regulations are weak, inspection and enforcement mechanisms are lacking, and informal food sectors dominate urban nutrition landscapes. Furthermore, antimicrobial resistance (AMR) among S. Typhi strains is escalating. The emergence of multidrug-resistant (MDR) and extensively drug-resistant (XDR) strains, particularly in parts of Asia

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and now increasingly in Africa, poses serious challenges to treatment [5]. The overuse and misuse of antibiotics in both human medicine and agriculture have accelerated this trend. Consequently, treatment failures, prolonged illness, and increased mortality have become more common, highlighting the urgent need for comprehensive surveillance, prevention, and control strategies. Despite advancements in diagnostics, vaccines, and public health awareness, typhoid fever continues to exert a heavy disease burden in endemic regions. In sub-Saharan Africa, limited access to safe drinking water and poor sanitation remain major risk factors. However, the role of foodborne transmission, particularly via informal and unregulated food markets, has not been adequately investigated or addressed in policy and intervention efforts [6]. The absence of robust food safety frameworks, coupled with the prevalence of asymptomatic carriers among food handlers, contributes significantly to the propagation of S. Typhi. Current surveillance systems often focus on waterborne transmission and neglect other critical vectors of infection, including contaminated street food, utensils, and surfaces [7]. This gap in understanding undermines the effectiveness of control measures and increases the vulnerability of populations, especially children and immunocompromised individuals. Moreover, as antimicrobial resistance becomes increasingly prevalent among S. Typhi strains, empirical treatment is becoming more difficult, costly, and less effective. In many resource-limited settings, laboratory confirmation of typhoid fever is rare due to a lack of diagnostic infrastructure, leading to misdiagnosis, overtreatment, or delayed treatment. This exacerbates the spread of drug-resistant strains and further strains healthcare systems [8]. Thus, there is an urgent need to investigate and quantify the contributions of foodborne transmission routes to the epidemiology of typhoid fever in sub-Saharan Africa. A comprehensive understanding of these routes is essential to inform targeted interventions, improve food safety policies, and ultimately reduce the incidence and severity of typhoid fever. The specific objectives of this study are designed to comprehensively investigate the role of foodborne transmission in the epidemiology of typhoid fever, particularly focusing on the prevalence and impact of *Salmonella Typhi* contamination in food items commonly consumed within high-risk urban and peri-urban communities. Firstly, the study aims to assess the prevalence of *S. Typhi* in selected ready-to-eat foods, which are often prepared and sold in informal markets with limited regulatory oversight. This assessment will provide critical data on the extent to which contaminated food contributes to typhoid transmission. Secondly, it will evaluate the hygiene practices of food vendors, examining how their behaviors and food handling procedures may be linked to the contamination of food by *S. Typhi*. Understanding these associations is crucial for identifying practical intervention points to reduce risk. Thirdly, the study will determine the antimicrobial resistance profiles of *S. Typhi* isolates recovered not only from food samples but also from clinical cases within the same communities, thereby revealing patterns and trends that can inform treatment protocols and guide antibiotic stewardship efforts. Fourthly, the study will explore the knowledge, attitudes, and practices (KAP) of food handlers regarding typhoid transmission and food safety, uncovering gaps in awareness that might hinder effective prevention. Lastly, the research will investigate how environmental sanitation and infrastructure intersect with food handling behaviors to influence the risk of foodborne typhoid fever. This holistic approach will elucidate the complex interplay between community sanitation, vendor practices, and disease transmission. In addressing these research questions, the study fills an important gap in typhoid fever control, moving beyond the traditionally emphasized waterborne pathways to highlight food as a critical transmission vector. The significance of this research lies in its potential to inform multi-sectoral public health strategies. It will provide evidence for policymakers to strengthen food safety regulations, especially targeting informal food markets where oversight is limited. Educational programs for food vendors can be tailored based on identified knowledge and behavior gaps to improve hygiene and reduce contamination risk. Antimicrobial resistance data will support clinicians in selecting appropriate treatments and managing drug-resistant infections effectively. Furthermore, by integrating food safety into broader typhoid surveillance and control initiatives, the study promotes a One Health approach encouraging collaboration among health, agriculture, and sanitation sectors. Ultimately, the findings aim to reduce disease burden, curb transmission, and contribute to regional goals of antimicrobial resistance containment and universal health coverage, enhancing resilience against typhoid outbreaks in vulnerable sub-Saharan African communities.

Biology and Pathogenesis of *Salmonella Typhi*

Salmonella Typhi, the causative agent of typhoid fever, initiates infection when ingested through contaminated food or water. Upon entry, the bacteria must survive the highly acidic environment of the stomach, a critical barrier that most pathogens fail to overcome [9]. Those that survive proceed to invade the intestinal mucosa, primarily targeting the specialized epithelial cells of the small intestine known as M cells. Here, S. Typhi penetrates the mucosal barrier and is taken up by macrophages, allowing it to evade the host's immune defenses. The bacteria then disseminate through the bloodstream, resulting in a systemic infection characterized by prolonged fever and other clinical symptoms. Importantly, some individuals become asymptomatic carriers, particularly when S. Typhi establishes chronic colonization in the gallbladder. These carriers can continuously shed the bacteria in their feces,

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posing a significant public health risk by contaminating food or water during preparation or handling. This chronic carriage plays a key role in sustaining transmission within communities, making control efforts challenging [10].

Foodborne Transmission Pathways

Foodborne transmission of *Salmonella Typhi* is a critical pathway through which typhoid fever spreads, especially in regions with inadequate sanitation and hygiene practices. This mode of transmission primarily occurs when individuals consume food contaminated with *S. Typhi* bacteria [11]. One major route is primary contamination, which happens at the earliest stages of food production. For example, vegetables and fruits irrigated with sewage-contaminated water can directly harbor *S. Typhi*, posing significant health risks when consumed raw or undercooked. Secondary contamination often takes place during food handling and preparation, where infected food handlers who do not practice proper hand hygiene can transfer bacteria to food, utensils, or surfaces. This risk is exacerbated in environments lacking strict food safety protocols. Another important factor is cross-contamination, which occurs when raw foods carrying *S. Typhi* come into contact with cooked or ready-to-eat foods through shared cutting boards, knives, or other kitchen equipment, thereby contaminating foods that are otherwise safe. Common food vehicles implicated in foodborne typhoid transmission include raw vegetables and fruits, unpasteurized milk and dairy products, meat and poultry, and street-vended foods, which often lack proper temperature control and hygiene standards. Understanding these contamination pathways is essential for developing targeted interventions to reduce foodborne typhoid infections [12].

Epidemiological Evidence from Outbreaks

Epidemiological evidence from various outbreaks around the world strongly indicates that foodborne transmission plays a significant role in the spread of typhoid fever. In South Asia, particularly in India and Bangladesh, several documented typhoid outbreaks have been directly linked to the consumption of contaminated dairy products such as milk and ice cream [13]. These items often become vehicles for the bacteria due to poor hygiene and inadequate refrigeration. Similarly, in parts of East and Central Africa, including Uganda and the Democratic Republic of Congo, improperly handled street foods have been identified as major sources of *Salmonella Typhi* transmission. The informal nature of street food vending, combined with limited access to clean water and sanitation, exacerbates the risk of contamination. Historically, in Chile, before widespread vaccination efforts were implemented, outbreaks were notably connected to the consumption of raw or inadequately washed lettuce and shellfish. Numerous case-control studies and detailed outbreak investigations emphasize that food handlers frequently act as critical contamination points, highlighting the importance of food safety training and hygienic practices to prevent typhoid spread through foodborne routes [14].

Sources of Contamination

Sources of contamination in foodborne illnesses are diverse and interconnected, posing significant public health challenges. Human carriers, particularly chronic carriers of pathogens like *Salmonella Typhi*, play a crucial role in the transmission of foodborne diseases. These individuals, often asymptomatic, may unknowingly shed bacteria while handling or preparing food, leading to contamination. Environmental and agricultural sources further contribute to the risk, especially when crops are irrigated with fecally contaminated water or fertilized using untreated human waste, commonly referred to as night soil. Such practices introduce harmful pathogens directly into the food supply at the pre-harvest stage [15]. Additionally, street food vendors and informal sellers often operate in settings with poor hygiene, lacking access to clean water, refrigeration, or proper sanitation facilities. These conditions facilitate microbial growth and cross-contamination, increasing the likelihood of foodborne outbreaks. Finally, food processing and distribution systems, particularly in industrial settings, can exacerbate contamination risks if sterilization protocols are inadequate or poorly enforced, potentially spreading pathogens across large batches of food products and amplifying the impact on public health.

Detection and Surveillance

Detection and surveillance of foodborne *Salmonella Typhi* have significantly advanced through the use of modern diagnostic and molecular tools, enhancing the ability to identify and track sources of infection effectively. Traditional methods such as culture and serotyping from food products and stool samples remain foundational for confirming the presence of *S. Typhi* and determining its specific strains. However, molecular techniques like polymerase chain reaction (PCR) and multiplex assays provide rapid, sensitive, and specific detection, allowing for timely intervention during outbreaks. The advent of whole-genome sequencing (WGS) has revolutionized outbreak investigation by enabling detailed characterization of bacterial isolates, facilitating precise source attribution and understanding of transmission dynamics [16]. Additionally, environmental surveillance, particularly the monitoring of wastewater, has emerged as a valuable tool to detect asymptomatic carriers who contribute to the silent spread of the pathogen. Genomic epidemiology, which integrates these advanced molecular methods with epidemiological data, plays a crucial role in mapping contamination pathways, tracking transmission networks, and informing targeted public health responses to control and prevent foodborne *S. Typhi* infections.

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Control and Prevention Strategies

Effective control and prevention strategies for foodborne illnesses are essential to safeguard public health, particularly in regions vulnerable to contamination. Implementing Hazard Analysis and Critical Control Points (HACCP) within food industries plays a pivotal role by systematically identifying and mitigating potential contamination risks throughout the food production process, ensuring safety from farm to table [17]. Hygiene and sanitation practices, such as regular handwashing, access to safe drinking water, and improved sanitation infrastructure, are fundamental in reducing fecal contamination that often leads to disease transmission. Routine screening and health education programs targeting food handlers especially in endemic areas—are critical to detect carriers of pathogens and prevent outbreak occurrences. Public awareness campaigns further empower communities by educating them on proper food handling, storage, and consumption behaviors, which are proven to significantly reduce transmission risks. Additionally, while typhoid conjugate vaccines (TCVs) do not directly address foodborne pathways, their widespread use effectively lowers the overall infection burden by reducing the reservoir of asymptomatic carriers, contributing indirectly to improved food safety and disease control efforts.

Research Gaps and Future Directions

Significant research gaps remain in understanding and controlling typhoid transmission, highlighting important areas for future investigation. First, there is a pressing need for studies that accurately quantify the relative contributions of foodborne versus waterborne transmission pathways across diverse geographic and socio-economic settings. This knowledge is crucial for tailoring targeted interventions. Additionally, the development of rapid, field-deployable diagnostic tools for detecting *Salmonella* Typhi in food samples is essential to enable timely identification and control of contamination sources, especially in low-resource environments. Behavioral research is also critical to evaluate how food safety education influences community practices and reduces typhoid incidence, providing evidence to guide public health messaging and interventions [18]. Furthermore, integrating environmental monitoring with advanced genomic surveillance can offer powerful early warning systems to detect outbreaks and track pathogen evolution in real time. Together, these research priorities will strengthen typhoid prevention strategies and support more effective, evidence-based public health policies globally.

CONCLUSION

This review underscores the critical role of foodborne transmission in the epidemiology of Salmonella Typhi, complementing the traditionally recognized waterborne pathways. It highlights multiple contamination sources along the food supply chain, including irrigation with contaminated water, unhygienic food handling by asymptomatic carriers, and cross-contamination in informal and street food settings that significantly contribute to typhoid fever outbreaks, particularly in low-resource urban and peri-urban areas. Advances in molecular diagnostics and genomic surveillance have improved outbreak detection and source attribution, yet persistent challenges remain due to inadequate food safety regulations and infrastructure. The growing threat of antimicrobial-resistant S. Typhi strains further complicates disease management and calls for integrated strategies combining food safety, public health education, and surveillance. Future efforts should focus on developing rapid detection tools, quantifying transmission pathways, and promoting behavioral interventions to reduce contamination risks. Ultimately, a multi-sectoral, One Health approach that strengthens regulatory frameworks, enhances hygiene practices, and supports community engagement is essential to curb foodborne typhoid transmission and improve public health outcomes in endemic regions.

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