EPIDEMIOLOGICAL RISK ASSESSMENT OF TICK-BORNE ENCEPHALITIS IN TEMPERATE CLIMATES

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https://doi.org/10.5281/zenodo.17629440

Introduction

Tick-borne encephalitis (TBE) is a neuroinvasive viral infection caused by the tick-borne encephalitis virus (TBEV), primarily transmitted through the bite of infected Ixodes ticks in temperate regions. The global incidence of TBE has been increasing, a trend closely linked to environmental transformations, climate change, and evolving human behaviors. This upsurge underscores the growing public health importance of TBE, particularly in endemic regions of Europe and Asia. Epidemiological estimates suggest that approximately 5,000 to 10,000 cases occur annually; however, the true burden is likely underestimated due to gaps in diagnostic capacity and underreporting. The epidemiology of TBE is shaped by a complex interplay of ecological, climatic, and socioeconomic factors. Variations in tick population density, reservoir host abundance, and environmental conditions contribute significantly to regional differences in disease prevalence. The observed disparities in reported cases also reflect variations in public health surveillance systems, vaccination coverage, and healthcare accessibility. Countries such as Estonia, Latvia, Slovenia, and the Czech Republic consistently report higher incidence rates, highlighting the regional heterogeneity of TBE transmission. The transmission of TBEV depends strongly on environmental factors that regulate tick survival and activity. Climate change acts as a critical driver of TBE epidemiology by altering temperature and humidity patterns, which directly affect tick life cycles, distribution, and host-seeking behavior. Warmer winters and extended vegetation seasons enhance tick survival and expand their geographic range, thereby broadening the risk zones for TBE infection. These ecological shifts are further compounded by anthropogenic influences, including land use changes, deforestation, and increased outdoor recreational activities that raise human exposure to infected ticks.Socioeconomic and behavioral determinants also play important roles in disease dynamics. Inadequate vaccination coverage, limited public awareness, and disparities in healthcare infrastructure contribute to persistent underdiagnosis and unequal disease outcomes. Political instability, poverty, and low investment in surveillance systems can further hinder effective disease control in some regions.

Epidemiology of Tick-Borne Encephalitis

Tick-borne encephalitis (TBE) is a neuroinvasive viral disease caused by the tick-borne encephalitis virus (TBEV), and its global incidence has been steadily increasing due to environmental, ecological, and behavioral changes. The annual incidence rates of TBE vary considerably across countries, reflecting a complex interplay of factors such as tick population density, the distribution of animal hosts, climatic conditions, ecological dynamics, and human activity patterns.

Higher incidence rates are frequently observed in the Baltic States, including Estonia, Latvia, and Lithuania, as well as in Slovenia and the Czech Republic, while some regions exhibit stable or declining trends. In endemic areas, approximately 5,000 to 10,000 new cases of TBE are reported each year, although this number likely underrepresents the true burden because of underdiagnosis and underreporting. Differences in incidence rates between countries are often linked to disparities in surveillance systems, diagnostic capabilities, vaccination coverage, and access to healthcare resources.

Socioeconomic and political factors, such as poverty, healthcare inequality, and regional instability, also influence long-term patterns of disease occurrence. Climatic factors play a crucial role in the transmission of TBEV, as temperature and humidity regulate tick survival, seasonal activity, and host-seeking behavior. Global climate change is predicted to extend the range of tick habitats northward and to higher altitudes, thereby expanding the regions at risk for TBE infection.

Modern ecological niche modeling and data-driven methods, including machine learning, are increasingly used to predict areas of heightened TBE risk by combining environmental and biological variables. Improved public awareness, more accurate diagnostics, and stronger surveillance systems—especially following the designation of TBE as a reportable disease within the European Union—have also contributed to a deeper understanding of its epidemiology. As a result, the apparent increase in TBE cases may reflect both a genuine rise in incidence and more effective detection and reporting practices.

Transmission and Lifecycle

The tick-borne encephalitis virus is primarily transmitted through the bite of infected ticks. The main vector species include Ixodes ricinus, Ixodes persulcatus, and Dermacentor reticulatus, which are widely distributed across temperate and sub-boreal regions and serve as efficient transmitters of the virus.

Vectors and Reservoir Hosts

The ecological relationship between ticks and their hosts is central to the maintenance of TBEV in nature. Small mammals such as the yellow-necked mouse (Apodemus flavicollis), wood mouse (Apodemus sylvaticus), and bank vole (Myodes glareolus) act as key reservoir hosts that sustain the viral cycle within ecosystems. These rodents facilitate viral persistence by infecting feeding ticks during blood meals. Larger mammals, such as deer, function as reproductive hosts, providing blood sources for adult ticks and supporting population growth.

Transmission Dynamics

The dynamics of TBEV transmission depend on ecological and biological interactions among ticks, hosts, and environmental conditions. Regions with high densities of rodent reservoirs tend to experience increased viral amplification, resulting in greater infection rates among local tick populations. Transmission occurs through both systemic and non-systemic routes. In non-systemic (co-feeding) transmission, infected and uninfected ticks feed simultaneously on the same host, allowing viral exchange even when the host does not develop viremia. This mechanism enables the virus to persist in the environment, particularly when reservoir hosts have short or mild infections.

Impact of Environmental Factors

Environmental and climatic changes are expected to significantly affect the transmission intensity of TBEV. Predictive models suggest that the basic reproduction number of the virus may increase substantially in the coming decades due to rising temperatures, altered humidity patterns, and shifts in vegetation. These conditions extend tick activity seasons and create new ecological niches suitable for their survival and reproduction.

Such environmental transformations emphasize the importance of integrating climate projections, vector surveillance, and ecological monitoring into public health strategies.

Developing adaptive prevention measures, expanding vaccination coverage, and employing predictive modeling tools are essential for mitigating the future risk of TBE in temperate regions.

Vectors and Hosts

The ecological interactions between ticks and their animal hosts are central to the transmission and maintenance of the tick-borne encephalitis virus (TBEV) in natural ecosystems. Small mammals, particularly rodents such as the yellow-necked mouse (Apodemus flavicollis), wood mouse (Apodemus sylvaticus), and bank vole (Myodes glareolus), act as reservoir hosts that sustain the viral cycle. These rodents harbor the virus and provide an ongoing source of infection for questing ticks, enabling the continuous circulation of TBEV within endemic habitats.

Larger mammals, such as deer, function as reproductive or amplification hosts, offering essential blood meals for adult ticks and contributing to the maintenance of large tick populations. Although these animals typically do not serve as effective viral reservoirs, they play a crucial ecological role by supporting the completion of the tick life cycle and promoting the geographical spread of infected tick species.

Transmission Dynamics

The transmission of TBEV is governed by intricate ecological and biological interactions among ticks, vertebrate hosts, and environmental conditions. The abundance and diversity of rodent reservoirs are particularly influential, as high densities of small mammals tend to correlate with greater local transmission of the virus. These rodents facilitate viral amplification by infecting large numbers of feeding ticks during their parasitic cycles.

TBEV can be transmitted through both systemic and non-systemic routes. In systemic transmission, an infected host develops viremia, allowing uninfected ticks to acquire the virus while feeding. In contrast, non-systemic—or co-feeding—transmission occurs when infected and uninfected ticks feed simultaneously in close proximity on the same host, permitting viral exchange even when the host does not develop detectable viremia. This co-feeding mechanism is particularly important in sustaining viral persistence within local tick populations, especially in ecological settings where transient or mild infections occur in reservoir hosts.

Impact of Environmental Factors

Environmental and climatic variables profoundly influence the intensity and distribution of TBEV transmission. Climate change, in particular, is expected to alter tick population dynamics and extend the geographical range of competent vector species. Projections suggest that the basic reproduction number of TBEV could increase substantially in coming decades due to warming temperatures, increased humidity, and prolonged vegetation periods that favor tick survival and host-seeking activity.

Rising average temperatures may lead to longer seasonal periods of tick activity, allowing more opportunities for virus transmission between hosts and vectors. At the same time, shifts in precipitation and vegetation cover may create new ecological niches suitable for ticks, even in previously low-risk areas. Understanding these environmental influences is essential for developing accurate risk assessments and designing adaptive public health interventions in temperate climates.

Risk Factors

The epidemiology of tick-borne encephalitis is shaped by a complex combination of environmental, socioeconomic, and behavioral risk factors. Recognition of these determinants is critical for effective prevention and control strategies.

Environmental Factors

Environmental variables such as temperature, humidity, vegetation type, and land use patterns play a decisive role in determining tick distribution and activity. Increased humidity, dense vegetation, and certain forested or grassland habitats enhance tick survival and increase the likelihood of TBEV transmission to humans. Climatic conditions, including mild winters and warm, humid summers, favor longer tick activity seasons, while irregular precipitation patterns can affect the abundance of both ticks and their reservoir hosts.

Interestingly, some studies have found that long-term temperature averages or cumulative vegetation periods have a limited direct correlation with the number of reported TBE cases, implying that short-term weather anomalies and microclimatic conditions may exert stronger influences. This suggests that local environmental variability—such as forest edge density, soil moisture, and small-scale vegetation structure—can be more predictive of TBE risk than broad climatic trends alone.

Socioeconomic and Behavioral Factors

Human behavior also contributes significantly to TBE risk. Increased outdoor recreational activities, agricultural work, and forest exposure elevate the likelihood of tick bites. Populations in rural or forested areas often face higher risk, particularly when vaccination coverage is low or when public awareness about tick prevention is limited. Socioeconomic disparities, healthcare accessibility, and regional differences in surveillance infrastructure further shape the spatial distribution and reporting of TBE cases.

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