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Review on Transmission Patterns and Zoonotic Importance of Bovine Tuberculosis

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Abstract

Bovine tuberculosis (bTB) is a chronic infectious disease caused primarily by Mycobacterium bovis and remains a major constraint to livestock production and public health worldwide. The disease affects cattle, wildlife, and humans, resulting in significant economic losses and serious zoonotic implications, particularly in developing countries. This review was conducted to summarize the transmission patterns, risk factors, zoonotic importance, diagnosis, prevention, and control strategies of bovine tuberculosis. The principal routes of transmission include inhalation of infectious aerosols, direct contact with infected animals, ingestion of contaminated feed, water, milk, or animal products, and environmental exposure. Factors such as animal movement, wildlife reservoirs, housing conditions, management practices, and host susceptibility contribute substantially to disease persistence and spread. Bovine tuberculosis poses a significant public health threat through zoonotic transmission, particularly where consumption of raw milk and close contact between humans and livestock are common. The disease also causes substantial economic losses due to reduced productivity, decreased milk yield, carcass condemnation, trade restrictions, and increased costs of disease control. Early diagnosis, effective surveillance, test-and-slaughter programs, pasteurization of milk, improved farm biosecurity, and implementation of One Health approaches are essential for reducing disease burden. Strengthening collaboration among veterinary and public health sectors is crucial for the effective control and eventual eradication of bovine tuberculosis.

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Introduction

Tuberculosis (TB) is one of the most important infectious diseases affecting both humans and animals, causing substantial morbidity, mortality, and economic losses worldwide. Despite significant advances in disease prevention and control, tuberculosis remains a major global public health challenge and is among the leading causes of death from infectious diseases. The disease continues to impose considerable burdens on human health, livestock productivity, and socioeconomic development, particularly in developing countries (WHO, 2013; Birhanu *et al.,* 2015).

Tuberculosis is a chronic communicable disease caused by members of the *Mycobacterium tuberculosis* complex (MTBC), which includes *Mycobacterium tuberculosis*, *Mycobacterium bovis*, *M. africanum*, *M. caprae*, and several other closely related species. Although *M. tuberculosis* is primarily adapted to humans and *M. bovis* predominantly infects cattle, cross-species transmission has been documented, with *M. tuberculosis* isolated from

cattle and *M. bovis* recovered from infected humans. Members of the MTBC share more than 99.9% nucleotide sequence similarity and are virtually identical in their 16S rRNA sequences, reflecting their close evolutionary relationship (Smith *et al.,* 2006; Brosch *et al.,* 2002).

Bovine tuberculosis (bTB), caused mainly by *M. bovis*, is a chronic granulomatous disease characterized by the formation of tubercles in various organs and tissues. The disease affects cattle as well as a wide range of domestic animals, wildlife species, and humans. Infected animals may shed the organism through respiratory secretions, milk, feces, urine, reproductive discharges, and exudates from affected lymph nodes, thereby facilitating disease transmission within and between species (Radostits *et al.,* 2007).

Beyond its veterinary importance, bovine tuberculosis represents a significant zoonotic and public health concern. Human infection can occur through the consumption of contaminated animal products, particularly raw milk, or through direct and indirect contact with infected animals. The disease is especially important in developing countries where close interactions between humans and livestock, inadequate disease control measures, and consumption of unpasteurized dairy products remain common. In addition to its impact on human health, bovine tuberculosis contributes to substantial economic losses through reduced livestock productivity, decreased milk yield, carcass condemnation, trade restrictions, and costs associated with disease surveillance and control programs (Ashford *et al.,* 2001).

Given its complex transmission dynamics, wide host range, and considerable public health and economic implications, a comprehensive understanding of bovine tuberculosis is essential for the development of effective prevention and control strategies. Therefore, this review aims to summarize the etiology, epidemiology, transmission patterns, zoonotic importance, diagnosis, prevention, and control measures of bovine tuberculosis.

Bovine Tuberculosis

Etiology

Bovine tuberculosis (bTB) is a chronic infectious disease primarily caused by Mycobacterium bovis, a member of the Mycobacterium tuberculosis complex (MTBC). Mycobacteria are non-motile, non-spore-forming, non-capsulated, obligate aerobic, acid-fast bacilli characterized by a lipid-rich cell wall containing mycolic acids. These lipids confer resistance to many disinfectants, environmental conditions, and antimicrobial agents while contributing to the slow growth rate of the organism (Jemal, 2016).

Mycobacterium bovis is the principal causative agent of bovine tuberculosis in cattle, although it can infect a wide range of domestic animals, wildlife species, and humans. The organism can survive for extended periods under favorable environmental conditions, particularly in cool, moist, and shaded environments. Environmental persistence contributes significantly to disease transmission and maintenance in endemic areas. Survival duration varies according to temperature, humidity, sunlight exposure, and the nature of contaminated materials (Verma *et al.,* 2014; Jemal, 2016).

Pathogenesis

The pathogenesis of bovine tuberculosis begins following the entry of M. bovis into a susceptible host, most commonly through inhalation of infectious aerosols, although ingestion of contaminated materials may also occur. Following entry, the organism is engulfed by macrophages but can evade intracellular destruction and multiply within these cells. This enables the bacteria to establish infection and spread to regional lymph nodes (Radostits *et al.,* 2007).

The disease generally progresses through two major stages: the primary infection stage and a subsequent chronic dissemination stage. The primary complex consists of lesions at the site of entry and in the associated draining lymph nodes. In respiratory infections, lesions commonly develop in the lungs and thoracic lymph nodes, whereas infections acquired through the alimentary route may involve the pharyngeal or mesenteric lymph nodes (Radostits *et al.,* 2007).

As the infection progresses, the bacilli may spread through lymphatic vessels, blood circulation, bronchi, or the gastrointestinal tract. The host immune response leads to the formation of granulomatous lesions (tubercles), which represent the hallmark pathological feature of tuberculosis. These lesions contain macrophages, epithelioid cells, multinucleated giant cells, lymphocytes, and varying degrees of caseous necrosis and mineralization (Geo *et al.,* 2013; Amente *et al.,* 2019).

Epidemiology

Bovine tuberculosis has a worldwide distribution and has been reported on all continents except Antarctica. Although several countries have successfully reduced or eradicated the disease through test-and-slaughter programs, surveillance, and movement control measures, bovine tuberculosis remains endemic in many developing countries, particularly in Africa, Asia, and parts of Latin America (Ali, 2006).

Mycobacterium bovis possesses one of the broadest host ranges among bacterial pathogens, affecting cattle, wildlife, and humans. Consequently, the epidemiology of bovine tuberculosis is complex and involves interactions among domestic animals, wildlife reservoirs, and human populations. In many developing countries, limited surveillance systems, inadequate veterinary services, and insufficient control programs contribute to the persistence and spread of the disease (Ali, 2006).

Countries such as Australia, several Caribbean islands, and parts of South America have successfully eliminated or substantially reduced bovine tuberculosis through rigorous control and eradication programs. Similarly, the disease has been reduced to very low levels in many regions of Europe and North America. Nevertheless, sporadic outbreaks continue to occur due to the movement of infected animals and the presence of wildlife reservoirs capable of maintaining and transmitting infection (Smith *et al.,* 2006).

Transmission Patterns of Bovine Tuberculosis

Sources of Infection and Routes of Transmission

Bovine tuberculosis (bTB) is a contagious disease transmitted through direct and indirect contact with infected domestic animals, wildlife reservoirs, and contaminated environments. Infected animals may shed *Mycobacterium bovis* through respiratory secretions, milk, feces, urine, vaginal discharges, and occasionally semen. Due to the chronic nature of the disease, infected animals may remain asymptomatic for extended periods while continuously transmitting the organism to susceptible animals. Consequently, the movement of undetected infected animals and interactions between livestock and wildlife play major roles in disease dissemination (OIE, 2016).

The principal route of transmission is the inhalation of infectious aerosols expelled during coughing, sneezing, or normal respiration. Direct nose-to-nose contact between animals also contributes significantly to disease spread, particularly in intensive production systems where overcrowding and poor ventilation increase the probability of exposure. In addition, transmission can occur through ingestion of contaminated feed, water, milk, or other materials contaminated with body secretions from infected animals (Anna, 2009).

Human infection commonly occurs through the consumption of unpasteurized milk and dairy products obtained from infected cattle or through inhalation of infectious aerosols during close contact with infected animals. Therefore, bovine tuberculosis remains an important zoonotic disease, especially in developing countries where consumption of raw milk and close human-animal interactions are common (Ashford *et al.,* 2001; Empress, 2012).

Direct Transmission

Direct transmission occurs primarily through inhalation of aerosolized droplets containing *M. bovis*. Aerosol particles less than 5 µm in diameter can penetrate deep into the respiratory tract and reach the alveoli, where infection is established. The frequency and duration of contact among animals, herd density, and housing conditions significantly influence transmission dynamics. Close contact among animals in confined housing systems facilitates rapid disease spread (Hatch and Gross, 2013).

Vertical transmission of *M. bovis* from infected dams to their offspring via the placenta has occasionally been reported. However, congenital infection is considered uncommon and contributes little to the overall epidemiology of bovine tuberculosis.

Pseudo-vertical transmission through contaminated milk is considered more important. Calves consuming milk or colostrum from infected cows may become infected, particularly in dairy production systems where milk from different animals is pooled and distributed among calves. This transmission route facilitates the spread of infection among young animals within a herd (Serrano-Moreno *et al.,* 2008).

Social interactions within cattle populations may also influence disease transmission. Cattle naturally establish dominance hierarchies, and dominant animals often have more frequent contact with herd mates and newly introduced animals, increasing their exposure to

infection. Conversely, subordinate animals may encounter infection through contact with contaminated environments and shared grazing areas (Harris *et al.,* 2007; Böhm *et al.,* 2009).

Indirect Transmission through Environmental Reservoirs and Fomites

Indirect transmission occurs when susceptible animals are exposed to environmental sources contaminated with *M. bovis*. The organism can persist for prolonged periods in soil, water, feed, hay, and other organic materials under favorable environmental conditions. Such persistence increases the likelihood of disease transmission among livestock and wildlife populations (Fine *et al.,* 2011).

Contaminated feed and water sources represent important vehicles for disease transmission. Wildlife reservoirs may contaminate grazing lands, feed stores, and watering points through saliva, nasal secretions, urine, and feces. As a result, susceptible animals may acquire infection through ingestion or inhalation of contaminated materials. Environmental persistence is enhanced in cool, moist, and shaded conditions, allowing the organism to survive for several months outside the host (Kaneene *et al.,* 2002; Palmer and Whipple, 2006).

Slurry and manure contaminated with *M. bovis* may also contribute to disease transmission. Infected animals may shed the organism into manure, which subsequently contaminates pastureland and water sources. The risk can be minimized through appropriate manure management practices such as prolonged storage, composting, exposure to sunlight, and chemical disinfection.

The organism may additionally persist in soil contaminated by secretions and excretions from infected domestic or wild animals. Such contamination may facilitate transmission between herds and contribute to the maintenance of infection within endemic regions. Wildlife species serving as reservoirs further complicate disease control efforts by continually contaminating the environment and facilitating transmission at the livestock-wildlife interface (Michel *et al.,* 2007).

Arthropod-Mediated Transmission

Arthropods, particularly ticks, have been investigated as potential vectors of *M. bovis*. Viable mycobacteria have been detected in ticks collected from infected hosts, and experimental studies suggest that ticks may retain the organism for extended periods. However, despite the theoretical possibility of tick-mediated transmission, current evidence indicates that arthropods play a limited role in the epidemiology of bovine tuberculosis. Consequently, their contribution to disease transmission under field conditions remains uncertain and requires further investigation.

Transmission Risk Factors

Cattle Movement and Contact Networks

Animal movement is one of the most important mechanisms for the spread of infectious diseases among livestock populations. Effective transmission occurs when susceptible animals are exposed directly or indirectly to infected animals through movements, shared resources, or contact networks. Therefore, understanding animal movement patterns and contact structures is essential for designing effective disease prevention and control strategies (Volkova *et al.,* 2010; Vernon, 2011).

Modern livestock production systems consist of interconnected networks of farms, markets, transport routes, and grazing areas. These networks can facilitate rapid dissemination of infectious agents, including *Mycobacterium bovis*, across large geographical areas. Network-based analyses have demonstrated that animal movement patterns play a significant role in the persistence and spread of infectious diseases, making movement control an important component of bovine tuberculosis control programs (Green *et al.,* 2011).

Animal Purchase

The introduction of new animals into a herd represents a major risk factor for bovine tuberculosis transmission. Purchased animals may introduce infection into previously disease-free herds, particularly if they originate from infected or inadequately screened populations. Consequently, pre-movement testing, quarantine procedures, and routine surveillance are important preventive measures.

The use of tuberculin testing and ancillary diagnostic methods, such as the gamma-interferon assay, can reduce the risk of introducing infected animals into susceptible herds. In several countries, including the United Kingdom, mandatory pre-movement testing has been implemented to minimize the movement of undetected infected cattle, although limitations in diagnostic test

sensitivity mean that some infected animals may still escape detection (Ramírez-Villaescusa *et al.,* 2010).

Markets, Transportation and Animal Gatherings

Although direct transmission during transportation is generally considered less important than transmission within herds, transport vehicles and animal movements can facilitate the geographic spread of infection. Contact among animals during transportation and at assembly points may create opportunities for disease transmission, particularly if biosecurity measures are inadequate (Probst *et al.,* 2011).

Livestock markets represent important points of contact where animals from different sources are brought together. Inadequate segregation and high animal mixing rates can increase the risk of disease transmission and dissemination through trading networks. Consequently, animal markets are recognized as critical locations in the epidemiology of several livestock diseases, including bovine tuberculosis (Robinson and Christley, 2007; García-Álvarez *et al.,* 2011).

Agricultural exhibitions and livestock shows may also contribute to disease spread when animals from different herds are temporarily mixed. However, strict biosecurity measures and limited duration of contact generally reduce the likelihood of transmission in such settings (Defra, 2010).

Within-Herd and Between-Herd Transmission

Within-herd transmission is strongly influenced by housing conditions, stocking density, and ventilation. The risk of transmission is generally higher in indoor housing systems where animals are maintained in close proximity and air circulation is limited. These conditions facilitate the accumulation of infectious aerosols and increase opportunities for direct contact among animals.

Studies have shown that bovine tuberculosis severity and transmission rates are greater in intensively housed cattle than in animals maintained under extensive grazing systems (Ameni *et al.,* 2006). In contrast, transmission is generally lower among cattle maintained on pasture because of reduced animal density, greater air circulation, and increased environmental dilution of infectious agents. Nevertheless, transmission can still occur through direct contact or exposure to contaminated environmental sources.

The spread of infection between neighboring herds may occur through indirect contact, shared grazing areas, contaminated environments, or exposure to common wildlife reservoirs. In many endemic regions, disease persistence is influenced by repeated introductions of infection from neighboring herds or wildlife populations, resulting in localized clusters of bovine tuberculosis (Defra, 2010).

Aerosols and Droplet Nuclei

Aerosol transmission is considered the most important route of bovine tuberculosis infection. *Mycobacterium bovis* is carried in small airborne droplet nuclei generated during coughing, sneezing, or normal respiratory activities of infected animals. Particles of appropriate size can remain suspended in the air for prolonged periods and reach the lower respiratory tract of susceptible animals following inhalation (Nardell, 2004).

Experimental studies have demonstrated that airborne *M. bovis* can remain viable for extended periods after aerosolization. The ability of the organism to persist in airborne particles supports the view that respiratory transmission is the primary mechanism by which bovine tuberculosis spreads within cattle populations. Consequently, control measures aimed at improving ventilation, reducing overcrowding, and minimizing close contact among animals are essential components of disease prevention programs (Gannon *et al.,* 2007).

Susceptibility Risk Factors

Nature and Nurture

Susceptibility to bovine tuberculosis is influenced by a complex interaction of genetic, environmental, physiological, and management-related factors. Disease occurrence within a population is determined not only by exposure to *Mycobacterium bovis* but also by the host's ability to resist infection and limit disease progression. These determinants can broadly be categorized into genetic and non-genetic factors, which act together to influence disease susceptibility and transmission dynamics (van der Eijk *et al.,* 2007).

Genetic Susceptibility

Host genetics play an important role in determining susceptibility or resistance to bovine tuberculosis. Studies have demonstrated breed-related differences in disease occurrence, suggesting that certain genetic

backgrounds confer greater resistance to infection. In addition, inbreeding has been associated with increased susceptibility to bovine tuberculosis in several animal species, highlighting the importance of genetic diversity in disease resistance (Trinkel *et al.,* 2011).

Genetic variation among cattle breeds has been shown to influence susceptibility to *M. bovis* infection. European *Bos taurus* cattle generally appear more susceptible to bovine tuberculosis than *Bos indicus* breeds. A study conducted in Ethiopia reported higher disease prevalence and more severe pathological lesions in Holstein cattle compared with zebu cattle. Furthermore, Holstein cattle were estimated to be more than twice as likely to develop disease than indigenous zebu breeds, indicating the importance of breed-related genetic factors in disease susceptibility (Ameni *et al.,* 2007).

Recent advances in molecular genetics have demonstrated that susceptibility to bovine tuberculosis possesses a heritable component. Variations in immune-related genes and breeding lines may influence host resistance to infection and disease progression. Consequently, selective breeding programs aimed at increasing resistance to bovine tuberculosis could become a valuable complementary control strategy.

Incorporating disease-resistance traits into breeding objectives may reduce disease occurrence while maintaining desirable production characteristics (Brotherstone *et al.,* 2010).

Variation within the pathogen itself may also influence disease outcomes. Differences among mycobacterial strains can affect virulence, transmissibility, host adaptation, and pathogenicity. Evidence from studies of *Mycobacterium tuberculosis* suggests that specific genotypes possess enhanced transmissibility and pathogenic potential. Therefore, interactions between host genetics and pathogen genetic diversity should be considered when evaluating disease epidemiology and developing control strategies (Hanekom *et al.,* 2011).

Non-Genetic Susceptibility Factors

Stress is an important non-genetic factor affecting susceptibility to infectious diseases. Chronic stress can alter immune function by shifting immune responses from cell-mediated immunity toward humoral immunity, potentially increasing susceptibility to *M. bovis* infection. Management practices such as weaning, transportation, overcrowding, poor housing conditions, handling, and social disruption may induce stress and compromise host resistance. Studies have shown that calves subjected to weaning stress exhibit measurable changes in immune competence that may influence disease susceptibility (O'Loughlin *et al.,* 2011).

Animals are frequently exposed to multiple pathogens simultaneously. Concurrent infections may alter host immune responses, enhance susceptibility to bovine tuberculosis, and influence disease progression. Interactions among pathogens can modify transmission patterns, disease severity, and diagnostic test performance, making disease management more challenging (Raoult, 2011).

Certain viral diseases may predispose cattle to bovine tuberculosis by suppressing immune function. Infections such as Bovine Viral Diarrhea (BVD) and Enzootic Bovine Leukosis (EBL) have been suggested to increase susceptibility to *M. bovis* infection by impairing the host's ability to mount effective immune responses. Consequently, control of immunosuppressive viral diseases may contribute indirectly to reducing bovine tuberculosis risk (Rua-Domenech *et al.,* 2006).

Parasitic infections, particularly helminth infestations such as *Fasciola hepatica* (liver fluke), may influence susceptibility to bovine tuberculosis. Helminths tend to stimulate T-helper 2 (Th2)-dominated immune responses, which can suppress the T-helper 1 (Th1)-mediated immunity required for effective control of mycobacterial infections. In addition, these immune alterations may reduce the sensitivity of diagnostic tests, including the tuberculin skin test and interferon-gamma assays, thereby complicating disease detection and control efforts (Flynn *et al.,* 2007).

Zoonotic Importance of Bovine Tuberculosis

Bovine tuberculosis (bTB) is an important zoonotic disease caused primarily by *Mycobacterium bovis*, which can be transmitted from animals to humans. Human infection is often underestimated and underdiagnosed because tuberculosis caused by *M. bovis* is clinically, radiographically, and histopathologically indistinguishable from that caused by *Mycobacterium tuberculosis* (Perez-Lago *et al.,* 2013). Although *M. bovis* is not the principal cause of human tuberculosis, it can infect humans through the consumption of contaminated milk, meat, and dairy products, as well as through direct contact with infected animals (Malama *et al.,* 2013).

The global burden of zoonotic tuberculosis remains a major public health concern. According to the World Health Organization, thousands of new human infections and deaths occur annually due to *M. bovis* infection. The disease is particularly important in developing countries where close contact between humans and livestock, inadequate veterinary services, and the consumption of unpasteurized milk are common. The African region carries a disproportionate share of the zoonotic tuberculosis burden, followed by Southeast Asia, whereas the disease is relatively uncommon in countries that have successfully controlled bovine tuberculosis and implemented strict food safety measures.

The true burden of zoonotic tuberculosis is likely underestimated because surveillance systems and laboratory diagnostic capacities remain limited in many countries. Furthermore, zoonotic tuberculosis frequently presents as extra-pulmonary disease, making diagnosis more difficult using conventional sputum-based diagnostic methods that are primarily designed to detect pulmonary tuberculosis caused by *M. tuberculosis*. Consequently, delayed diagnosis and under-reporting continue to hamper effective disease management and control.

The lack of routine species identification among *Mycobacterium* isolates also contributes to underestimation of the disease burden. Many extra-pulmonary lesions are not subjected to mycobacterial culture or molecular characterization, limiting the ability to distinguish *M. bovis* from *M. tuberculosis*. Accurate species identification is essential for epidemiological investigations, source tracing, and the development of effective control strategies (Theon *et al.,* 2009; Nwanta *et al.,* 2010; Schiller *et al.,* 2011).

A further challenge arises from the natural resistance of *M. bovis* to pyrazinamide, one of the four first-line anti-tuberculosis drugs commonly used in standard treatment regimens. Because species identification and drug susceptibility testing are not routinely performed in many settings, infected patients may receive inappropriate treatment, potentially contributing to prolonged illness and the emergence of drug-resistant tuberculosis strains. Resistance to additional first-line drugs has also been reported in some *M. bovis* isolates, further complicating treatment and disease control efforts (Schiller *et al.,* 2010; Smith *et al.,* 2014).

Beyond its public health implications, bovine tuberculosis causes substantial economic losses in livestock production systems. Infected cattle often exhibit reduced milk production, decreased growth rates, poor reproductive performance, increased susceptibility to other diseases, and premature culling. These effects directly reduce farm productivity and profitability. In addition, carcass condemnation, restrictions on animal movement, and limitations on international trade of livestock and livestock products impose significant economic burdens on producers and national economies.

The dairy sector is particularly vulnerable to the effects of bovine tuberculosis. Infection may lead to reduced milk yield, decreased milk quality, and the need to discard contaminated milk, resulting in financial losses for dairy farmers. Furthermore, public concern regarding food safety can reduce consumer confidence in milk and dairy products, thereby affecting market demand and profitability.

At the household level, bovine tuberculosis can significantly affect the livelihoods of livestock-dependent families. Farmers may experience reduced income due to production losses, veterinary expenses, testing costs, and the compulsory removal of infected animals. In many developing countries, where livestock serve as major sources of income, food security, and social status, these losses can have profound socioeconomic consequences.

The disease also imposes considerable costs on affected individuals and public health systems. Human infection can result in prolonged illness, loss of productivity, increased healthcare expenditures, and reduced quality of life. The financial burden becomes even greater when patients require extended treatment or management of drug-resistant infections. Consequently, bovine tuberculosis represents not only a veterinary and medical problem but also a significant socioeconomic challenge.

Given its impacts on public health, livestock productivity, food security, and economic development, bovine tuberculosis remains a priority disease requiring integrated control efforts under a One Health approach that promotes collaboration among veterinary, medical, environmental, and public health sectors.

Diagnosis, Control and Prevention

Bovine tuberculosis requires effective prevention and control because of its adverse effects on animal health, livestock productivity, public health, and economic development. The disease causes significant production

losses through reduced growth, decreased milk production, reproductive inefficiency, carcass condemnation, and mortality, while also posing a risk of zoonotic transmission to humans (Cousins, 2001).

Despite these consequences, control programs in many developing countries remain inadequate due to financial limitations, shortages of trained personnel, weak surveillance systems, and insufficient political commitment (Theon *et al.,* 2009; Krauss *et al.,* 2003).

Many developed countries have successfully reduced or eradicated bovine tuberculosis through test-and-slaughter programs, movement controls, surveillance systems, and strict biosecurity measures.

These strategies have contributed significantly to disease control in several European countries and other regions where bovine tuberculosis was previously widespread (Pavlik *et al.,* 2002).

Reducing the risk of zoonotic transmission requires strict control of contaminated animal products entering the food chain. The implementation of effective milk pasteurization programs, proper meat inspection procedures, and rigorous ante-mortem and post-mortem examinations are essential for protecting public health. Animals intended for human consumption should be routinely inspected to identify and remove infected carcasses from the food supply chain (Rodríguez-Campos *et al.,* 2014).

The tuberculin skin test remains the primary screening tool for bovine tuberculosis surveillance and control. Additional diagnostic methods, including the gamma-interferon assay, bacteriological culture, molecular diagnostics, and post-mortem examinations, may improve diagnostic accuracy and facilitate early detection of infected animals (Schiller *et al.,* 2011). Abattoir surveillance provides an additional opportunity to identify infected animals and trace infections back to their herds of origin.

The test-and-slaughter strategy continues to be one of the most effective approaches for bovine tuberculosis control where resources permit. Regular herd testing, prompt removal of infected animals, movement restrictions, and enhanced biosecurity measures reduce opportunities for disease transmission. In addition, wildlife monitoring and management may be necessary in regions where wildlife reservoirs contribute to disease persistence.

Successful control and eventual eradication of bovine tuberculosis require continuous monitoring and evaluation of control programs. The integration of advanced molecular epidemiological tools, effective surveillance systems, and comprehensive One Health approaches can strengthen disease prevention and control efforts. Close collaboration among veterinarians, physicians, epidemiologists, public health professionals, policymakers, and livestock producers is essential for reducing the burden of bovine tuberculosis and protecting both animal and human health (Kahn *et al.,* 2007; Verma *et al.,* 2014).

Conclusion and Recommendations

Bovine tuberculosis (bTB) is an important chronic zoonotic disease caused by *Mycobacterium bovis* that affects animal health, public health, and livestock productivity. The disease is transmitted mainly through inhalation of infectious aerosols, direct contact with infected animals, ingestion of contaminated milk and feed, and exposure to contaminated environments. Its zoonotic significance is particularly important in developing countries where close human-animal contact and consumption of unpasteurized milk are common. In addition to its public health impact, bovine tuberculosis causes substantial economic losses through reduced productivity, carcass condemnation, trade restrictions, and increased disease control costs.

Regular surveillance, tuberculin testing, and early detection programs should be strengthened to reduce disease spread. Consumption of raw milk should be discouraged, and milk pasteurization should be promoted to minimize zoonotic transmission. Improved farm biosecurity, regulation of animal movement, and control of wildlife reservoirs should be encouraged. Furthermore, stronger collaboration between veterinary and public health sectors through a One Health approach is essential for the effective prevention and control of bovine tuberculosis.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability Statement

The data generated and analyzed during this study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

Not applicable.

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