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Review

One Health in the shrinking world: Experiences with tuberculosis at the human–livestock–wildlife interface

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ABSTRACT

Tuberculosis (TB) is a global anthropozoonotic infection that has raised awareness of the impact of disease at the human–livestock–wildlife interface. There are examples of transmission from livestock resulting in establishment of reservoirs in wildlife populations, and exposures from interactions between humans and wildlife that have resulted in disease outbreaks. A One Health approach is crucial to managing and protecting the health of humans, livestock, wildlife and the environment. Although still in its infancy in many areas of the world, the use of transdisciplinary teams to address wildlife–human–livestock boundary diseases will broaden the scope of options for solutions. This paper reviews some less commonly known examples of threats and outcomes using lessons learned from tuberculosis.

Contents

1. Introduction

One Health embraces a holistic approach incorporating humans, animals, and the environment into a model where practitioners, scientists, stakeholders, and policymakers work toward the goal of ecosystem health [46]. Although tuberculosis (TB) is a regulated disease in most developed countries, it continues to be a global threat to the One Health paradigm. It serves as an example of the complexity of a disease that crosses boundaries between humans, livestock, and wildlife, and is impacted by the conditions of host, pathogen, environmental, political and socioeconomic factors. Studying tuberculosis in one set of hosts or environmental conditions may not be applicable to another. However using the principles of One Health, some

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general lessons may be learned that may be useful to other disease scenarios.

Mycobacterial infections have existed from before recorded history [11]. *Mycobacterium tuberculosis* complex organisms have traditionally been associated with humans and domestic livestock. As molecular diagnostic and epidemiologic techniques have advanced, the detection of mycobacterial infection in new hosts has improved. No longer considered solely a disease of humans and livestock, tuberculosis has become established in wildlife populations [6] and threatens to spread as environmental, host, and pathogen characteristics change [22]. Specifically, the risk of *Mycobacterium bovis* infection at the "human–animal" interface has been recently reviewed by Michel et al. [35].

The tuberculous mycobacteria are considered significant global threats to human and animal health. The World Health Organization (WHO) estimates that one third of the world's human population is infected with tuberculosis [47]. WHO reported that in 2009 there were 9.4 million new TB human cases and approximately 1.7 million deaths attributed directly to TB (equal to 4700 deaths a day). *M. tuberculosis* is the etiologic agent of most human TB cases in the world. However, the number of cases of *M. bovis* in humans and animals is underestimated or unavailable in many areas of the world, especially in developing countries. *M. bovis* is still widespread in livestock in developing countries due to the lack of or sporadically applied control measures and pasteurization of milk and/or milk products [7]. The risk of disease transmission between species is increased when there is habitat encroachment by humans and livestock into wildlife areas, competition for resources between wildlife and livestock, and inadequate veterinary infrastructure for disease control. *M. bovis* has now become established in a number of wildlife reservoirs around the world due to the introduction and interaction with livestock [41].

A more holistic approach is required to address the public health, agricultural, conservation, management, and regulatory implications of this disease. An understanding of variations in pathogenesis and transmission is required for animal managers, regulatory decision-makers, clinicians, and scientists to create informed policies to protect human and animal health. Although tuberculosis classically presents as a pulmonary disease transmitted by aerosol, in some hosts, transmission routes may be through ingestion or bite wounds leading to infection of the gastrointestinal tract or skeletal system (for example, in carnivores) [34]. The One Health challenge is to develop new concepts about the pathogens, pathogenesis, comparative immunology of the various hosts, epidemiological dynamics and understand the role environmental factors play in each of the diverse systems. Lessons learned from the study of tuberculosis at interfaces may provide innovative approaches that may be applicable to other diseases affecting wildlife, livestock and humans. This paper reviews some less commonly known examples that illustrate the complexity of these interactions (Table 1) and the importance of One Health in addressing solutions to improve health.

Table 1
Examples of tuberculosis cases at human–livestock–wildlife interfaces.

Affected species	Suspected source	Country	Reference
Asian elephant	Humans	Nepal	[15]
Asian elephant	Humans	Thailand	[3]
Asian elephant	Humans	India	[15]
Chacma baboons	Humans	South Africa	[40]
Panther	Cattle	Argentina	[45]
American mink	Cattle	Argentina	[32]
Jaguar	Cattle	Venezuela/USA	[24]
Humans	Cattle products	USA	[42]
Humans	White rhinoceros	USA	[10]
Humans	Asian elephant	USA	[38]
Humans	Sea lions	Netherlands	[27]
African lions	African buffalo	South Africa	[41]
African buffalo	Cattle	South Africa	[41]
White-tailed deer	Cattle	USA	[6]
European badger	Cattle	UK/Ireland	[6]

2. Elephant–human interface in Asia

Habitat loss, human–elephant conflict, and disease are some of the factors that have contributed to the endangered status of the Asian elephant (*Elephas maximus*). One of the diseases that affects both ex situ and in situ captive elephants is tuberculosis caused by *M. tuberculosis*. It has been estimated that the prevalence could be as high as 11–25% in captive elephants (US, India, and Nepal) [15]. The Nepal Elephant HealthCare and TB Surveillance Program, a One Health Initiative, was created to integrate government, NGO, academic, human clinical and research resources to address TB as one of the cross-species issues in Nepal. During testing of the captive elephant population (85% completed), it was found that 23% of the elephants were serologically positive for tuberculosis. Nepal is considered to have a high rate of human tuberculosis (240/100,000) [43]. Therefore, it is hypothesized that due to the close contact between humans and working elephants, infected handlers may be serving as a source of infection for the animals. Similarly in Thailand, *M. tuberculosis* isolated from captive elephants was sequenced and strains appeared to have originated from humans [3].

From a conservation perspective, captive elephants play a critical role by patrolling national parks that provide habitat for other endangered species, create revenue through ecotourism, and convey educational messaging. An interface between the working and wild elephants occurs when individuals interact for breeding, or share feeding and watering areas. This raises the potential for direct transmission and environmental contamination with mycobacterial organisms from infected captive elephants as well as spillover to incidental hosts that also share these resources. The combination of high human disease prevalence, close human–captive elephant contact, and captive–wild elephant interface stress the importance of understanding the pathogenesis, epidemiology, and building the collaborative relationships that support the One Health approach to address the complexities of this issue.

Nepal's government has endorsed a nation-wide elephant TB testing program to identify and protect elephants and the public from further spread of the disease [15].

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