



Review

Can the European Hedgehog (*Erinaceus europaeus*) Be a Sentinel for One Health Concerns?

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Abstract: *Erinaceus europaeus* is a cosmopolitan mammalian species broadly distributed in Europe, from natural to suburban areas. Due to its ecological role and susceptibility to distinct zoonotic agents, *E. europaeus* could be a suitable sentinel candidate for many global problems that negatively affect human and animal health. Hedgehogs can work as bioindicators to environmental contamination and can be hosts for multiple tickborne zoonotic agents. Thus, people who directly or indirectly make physical contact with this species are exposed to a variety of threats. Moreover, it has also been studied as an indicator for antibiotic resistance, which was already confirmed for tetracyclines. Additionally, it was also reported as a reservoir for methicillin-resistant *Staphylococcus aureus* (MRSA). More recently, hedgehogs have been recently recognised as potential reservoirs of MERS-CoV-like strains. Among other animals, this species can possibly represent an intermediate reservoir for SARS-CoV-2. The aim of this review is to briefly expose the scientific attainments about hedgehog health, namely agents, diseases, and threats that significantly affect general health concerns and that contribute to achieve One Health principles.

Keywords: european hedgehog; one health; zoonotic agents; bioindicator; environmental contamination; antibiotic resistance; MERS-CoV; SARS-CoV-2



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1. Introduction

Erinaceus europaeus, also known as the European hedgehog or western-European hedgehog, classified under “Least Concern” by the International Union Conservation of Nature (IUCN), is broadly distributed in continental Europe (including Russia) [1]. It is also present on some Mediterranean islands, the Azores, and New Zealand [2]. Hedgehog habitats are very diverse, from very natural spaces to rural and urban areas. Though they usually prefer areas with rich food supply and large amounts of vegetation, they have recently been found in high densities in green city parks, which demonstrates their adaptability and resilience [3].

The presence of predators, such as badgers (*Meles meles*) and foxes (*Vulpes vulpes*), and the massive changes in agricultural and rural landscapes (the use of pesticides) have had a severe impact on the hedgehog population size, particularly in the UK [3,4]. Nevertheless, the current hedgehog abundance and general distribution are generally stable in most European countries [5,6].

Hedgehogs are hibernators, mainly nocturnal, and insectivorous. Visually, they are known for their spines and back muscles, which allow them to roll up. Their diet is primarily composed of earthworms, caterpillars, slugs, earwigs, millipedes, and beetles.

Very rarely, they may also eat mice, snakes, small birds, bird eggs, and pet food found in private gardens [7].

One Health is defined as the assumption that human health is strongly connected with animal health and the environment. Even though it is not a new concept, One Health principles and approaches are becoming more and more important in recent years due to human population growth, global movement of people and food, wildlife habitat loss, and climate change, among others [8].

Wildlife disease surveillance represents a crucial tool to achieve One Health principles and prevents us from the remarkable consequences of an epidemic or pandemic disease in the human population. The Ebola virus epidemic and the SARS-CoV2 pandemic perfectly illustrate how important it is to improve the basic knowledge of wildlife infectious agents and threats to prevent a world catastrophe. In fact, most emerging infectious diseases are zoonotic (which means they affect humans and at least one other vertebrate species). Zoonoses result in thousands of human deaths per year [9], not to mention economic losses, making the overall consequences of a single outbreak extraordinary. Prevention and early control of disease outbreaks and environmental changes could be the keys to reduce the impact of these situations, which requires transdisciplinary research approaches [10].

A sentinel species is an organism that provides an advance warning of a threat that potentially represents a risk to humans or other species, namely infectious agents or environmental changes [11]. The biology of some hedgehogs and aspects of ecology should raise awareness for the possible involvement of *E. europaeus* in several potentially emerging pathogens and diseases [12], namely their frequently occupied trophic levels and their extensive geographical distribution. Consequently, this review aims to summarise information about the hedgehog that is directly related to the One Health concept, indicating that it may be a possible sentinel for health hazards. Some interactions between hedgehogs, zoonotic agents, and environmental conditions are illustrated in Figure 1.

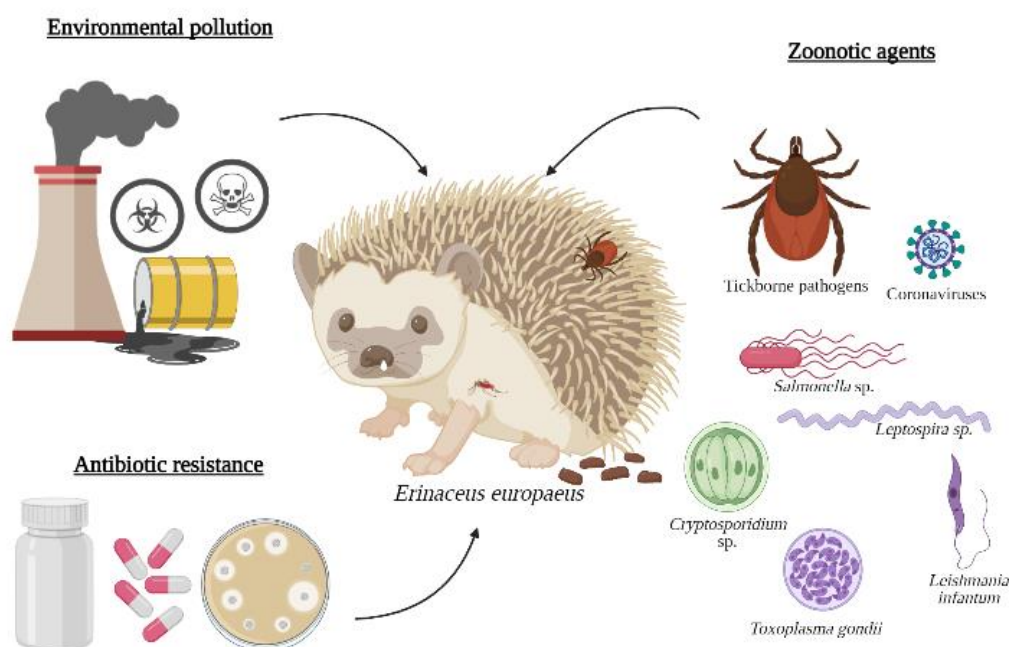


Figure 1. One Health threats related to the European hedgehog: environmental contamination, zoonotic agents, and antibiotic resistance.

2. Methodology

To produce this literature review, the Scopus® search tool was used with the key words ((european AND hedgehog) OR (erinaceus AND europaeus)) AND (zoonotic OR zoonosis OR pollution OR disease OR one AND health OR parasite OR bacteria OR virus

OR rodenticide OR poison OR contamination)). The 86 documents obtained were the base of this review. Some of them were unrelated to the field (e.g., the sonic hedgehog factor; embryology) and were excluded for this reason.

3. Zoonotic Agents

The potential zoonotic agents that have already been reported in *E.europeaus* are mentioned in Table 1.

Table 1. Agents detected in *E. europaeus* with public health importance.

	Agents	Ref
Bacteria	<i>Campylobacter jejuni</i>	[13]
	<i>Salmonella</i> sp. ¹	[14]
	Shiga toxin-producing <i>E. coli</i>	[13]
	ESC-resistant <i>E. coli</i>	[13]
	<i>Yersinia pseudotuberculosis</i>	[14]
	<i>Mycobacterium marinum</i>	[13]
	<i>Coxiella burnetii</i>	[15]
	<i>Borrelia burgdorferi sensu latum</i> (s.l.) ²	[16]
	<i>Borrelia miyamotoi</i>	[16]
	<i>Listeria monocytogenes</i>	[17]
	<i>Leptospira interrogans</i> s.l.	[18]
	<i>Klebsiella</i> sp.	[13]
Virus	Herpesvirus ³	[19]
	TBEV ⁴	[20]
	CCHFV ⁵	[21]
	Tahyna virus	[22]
	Bhanja virus	[23]
	Influenza A virus	[12]
	Influenza D virus	[12]
	Coronavirus	[24]
	SFTSV ⁶	[25]
Parasites	<i>Anaplasma phagocytophilum</i>	[26]
	<i>Giardia</i> sp.	[27]
	<i>Cryptosporidium parvum</i>	[28]
	<i>Cryptosporidium hominis</i>	[13]
	<i>Rickettsia helvetica</i>	[26]
	<i>Toxoplasma gondii</i>	[29]
Fungi	<i>Leishmania infantum</i>	[30]
	<i>Trychophyton mentagrophytes</i> var. <i>erinacei</i>	[31]
	<i>Microsporium</i> spp.	[13]
	<i>Candida albicans</i>	[13]

¹ namely *S. typhimurium*, *S. kottbus*. ² including *Borrelia afzelii*, *Borrelia bavariensis*, and *Borrelia spielmani* [13,16]. ³ as Herpes simplex. ⁴ TBEV—Tickborne encephalitis virus. ⁵ CCHFV—Crimean-Congo hemorrhagic fever virus; only antibodies were detected. ⁶ SFTSV—Severe fever with thrombocytopenia syndrome virus, a phlebovirus, from *Bunyaviridae*.

Hedgehogs are considered by some as “melting pots” for tickborne zoonoses [16]. Lyme borreliosis is one of the most common vector-borne zoonotic diseases in Europe, caused by the *Borrelia burgdorferi sensu latum* (s.l.) complex and transmitted by *Ixodes ricinus* and *I. hexagonus*. Improving knowledge about the cycle of these pathogens between ticks and their vertebrate hosts is epidemiologically relevant. Some authors suggest that hedgehogs influence the epidemiology of some species of the *B. burgdorferi* s.l., affecting their abundance and distribution in distinct habitats. The younger and immunocompromised are the most important reservoirs for *B. afzelii*, *B. spielmanii*, and *B. bavariensis* [32,33]. Another pathogen transmitted by *I. ricinus* is *Anaplasma phagocytophilum*. This pathogen is responsible for granulocytic anaplasmosis in horses, dogs, and humans and tickborne fever in ruminants [34]. In Hungary, a survey that analysed the ticks of road-killed hedgehogs showed a prevalence of 74% *A. phagocytophilum*, 26% *B. burgdorferi* s.l., and 52% *Rickettsia*

helvetica [26], even though they might not be representative of the population. Furthermore, in Switzerland, tickborne encephalitis virus (TBEV) antibodies were detected for the first time in a European hedgehog. TBEV antibodies and virus RNA were detected in the same individual, which means that the European hedgehog is a suitable host for the disease and leads to the reasonable assumption that it is a reservoir. However, its occurrence at the population level is not known [20].

Salmonellosis is a complex of some of the most common zoonotic diseases worldwide, whose nomenclature is often complex due to the variety of species, subspecies, and phage types [35]. On the European continent, *E. europaeus* have been reported with different phages of *Salmonella enteritidis* as well as with *S. typhimurium* and *S. kottbus*. The prevalence of infection is generally low (3–4%), particularly when determined by fecal samples or rectal swabs. Nevertheless, in feeding areas shared with humans and birds, this value increases substantially (71%), possibly due to cross-contamination [14]. In Norway, some outbreaks and sporadic human cases were investigated, and salmonella-infected hedgehogs and birds were proposed as a primary source of infection in some of them [36]. Hedgehogs, which are normally asymptomatic, can also carry these bacteria in their coat and spines and can get infected through the ingestion of contaminated food, such as beetles or maggots, easily spreading it in the environment. High mortalities in recovery centers are normally restricted to immunosuppressed or young individuals, who can show clinical signs of enteritis, hepatitis, or peritonitis, and whose differential diagnosis could include *Klebsiella* sp., *Yersinia pseudotuberculosis*, and coccidiosis, all of which are zoonotic [14].

Leptospirosis is a clinically relevant zoonotic disease, caused by spirochete bacteria. In France, some species, namely hedgehogs and mustelids, were investigated as carriers of leptospirosis. In this study, hedgehogs were considered as a potential reservoir for *L. interrogans* Australis [37]. In Azores, where leptospirosis is already recognized in humans and in bovines, several insectivorous species, including the *E. europaeus*, have been identified as reservoir hosts. On São Miguel island, the hedgehog seems to carry *L. serovar copenhageni* (from the *Icterohaemorrhagiae* group). In contrast, in New Zealand, where hedgehogs were also positive for this disease, the reported serovar is *ballum* [18,38].

Furthermore, in one study, 5 out of 26 *E. europaeus* brain tissue samples (19.2%) were positive for *Toxoplasma gondii* [29]. Although not showing high prevalence in hedgehogs, *Cryptosporidium parvum*, a zoonotic coccidian parasite, was already detected in hedgehogs, in places such as Great Britain [28] and the Netherlands [13]. In the same way, *Giardia* sp., a flagellated protozoan parasite responsible for a considerable number of human cases of enteritis worldwide, had already been detected in hedgehogs, at least in the Netherlands [13] and New Zealand [27]. Moreover, in 2013, in northern Spain, *Leishmania infantum* was identified in the European hedgehog for the first time, adding to the list of wildlife reservoirs for this disease that affects humans and domestic dogs [30].

Coronaviruses can affect a variety of animal species and usually cause respiratory, enteric, or neurological diseases. Over the last two decades, it has become more than clear that potentially zoonotic betacoronaviruses can represent massive public health threats, such as those related to Middle East respiratory syndrome coronavirus (MERS-CoV), or more recently and globally with severe acute respiratory syndrome coronavirus (SARS-CoV-2). Recent findings of MERS-related CoVs in hedgehogs from Germany [39], France [24], and Great Britain [40] suggest that *E. europaeus* represents a wild reservoir of betacoronaviruses named as Erinaceus CoVs (EriCoVs) [12,41]. In 2020, a study that analysed virological and epidemiological data of COVID-19 outbreaks in Wuhan, China, comparing it with SARS-2002 and MERS-2012 outbreaks concluded that, among other findings, the responsible agent was genetically close to SARS-related viruses isolated from bats. However, an additional reservoir of the virus could work as an intermediate host, perpetuating and helping to spread the disease. The geographical distribution and usual eating habits of the hedgehog make this species an improbable candidate to this role, even though it is mentioned by the authors [42]. Moreover, genomic, structural, biological, antigenic, and pathogenic properties were detected between hedgehog (and

other mammalian species) hepatoviruses and the human hepatitis A virus, suggesting a common evolutionary origin [43].

4. Environmental Pollution

In addition to measuring the level of pollutants in soil or water, biomonitoring animal species is helpful to quantify the amount of hazardous substances that the animal has been exposed to, to determine how much has been absorbed, to predict and describe the consequent organic lesions, and eventually, to develop exposure mitigation strategies. Different studies have been performed to analyse the organs of European hedgehogs, namely the blood, liver, kidneys, hair, and spines for trace elements and organic pollutants (such as organochlorines and organobromines). While hair and spines can be used to evaluate exposure, internal organs and blood may provide information on its distribution, accumulation, and induced damages [44–47].

The leading causes for the admission of *E. europaeus* in rehabilitation centres are collisions and traumas, but poisoning is also reported [48]. In general, insectivores (hedgehogs) and carnivores tend to show higher levels of pollutant residues and subsequent clinical signs than herbivorous animals due to the bioaccumulation effects between trophic levels [49].

Hedgehogs tend to have higher levels of lead (Pb) than omnivores or herbivores due to the consumption of insects and earthworms, which bioaccumulate notably high levels of Pb and, consequently, represent a potential way of perpetuating Pb in distinct food chains [50]. Moreover, they usually occupy areas with a high level of urbanisation, where this compound is more frequently present [49]. In contrast, in more natural and unpolluted areas, the amount of heavy metals and metalloids found in hedgehog organs is usually lower and strongly related with the individual age of the hedgehog, which is directly linked with exposure time [51].

Traditionally, the rodenticide poisoning cases in wildlife were only attributed to the ingestion of contaminated rodent carcasses. However, significant detections of brodifacoum, bromadiolone, and difenacoum in urban hedgehogs may suggest other sources of contamination since the ingestion of rodents by hedgehogs is not common. Explanations for these results include the use of rodenticides in urban areas, leading to hedgehog exposure and ingestion of sub-lethal levels in baiting stations [52].

However, environmental pollution is not only chemical. A pilot study performed in Berlin was designed to understand how a music festival, with all of the associated sound pollution and high density of people, affected the hedgehog population of that urban park. Some individual hedgehogs were monitored with different non-invasive technology equipment before and during the festival, and they exhibited particular behaviour patterns and translocations as individual strategies to deal with that environmental aggression. This study allows us to understand how wildlife, especially urban wildlife, adapts to human disturbance [53].

5. Antibiotic Resistance

When bacteria selectively change in response to the use of antibiotic drugs, they become antibiotic-resistant. Consequently, those antibiotics are no longer effective to treat the same bacterial infections, as they were in the past [54]. Antibiotic resistance is a critical worldwide problem that is becoming increasingly prevalent among wildlife studies. The presence of bacteria carrying genes for antimicrobial resistance in wildlife is an indicator that a problem of human and domestic species origin has spread to wild environments and has become global. Furthermore, it represents an additional One Health challenge since wild animals could act as effective reservoirs and links between environments, humans, and domestic animals. Consequently, hedgehogs not only indicate that this worldwide problem is happening, but indeed represent a reservoir of microbes with antibiotic resistance genes, perpetuating this situation [55,56]. In Germany, other mammalian species, such as the

wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*), have been identified as having the potential to be reservoirs for zoonotic agents and sentinels for threats to One Health [56].

Tetracyclines comprise one of the most globally used groups of antimicrobials in human and veterinary medicine due to their large spectrum of activity, facility of administration, and low cost [57]. Consequently, resistances to tetracyclines have been reported since 1953 [58]. In 2020, a study aimed to find tetracycline resistance genes in different tissues of European hedgehogs and crested porcupines (*Hystrix cristata*) reported that all hedgehogs tested from Italy and 50% of the hedgehogs tested from Switzerland had at least one resistance gene. According to these authors, small mammals may work as reservoirs, sentinels, or potential vectors for resistance genes or antibiotic-resistant bacteria in the environment and transmission to other hosts, such as humans [59].

Moreover, methicillin-resistant *Staphylococcus aureus* (MRSA) represents a significant problem for infection control and antibiotic treatment worldwide. In Sweden, two hedgehogs with severe infections caused by MRSA—one with lethal septicemia and bacterial presence in the kidneys and brain and the other with severe dermatitis—were considered reservoirs for different precursors of resistant genes [60].

As mentioned above, *Salmonella* spp. is one of the bacterial zoonotic diseases registered in hedgehogs, mainly in recovery centers. In Catalonia, Spain, different admitted animal species were tested for different *Salmonella* species and serovars. Its antibiotic resistance pattern was determined before the initiation of any treatment. One of the tested *E. europeaus* was positive for *S. enterica* subsp. *enterica* serovar kottbus and showed resistance to ampicillin, streptomycin, tetracycline, sulphamethoxazole, trimethoprim/sulfamethoxazole, and nalidixic acid [61].

6. Conclusions

Nowadays, the impact and difficulty to control certain human health problems and infectious diseases, namely SARS-CoV or Ebola, can be interpreted as an urgent call for more transdisciplinary approaches in their prediction, prevention, and management, considering the One Health principles. A variety of researchers, mainly focused on wildlife surveillance and disease control among wild populations, have simultaneously improved our baseline knowledge of infectious zoonotic agents and the subsequent risk of exposure [10].

Nevertheless, there is a significant knowledge gap that might function as a stimulus for developing future projects in this area. Given the variety and prevalence of zoonotic agents in hedgehogs and their proximity to humans, they could indeed be a sentinel candidate for human threats to One Health. However, it remains necessary to quantify the actual threat it represents and to evaluate its quality as a sentinel. In other words, are they a main source of infection for humans regarding the aforementioned zoonotic diseases? Are there any better species to evaluate the aforementioned problems? Can they give practical and consistent information to predict an epidemic or a pandemic disease? Some authors specifically suggest, for instance, that comparisons between isolates obtained from wildlife (namely hedgehogs) and human isolates should be made [13].

Thus, the answer to the title is currently unknown, but the information shared in this review should act as encouragement for future research on the role of mammals, including *E. europeaus*, in One Health problems.

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