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Opinion

Zoonotic Parasites of Reptiles: A Crawling Threat

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Reptiles are reservoirs of a wide range of pathogens, including many protozoa, helminths, pentastomids, and arthropod parasitic species, some of which may be of public health concern. In this review we discuss the zoonotic risks associated with human–reptile interactions. Increased urbanization and introduction of exotic species of reptile may act as drivers for the transmission of zoonotic parasites through the environment. In addition, being a part of human diet, reptiles can be a source of life-threatening parasitoses, such as pentastomiasis or sparganosis. Finally, reptiles kept as pets may represent a risk to owners given the possibility of parasites transmitted by direct contact or fecal contamination. Awareness of reptile-borne zoonotic parasitoses is important to advocate control, prevention, and surveillance of these neglected diseases.

Humans, Reptiles, and…Their Parasites

Crawling creatures, identified as reptiles (from the Latin *repere* 'to crawl'), include a **polyphyletic** (see Glossary) group of animals belonging to different orders and a large number of species (Box 1) [1]. In many aspects, reptiles represent enigmatic creatures and arouse an incredible range of feelings in humans as they are perceived, according to different cultures, as fascinating and even worshipped in some African and Asian societies, such as the ball pythons (*Python regius*) and black cobra (*Naja melanoleuca*) in Africa, or scary and disgusting wild creatures crawling on earth, mainly in the western world [2]. Accordingly, the symbolic usage of reptiles varied through history in many cultures. The range of attitudes of humans toward reptiles commonly affects their conservation, being often persecuted as dangerous creatures (P. Luís Ceríaco, Master's Thesis, Évora University, 2010). Nowadays, reptiles have become popular exotic pets and account for an estimated 21% of the value of the live animal trade [3]. In addition, in some parts of the world, the reptiles are used as important source of food, medicines, and materials (e.g., the leather industry) (Box 2).

As other animals, reptiles are hosts of viral, bacterial, and parasitic pathogens, some of which are of zoonotic concern [4]. In particular, *Salmonella* bacteria are the most common causative agents of zoonotic disease due to their biological characteristics (e.g., fast logarithmic growth rate, tolerance to a wide variety of environmental temperatures and humidity, and potential to colonize artificial environments created by humans), as well as their natural affinity with this group of hosts [5]. Most of the available studies on parasites of reptiles have dealt with ecological investigations of hosts and have focused on the conservational aspects rather than on the zoonotic potential [6]. As a result, zoonotic parasites have been less studied, and information on the biology, ecology, and zoonotic potential of most of them is scarce, being historically neglected even in endemic areas. The transmission of reptile-borne parasitic zoonoses is mainly related to organisms for which these animals are intermediate or paratenic, rather than definitive hosts [4]. In the first case, humans are infected usually through consumption of reptiles, whereas in the latter, the parasite stages are shed into the environment, where humans are exposed to

Highlights

Species of protozoa, helminths, pentastomids, and arthropod vectors exploit reptiles as definitive or paratenic hosts, which may represent a public health concern.

The zoonotic risk is associated with human–reptile interactions and includes environmental contamination, reptile consumption, or keeping reptiles as pets.

Exotic reptile species may introduce new zoonotic parasites in a previously nonendemic region.

Pentastomiasis and sparganosis are life-threatening food-borne parasitoses.

In our households, if precautions are not taken, reptiles may transmit zoonotic parasites by direct contact or fecal contamination.

Trained veterinarians, physicians, and public health officials are important to advocate for proper diagnostics, parasite identification and treatment, as well as for surveillance strategies and food inspection in areas where reptiles are consumed.

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Box 1. Evolution, Biodiversity, and Ecological Relevance

Reptiles are among the most diverse group of animals that inhabit almost all continents and environments and, as a matter of fact, one of the most ancient groups of animals alive, having their ancestors in dinosaurs (i.e., **reptiliomorph** tetrapods) that colonized the earth during the Carboniferous period, around 300 million years ago [91]. However, a relatively low number of species survived the mass extinction events during the Cretaceous–Paleogene period (i.e., around 65 million years ago) [92]. This class of animals includes about 1200 genera, and more than 10 000 species have been described, mainly within the group Squamata (i.e., 10 417 species of lizards, snakes, and worm-like amphisbaenians), Testudines (i.e., 351 species of turtles and tortoises), Crocodylia (i.e., 24 species), and Rhynchocephalia (i.e., 1 species of tuataras) [93]. Some reptiles are of great ecological significance as they represent in nature either the first (e.g., lizards, geckos) or the higher level (e.g., crocodiles) of the food chain. In the latter case, given their aquatic habits and longevity (generally >50 years), crocodilians have also been suggested as potential indicators for environmental pollution as they reflect changes in an area over longer periods.

them (Figure 1). Moreover, reptiles are a source of blood meal for arthropods, acting as reservoirs of several zoonotic vector-borne diseases (VBDs) (Table 1). Overall, zoonotic parasites may be transmitted through different modalities (e.g., environmental contamination, food, or by direct contact with captive animals), and also according to the geographical area and human level of interaction with reptiles (Table 1). In this article we discuss the risks of transmission of reptile-associated parasitic zoonotic diseases in different contexts, answering practical questions from a veterinary and medical perspective.

Parasitic Zoonotic Infections in Our Backyard: Synanthropic and Invasive Species

Reptiles live in our houses, backyards, or any place where they can find shelter, food, and heat. Thus, it is not surprising that increasing urbanization and habitat loss have facilitated the encounters with humans and enabled numerous reptile species to adapt to peridomestic environments [7]. As a matter of fact, parasite transmission from reptiles to humans depends not only on their biology and abundance in a host population but also on environmental conditions. Thus, the transmission of some parasites could be trigged, but also limited, by urbanization [8]. Undoubtedly, in peridomestic areas, the synanthropic species (i.e., geckos and lizards) may transmit zoonotic protozoa and pentastomids through contamination of the environment (Table 1) [9,10]. Meanwhile, invasive/exotic reptile species may be a source of spill-over of parasites to native species, eventually representing a further threat for public health [11,12]. It was an invasive Burmese python (*Python bivittatus*), introduced into Florida and bringing Asiatic pentastomids (i.e., *Raillietiella*

Box 2. Reptiles as Food and Medicaments

Reptiles have represented an important source of protein in the diet of humans in many parts of the world and are still important in tropical countries and as gourmet specialties in Europe and North America (i.e., crocodilian meat) [94]. Infection by the food-borne pathogens closely depends on the way in which the reptile meat is prepared and eaten. In many areas of the world reptiles are eaten as any other protein source; however, it is also broadly believed that reptile meat and organs have medicinal properties [95]. While the usage of dry or alcohol-based remedies is rather safe, most of the clinical reports of reptile-associated helminthiases of humans are connected with the consumption of raw meat, organs, blood, or bile of snakes or lizards. In some part of Asia, applying snake meat as a poultice to a wound represents an alternative route of human infection by *Spirometra* [52]. Usually, when reptiles are cooked as a dish, the risk of parasite transmission relates mainly to the way in which the animal was kept at home prior its slaughtering, evisceration, and food preparation, rather than to consumption of the resulting meal.

To illustrate, here is the traditional finger-licking recipe from Gabon made with African rock python: 'Take medium to large size African rock python. Skin the snake, chop to small pieces and place into a large pot. Sprinkle with salt, add cold water and lemongrass (to reduce snake smell), bring to boil and simmer shortly. Remove snake pieces from water, put into larger pan with hot vegetable oil and gently fry the meat with curry and black pepper. Add little water, bring to the boil, cover with lid and boil for another 20 minutes. Serve with tomato sauce and steamed rice.'

Interestingly, similar recipes are popping up in the USA as a reaction to the growing presence of invasive Burmese pythons, for example, in the Everglades.

Glossary

**Ophidian:** a reptile of the group Ophidia (snakes).
Plerocercoid: an elongate flat vermiform larval stage of pseudophyllidean tapeworm.
Poikilothermic: refers to organisms that cannot regulate their body temperature except by using behavioral options such as basking or burrowing. Therefore, their body temperature depends on that of the environment where they live.
Polyphyletic: refers to a group of organisms derived from more than one common ancestor.
Reptiliomorpha: a clade of late Paleozoic tetrapods (i.e., four-legged animals) more closely related to amniotes than to amphibians.
Varanids: any lizards of the saurian family Varanidae (monitor lizards).
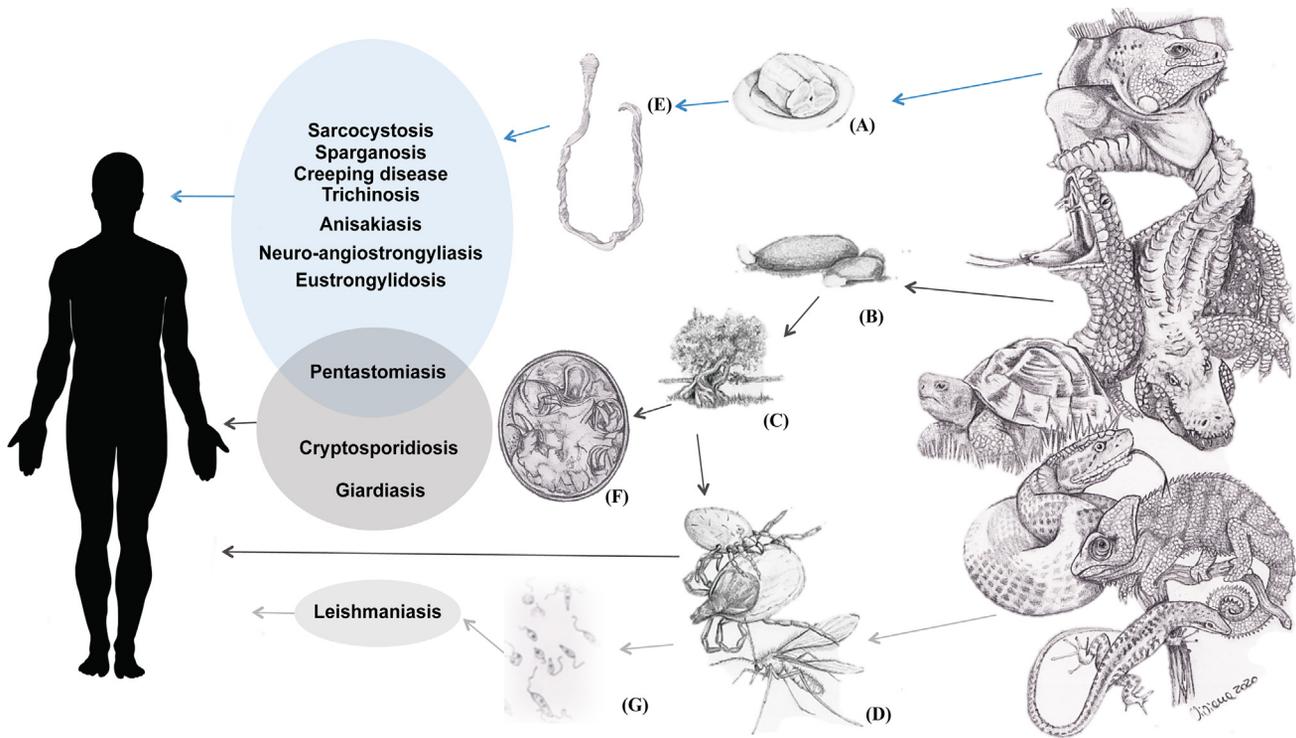
Figure 1. Transmission Pathways of Main Reptile-Borne Zoonotic Parasitic Diseases. Representation of the main transmission modalities of reptile-borne zoonotic parasitic diseases that are (A) food-borne, (B) transmitted by direct contact with feces, (C) spread through environmental contamination, and (D) vector-borne. The most representative parasites for each pathway are also illustrated: (E) *Spirometra* spp., (F) egg of *Armillifer* spp., (G), *Leishmania* spp.

orientalis), which eventually infected native species of snake [12]. Although the majority of human infections by pentastomids occur through the ingestion of snake meat (which is typical in Asian and African countries), clinicians should be aware that alternative routes of infection exist, for example, through exposure to snake nasal secretions, saliva, and feces [13], suggesting the potential risk for humans. Such transmission routes may explain some of the human cases recorded in the USA, where this infection is unexpected or considered to be of travel-medicine concern. In addition, when the same species of python was transported back to Asia it carried American pentastomids (i.e., *Raillietiella bicaudata*) into local populations [14]. In tropical Asia, muscular sarcocystosis of humans has been associated with ingestion of sporocysts of *Sarcocystis nesbitti* (Figure 2A), probably originating from snake feces [15–17]. Overall, veterinarians play a pivotal role in avoiding zoonotic infections through coprological screening of captive snakes.

Reptiles serve also as a blood source for many species of hematophagous arthropods (e.g., mites, ticks, sand flies, mosquitoes) and then as possible reservoirs for bacterial, viral, and protozoan pathogens (Table 1) [18,19]. For example, some species of tick (Ixodidae and Argasidae) and mites (Macronyssidae, Trombiculidae) often feed on reptiles as well as on humans (Table 1). The macronyssid mite *Ophionyssus natricis,* one of the most widely distributed mite species of snakes, is a mechanical vector of *Aeromonas hydrophila,* the causative agent of hemorrhagic disease in reptiles as well as of gastroenteritis, and in rare cases, of necrotizing fasciitis in humans [20,21]. In the past decade, the epidemiological role of argasid and ixodid ticks as vectors of zoonotic pathogens has received great attention. For example, *Ornithodoros turicata*, an argasid tick parasitizing mainly tortoises, is the vector of *Borrelia turicatae*, of the

Table 1. Zoonotic Parasites of Reptiles Grouped According to the Modality of Transmission

| Pathogens (zoonosis)	Geographic origin of reports	Reptile hosts	Categories of zoonotic importance[a]	Main clinical signs in humans	Refs
Protozoa					
Giardia duodenalis (giardiasis)	Spain	Lizards	UI	Diarrhea	[10]
Cryptosporidium parvum subtype: IIaA15G2R1 (cryptosporidiosis)	Italy	Snakes, lizards and turtles	UI	Acute to persistent diarrhea	[75,76,78]
Sarcocystis nesbitti (sarcocystosis)	Mainly Southeast Asia	Snakes	LI	Muscular sarcocystosis	[17]
Leishmania tropica, *Leishmania. donovani*, *Leishmania turanica* (cutaneous and visceral leishmaniasis)	Asia	Lizards, snakes	UI	Unknown	[40]
Trypanosoma brucei (sleeping sickness)	Africa	Monitor lizards	UI	Unknown	see Box S1[b]
Cestoda					
Spirometra erinaceieuropaei, *Spirometra mansonoides* (sparganosis)	Americas, Europe, Asia, Australia	Snakes	HI	Blindness, paralysis, death	[51]
Pentastomida					
Armillifer armillatus, *Armillifer moniliformis*, *Armillifer grandis*, *Armillifer agkistrodontis* (pentastomiasis)	Asia, Africa	Snakes	HI	Organ damage by larvae	[83]
Raillietiella hemidactyli (creeping disease)	SE Asia	Lizards	LI	Subcutaneous pentastomiasis	[59]
Nematoda					
Trichinella zimbabwensis, *Trichinella papuae* (trichinosis)	Worldwide	Crocodiles, snakes, Monitor lizards, turtles	LI	Fever, myalgia, gastrointestinal symptoms	[47]
Contracaecum spp., *Anisakis* spp., *Pseudoterranova* spp. (anisakiasis)	Worldwide	Crocodiles	UI	Eosinophilic granulomas	[47]
Eustrongylides spp. (eustrongylidosis)	Worldwide	Crocodiles	UI	No specific symptoms recorded so far	[84]
Gnathostoma binucleatum, *Gnathostoma doloresi*, *Gnathostoma hispidum*, *Gnathostoma nipponicum*, *Gnathostoma spingerum* (gnathostomosis)	Africa, Asia, Central America	Snakes (but mainly fish)	LI	Cutaneous or visceral larvae migrans symptoms	[85]
Angiostrongylus cantonensis (neuroangiostrongyliasis)	Subtropics	Monitor lizards	HI	Eosinophilic meningitis	[86]
Trematoda					
Alaria and *Echinostoma* (echinostomiasis)	Asia	Turtles and crocodiles	LI	Catarrhal inflammation Peripheral eosinophilia	[87]
Ixodida					
Amblyomma spp.	Africa, Asia	Monitor lizards, tortoises, snakes	LI	Dermatitis and VBDs	[44,88]
Bothriocroton hydrosauri	Australia	Snakes, lizards	HI	Vector of Flinders Island spotted fever	[33]
Haemaphysalis spp.	Europe, Africa, Asia	Lizards, viperid snakes	LI	Dermatitis and VBDs	[88]

Table 1. (continued)

Pathogens (zoonosis)	Geographic origin of reports	Reptile hosts	Categories of zoonotic importance[a]	Main clinical signs in humans	Refs
Hyalomma aegyptium	Africa	Tortoises	LI	Dermatitis and VBDs	[88]
Ixodes spp.	Europe, North America	Snakes, lizards	HI	Dermatitis and VBDs	[35]
Ornithodoros spp.	Africa, North America	Tortoises and viperid snakes	LI	Dermatitis and VBDs	[88]
Mesostigmata					
Ophionyssus natricis	Worldwide	Snakes, lizards	LI	Dermatitis	[89,90]
Prostigmata					
Eutrombicula spp.	Americas	Snakes, lizards, turtles	LI	Dermatitis	[35,90]
Neotrombicula autumnalis	Europe	Lizards, snakes	HI	Dermatitis	[35,90]

[a]Zoonotic importance categorized as follows: high importance (HI): causing severe or lethal cases in humans clearly associated with reptiles; low importance (LI): causing human cases that are likely linked to reptiles, even though rare or accidental; unknown importance (UI): possibly zoonotic parasites that were isolated from reptiles (including spurious parasites) but causative link of reptiles to a human disease was not proved.
[b]For a full reference list see Box S1 in the supplemental information online.

relapsing fever clade [22], which has been associated with tick-borne relapsing fever in five cases among employees who worked in caves in the USA [23]. Exotic tick species, along with the pathogens they carry, may be imported in nonendemic areas together with reptiles (Box 3). This is the case of tortoises infested by *Hyalomma aegyptium* illegally imported into Italy [24]. This tick species has been found to be molecularly positive for pathogens of zoonotic concern (Box 3) [25–27]. In addition, some of the tick species parasitizing reptiles were vectors of *Coxiella burnetii*, the agent of Q fever (e.g., *H. aegyptium* ticks in the Mediterranean basin) [28]. Reptiles also participate directly in the epidemiology of some pathogens of the Rickettsiaceae family [29]. This is so in the case of African fever, a human disease caused by *Rickettsia africae* and transmitted by *Amblyomma variegatum* [30], detected in ticks imported, with reptiles, into North America from Africa [31]. In Australia, *Rickettsia honei*, the causative agent of the Flinders Island spotted fever in humans, has been detected in ticks (e.g., *Bothriocroton hydrosauri*) infesting a range of reptile species, which act as the main reservoirs for this pathogen [32,33]. Also, *Rickettsia anan* was detected in ticks from the species *Amblyomma exornatum* in **varanid** lizards imported into the USA [34]. Finally, lacertid lizards are primary hosts of immature stages of *Ixodes ricinus* ticks (Figure 2B), playing a role in the epidemiology of some tick-borne pathogens, such as *Borrelia burgdorferi* sensu lato group, causing Lyme borreliosis [35].

Phlebotomine flies, mainly of the genus *Sergentomyia*, are herpetophilic hematophagous invertebrates that were, until recently, associated with the transmission of the nonpathogenic species *Leishmania tarentolae* [36]. However, recent studies have demonstrated that *Sergentomyia* spp. can also harbor pathogenic *Leishmania*, such as *Leishmania infantum* and *Leishmania major* [37–39]. Moreover, other pathogenic species of *Leishmania* have been detected in lizards (e.g., *Leishmania turanica*, *Leishmania tropica*, and *Leishmania donovani*) [40,41] (Table 1), raising the hypothesis that lizards and associated sand flies could play a role in the epidemiological cycle of leishmaniasis. This issue should be better and fully addressed. Indeed, studies on vector-borne pathogens represent a unique opportunity to integrate veterinarians, physicians, and public health officials toward elucidating the impact of reptile vector-borne pathogens under the context of One Health.
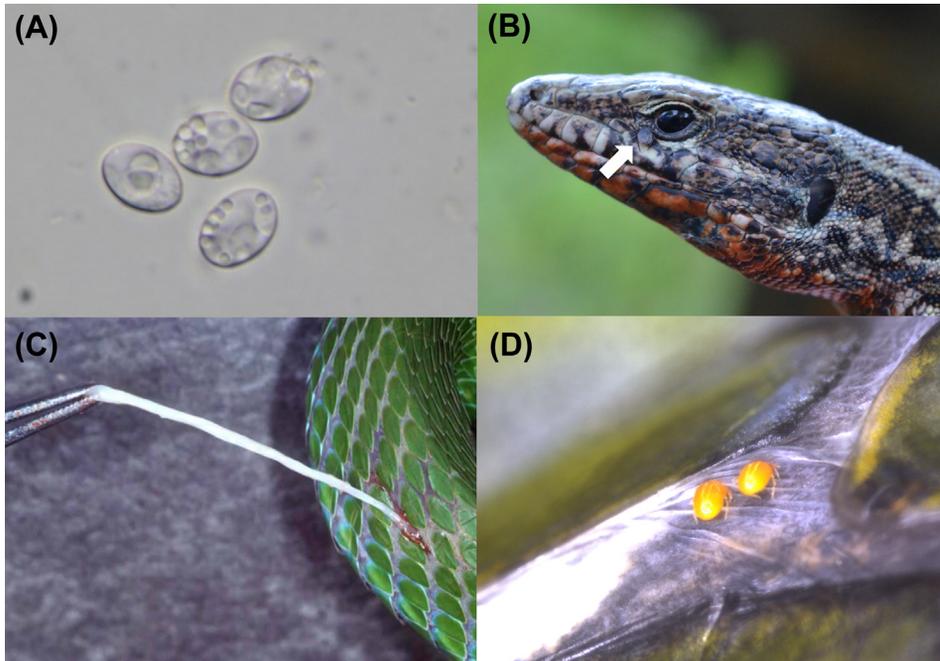
Figure 2. Representative Examples of Reptile-Borne Zoonotic Parasites. Endoparasites and ectoparasites of reptiles causing zoonotic diseases through (A) direct contact with feces (*Sarcocystis singaporensis*), (B) infestation by ticks from the environment (white arrow is a nymph of *Ixodes ricinus*), (C) ingestion of contaminated food (*Spirometra* spp. in subcutaneous tissue), or (D) chigger mites (*Eutrombicula alfreddugesi*) from the environment.

Parasitic Zoonotic Infection of Reptiles in Our Dish

Reptiles represent an essential part of the food web in many ecosystems [42]. While large carnivorous reptile species (e.g., crocodilians, monitor lizards, a range of snakes, marine and aquatic turtles) act as top predators, the smaller reptile taxa (mainly in Squamata) represent a common prey for many carnivores. Therefore, it is not surprising that a wide range of heteroxenous protozoan and metazoan parasites cycle through reptiles, using them as intermediate or final hosts [43]. Also, humans, as large omnivorous primates, play their role in the food chains that involve reptiles (Box 2). The largest carnivorous reptiles, such as crocodiles, can occasionally hunt and consume

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Box 3. The Reptile Trade, and the Risk of Importing New Tick Species

The worldwide trade in live reptiles has increased considerably during the past decades. The 96.8% of the reptiles imported globally (e.g., over 18.8 million, between 1996 and 2012) for commercial purposes are captive-bred, or from farming/wild caught, with Green iguana (*Iguana iguana*) being at the top of the list followed by ball python (*Python regius*) [96]. However, a portion of the whole global trade is still represented by illegal trading [96] and this poses concerns about the potential risk for the dissemination of infectious agents, as well as exotic tick species and the pathogens they may transmit. For example, *Testudo graeca* (also known as the Eastern Spur-thighed Tortoise) is an endangered species present in southeastern Europe, western Asia and North Africa and it is the most frequently reported host of the tortoise tick *Hyalomma aegyptium* [97]. These tortoises are often illegally treated in southern Mediterranean and Middle East regions. For example, of the 585 tortoises illegally imported into Italy from North Africa, 37.8% (*n* = 221) were infested with *H. aegyptium* [24]. Although *H. aegyptium* adults are typically associated with tortoises of the genus *Testudo*, immature stages parasitize a wide range of reptiles, birds, and mammals, including humans [98]. This tick species has also been collected from tortoises in other countries where they have been associated with *Anaplasma phagocytophylum* (in Romania; [25]), with the Crimean Congo Hemorrhagic fever virus (in the Middle East; [26]), and with spotted fever group Rickettsia (in Qatar; [27]). Similarly, four species of *Amblyomma* ticks, parasitizing lizards and tortoises, were introduced into Florida, USA, and were found to be infected with *Ehrlichia ruminantium* or 'Heartwater' disease as well as *C. burnetii*, the agent of Q fever [31].

even adult humans, however, these are rather unusual extreme cases [44]. Conversely, various reptiles represent an important part of human diet throughout the world and, in many areas, this habit persists until today. Besides consumption of wild-caught reptiles, reptile farming was developed in past decades in order to cover growing demand and to replace the animals from diminished wild populations [45]. Among the farmed reptiles, crocodiles probably form the largest proportion; however, snake and turtle farming are fast developing in South Eastern (SE) Asia, and iguanas are locally farmed in South America [46]. This farming system is in urgent need of defined food-inspection protocols as well as trained professionals, through updating animal science curricula. In addition, reptiles are used as part of traditional medicine, mainly in Asia (Box 2).

Cases of zoonotic helminthic infections are reported throughout the world, being associated with reptile consumption or with reptile meat used in medicinal practices [47]. In all food-borne parasitoses associated with reptile consumption (e.g., *Anisakis* spp*., Gnathostoma* spp., *Spirometra* spp., *Alaria*, *Angiostrongylus cantonensis*, *Trichinella* spp. and several pentastomids, Table 1) humans represent aberrant or dead-end hosts. Pseudophyllidean tapeworms of the genus *Spirometra* (Diphyllobothriidae) are the most frequent reptile-borne zoonotic helminths – *Spirometra erinaceieuropaei*, *Spirometra mansonoides*, and *Spirometra proliferum*, being among the most commonly reported species. The life cycle of *Spirometra* spp. typically involves carnivorous mammals as definitive hosts and freshwater crustaceans (i.e., cyclops) and **poikilothermic** vertebrates as first and second intermediate hosts, respectively. The infective larval stages (i.e., the **plerocercoids**, commonly referred to as *sparganum*, or *spargana* in plural) are typically found in subcutaneous tissue (Figure 2C) and/or muscles of reptiles and may become infective to humans by eating uncooked meat. After the infection, plerocercoids migrate to various organs and tissues in the human body, including subcutaneous tissue, muscles, lungs, the pleural cavity, urogenital and abdominal viscera, and, importantly, to the central nervous system [48,49]. Therefore, depending on which organs are invaded, disease is usually classified as subcutaneous, ocular, cerebral, or visceral sparganosis [50]. It may occur that plerocercoids asexually multiply within the human host, causing a severe clinical condition known as proliferative sparganosis [51]. Most of the cases of human sparganosis are confined to SE Asia, apparently due to locally common consumption of raw or inadequately cooked snakes, frogs, and tadpoles infected with the plerocercoid. Cases recently reported from Europe were foreigners who had probably acquired infection in other continents [49]. Drinking untreated water with infected copepods (i.e., first intermediate hosts) or applying the meat of infected snake or frog as a poultice to a wound, are alternative routes of human infection [52]. As the disease in humans is difficult to identify at a preoperative stage, the anamnesis is pivotal to expedite diagnosis and treatment.

A. cantonensis is a metastrongyloid nematode of emerging concern causing eosinophilic meningitis in humans [53]. This parasite exploits various species of rat as a definitive host and a broad range of molluscs as intermediate hosts [54]. Amphibians and reptiles represent paratenic hosts that are able to accumulate infective L3 larvae in liver and other tissues. Although the major source of infections by *A. cantonensis* in SE Asia is through the consumption of molluscs, prawns, and shrimps, eating raw meat of varanids was documented as an alternative infection route [55,56]. Nonetheless, the importance of poikilothermic hosts in the circulation of *A. cantonensis* in the food chain is not fully understood. *Trichinella* spp. are nematodes with a high potential for zoonotic infections. While the majority of species (the encapsulated ones) are infective only for mammals, two nonencapsulated species – *Trichinella zimbabwensis* and *Trichinella papuae* – are found also in large carnivorous reptiles, namely in crocodiles and monitor lizards [57]. Completion of the *Trichinella* spp. life cycle in these hosts was confirmed also experimentally [58]. Trichinellosis cases associated with the consumption of meat from monitor lizards and turtles have been documented in Thailand, even though the *Trichinella* species involved was not identified.

Pentastomids are currently considered as a unique lineage of crustaceans, adapted to endoparasitic life in vertebrates. Without doubt, pentastomids are parasites typically associated with Reptilia, as the vast majority of existing species are described from these hosts. They are known as serious pathogens in captive reptiles, and several species may cause zoonotic infections in Africa (i.e., *Armillifer grandis*, *Armillifer armillatus*) and Asia (i.e., *Armillifer moniliformis, Armillifer agkistrodontis*). Other published zoonotic records (such as '*Porocephalus taiwana*' in China and *Porocephalus crotali* in South America) need careful scrutiny [59,60]. The life cycle of *Armillifer* spp. is typically heteroxenous in that vermiform adults reside in the lungs of large snakes (i.e., pythons, large vipers, cobras) and shed infective eggs with typical larvae in feces. A range of mammals serve as intermediate hosts, in which the larvae develop in connective tissues and parenchymatous organs. Even though they occur frequently in some areas of West and Central Africa, human infections are usually asymptomatic, diagnosed incidentally as liver calcifications by X-ray or ultrasonography, or, at autopsy [61–63]. Human cases of pentastomiasis are associated with consumption of snake meat, though infection by eggs in the contaminated environment represents a risk in endemic areas [64], as well as from captive reptiles (see later). Massive infections leading to rare lethal cases are tentatively associated with incidental ingestion of the entire gravid female of *Armillifer* spp. [65]. Historically, postmortem prevalence in humans has been recorded up to 23% in Central (Congo) and southern Africa (Zimbabwe) and 40% in SE Asia (i.e., Malaysia, [66]).

Parasitic Zoonotic Infection of Reptiles in Our Bedroom: The Pet Scenario

Reptiles are common animals kept as pets. From calm ball pythons, charming green iguanas, to long-living tortoises, nowadays keeping reptiles in our houses is becoming a regular habit, rather than an exclusive hobby [67]. For example, in the USA 2.4% of the pet population is represented by reptiles and amphibians [68–70]. The information regarding husbandry and basic care for many kept species is scant, and these animals are still among the most inhumanely treated in the pet market [71]. Therefore, veterinarians need to be aware of the increasing need for medical care given that keeping reptiles in captive conditions usually comes with unnatural events (e.g., metabolic imbalances, low immunity, scarce hygiene of enclosure), which facilitates transmission of parasites. Therefore, in poor husbandry conditions, and without regular veterinary follow-up, zoonotic parasites could infect the pet owners, especially those with immunosuppression, or children [4,71–73]. The risk of zoonotic agents (mostly bacteria but also parasites) being transmitted to the above-mentioned groups of people has raised concerns by public health agencies, such as the Center for Disease Control and Prevention (CDC), which discourage the tenure of reptiles as pets [71]. Moreover, the reptile pet trade has been pointed out as a possible source of introduction and emergence of exotic parasites in nonendemic countries [71,74].

Zoonotic parasites associated with pet reptiles (Table 1) include protozoa (e.g., *Cryptosporidium*, *Sarcocystis*), pentastomids, and ectoparasites (e.g., Trombiculidae and Macronyssidae) (Figure 2D) [71,75,76]. In recent years *Cryptosporidium* species with zoonotic potential have been isolated from pet reptiles by the molecular detection of *Cryptosporidium muris*, *Cryptosporidium tyzzeri* and, most importantly, subtypes of *Cryptosporidium parvum* previously detected in humans [76–78]. The detection of zoonotic *Cryptosporidium* spp. in snakes is associated with the ingestion of infected prey (e.g., rodents) since they do not develop in the **ophidian** host. However, also a number of lizards, snakes, and tortoises have been found excreting *Cryptosporidium* oocysts potentially pathogenic to humans [75–78]. Larger species of pet snake, such as ball pythons or large African vipers, are typical hosts of pentastomids [79], which may represent a serious zoonotic risk through fecal egg contamination of the environment [67,68].

In addition, the parasitic fauna of captive reptiles, besides some species having zoonotic potential, can help to distinguish animals that were caught from their natural environment from those

animals that were bred in captivity [80]. This is particularly true for various hemoprotozoa that are found only in reptiles that had contact with the infected vector in the natural environment to which these animals are native [81]. Therefore, the proper identification of the parasitic fauna of captive reptiles has turned into a useful tool to control and prevent the illegal reptile trade, as well as a surveillance strategy for potential public health risks associated with this diverse group of animals.

Finally, in order to minimize the risk of zoonotic pathogen transmission in the household setting, good and proper sanitary precautions should be taken along with personal hygiene when handling these animals – as well as good husbandry conditions and separating reptiles from areas where food is prepared. Also, when keeping reptiles as pets, animals need to be periodically checked and examined for parasites and other pathogens, and proper quarantine measures should be carried out to avoid introducing diseases to a healthy population of reptiles. It is also important for public health officials to have updated population statistics of reptiles kept as pets to advocate policies of good care and hygiene.

Concluding Remarks

Reptile-borne zoonotic pathogens have been generally associated with bacterial infections (e.g., *Salmonella*). On the other hand, parasitic zoonotic diseases have received little attention in the past decade. Although pentastomiasis and sparganosis are among the main parasitic zoonoses, the role of reptiles as reservoirs and hosts of zoonotic parasites, mainly for VBDs, has not been fully elucidated (see Outstanding Questions). Therefore, the risk of parasites of reptiles with zoonotic potential that could be introduced by invasive species is difficult to estimate given the scarce data available. Furthermore, the recent COVID-19 pandemic has highlighted the risk that anthropic pressures may be exerted on wild-animal populations, resulting in the emergence of new zoonotic diseases [82]. Thus, health authorities, veterinarians, and the general public should be aware of the risks that reptile parasites represent, so that preventative and control measures can be undertaken in all of the levels discussed herein (i.e., environmental, food, captive, or pets). Undoubtedly, multicentric studies monitoring reptile-borne parasitic pathogens are warranted, in order to elucidate the origin of introduced parasites and the role of reptiles as definitive, intermediate, and paratenic hosts in nonendemic areas. This could contribute to reducing the risk of zoonotic transmission and, at the same time, in improving welfare and conservation efforts for these creatures. Finally, as the consumption of reptile meat has increased in recent years, veterinarians should advocate for proper food inspection and the control of parasitic diseases and animal welfare of ectothermic tetrapods. Hence, given all of the above, there is still much crawling to do.

Outstanding Questions

Do we really know the role of reptiles as reservoirs or sentinels of VBDs?

What is the risk of introducing new exotic parasites with reptiles entering trade directly from the wild?

What is the risk of spill-over of parasites, with zoonotic potential, from invasive reptile species to native fauna?

Which are the most useful parasitic species for the surveillance of illegal trafficking of reptiles?

Should we advocate avoiding consumption of reptile meat given the high zoonotic risk?

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