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Emerging zoonotic parasitic infections in the anthropocene: Implications for one health and global public health

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Abstract

Background: Emerging zoonotic parasitic infections represent a growing global health challenge, particularly under the environmental and societal transformations of the Anthropocene. Increased human-animal-environment interactions have intensified the risk of pathogen spillover and disease emergence.

Aim: This review aimed to synthesize current knowledge on the drivers, transmission dynamics, and public health implications of emerging zoonotic parasitic infections, with emphasis on the One Health framework.

Methods: A comprehensive narrative review approach was applied, integrating recent literature on zoonotic parasites, environmental change, transmission pathways, and global health responses. Key domains included parasite diversity, host-reservoir interactions, climate change effects, diagnostic challenges, and prevention strategies.

Results: The findings demonstrated that more than 50% of zoonotic diseases are parasitic in origin, with approximately 75% of emerging infections linked to wildlife reservoirs. Anthropogenic drivers such as climate change, urbanization, and land-use alterations were shown to significantly expand vector distribution and enhance host-switching events. Transmission was primarily associated with environmental exposure, contaminated food and water, and direct animal contact. Diagnostic limitations were highlighted, where conventional microscopy exhibited reduced sensitivity compared to molecular tools yet remained essential in resource-limited settings. The review further identified substantial gaps in surveillance systems, particularly in low- and middle-income countries, leading to underreporting and delayed outbreak detection. Economically, zoonotic parasitic infections were associated with significant losses in livestock productivity and increased healthcare costs.

Conclusion: Emerging zoonotic parasitic infections are driven by complex ecological and socio-environmental factors. Strengthening integrated surveillance, improving diagnostic capacity, and adopting a One Health approach are essential to mitigate future global health risks.

Keywords: Carcass characteristics, weaner pigs, meat quality, palm kernel cake

1. Introduction

Emerging zoonotic infectious diseases are a significant threat to global public health, as emphasized by the pandemic. Emerging zoonotic parasite infections of likely pandemic potential are also widely present among humans, created by the human-induced changes of the Anthropocene in climate, ecology, and society ^[1].

The Anthropocene favors the emergence of zoonotic infections because it drives the ecological overlap between wildlife, domestic animals, and humans, in the form of anthropomorphic landscapes, farming, and domestication. These new landscapes make contact between human and animal hosts of zoonotic pathogens more likely by increasing the diversity and number of potential hosts, vectors, or reservoirs. Land-use changes also alter abiotic factors that favor the establishment and spreading of zoonotic parasites in new environments by altering temperature or vegetation cover. Together, these changes may result in the host switch leading to the establishment of zoonotic parasites, which were previously non-infective, in new hosts. Furthermore, these ecological changes affect social structures and promote population

displacement, migration, and high-density living in megacities, with inappropriate waste management and limited access to water and health services. These minimize the implementation of adequate and integrated control measures and contribute to the high contact rates among populations, which facilitate pathogen transmission. Such contact with domestic or wild animals, the consumption of raw products of animal origin, participation in animal slaughter, and the practice of ritual acts enhance the likelihood of being infected by zoonotic pathogens [2].

1.1. Definition of Zoonotic Parasitic Infections

Until the middle of the 20th century, parasitic diseases known to have zoonotic importance were considered mainly caused by helminths such as tapeworms, flukes, and roundworms of the genera *Echinococcus*, *Taenia*, *Fasciola*, *Clonorchis*, *Opisthorchis*, *Ascaris*, *Trichinella*, *Anisakis*, *Gnathostoma*, and *Schistosoma*. However, in recent decades, a number of zoonotic protozoan and metazoan pathogens, such as *Toxoplasma*, *Cryptosporidium*, *Balantidium*, *Giardia*, *Leishmania*, *Pneumocystis*, and infections caused by free-living amoebae have emerged. Most of these 'new' potential zoonotic pathogens have been described first in animals and later in humans. It is interesting to see that the category of emerging zoonotic parasites has expanded even more recently with the inclusion of new candidates such as *Diphyllobothrium latum*, *Angiostrongylus cantonensis*, and others, which are supposed to be primarily fish and food-transmitted zoonotic helminths, respectively. With the increased number of potential zoonotic parasitic agents, the zoonotic focus has moved into the field of other research interests, including population genetics and transmission dynamics, pathogen biology including the identification of virulence determinants, and host-microbe interactions [3].

So far, various organizations have cooperated to control and prevent the spread of parasitic diseases. However, since the early 21st century, many zoonotic parasitic agents were reclassified due to their unforeseen origins and mechanisms of infection, which has become possible through population genetics and molecular genetic approaches. Besides, scientific research into emerging zoonotic parasites in the degraded environment stipulates the integration of One Health strategies to accomplish surveillance, and the prevention as well as control of presumed emerging zoonotic parasites. To address the contemporary 'One Health Approach' in public health systems to allow for rapid action against newly identified parasites spreading from animals to humans [4].

1.2. The Anthropocene Era and Its Impact on Disease Emergence

Arguably, the impact of humanity on the environment, given our growing numbers, economies, technological advances, and the speed at which we are changing planetary systems, is so significant that it is safe to assume that the effect of humans on the Earth will be more identifiable in the geologic record than any other natural processes occurring now. The scale of human influence on the Earth has led to the suggestion that we are in a new epoch: the 'Anthropocene,' an epoch that started when humanity first had a significant impact on the Earth's ecosystems, and many argue this started at the birth of the industrial revolution. Since the industrial revolution, the human population has increased almost exponentially and is expected to reach 9 billion by 2050, and our changing lifestyle and high consumption have increased our demand on global ecosystem resources more than the

other 6 billion humans that have lived from the beginning of modern humans about 200,000 years ago, leading to the acceleration of changes in the Earth system and the creation of a new and distinct geologic epoch [5].

2. Zoonotic Parasites and Their Reservoir Hosts

Host switching is a key adaptive step in the life cycle of a zoonotic parasite that intends to be transmitted from animal to human. There is extensive knowledge about many zoonotic parasitic diseases, including the identity of the agents, their life cycles, reservoir hosts, and zoonotic potential. However, the complex changes currently occurring in the interfaces between zoonotic parasites, their reservoir hosts, and accidental hosts are creating challenges in our understanding of the risks they pose. This review focuses on successful zoonotic parasites classified into four categories according to their preferred group of reservoir hosts: (1) those that use only the environmental assemblage to successfully switch hosts; (2) those that require genetically similar hosts; (3) those that require a wide range of similar hosts; and (4) those that require the involvement of some accidental end hosts. The development of high-impact multidisciplinary and integrated surveillance systems is required for tracking the complex interactions between parasites, reservoir hosts, exposure sites, and human behavioral risk, using data-driven innovations to reduce public health threats determined by zoonotic parasites [6].

Shifting environments and anthropogenic ecological chaos are upsetting the delicate balance that has allowed a large number of zoonotic parasites to successfully use animal reservoirs to regularly infect human beings, contributing to their maintenance or sexual replication. The fact that more than 50% of zoonotic diseases are of parasitic origin and the increase in the attention given to the complexities of zoonotic disease ecology reflect the prominence of transitioning zoonoses on the international stage. Paradoxically, specific attention has focused on the dynamics of only some of the zoonotic parasites hosted in the unruly human and animal world. There is rightful emphasis on those surrounding a group of extracellular parasites, which is important from both a public and animal health perspective, but we have much less awareness about the full range of functions of the host, pathogen, and environment as related to zoonotic helminths. Indeed, a comprehensive list of zoonotic helminths is not available in the medical literature [7, 8].

2.1. Key Zoonotic Parasites

The insertion of a One Health paradigm in the Global Health security agenda is overwhelmingly justified by the increasing number of zoonotic infections, especially in the category of neglected zoonoses. This class groups mostly underdiagnosed and underreported infectious diseases that share common features. They are naturally maintained by a plethora of mammalian species, have a high ecological plasticity, and are spread largely through the animal population, reaching humans principally through sociocultural factors. Approximately 75% of emerging zoonotic infectious diseases that have affected humans during the last decades are pathogens of wildlife origin. The emergence of zoonotic infectious diseases is mostly linked to the anthropogenic changes driven by globalization, as well as socioeconomic and environmental phenomena driven by humanity [9].

In the group of neglected zoonoses, several are caused by protists and helminths, and there are obligate and facultative zoonotic parasites present in different phyla. In general,

zoonotic protists emerge from wildlife and enter a new ecological niche, spilling over to domestic animals and finally reaching human populations by different routes of transmission. Helminth parasites such as *Echinococcus*, *taeniasis*, *diphyllobothriasis*, and *capillariosis* mainly affect important pathogens for the health of domesticated animals with a direct economic impact, with the additional risk to human health consequent to the existence of domesticated or semi-domesticated animal reservoirs. In terms of burden on global public health, the distribution of these zoonotic helminths is mainly focal, and the populations suffering most are the poor in developing countries, with the lowest standard of public health and precarious socioeconomic environments^[10].

3. Transmission Dynamics of Zoonotic Parasites

The transmission and spread of zoonotic parasites are influenced by many factors that can be intrinsic to their biology, their hosts and hosts' ecosystems, and changes in environmental characteristics. Critical factors of zoonotic parasitic infections are a complex interplay of definitive hosts, intermediate hosts or vectors, reservoir hosts, and environmental factors. Among these factors, definitive hosts are pivotal: zoonotic parasites that occupy defined niche spaces in their definitive hosts usually have specific transmission patterns or sporadic transmission events, which determine infection rates within hosts in specific geographical settings and the ensuing distributions of infections between hosts and populations. The zoonotic transmission of parasites, especially vector-borne parasites, is another complex issue involving ecosystems, climate change, and patterns of human or socio-economic development. In general, several factors and mechanisms are involved in the distributions and transmission patterns of parasites in the emergence of human zoonotic infections. Different degrees of associations and co-evolutionary histories between hosts, genetic diversity of parasites and hosts, and pathogen-phenotype associations are involved. Furthermore, animal trade and transportation can speed up the potential dissemination of pathogens and the emergence of new infections through geographic expansion and enhanced opportunities for pathogen exposure to naive hosts. Additionally, travel, migration, and contact between different animal populations and human communities also contribute to the spread of parasites and play crucial roles in the interactions between human parasites and zoonotic parasites. Finally, we should also consider that improvements in the sensitivity and specificity of detection methods, the development of newer molecular methods or combinations of techniques, pathogen discovery and characterization, long-term pathogen surveillance and monitoring systems, and the enhancement of the capacity of diagnostic laboratories are important in the surveillance of zoonotic parasites^[11].

3.1. Modes of Transmission

Transmission routes: In zoonoses, such as those caused by parasites, the point of origin of the pathogen is an infected vertebrate animal, and human infection is often acquired by contact with contaminated food, water, soil, or directly with the reservoir host species or their parasites. Ingestion, usually via food and water sources contaminated with animal feces, is the major transmission mode for many of the intestinal parasitic pathogens. Some soil parasites have a developmental stage in their life cycle that specifically leaves the human host and is capable of surviving and being transmitted in the environment. Humans are exposed through daily behaviors, such as walking, e.g., barefoot, or when doing agricultural

activities, when defecating outside, and through close interaction with domestic animals such as cats, dogs, or pigs. A substantial proportion of the worldwide burden of zoonotic helminthiases and select protozoan zoonoses originates from parasites in the natural environment, and the risk related to interactions among different hosts and changing host habitats is likely to increase^[12].

Despite the recognition that helminths and some protozoa are common and widely transmitted between animals and humans, prevention efforts have traditionally focused on parasite elimination in humans, rather than the source of infection. Theoretical and empirical evidence shows that preventing parasite invasion at the level of the free-living stages of pathogens and reducing environmental contamination could dampen disease incidence or eliminate zoonotic or anthroponotic chains of transmission in humans. Especially for captive exotic animals, tourism, and conservation programs such as conflict mitigation, it is important to develop mitigation strategies to prevent zoonotic pathogen transmission to protect the health and welfare of animals, humans, and the vitality of the ecosystem^[13].

4. Impact of Climate Change on Zoonotic Parasitic Infections

The climate of the Earth is always changing, but the rate of increase in mean global temperature has cascading negative impacts. The interconnected set of challenges that the climate crisis presents includes increased frequency of extreme weather events, such as heat waves, alterations in patterns of rainfall causing desertification and other man-made droughts, a deterioration in air quality, and changes in the global range of vectors of disease. These and other linkages with health are explored in this chapter through the vehicle of emerging zoonotic parasitic infections. Anthropogenic activities such as inadequate public health infrastructure, land use, and dietary changes have created ideal living conditions for parasitic pathogens to invade a variety of animal species, triggering a chain reaction that is leading to spillover events into humans. Given the fragmentation of the governance of public health, animal health, and environmental health, a One Health approach, with the joint work of several public policy institutions and relevant stakeholders including the general public, is required to address these escalating problems. Accompanying alterations in patterns of food production and industrialization have also interacted with changing climate and sometimes accelerated the speed with which a variety of parasites are now exploiting and adapting their life cycles to exploit their new ecological niches. Most threats posed by the temperature-related expansion of parasitic diseases are anticipated to occur in regions with existing high infection rates and levels of human poverty. At the root of this crisis is the rapid developmental control and environmental changes within developing countries that are disproportionately affected as cargos across borders increase in frequency and complexity. Here, we discuss the intricacies of these challenges in the context of the impact of climate change on emerging zoonotic parasitic infections, focusing on specific genera, species, and strains capable of inflicting significant impacts while providing a succinct background to the approach of the One Health concept to these impending challenges^[11].

4.1. Changes in Vector Distribution and Habitat

Over the last decades, anthropogenic and global environmental changes have been associated with

unprecedented geographical changes in the distribution of human and animal pathogen vectors. For example, a geographic distribution expansion of *Ixodes scapularis* and *Ixodes pacificus* ticks in North America, both vectors for *Borrelia burgdorferi*, was reported. The number of new Chagas disease cases reported in North America has been associated with the deforestation and urbanization caused by increasing migration of Central American people to the United States. The recent emergence of new *P. knowlesi* malaria cases in previously unaffected countries of Southeast Asia and the huge burden of zoonotic TB cases in pastoralists in East Africa has been attributed to climate change, forest migration, and pathogen spillover from infected animals. For North America, a risk map of mosquito vector incursion using various scenarios of climate change and projected population behavior was developed. Possible geographic incremental expansion behavior in future seasons could further contribute to the risk of on-the-ground introduction of vector-borne and zoonotic diseases that do not occur in the area yet ^[14].

5. One Health Approach to Zoonotic Parasitic Infections

Zoonotic parasitic infections are distributed worldwide and constitute some of the most important emerging and re-emerging diseases in both humans and animals. The incidence of new emerging and re-emerging zoonotic parasitic infections has significantly increased over the last few decades as a result of complex interactions among the two most affected primary victims, humans and animals, and the continuously changing environment. The One Health approach is increasingly recognized as more effective in controlling and preventing zoonotic parasitic infections rather than using the traditional approach. In the One Health approach, human health, animal health, and environmental health sectors collectively work together to prevent, control, and mitigate these zoonotic infections or diseases at the animal-human-ecosystems interfaces. To effectively tackle these global challenges, international cross-disciplinary efforts are needed. The purpose of this review is to compare the traditional, yet fragmented, approach with the One Health approach and to discuss the latest findings and knowledge concerning the most critical aspects of emerging zoonotic parasitic infections in humans ^[15].

Our ancestors experienced both natural and unnatural parasitic infections or disease epidemics that occurred between humans and the animals with which they camped or kept in confined conditions. Today, many zoonoses or parasitoses are also caused by infections with or exposure to contact with animals and humans, brought close to each other by the environment and global changes. In the Anthropocene, climate change, urbanization, population growth, human conflict and displacement, collapsing infrastructure, and increasing political and ecological disease vulnerabilities are drivers of the global health threats associated with zoonotic parasitic infections. In ecology, the anthroponosis of parasites or the zoonosis and reverse zoonosis of parasites refer to the acquisition of parasitic organisms from people and animals or the dispensation of parasitic organisms to people and animals. To address these global challenges, the interdisciplinary One Health approach is needed ^[16].

5.1. Concept and Principles of One Health

One Health is a concept that recognizes the link between people and their animal companions, the environment where they reside, and the plants that their lives depend upon for food. Mankind lives in a closely interrelated ecosystem with a

wide variety of animal hosts and vectors, which will impact global health and the economy. One Health is about those who have a vested interest; those who live with them and love them; those who feed the world; those who believe in sustainable development; and those who believe in preservation and protection. One Health is about everyone who cares about the health of all species, all citizens who believe that the Earth's resources are finite and should be consumed at an appropriate level for the future. One Health reaches across many sectors and involves researchers from various disciplines such as nanotechnology, bioinformatics, and diagnostic technologies. One Health needs research into new vaccines and antimicrobials, research that scientists from public and private entities are not endeavoring to address, so that the global community is prepared for the arrival of the next pandemic. To deny this approach leads to a severe reduction in occult infectious diseases; it marginalizes the ability of the field to partake in emergency animal diseases; it ignores the significance of infection and control of diseases of wildlife origin and compromises the operational capacity of organizations charged with the prevention of mass zoonoses. It is through communication, strong rapport, and long-lasting partnership building that we can create a roadmap for One Health. One Health is not a new concept; however, it has become more relevant in recent decades. As the global population continues to rise and poverty and inequality continue to increase, the potential for a significant burden of zoonotic diseases will also continue ^[17, 18].

6. Global Public Health Response to Emerging Zoonotic Parasitic Infections

Active public health measures are needed to prevent and control emerging zoonotic infections. For many emerging or re-emerging diseases, we make protective choices based on expected benefits and potential dangers. However, when it comes to certain pathogens, the risks and potential dangers eclipse the expected benefits of strategies for containment, preventive measures, and vaccine development. Without neutralizing antibodies and the accompanying vasodilation and platelet effects to limit pathogen survival and dissemination, immunity is unlikely to arise without an innate and durable response. Public health interventions should focus on early diagnosis by health providers as well as in disease-endemic areas aimed at breaking human-to-human transmission instead of controlling animal transmission. Increased international cooperation and collaboration are needed to conduct surveillance and early recognition of any outbreaks to prevent the spread of these diseases. Currently, efforts to diminish poverty as much as possible will contribute to a reduction in these and similar parasitic diseases. Furthermore, the devastation brought on by infection with these poverty-associated neglected diseases can both create and increase poverty in vulnerable populations. Agencies have established and are running several programs dedicated to the recognition, control, and prevention of emerging infectious disease agents, vectors that are transmissible via food and water, as well as other high-threat pathogens. Among those most recently listed are Crimean-Congo hemorrhagic fever, Nipah virus encephalitis, Ebola virus, and another list of eight hemorrhagic fever viruses ^[19].

6.1. Surveillance and Monitoring Systems

One of the greatest challenges to controlling emerging zoonoses, including zoonotic parasites, is early detection. Most emerging infections of national or global public health

concern exist in animals and humans undetected or unrecognized until it is too late. Early detection is predicated on the presence of a robust, comprehensive national surveillance system that can detect, monitor, and identify emerging infections. To detect and monitor, all surveillance systems must collect relevant data systematically, at good spatial and temporal resolution, analyze and interpret those data, and report results in a timely manner. The information collected as part of surveillance programs typically includes surveillance, epidemiological, serology, and laboratory-based data. Most countries, particularly low- and middle-income countries, are not prepared to meet global surveillance needs for human, animal, and environmental pathogens^[20].

Currently, national surveillance systems for zoonotic parasites, much less all known parasites worldwide, do not exist for many countries. Although a priority, it is politically difficult to maintain surveillance systems without specific foreknowledge of many of these parasites. As a result, most countries have an over-reliance on a limited number of parasite-based national surveillance programs that are predicated mainly on historical data, including prevalence estimations. Critically, many countries have inadequate diagnostic capacity and knowledge, murine and laboratory tools, equipment, and facilities that can support these surveillance activities. The overarching objective of surveillance systems is to provide timely, accurate, reliable data for making decisions to prevent parasite emergence and to guide, monitor, and evaluate effective and efficient interventions. Furthermore, organization at the national level, as well as international collaboration and partnership at the regional and global levels, is essential to achieve early detection. The world needs to create and support early detection of a robust global surveillance system that can detect, monitor, and identify emerging zoonotic parasites and other microbes of concern in higher-risk geographic areas^[11].

7. Economic Burden of Zoonotic Parasitic Infections

Financial resources are needed to run government health care services that cater to zoonotic parasitic infections in both animals and humans. Subsequent diagnosis and treatment of these conditions need full commitment from governments and animal owners, and it is these that see the substantial loss of money. When local livestock become infected, owners can sell their animals only at reduced prices, thus interrupting livestock production. All pathogens that might infect wild or domestic animals including zoonotic infectious bacteria, viruses, parasites, fungi, diseases, and protozoa pose significant threats^[21-26]. Sanitation must be maintained by pet owners, and stray dogs and cats that roam the streets should be removed immediately, thus reducing the threat from these possible reservoirs of infection. Because animal resources are scarce and rearing them is very costly, it is vital to give extra cash to people in areas that have been seriously disadvantaged. Developing proper public knowledge with the help of responsible biodiversity should be regarded as a pro-health factor in the program's success. In addition, possums with tuberculosis and rabies can transfer the disease to cattle, while salmonellosis in bandicoots and rats may also pass on the infection to cattle. It also adds to the growth cost throughout wildlife-related diseases. Preventing and managing zoonotic infections in the community health sector, on the other hand, presents a special set of challenges observed nowhere else, thus presenting opportunities for science. At the very least, zoonoses can easily spread in

wildlife as it is a safety net for diseases and problems in both humans and animals^[27].

7.1. Costs of Treatment and Prevention

Though most zoonotic infections can be prevented or treated if public health and veterinary systems are strong and functioning, translating that potential into billions of healthy animal and human lives is costly. Costs associated with treatment include those that are direct and immediate, both nonmedical and medical. Costs of prevention include, in the case of zoonotic parasites, program inputs such as healthcare infrastructure, employee time, diagnostics, drugs, equipment, and information to apply them effectively, plus program outputs such as actual delivery of and adherence to preventive interventions. These include behavior changes that mitigate the risk of infection but also promote the realization of the benefits of treatment. There are major disparities in the costs among nations, as multibillion-dollar costs of zoonotic parasite infections on global society disproportionately disadvantage the economically underserved parasitosis-endemic regions^[28].

8. Challenges in Diagnosis and Control of Zoonotic Parasites

Zoonotic parasites and their impact continue to grow as global climate and land use changes influence the earth's ecosystem and terrains. However, control measures for parasites through vaccines or treatments, including drugs, are non-existent or challenging to enforce. Improved diagnostics offer great potential for assessing causes, prognosis, and monitoring of infectious diseases. For zoonotic diseases, the presence of the reservoir phases of their infection cycles is unknown in a substantial fraction of transmission routes. The presence of parasites is difficult to track in the pathogen reservoir and during disease outbreaks due to the typically low sensitivity of microscopy-based diagnostic methods for neglected parasitic diseases^[14].

The clinical symptoms of common zoonotic agents often resemble those of non-zoonotic agents and similar syndromes. It is important to diagnose zoonotic infections since their treatment and/or management of sequelae can significantly differ. Diseases affecting humans are of clinical importance to the extent that infected individuals may consult clinical experts for medical care. Multiple factors affecting treatment success and patient compliance include the phase and severity of the infection. However, the correct medical treatment can be compromised by the phase distribution of the pathogen species, poor diagnostics, or cohabitation with zoonotic parasites in mammals, livestock, and wildlife. Effective control of zoonotic parasitic infections will require more detailed data on disease distributions. With climate and land use changes, such patterns will shift over time, making control strategies using eco-epidemiological knowledge difficult to implement^[8].

8.1. Diagnostic Techniques

The control of parasitic zoonoses significantly depends on the simultaneous control of these infections in human and animal reservoirs. Therefore, the diagnosis of zoonotic parasitic infections is the initial and significant step towards the sustainable control of these infections. Conventional techniques are the subject of criticism, causing low sensitivity and reproducibility in comparison with advanced techniques, particularly in the early, prepatent period of parasitic infections. However, advanced techniques are not available in

most laboratories located in endemic regions and are relatively expensive, especially in resource-limited regions. Despite the increasing advantages and relative precision of multiple molecular diagnostic methods, light microscopy persists as a cornerstone in the proper detection, differentiation, counting, and monitoring of parasites. Light microscopy generates practical, efficient, and beneficial means of diagnosis due to inexpensive costs, simple procedures, rapid analysis, and detailed ultrastructural diagnosis of the majority of parasites at different developmental stages according to clinical samples [29, 30].

Despite its wide application, integrated diagnostic strategies using both conventional and advanced techniques are fundamental to determine the comprehensive parasitic epidemiology. Although advanced molecular diagnostic techniques can speciate and differentiate parasites more efficiently, many molecular diagnostic methods are challenged to diagnose low-level and persistent parasitic infections in infected individuals. Prompt and accurate diagnosis is fundamentally important for optimal control measures, especially in sensitive periods, such as the gestational period, infancy, and immunodeficiency. Antibody-based tests, detecting immune responses against parasite antigens, rarely indicate the presence of persisting and/or latent parasitism. Moreover, host factors, such as nutrition, stress, and coinfections, impair antibody production against the target parasite, which can be difficult to differentiate from a tacit early stage of immune response if infected by multiple species. Likewise, parasitological test results with high false-negative rates can be observed due to the consumption of larvicidal, abortifacient, and microfilaricidal drugs, and low circulatory parasite density in sensitive periods of parasitic diseases. Consequently, combined diagnostic techniques with diverse performance attributes are irreplaceable in clinical practice and public health, especially in endemic and resource-limited regions, ultimately enhancing the availability and global implementation of One Health [31].

9. Innovations in Prevention and Control Strategies

Existing approaches to prevent and control zoonotic parasitoses, such as medical interventions, mass drug administration, vector control, and preventive chemotherapy, have several shortcomings. These include emerging drug resistance, unsustainable integration of public health programs, high costs, lack of evidence of human benefit, and unrealistic criteria for the success of the implementation of one strategy on its own. Moreover, wide-scale agriculture and the anthropocentric allocation of environmental services have altered the habitats of parasites and vectors in such a way that it predisposes hosts to infection. This review explores early interventions and advances in prevention and control strategies, including a One Health approach such as a vaccine, genetically modified vectors, and paratransgenic manipulation, combined with innovative tools and empirical therapeutic approaches that take into account the complex network of interactions and interdependencies between humans, animals, plants, and their various types of environments to achieve the common and most impactful solution of preventing and controlling zoonotic parasitic diseases. Some zoonotic parasitic infections are neglected, and the burden of emerging infections' complex factors and various direct and indirect consequences are not fully understood. Therefore, we suggest some innovations in the highlighted existing approaches and those suggested in our previous risk framework to prevent and control zoonotic

parasitoses. The next section provides an explicit rationale for the inclusion of each innovation in One Health and incorporates consideration for the ethical implications of the development of innovative interventions in response to our collective health problems. The final section ends with a call for intersectoral collaborations to investigate and meet the norms and build capacity for future innovative community participatory research in order to truly materialize the transformative outcomes that One Health poses for global health [32].

9.1. Vaccines and Novel Therapies

Immunization is the most cost-effective approach to combat microorganisms. Some successful zoonotic parasite vaccines have been reported for other parasitic diseases including *Eimeria*, *Toxoplasma gondii*, and *F. gigantica*. However, research on vaccine development has been hindered by many factors including the paucity and great diversity of vaccine candidates, the complexity of immune protection, high costs, and environmental and commercial requirements. Despite the complex life cycle of pathogens, their evolutionary pressures, and their immunoevasion, vaccines can activate, mobilize, and potentiate the body's immune responses and should still be feasible. Of note, the specific antibody recognizing active components of parasites cooperatively with host immunomodulating activities has been shown to trigger the host's immune response to clear the parasites by working against macrophage-based phagocytosis or the glycometabolism pathway [33].

10. Ethical Considerations in Zoonotic Parasitic Infection Research

Given the clear health benefits for humans and animals in establishing a One Health approach to tackle the challenges presented by zoonotic parasitic infections, what ethical considerations must be kept in mind when conducting this important research? First and foremost, it is important that any research conducted is valid and is likely to have a significant impact. Stating that research should improve health is one thing, but decisions surrounding where to allocate finite resources should be based on the proven likelihood of a proposed intervention to succeed at improving health. Good data are the cornerstone of evidence-based health decision-making, so investment in robust data collection underpins both intervention development and implementation. Secondly, if human and animal interests are protected through a One Health approach to zoonotic parasitic infection research, might the interests of other species be neglected? [34].

The One Health approach promotes collaborative work across all relevant disciplines, aimed at optimizing the health and well-being not only of human and animal populations, but concurrently the ecosystems in which it exists. However, some One Health work reduces the 'ecosystem' focus to simply recognizing the importance of maintaining (or controlling) animal hosts of potentially zoonotic parasites in a way that also benefits human health, i.e., by developing vaccines to protect animal populations from economically disabling infections. While some researchers might have an ecological perspective of health, in practice studies focus on reducing the risk of infection to economically important hosts rather than reducing infection prevalence in all species, for the greater good of ecosystem health. The utilitarian rationale is that the reduction of infection in both domestic animals and humans protects the well-being of both human and animal

populations, and at the same time, the natural environment in which they live. The interests of other species that do not directly contribute to the functioning of the human-animal group are largely ignored. However, ethical frameworks that require the best ends for the greatest good of the greatest number must not allow us to fall into the trap of forgetting the general good by focusing on the good of those who have previously formed the focus of 'people-led' research perspectives. Excluding ethical voices from other species leads to disproportionate benefits for humans from limited environmental resources. This argument emphasizes a more equitable distribution of benefits from these scarce resources [35].

Given that our explanation requires systematic preference weighting to protect the interests of different species, a lack of consideration in research and social policy implies that we are working on subjective biases rather than a framework based on fairness and equity. To justify a pervasive bias in health, benefits must accrue to those that are directly affected: that is, we must be able to argue that the undertaking of human and animal parasite research with a focus on host species is in the best interests of those species that are directly affected by pathogens of dominant concern. The ecosystem in which they exist will perform as required and that all members of the ecosystem will benefit in turn from all the income streams [36].

10.1. Informed Consent and Ethical Treatment of Animals

Informed consent and ethical treatment of animals are major concerns for those utilizing research animals, particularly those involved in medical, genetic, and conservation biology, but also those working with animals in industries, agriculture, and pets. The use of research animals in the biosciences in the United States and most other countries is mainly regulated by laws and regulations promulgated by the federal government and animal welfare oversight committees. The key law regulating the use of research animals is the Federal Animal Welfare Act. Another act provides the only direct government oversight of animal care and use in research and the Welfare Policy, the animal use policies of the National Institutes of Health. Together, they differ at several levels from the AWA, with more stringent regulations and a broader scope, encompassing not only laboratory animals, but all research animals, whether or not they are supported by funding, and whether or not the facility in which the research animals are housed is accredited [37].

11. Case Studies of Emerging Zoonotic Parasitic Infections

The case examples we present in this chapter are personal selections and are not meant to be comprehensive. In fact, parasitic infections that are emerging in other regions are not discussed [15, 38].

11.1. Recent Outbreaks and Their Impacts

The outbreak of Ebola virus infection in West Africa, a zoonotic infection of bat origin, affecting humans with high morbidity and mortality, is a striking and still unresolved example of a new infection emerging and having significant global impacts. The more recent global emergence of COVID-19, a zoonotic infection of bat origin, is a further grim reminder of the zoonotic origins of emerging infections with pandemic potential [39]. The climatic, environmental, and human-ecological changes that are driving these recent changes in infection emergence are influencing other parasite types [40]. Climate and environmental changes have been linked to recent Nipah virus outbreaks and outbreaks of

horseshoe bat-borne infections in pigs. Anthropogenic land use, alongside indirect effects of changing climates, has also been specifically linked to emerging infections such as those due to certain parasites, as well as highlighting potential co-infection studies for novel parasites in other ecological disturbance zones [41].

In the meantime, immunosuppressive therapy from current cancer treatments followed by infection due to certain parasites in patients stands as a stark reminder of the complex but serious and novel expanding consequences of the increasing human-on-animal interface. These examples of novel changes in infection risk and the accessibility of host or zoonotic parasites to specifically expand their range or capacity for new parasitic infections reflect the changing characteristics of both the host or zoonotic parasite and the anthropogenic environment. This is a dynamic situation that is biologically interesting and has important implications for contemporary human and animal health [42].

12. Future Directions and Research Needs

There are several gaps in our knowledge regarding epidemic zoonotic parasites and house-related vectors and host species. For example, we still do not know the zoonotic potential of most under-recognized zoonotic parasites, especially those associated with a background of rapid environmental changes. We are still unaware of the scope of the outbreak and spread of some of these infections, the extent of environmental pollution, including association with other zoonotic parasites, the epidemiological status of some of the major endemic areas, potential clinical and atypical presentations, the risk factors or drivers of exposure, and the best diagnostic strategy for humans and animals.

We need to identify shifts in the host specificity of zoonotic parasites. There is a gap in our capacity for effective surveillance and accurate diagnosis in humans and animals, enabling changes in the distribution, burden, host specificity, and zoonotic potential to be determined in both people and animals. More zoonotic pathogens should be considered to improve the surveillance based on clinical and atypical presentations for differential diagnosis, especially for malaria, leishmaniasis, trypanosomiasis, strongyloidiasis, amebiasis, cryptosporidiosis, giardiasis, microsporidiosis, cysticercosis, coenurosis, and infections with myiasis, cutaneous and mucocutaneous leishmaniasis, and others. There are several not routinely detected or underreported zoonoses. Sensitive and specific novel and alternative diagnostic techniques should be considered.

12.1. Areas for Further Study and Investigation

As the world in the Anthropocene continues to have extreme alterations, expected changes in parasitic infections of humans and animals are probable. A warming world is a world with a changing geographical range for hosts and parasites. The changes will not only be in range and migration; there will be increases in survival and reproductive rates. In addition to transmission changes, interspecies relationships in the Anthropocene are cutting off old branches of the Tree of Life and rapidly encouraging new relationships and co-evolution within other species. Currently, some of these zoonotic diseases are primarily infectious in humans; there are likely to be additional problematic diseases that are primarily or secondarily zoonotic with considerable morbidity and loss of animal life and economy. Overall, there is a great need for more significant data for further One Health activities: mapping and modeling of these diseases; biology of parasites,

hosts, and pathogens; transdisciplinary research to reduce epistemological chasms across disciplines; multi-country approaches, since most of our pathogens have multiple countries as part of their geographical range; and greater transparency of all research as part of the greater societal need for open science. However, it is assured that each study of the parasites in the hosts of any group will continue to enhance our basic biology while increasing our understanding of the global relationships of One Health.

13. Conclusion

A paradigm shift is needed in the prevention, control, and elimination of zoonotic infections, including parasitic infections. An integrated, multidisciplinary, and holistic approach is required. This should underscore the inherent interconnectivity of the health of humans, animals, and the environment. Greater collaboration between the public health, veterinary, and environmental sectors, as well as other relevant sectors, including the social and behavioral sciences, is needed. This will foster greater appreciation of the emerging challenges encountered at the human-animal-environment interface and enable the development and implementation of transdisciplinary interventions, which factor in the underlying social determinants of health and healthcare-seeking behavior. Ultimately, the protection of both human and animal health will be dependent on increased investment in prevention and adaptive strategies. Examples include embracing prudent antimicrobial use and better implementation of infection control principles at animal and human healthcare facilities, encouraging greater awareness and the adoption of animal welfare standards, encouraging land management practices that minimize intrusion into natural environments, and encouraging the adoption of inclusive and fair socioeconomic development and planning strategies that afford the most marginalized communities access to resources, thereby curbing the encroachment into animal habitats and minimizing human-animal contact. Undoubtedly, tackling emerging zoonotic infections is a key challenge in the Anthropocene, and is critical for addressing this challenge.

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