Review

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Review

Lyme Disease- in Purview of "One Health"

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Abstract

Zoonotic diseases are those that are caused by pathogens naturally transmissible between humans and wild or domestic animals. Amidst rise of synanthropic ecosystems, rising urbanization, trade, travel and habitat fragmentation, there has been increase in the spillover of pathogens from the sylvatic cycle to domestic cycle leading to rise in zoonotic diseases. Wildlife plays an important role in disease dynamics, acting as host, reservoir as well as vector to a large number of diseases. Lyme disease is one such zoonotic disease that has its root in wildlife. Lyme disease is caused by the spirochete bacteria *Borrelia burgdorferi* and *Ixodes* sp. ticks serve as vector to the bacteria. Presence of Lyme disease spirochete has been reported in a large variety of species like deer mouse (*Peromyscus maniculatus*), wood mouse (*Apodemus sylvaticus*), birds such as *Parus major, Carduelis chloris* and many others. Army personnel have been found evidently to be affected with the disease mainly due to their working environment. However, due to lack of reporting in other working groups and effective collaboration between veterinarians, medical practitioners, biologists and other stakeholders, the control and prevention of Lyme disease has not been properly designed. One health strategy is imperative to manage zoonotic diseases and thus needs to be implemented to fulfill the existing lacunae in knowledge about dynamics of Lyme disease.

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1. Introduction

Zoonoses are caused by pathogens naturally transmissible between humans and wild or domestic animals (Desvars-Larrive et al., 2024). The toll of zoonotic diseases has been continuously on the rise with nearly 1 billion cases of illness and millions of death occurring every year due to zoonosis. It is estimated that nearly 60 percent of emerging infectious diseases that are reported globally are zoonotic (WHO EMRO, 2014). Loss of habitat, admixture of species and anthropogenic factors such as urbanization, environment degradation, climate change, trade, travel and tourism are responsible for the spread of zoonotic diseases. Zoonotic diseases spread through direct contact or through food, water or the environment (WHO, 2020). Ticks play an important role as vector for many diseases such as *Ehrlichia, Babesia, Anaplasma* and many others.

Wildlife play a crucial role in the transmission dynamics of zoonotic diseases, acting as both hosts and vectors for various pathogens (Ojeyinka and Omaghomi, 2024). Zoonotic diseases that have their origin in wildlife include Nipah virus, Ebola fever, Kyasanur forest disease and others. Lyme disease is one such zoonotic disease that trace its roots to wildlife and is transmitted by *Ixodes* ticks. Amidst rise of synanthropic ecosystem due to human habitats in vicinity of wildlife, tick lifecycle pervades to human settlements. The conditional relapse of tick vectors and their vivid routes of transmission and growing crises of acaricide resistance, all together contribute to public health

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puzzle. The first case of Lyme disease was described in Lyme, Connecticut in 1975. Today it has spread to many countries around the world beyond few endemic foci. An outbreak of Lyme disease was reported in Maine, North America in 2023. Similar outbreaks have been reported elsewhere in the world too. Incidence of Lyme disease has been reported in armed forces in India by Praharaj et al. (2008) and Tilak et al. (2022) which has been correlated with exposure to ticks when frequenting forest areas.

The challenge of zoonotic diseases can be tackled using a 'One Health' approach. Integrated efforts are required pertaining to sampling of animals, ticks and humans; molecular and serological detection of the pathogen and surveillance of vector and reservoir species. Keeping in mind the dearth of awareness pertaining to the issue, this topic has been chosen for a detailed introspection of the disease current scenario.

2. Epidemiology

2.1. Etiological Agent

Borrelia burgdorferi is the most common causative agent of Lyme disease in the USA and responsible for more than 80% of tick-borne illness cases documented from 2004 to 2016 (Rosenberg et al., 2018). While other reported species are *B. afzelii, B. garinii and B. bavariensis* (Radolf et al., 2021).

2.2. Vector

The primary vectors of *Borrelia* bacteria are: *Ixodes scapularis* (the blacklegged or deer tick), *Ixodes pacificus* (the western blacklegged tick), *I. ricinus, I. persulcatus* (Franke et al., 2013). Dog tick (*Rhipicephalus* spp.) is also reported to serve as a vector. However, *Borrelia anserina* causative agent of the Avian relapsing fever is transmitted by *Argas* spp.

Ixodes ticks spend almost their entire life in the vegetation where there is sufficient rainfall. They are mainly found in deciduous woodland containing small mammals and deer. The use of the soil and anthropological activities can change the habitats of ticks and the composition of animal population. *Ixodes* ticks are abundant in the ecotone at a forest's edge which serves as the hub for their proliferation and transmission of pathogen. The vertebrate animals and humans crossing the ecotone which is the area between forests and human settlements thus determine the risk of infection at that site (Richter and Matuschka, 2006).

Tick nymphs attack hosts more actively from spring to autumn in microenvironments with over 85% relative humidity. The months of summer and early Monsoon i.e., June- July make up the period of maximum incidence of Lyme disease due to favourable weather conditions for ticks (Chalabi, 2023). In suitable tick vectors, tick borne pathogens have the ability to persist throughout the molting process to the next instar, a phenomenon called trans-stadial or vertical transmission. Gray et al. (2002) and Van Duijvendijk et al. (2016) found 40% trans-stadial transmission in *B. microti*. But such transmission has not been reported for *B. burgdorferi*.

Ixodes tick has a four stage life-cycle, i.e., egg, larva, nymph and adult, requiring only one blood meal during every active stage. The time for *I. ricinus* to complete its life-cycle varies between three and six years, depending on climate and host availability. Adult ticks carry the infection two times more than the nymph. But 90% of the human disease is transmitted by nymphs as they are far more abundant (Mahajan and Vikram, 2023).

2.3. Reservoir- Lyme Disease in Wildlife

Presence and availability of reservoir hosts is important for determining the risk of transmission of pathogen and vector survival (Ozdenerol, 2015). Species that can competitively act as reservoir for *B. burgdorferi*, include small rodents like Deer mice (*Peromyscus maniculatus*), Western gray squirrels (*Sciurus griseus*) and chipmunks (Salkeld et al., 2008). While species like *Apodemus flavicollis, Apodemus sylvaticus,* (Wood mouse) *Myodes glareolus* (Vole) and birds such as *Parus major, Carduelis chloris* have

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also been suggested to act as reservoirs of *B. miyamotoi* (Wagemarkers et al., 2017 and Szekeres et al., 2019). Hedgehogs act as propagation hosts for *Ixodes* ticks in urban localities (Sprong et al., 2018).

Lyme disease infection has been reported in wild and domestic canine species too. Antibodies against *B. burgdorfer* were demonstrated in gray wolves (*Canis lupus)* by Thieking et al. (1992) While in Sapporo, Hokkaido, Japan, presence of Lyme disease spirochetes was demonstrated in visceral organs of a wild female fox (*Vulpes vulpes schrencki*) by darkfield microscopy by Isogai et al. (1994).

Isolates belonging to *Borrelia turcica* and unknown *Borrelia* species were isolated from imported tortoise and their ectoparasites. Thus, tortoise may also act as reservoir for the *Borrelia* species (Takano et al., 2010).

Jiang et al. (2021) examined 337 seized Malayan pangolins during anti- smuggling operations in cities of Southern China. Ticks of genus *Amblyomma javanense* collected from animal's body were screened for various pathogens and 12 tick samples were found positive for *Borrelia johnsonii* strain.

However White-tailed deer are considered to be non-competent reservoirs for *B. burgdorferi* (Pearson et al., 2023). Similar findings have been found in other deer species too like Red deer, Sika deer, Mule deer, Fallow deer and Roe deer (Bhide et al., 2005 and Ullmann et al., 2003) as their serum is found to be borrelicidal as killing of the *Borrelia* spp. bacteria is facilitated by complement component of deer immune system.

2.4. Lyme Disease in Humans

Tick exposure and Lyme disease cases are associated with greater time spent outdoors in natural areas and pet ownership (Lane and Lavoie, 1988; Salkeld et al., 2014 and Salkeld et al., 2019). Humans participating in outdoor recreational activities more likely expose themselves to questing ticks. The most vulnerable population includes farmers, campers and population residing in forest areas (Bacon et al., 2008). Co-infection by one microorganism affects susceptibility of host to tick- borne diseases. The risk of transmission of the disease is also influenced by factors such as tick bite duration, stay in the endemic zones and duration of tick attachment over the body (Bhatnagar et al., 2023).

3. Pathogenesis

Borrelia spp. bacteria make use of outer surface proteins OspA, OspC and TROSPA protein to invade the *Ixodes* spp. tick gut (De Silva and Fikrig, 1995; Stevenson et al., 1995 and Pal et al., 2004). *Ixodes* ticks cling to vertebrate host as it passes near the vegetation and the pathogen *Borrelia* spp. enters the skin via the tick bite. As per Coburn et al. *(*2022), the bacteria then invades the blood vessels evading the innate immune system and colonise the tissues of different systems like the skin, joints, nervous system and cardiovascular system leading to different affections and lesions as per the system involved.

The tick bite is usually painless and goes unnoticed. In response to invasion by *B.burgdorferi* bacteria, there is production of mononuclear cells like the CD4+ and CD8+ cells (Steere et al., 2016). Prostaglandins in tick saliva counter the host's local immune response.

4. Clinical Signs and Symptoms

There are different forms observed in the infected individuals. Rheumatological form is characterised by transient, migratory mono/ poly arthritis, migratory musculoskeletal pain, Baker's cyst, recurrent arthralgia in humans as well as dogs (Littman et al., 2018*)*. Arthritis and neuroborreliosis are mainly linked to *B. burgdorferi* (Mahajan and Vikram, 2023).

Cardiac form is characterised by conduction abnormalities, myocarditis, pericarditis are common signs. Renal form has been characterized by Lyme nephritis in dogs (Littman et al., 2018*).*

Neurological form is characterised by meningitis, encephalomyelitis, encephalopathy, motor/ sensory radiculoneuropathy, myelitis and acute encephalitis are reported signs (Hansen et al., 2013). While Divers et al. (2022) reported a case of tick induced neuroborelliosis in an 11 year old Swedish

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Warmblood mare in Connecticut, USA. There was acute onset of fever (40°C) with neurologic signs like obtundation, ataxia in all limbs and anisocoria.

Other clinical signs of the disease have been observed as conjuctivitis, keratitis, uveitis, mild hepatitis, spleenomegaly.

Dermatological form is the most common lesion and characterized by lesion called Erythema migrans and is a bull's eye-shaped erythematous rash at the site of tick bite.

Even after treatment, some patients persist to have muscle or joint aches and nervous system symptoms, which is referred to as post treatment Lyme disease syndrome (PTLDS) (Sunitha et al., 2018). Sometimes Lyme disease is called the 'great imitator' owing to the wide variety of symptoms that can extend to every organ of the body. A recently published book identifies over 300 medical conditions that present with the same symptoms as Lyme disease (Cook and Puri, 2020).

There is lack of data about the necropsy lesions found in animals suffering from lyme disease. However Isogai et al. (1994) reported the histopathological findings in a female red fox that died due to a traffic accident in Sapporo, Hokkaido. *Ixodes* ticks were isolated from the carcass and DNA isolation of the ticks revealed the presence of *B.burgdorferi.* Histologically inflammatory response of lymphocytes, plasma cells, neutrophils, and eosinophils with perivasculitis was observed in the skin lesions. Infiltration of lymphohistiocytes and plasma cells was seen in liver (hepatitis), kidney (pyelitis) and eye (conjunctivitis). Lymph nodes and spleen had atrophic lymphoid follicles.

5. Recent Outbreaks- World

The estimated incidence for Lyme borreliosis in Europe for 2018 was estimated to be 2,520,000 cases. While for North America, 790,000 cases were reported and the estimate for the worldwide case burden was found to be 11 million cases per year (Cook and Puri, 2020). The Lyme borreliosis has been recorded as the most leading tick borne infectious disease in Russia (Dedkov et al., 2017).

Lyme disease is the most reported tick- borne disease in New York, followed by anaplasmosis and babesiosis, which are all transmitted by the *Ixodes* tick. Lyme disease remains endemic to the north eastern coastal region of North America as highlighted by Companion animal parasite council (2023).

In 2022, there was an outbreak of Lyme disease in Maine, North America and a total of 2,617 probable cases of Lyme disease were reported by Tick-borne Disease Advisory (2023). Interestingly majority of the case percentage have been correlated to history of travel that can be due to exposure to tick- prevalent areas. While 43% of cases were female, 57% of cases were male. The median age of cases in 2022 was 59 years of age. Cases positive for presence of Erythema migrans lesion and validated by two- tier serological testing by Enzyme immunoassay followed by Western blot test.

6. Lyme Disease in India

The Centre for Disease Control and Prevention (CDC) carried out Lyme disease surveillance in India in 1982 and 1991 and Lyme disease got classified as a reportable disease (Vasudevan and Chatterjee, 2013).

The first case of Lyme disease in India was reported by Patial et al. (1990) in a teenage boy in Shimla. There was no history of tick bite or itching. The boy had chills, joint pain in the knee and elbow joints. Antibody titers were not estimated. His peripheral blood smear was observed under darkfield microscopy and found positive for *Borrelia* spp. bacteria.

Babu and Murthy (2010) reported the case of Lyme disease induced neuroretinitis in a 45 year old woman from Wayanad district of Kerala with reported lesion of Erythema migrans and history of tick bite. The case was confirmed using Western blot test.

Jairath et al. (2014) reported a case series of 5 cases for presence of Lyme disease in Rohtak, Haryana, which is a non endemic zone for Lyme disease. It shows the variability in case incidence. Diagnosis was done based on history, symptoms and serological tests- commercial ELISA and Western blot kit. IgM antibodies against *B. burgdorferi* detected.

Sharma et al. (2017) reported the case of a 10-year old boy in Himachal Pradesh who presented erythema migrans after visit to a nearby forest. The case was diagnosed using enzyme immune assay against OspC antigen of *B. burgdorferi.*

Babu et al. (2020) screened the forest workers and staff of Nagarahole and Bandipur forest ranges in South India for Lyme disease. They found a seroprevalence of 19.9% by ELISA; and about 15.6% by western blot confirmation. Significant correlation was found between seropositivity and exposure to ticks. Negi et al. (2021) noted that maximum incidence of lyme disease have been reported in the states of Arunachal Pradesh, Meghalaya, Manipur, Nagaland.

Vinayaraj et al. (2021) reported the clinical and laboratory evidence of endemic Lyme disease i.e., *B. burgdorferi* in North India. Of the 252 patients included in the study, 218 (86.51%) were adults (≥18 years) and 34 (13.49%) were children. Clinical signs of lymphocytic meningitis, cranial neuritis, carditis, radiculoneuropathy or joint swelling were explored. Case confirmation was done by performing real- time PCR and immunoblot test. Exposure history to potential tick habitats known to harbour *Ixodes* ticks was reported in 166 (65.87%) patients. Neurological involvement was reported in 14 (77.78%) patients, whereas joint and heart involvement was reported in five (27.78%) and three (16.67%) patients, respectively. The author highlighted the importance for travel medicine practitioners and physicians to evaluate for Lyme disease in clinically suspected patients with compatible symptoms and a history of travel to tick risk areas.

Sehgal and Bhatt (2021) presented 3 paediatric cases in New Delhi with neurological symptoms diagnosed with Lyme disease. But there was no associated history of tick bite. Puri et al. (2022) reported Lyme disease characterized by Erythema migrans in a 68 year old man in Nainital, Uttarakhand few days after a dog tick *Rhipicephalus* spp. was located on his body. Thus, several cases of lyme disease have been reported in different age groups of people in different parts of India.

Armed force personnels make up an important part of population especially vulnerable to Lyme disease as they spend considerably large periods of time in forest habitats thus crossing tick habitats. Thus the risk of contracting tick- borne diseases is increased. The cases pertaining to Lyme disease incidence in armed forces. Praharaj et al. (2008) examined a total of 500 subjects including service personnels and their families native to and posted in north eastern states of India- Arunachal Pradesh, Meghalaya, Manipur, Nagaland and Assam using blood sample. The sample was examined for antibodies against flagellar antigens of *Borrelia* spp. using ELISA. Seroprevalence rate was found to be nearly 18% in Arunachal Pradesh and almost 10 percent in other 4 states. The authors attributed the high seroprevalence to the presence of the *Ixodes* ticks in the Himalayas.

Tilak et al. (2022) carried out a cross-sectional survey among the troops not native to and posted in the two states of northeast India, i.e., Sikkim and Arunachal Pradesh for more than one year. All the troops (793 personnel) moving to the forested areas from these selected sites were included in the study. History of tick bite, rash, erythema migrans, migratory muscle pain, migratory joint pain and numbness was reported by the troops. The seroprevalence of Lyme Borreliosis in Sikkim and Arunachal Pradesh among troops was found 2.3% and 4.1%, respectively. The seroprevalence in this study is much lower than in the study by Praharaj et al. (2008). There was no association between clinical symptoms of Lyme Borreliosis and IgG seropositivity. Hence the findings highlight the need for clinicians to suspect and inspect cases and symptoms for Lyme disease especially in areas with tick prevalence or high scale of outdoor activities.

Around 106 species of Argasid and Ixodid ticks have been documented in domestic and wild animals in the Himalayan region (Dhanda and Kulkarni, 1969; Rao et al., 1973 and Geevarghese et al., 1997). A study of the tick population in India has demonstrated ticks of the *Ixodes* genus in several mammals viz., buffaloes and cattle in Arunachal Pradesh (Ronghang and Roy, 2016) and in the Western Ghats (Sadanandane et al., 2018).

7. Diagnosis

A large number of cases go unnoticed or unreported due to lack of or delayed diagnosis (Mead et al., 2015). Lyme disease is considered an “extremely misunderstood” disease as the most

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commonly used diagnostic test available for screening this disease can overlook up to 70% of early-stage cases.

The diagnostic tests available for detection of lyme disease cannot distinguish among resolved, active and recurrent infections leading to diagnostic confusion (Parmar et al., 2022).

7.1. Primitive Techniques

B. miyamotoi can sometimes be identified by microscopic examination of thin blood smears or a spun sample of cerebrospinal fluid stained with Giemsa or Wright stain that stains the spirochete blue. Warthin Starry silver stain demonstrates spirochetes by staining them black while the tissue is stained yellow and can be used to stain tissue slides suspected for presence of Spirochete bacteria. Steiner and Steiner method is also used for histological staining of tissue for visualizing spirochete bacteria (Zanconati et al., 2014). Motile spirochetes may be detected by dark-field or phase contrast microscopy.

7.2. Modern Techniques

PCR assays for the detection of *B. miyamotoi* DNA in whole blood, plasma, CSF and tissues, uses primers specific for 16S ribosomal RNA and for the flaB and glpQ genes (Burde et al., 2023). Vinayaraj et al. (2021) used BLOT- LINE *Borrelia* IgG and IgM line immunoblot assay for diagnosis. The assay uses recombinant antigens OspC and internal flaggelin antigen of *Borrelia* spp. Glycerophosphodiester phosphodiesterase (GlpQ) antigen produced by *B. miyamotoi* is not produced by *B. burgdorferi*. It is used in ELISA and Western blot assays to distinguish *B. miyamotoi* from *B. burgdorferi* (Reiter et al., 2020).

8. The One Health Perspective

The prevention, control and management of infectious diseases demand the understanding, identification and disruption of the complex chain of the pathogen, the vector and the host. Wildlife acts as an unexplored sea of pathogens. At such times, the prevention and termination of disease cannot be done in a silo approach but requires the consultancy and expertise of all fields.

The One Health concept recognizes the interconnectedness of human, animal, and environmental health. One health approach brings together scientists, extension officers, physicians, veterinarians and technicians and better extension services at the farm or community level together for discussion and research to tackle zoonotic diseases (Ashagrie et al., 2023). It aims to promote collaboration and communication across different sectors to address health risks that arise at the intersection of these domains. While One Health is an important approach for addressing emerging infectious diseases, it alone cannot prevent the emergence of new diseases. To prevent future pandemics, a multifaceted approach is needed that includes One Health, as well as improved surveillance, rapid response capabilities, and better communication and coordination among public health authorities at a global level. In simple words, what is needed is unity, teamwork, and transparency (Horefti, 2023).

Torres et al. (2012) has proposed a number of steps for implementing the One health approach to control Lyme disease. He suggests the setting up of online setup of online portal or repository of cases of tick bites in veterinary or medical setting for effective exchange of information between veterinary and medical settings. He emphasizes that effective history taking by veterinarians and medical doctors is necessary to trace anamnesis of symptoms. Laboratory capabilities need to be for diagnosis for Lyme disease in endemic or suspected tick- prone areas. Education campaigns and awareness drives need to be organized to raise knowledge about tick- safety and significance of doctor's consultation. There is need to regularize import- export of animal and screening of animals to prevent the introduction of ticks, their associated pathogens and other zoonotic diseases for effective management. Habitat fragmentation has to be controlled that may lead to spread of ticks and associated pathogens to new ecosystems.

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8.1. Information and Technology Tools for One Health

8.1.1. LymeMIND Commons

The LymeMIND center at the Icahn School of Medicine at Mount Sinai, New York, USA has developed an online database and search engine named- LymeMIND Commons (https://commons.lymemind.org/). It has aggregated information about the data and metadata that is collected by the Cohen Lyme and Tickborne Disease initiative and provides the same for search and download.

8.1.2. Lyme Disease Biobank

It is a collection of more than 900 human biological samples that facilitates research in the field of LD and other tick-borne infections (TBI) that were collected from various cities of North America from patients. Related information with the samples, including details about symptoms, current medications, history of LD and other TBI, medical history and demographics is recorded. The samples are processed for immune profiling, transcriptomics, proteomics, metabolomic and microbiome based studies.

Remote sensing, geographic information systems (GIS) and epidemiological modelling can be useful in investigating the interaction between wildlife, livestock and humans in the context of disease transmission (De Marinis et al., 2021; Carella et al., 2022 and Suresh et al., 2022).

9. Preventive Steps

9.1. Vaccine- Types and Trend

Vaccination aims to protect an individual from a disease as well as generate herd immunity against the pathogen. But *B. burgdorferi* cannot be transmitted by infected dog to another dog or human by itself as it is a vector- borne disease. Some vaccine manufacturers argue that it helps neutralize the infected ticks as they feed on vaccinated dogs and contract antibodies. But it is not effective method for the widely present pathogen or its vector ticks that self-sustain in sylvatic transmission cycles (Vogt and Stevens, 2021). However following vaccines are in use presently.

Currently no vaccine is available for use in US against Lyme disease in humans (Ho et al., 2021). An experimental mRNA vaccine against Lyme disease pathogen for humans has been developed in Perelman School of Medicine, University of Pennsylvania that targets OspA protein of *B. burgdorferi* and generates significant antibody generation in host (Penn Medicine, 2023).VALOR or 'Vaccine Against Lyme Disease for Outdoor Recreationists' is an initiative by Pfizer Inc. under which phase three trails have been conducted for VLA15 that is a multivalent protein subunit vaccine that targets OspA protein of *B. burgdorferi*. The trials are expected to end by 2025. It covers six serotypes of OspA (Valneva, 2023).

Wilczek et al. (2022) vaccinated 183 dogs in Amberg, Germany with commercially available bivalent vaccine. He compared the efficacy of two vaccine regimes i.e., 0, 21, 365th day vs 0, 21, 180 and 365th day and found better immune status with presence of antibodies in the second regime.

9.2. Drugs in Use

Jairath et al. (2014) reported to use oral doxycycline and oral amoxyllin with clearance of lesions in 14 days. Tilak et al. (2022) also reported the use of Doxycycline in armed forces. Hygromycin A is a novel antibiotic treatment for Lyme disease developed by professor Kim Lewis found to clear Lyme spirochete infections in mice without any toxicity to animals (Hibbert, 2024).This long overlooked antibiotic specifically targets spirochetes, leaving the microbiome of the gut intact unlike the broad spectrum antibiotic, doxycycline, typically used to treat Lyme disease. It is yet to be cleared in human drug trials.

10. Tick Management

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10.1. Tick Surveillance

Vector and reservoir surveillance is importance method of tick control. Investigations are required to better distinguish between ticks that carry potential pathogens and those that are competent to transmit pathogens to a host. The rarity of tick borne diseases poses a major challenge to surveillance and diagnostics as it the disease remains unsuspected in low incidence settings.

Ongoing surveillance of both human cases and tick vectors is required to determine the true burden of disease and to raise awareness in the healthcare providers and public (Dykstra et al., 2020).

10.1.1. Active Tick Surveillance

It generally refers to the systematic collection of ticks. Locations for active surveillance of ticks with relevance to Lyme disease are typically chosen based on the likelihood of human-tick contact, suitable habitats for ticks and pre-existing surveillance data. Various methods (Lyons et al., 2021) for the same include the following:

10.1.2. Carbon Dioxide Baited Tick Trap

Carbon dioxide traps work on the principle that ticks have well-developed chemo-receptors and are attracted to carbon dioxide to find a host. Traps consist of a solid base to hold dry ice (a solid form of carbon dioxide) within an insulating material that is surrounded by a sticky tape to capture ticks attracted to the carbon dioxide released as the dry ice sublimates.

10.1.3. Drag Sampling or Flagging

It typically involves the use of a 1 m wide by 1 m long flannel, denim or other sturdy white fabric with sufficient texture for ticks to grip. The tick drag or flag is moved horizontally across vegetation or leaf litter (drag) or more vertically (flag). This method of sampling provides good spatial precision for documenting the occurrence and/or abundance of ticks in a region.

10.1.4. Passive Tick Surveillance

It involves the submission of ticks collected from humans and vertebrate hosts (pets, livestock) by veterinary or medical professionals to researchers or government agencies for tick identification or pathogen detection. The method lacks geographical and temporal precision as tick encounter is incidental.

10.2. Tick Eradiction in the Wild

10.2.1. Zooprophylaxis

Richter and Matuschka (2006) studied the ticks in a cattle pasture and in non- grazing land near Pfalzer Wald–Vosges du Nord biosphere reserve of UNESCO in France. They found a lower infection rate in ticks in land where cattle are present compared to land where cattle are absent. It is known that vertebrate animals serve a role as zooprophylactic in endemic site as they divert the invertebrate vector from feeding on humans (Russell et al., 1963). Similar concept exemplifies here as by supporting the feeding of ticks, cattle divert vector ticks from feeding on reservoir competent hosts.

Cattle thus prevent the transmission of pathogen and obstruct the infective agent lifecycle in ticks. Domestic and wild ungulates play an important role as zooprophylactic agents as they are incompetent for Lyme disease pathogens. They can reduce the probability of ticks feeding on transmission-competent hosts and consequently decreases the infection prevalence of pathogens. Not only do non-infected ticks that feed on these mammals fail to acquire spirochetes, but also infected ticks lose their infection during the course of such a bloodmeal.

10.2.2. Prescribed Burning Method for Tick Control

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In the period of 2000 to 2001 there was wide spread animal mortality in the Ngororongoro crater reserve, Tanzania, an UNESCO world heritage site. Large number of wild buffalo, lions and rhinoceros succumbed to death owing to tick- borne diseases and starvation in 2001. The period was preceded by drought season.

In the period of 1990s, to promote tourism, the Maasai tribes were relocated from Ngorongoro crater reserve that lead to an end of shifting cultivation culture. The tribes burnt large parts of grasslands in rotational manner that promoted the existence of short grasses compatible for grazer animals. The short grasses were unfavourable for ticks survival owing to dessication and ultraviolet light.

But over the next 30 years the mentioned species population declined and there was rise of tall grasses. The population of buffalo which graze on tall grasses increased. The changed ecological specie pool led to tick population rise. This hike of tick population was fuelled by alternate wet and dry seasons due to intense rainfall in 1997-98 period. Coarse grazing animals like wild buffalo, that were starving and immunosuppressed succumbed to tick toxicosis or tick-borne pathogens that are normally harmless at low vector densities.

A strategically-timed, sectional burning regime of the crater floor was then designed in order to control ticks. It had two effects- i.e., direct killing of immature ticks that are abundant during the dry season. Secondly, fire exposed grassland habitat to desiccation and ultraviolet light making it less favourable for oviposition, tick survival or questing.

Fyumagwa et al. (2007) monitored the subsequent effects of prescribed burning on tick densities for two and a half years. The burning regime was demonstrably successful in significantly lowering tick numbers initially and ecological factors resulting from burns maintained them at low levels thereafter.

Gleim et al. (2019) conducted a similar study in southwestern Georgia and northwestern Florida which is dominated by pine forests and agriculture and where prescribed burning is commonly used to maintain open pine forests ecosystems. They think that prescribed fire, when performed on a regular basis significantly reduces encounter rates with ticks infected with pathogenic bacteria. While the reduced encounter rates are primarily due to overall reductions in tick abundance at sites subjected to long-term prescribed fire, regular prescribed fire may also be capable of reducing the transmission of certain tick-borne bacteria. Further investigation into how long-term prescribed fire might affect pathogenic bacteria such as *B. burgdorferi* in the northeastern U.S. is warranted.

10.2.3. The Indian Context

Bhaskar et al. (2019) conducted a study in the grasslands of Parambikulam Tiger Reserve and Eravikulam National Park, Kerala, India. The author mentioned that prescribed burning is a controversial debated method to manage open habitat types. The method was used in the aforementioned areas to manage the habitat of Nilgiri Tahr. However, the author found inefficient fire management lead to decline to grasshopper abundance.

Hence it can be rightly said, 'Fire is a great servant but a bad master' (Forest research institute, 2018). Limited and controlled fires were considered useful for healthy forest growth. It helps clear invading shrubs, weeds and forest floor litter. But in recent years, uncontrolled forest fires have created havoc in the country and hence forest fire no longer remains instrumental tool for tick control in the world.

11. Preventive Protocol in Tick- Infested Areas

Person venturing to tick- infested areas should preferably wear light colored clothes for easy spotting of attached ticks. Full- sleeved clothing should be worn as it limits the tick's ability to latch. Application of topical insect repellents like DEET (N, N-Diethyl-meta-toluamide), also called diethyltoluamide; picaridin and permethrin are recommended before visit to tick- prone areas (CDC, 2010). Diethyl phenyl acetamide (DEPA) may also be applied on uniforms. After visit to tick-populous areas person vlothes should preferably be washed and dried at high temperature.

Tilak et al. (2022) described the use of (IEC) Information, education, communication training module for soldiers frequenting to tick prevalent landscapes, forests to raise awareness about Lyme disease. Illustrations and photos related to ticks, their habit and habitat, signs of tick bite especially Erythema migrans were used for training. The troops were trained to do buddy checks-i.e., check each other's bodies for presence of ticks after visit to tick populous areas. They were directed to practice scrubbing while bathing for early detachment of infested ticks to prevent transmission of *Borrelia* spp. bacteria. Similar steps may be incorporated in the protective regime of other vulnerable population too.

12. Conclusion

To achieve our SDG i.e., sustainable development goal number- 2 'Health for all', we need to ensure all the players in the game of One Health are brought together to the same pitch as disease management is not a single player game. Today, Lyme disease is no longer limited to sporadic incidence but has perpetuated to entire world and attacking and invading new reservoir hosts in changed ecological scenario. We need to implement One- health strategy for monitoring wildlife, domestic animals as well as human subjects. There is need to develop better inventory and record of incidence of tick- bite or lyme disease cases like other infective diseases. Emphasis on tick surveillance will be rewarding for better understanding changing disease dynamics and vector biology. Effective data collection pertaining to environmental and climatic, biotic and abiotic variables to identify the determinants for spatial variation of Lyme disease risk will help implement better preventive and control strategies (Ozdenerol, 2015). We need to protect and promote biodiversity and natural habitats to prevent spillover of pathogens from sylvatic to domestic cycles and maintain the balance in nature between pathogens, vector and environment.

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