Forum

Echinococcosis on the Tibetan Plateau, where to go?

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The post-COVID-19 era has exacerbated challenges in controlling echinococcosis on the Tibetan Plateau, the epicentre of alveolar and cystic echinococcosis, where reduced funding for neglected tropical diseases (NTDs) coincides with growing tourism and trade. This convergence heightens transmission risk, and we provide a novel synthesis of context-specific, integrated control strategies.

Echinococcosis and the Tibetan Plateau situation

The World Health Organization (WHO) 2021–2030 roadmap for neglected tropical diseases (NTDs) sets an ambitious goal of reducing the global disease burden of echinococcosis, including both alveolar echinococcosis (AE) and cystic echinococcosis (CE), through improved prevention and control [1]. China bears the highest burden of AE and CE globally, with substantial morbidity and economic losses, especially in the pastoral regions [2]. The Tibetan Plateau (TP), a vast, high-altitude region in western China spanning Tibet, Qinghai, and Sichuan, stands out as a critical hotspot, reporting the highest annual incidence of AE and CE worldwide, thereby necessitating urgent action to address this persistent public health threat [3].

The urgency of this situation has been further intensified by the COVID-19 pandemic, which has disrupted resource allocation for NTDs and reduced funding for echinococcosis in China [3]. Additionally, the post-pandemic economic recovery on the TP has spurred sharp growth in tourism and trade, increasing human and goods mobility (Figure 1). This increased movement heightens interactions among local pastoralists, animals, traders, goods, and visitors, raising transmission risks and complicating prevention efforts. It is, therefore, a critical moment to work on precise and efficient intervention measures tailored to the TP's unique socioeconomic and geographic context to meet these challenges.

Echinococcosis epidemiology on the TP

Although echinococcosis prevalence on the TP shows an overall declining trend in recent years, this masks several overlooked factors and persistent challenges. First, contrasting global CE predominance, AE – the more lethal form – is more prevalent on the TP, particularly in Sichuan Province [4]. Around 86% of confirmed AE patients worldwide originate from the TP, underlining its status as the global epicentre of AE [3]. Second, clinical data from 2004 to 2022 indicate that 71.25% of AE cases in China remain unresolved, posing significant therapeutic challenges [3]. Third, the postoperative recurrence rate is high, at approximately 16% for AE and 8% for CE, reflecting these infections' chronic and persistent nature [5,6]. Fourth, detection rates of new echinococcosis cases in Sichuan Province, particularly among children, showed signs of resurgence in 2023, which shows the importance of continuous monitoring of the epidemic dynamics and reinforcement of control measures [4].

In addition, recent genomic studies revealed a complex and diverse epidemiology of *Echinococcus* species across the TP. Multiple genotypes of *Echinococcus granulosus sensu lato*, including G1, G6, and G3, as well as distinct *E. multilocularis*, have been identified, each adapting to specific host dynamics involving livestock, dogs, and wildlife [7]. Together, these epidemiological and molecular findings highlight the complexity and the urgent need for targeted strategies to address the evolving burden of echinococcosis on the TP.

A holistic analysis of echinococcosis on the TP

We propose a One Health approach to address echinococcosis on the TP, integrating humans, animals, and the environmental factors (Figure 2) [8–12]. Though humans are accidental intermediate dead-end hosts in the transmission cycle of echinococcosis, their activities may drive the transmission of *Echinococcus* spp. [11]. Livelihoods on the TP rely on herding and farming; therefore, humans are in frequent contact with domestic dogs and wildlife, which might be infected with *Echinococcus*. Deeply rooted endemic cultural practices – including great admiration and respect for all forms of life, thus not to kill, canine feeding on uncooked viscera, consumption of untreated water, and dietary exposure to contaminated food – sustain *Echinococcus* spp. transmission [8,12]. The situation is aggravated by the resource-limited healthcare system in remote, high-altitude settings, resulting in delays in diagnosis and treatment [8,10].

Recently, the steady influx of tourists and booming trade in the TP have increased the risks of *Echinococcus* transmission. The post-pandemic tourism and trade boom has intensified movement across this region and is likely linked to the rise in infections reported in non-endemic areas of eastern China [12]. Pastoralists trading animal products, selling Tibetan mastiffs to low-altitude regions, and contacting visitors may amplify the spread of echinococcosis by facilitating human–wildlife–livestock interactions that promote parasite transmission.

Animals are central to echinococcosis transmission cycles – dogs, ubiquitous

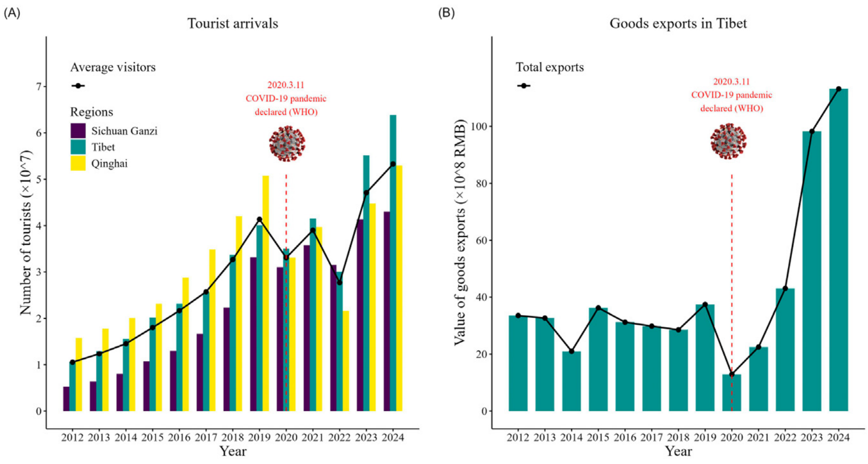

Figure 1. Trends in tourist arrivals and goods exports within the Tibetan Plateau (TP) (2012–2024). (A) The number of tourists visiting the TP (2012–2024)[i,ii,iii]. (B) The value of goods exported from Tibet (2012–2024)[i].

among pastoralist communities, serve as definitive hosts, shedding eggs, while livestock such as yaks and sheep are intermediate hosts of *E. granulosus*. The Plateau's unique wildlife – including red foxes, Tibetan foxes, plateau pikas and Qinghai voles – complicates transmission dynamics, acting as reservoirs for diverse *Echinococcus* spp. [11]. These species thrive in the TP's rugged ecosystems, linking domestic and wild transmission cycles.

Environmental contamination with *Echinococcus* eggs, shed in canine feces, elevates transmission risk, particularly where sanitation is poor and clean water is scarce [8]. Meanwhile, some environmental factors are associated with the high prevalence of echinococcosis on the TP, including precipitation, temperature, high altitude, water accessibility, and grass area ratio [9]. The specific geographical environment of the TP profoundly influences the life cycle of *Echinococcus*, the distribution of wildlife hosts, and human activity patterns.

Given the current situation on the TP, a comprehensive One Health approach for echinococcosis control, integrating human, animal, and environmental factors, is urgently needed. Accordingly, the development of new tools and technologies tailored to the specific conditions of this region is essential.

Advanced techniques in echinococcosis prevention and control

Recent technological advancements are providing new opportunities for the prevention and control of echinococcosis. In human diagnostics, emerging tools, such as cell-free DNA (cfDNA), offer promising potential for earlier and more objective detection of AE and CE [13]. Artificial intelligence (AI)-assisted ultrasound models have also demonstrated enhanced diagnostic accuracy, outperforming experienced radiologists in TP [10]. These innovative technologies provide technical support for the early detection and intervention of echinococcosis in remote areas with insufficient capabilities, by enhancing the accuracy and efficiency of diagnosis and monitoring.

Preventive efforts against echinococcosis have made notable progress in animals.

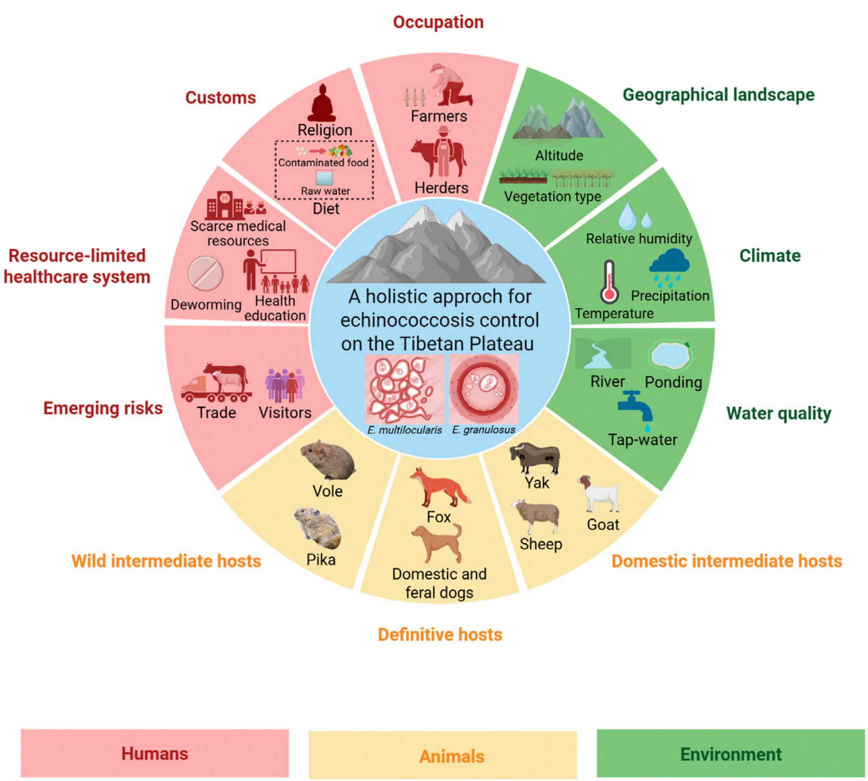

Figure 2. A holistic approach for echinococcosis control on the Tibetan Plateau. This figure was created using BioRender (*Echinococcus multilocularis* and *Echinococcus granulosus* icons were from [11]).

The EG95 vaccine against CE for livestock has shown efficacy in reducing transmission by protecting intermediate hosts. Although no vaccine has yet been licensed for dogs, ongoing research in canine immunology is progressing toward viable options [2]. Monthly dosing of dogs with praziquantel (PZQ) works well in most communities, but is challenging in pastoral areas such as TP [2]. Subsequently, Internet of Things (IoT)-enabled devices like smart collars were invented. It is a novel tool to deliver PZQ baits to dogs automatically and regularly, which also serves as a smart digital management platform to monitor echinococcosis epidemiology in real time, allowing for remote, automated dog deworming and tracking, significantly improving disease monitoring in the TP [14].

Environmental monitoring is undergoing a revolution with the advent of environmental DNA (eDNA) technology. This method enables non-invasive sampling of soil, water, and feces to detect pathogen and parasite DNA, including that of *Echinococcus* spp., complementing existing human and animal surveillance data and further revealing the spatiotemporal distribution of the pathogens [15]. Hopefully, eDNA will improve the scope and efficiency of monitoring, meeting the requirements of precise prevention and control, particularly in remote regions such as the TP.

Future research directions

To achieve the WHO's 2021–2030 targets for echinococcosis elimination, future research should prioritize early detection and surveillance. On early diagnosis, large-scale cohort studies in AE and CE endemic regions could validate the effectiveness of biomarkers like *Echinococcus* cfDNA, particularly in asymptomatic individuals [13]. Effective surveillance is equally important. Without robust surveillance systems, comprising clinical baseline data and sustained monitoring in livestock, dogs, and wildlife, it is impossible to evaluate the real-world impact of interventions or justify continued investment in resource-intensive control measures [3].

Additionally, genomic analysis will be essential for elucidating the full spectrum of *Echinococcus* diversity and its implications for treatment and vaccine development. Besides, to make vaccination really work, it must always be accompanied by public health measures. Precise genotyping will allow public health authorities to design targeted interventions that address the specific host–parasite dynamics in different regions. Moreover, establishing biobanks to store biological samples, imaging data, and multi-omics data would support future research and facilitate comparative studies across regions and populations.

Studies addressing ecological drivers of transmission remain limited. Future research should explore how the unique landscape of the TP influences parasite ecology. Integrating climatic, ecological, and socioeconomic variables into mathematical models can help to simulate transmission dynamics and assess the impact of interventions under different scenarios. This systematic feedback can help policymakers to optimize resource allocation for more effective public health strategies.

The increasing movement of people and goods across the TP and its surrounding regions has highlighted the risk of parasite transmission [12]. To effectively address this challenge, it is crucial to implement adaptable surveillance systems, deploy portable diagnostic tools, and promote targeted health education among mobile populations. Achieving sustainable echinococcosis control will require coordinated, cross-sectoral, and interdisciplinary efforts.

Concluding remarks

The increase in tourism and trade following the COVID-19 pandemic, along with the persisting risk factors, underscores the distinctive and critical challenges posed by echinococcosis on the TP. Through a One Health approach, we can understand, analyse and interrupt the transmission cycles in this complex ecosystem. Innovations like AI diagnostics and IoT-based strategies provide hope for echinococcosis control in this vast, pastoral region. However, persistent gaps in diagnostics, surveillance, and treatment demand further investigation. Addressing these challenges is essential for achieving long-term control of echinococcosis on the TP, in China, and even globally, thus achieving the WHO 2030 goals for this NTD.

Acknowledgments

This work was supported by the Science and Technology Program of Xizang Autonomous Region (XZ202303ZY0008G) and the National Key Research and Development Program of China (No. 2021YFC2300800, 2021YFC2300804).

Declaration of interests

The authors declare no competing interests.

Resources

[i]www.xizang.gov.cn/zwgk/zfsj/ndtjgb
[ii]http://tjj.qinghai.gov.cn/tjData/yearBulletin
[iii]www.gzz.gov.cn/tjxxtjgb

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https://doi.org/10.1016/j.pt.2025.07.001

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