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Human Pathogen Crossing Species Barrier: Reverse Zoonosis

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Abstract

Background: Reverse zoonosis, or zooanthroponosis, refers to the transmission of pathogens from humans to animals. This phenomenon has gained increasing attention as growing human-animal interactions through urbanization, wildlife tourism, and livestock intensification create new opportunities for disease spillover. Such transmission not only threatens animal health and biodiversity but can also lead to the establishment of new animal reservoirs capable of reintroducing infections back to humans. **Aim:** The aim of this narrative review is to provide a comprehensive understanding of reverse zoonosis, emphasizing its growing significance in context of human, animal, and ecosystem health. This review compiles and analyzes existing literature to highlight how human derived pathogen affect domestic animal, wildlife, and livestock populations. It also seeks to identify key research gaps and highlight the importance of a One Health approach for effective surveillance, prevention and policy development. **Methods:** This narrative review was conducted by systematically searching peer-reviewed articles, case reports and relevant reports that describes human to animal disease transmission and animal to human disease transmission. Literature was sourced from electronic databases including PubMed and Google Scholar, using key words such as “reverse zoonosis”, “anthroponosis”, “zoonosis”, “one health” and “biosecurity” **Results:** Human to animal transmission has been reported in domestic, captive, and wildlife species, with domestic animals most affected due to frequent human contact. Viral agents such as SARS-CoV-2 and influenza, and bacterial pathogens like *Mycobacterium tuberculosis* and Methicillin Resistant *Staphylococcus aureus*, are most frequently documented. Key contributing factors include pathogen mutation, antimicrobial resistance, urbanization, environmental change, climate variability, and human behavior. Preventive strategies include One Health based interventions, vaccination, surveillance, and biosecurity. **Conclusion:** Reverse zoonosis underscores the interconnectedness of human, animal, and ecosystem health. Strengthened One Health surveillance, strict biosecurity in wildlife contact settings, and public awareness are crucial to mitigate future risks. Addressing knowledge gaps and implementing proactive interventions like vaccination and environmental management are essential to safeguard both animal and human health.

Keywords

Reverse zoonosis; Zooanthroponosis; Wildlife; One health

1. Introduction

Zoonosis are diseases that can be transmitted from living animals to humans [1]. The word comes from Greek origin where, zóon means “animal or living entity” and nósos means “illness”, and -osis means “condition or process” [2]. The concept of zoonosis was first recognized by Rudolf Virchow, who introduced the term to describe the infectious diseases linking animal and human health [3]. Virchow’s research on *trichinellosis* helped to convince him regarding the significance of connecting human and veterinary medicine [4]. Approximately 75% of new infectious disease originate from animals [5]. Crossing species is an intrinsic characteristics of pathogens. It is thought that the majority of newly identified human pathogens, or those yet to be found in humans, are probably pathogens that have crossed species from other vertebrate animals. If animal source was in past but animals are no longer required to continue the transmission cycles, can we still refer to these as zoonosis? In 21st century, conceptualizing HIV as a functional zoonosis disease is challenging [2]. The definition of zoonosis has evolved over the time as our understanding of disease transfer between human and animals has progressed. Early bacteriological and ecological models approached zoonosis by focusing on population cycles of animal infection, while contemporary ideas highlight the emergence of pathogens and species-jump occurrences at the individual level [6]. Despite these evolutions, in today’s world there are different definitions of zoonosis which is result of historical shifts in terminology, differ scientific interpretations regarding what defines zoonotic transmission, and the absence of a cohesive update by global bodies like WHO, FAO, and WOAH. The versions of definition of zoonosis by WHO are:

“a) A zoonosis is defined as the disease and infection naturally transmitted between people and vertebrate animals (http://www.emro.who.int/about-who/rc61/zoonotic-diseases.html)

b) A zoonosis is any disease or infection that is naturally transmissible from vertebrate animals to humans (https://www.who.int/news-room/fact-sheets/detail/zoonoses)

c) A zoonosis is an infectious disease that has jumped from a non-human animal to humans. (https://www.who.int/news-room/fact-sheets/detail/zoonoses)” [2]

Anthropozoonosis is term to denote transmission of pathogen from non-human to humans and zooanthroponosis or reverse zoonosis is term used to denote transmission of pathogen from human to non-human [1]. However, the frequent interchange between these terms by scientists led to added confusion, which was clarified in a 1967 Joint Food and Agriculture and World Health Organization committee meeting that advised using term “Zoonosis” to denote the mutual exchange of infectious pathogen between humans and animals. Reverse zoonosis specifically refers to as disease transmission in which direction of transmission is from human to animal. However, debate remains regarding whether disease should be categorized into epidemiologic classes by infections source or the direction of transmission, especially in case of some disease transferred from arthropod vectors such as dengue, zika fever, urban yellow fever, and malaria [1, 7].

Reverse zoonosis can be defined as “an infection or disease that is transmissible from humans to animals under natural conditions” [8]. Reverse zoonosis endangers both animal and public health because it can lead to the establishment of disease reservoirs in animals [9]. For example; cats can get infected with human illness such as Influenza A. A flu outbreak in cats could be catastrophic for the feline community. It might also pose a risk if the pathogen evolved and returns to humans as a strain resistant to treatment [10]. Historically, much scientific research has focused on zoonotic diseases, with animals serving as the main source of infection. Nevertheless, recent studies increasingly emphasizes the role of humans in maintaining and spreading zoonotic diseases pathogens to animals highlighting the importance of reverse zoonosis [11]. Acknowledging humans as source of pathogens is crucial for public health strategies, as it identifies vulnerable populations and underscores the growing threat of human to animal disease [12]. Proof of reverse zoonosis can be observed in household pets or wildlife in captivity, while there is less evidence of reverse zoonosis in free ranging wild animals [13]. However, the fact that there is less current evidence indicating that, wildlife is significantly impacted may not be entirely comforting, given that there are no existing effective surveillance programs to produce evidence. If that evidence existed, it might already be too late to effectively manage any outbreaks [14].

Multihost pathogens are highly common among human pathogens (61.6%) and even more so in domestic mammal pathogens (livestock 77.3%, carnivores 90.0%). This broad host range increases the likelihood of transmission [15]. Despite the potential risk, documented on cases of reverse zoonosis are very few compared to magnitude of threat. Since 1988, research on reverse zoonosis has progressed from examining fungal pathogens to primarily concentrating on bacterial infections like MRSA and *Mycobacterium tuberculosis,* and subsequently on viral pathogens such as influenza, particularly following the 2009 H1N1 pandemic. But, numerous prevalent and harmful pathogens, have not been studied as reverse zoonosis risks to animals, highlighting a considerable deficiency in the academic literature. A broader awareness and comprehension of reverse zoonosis must be pursued for an effective One Health strategy [16].

2. Methodology

This narrative review was conducted by searching for relevant peer-reviewed articles, case reports and reports that describes human to animal disease transmission and animal to human disease transmission, in electronic databases (Google Scholar, PubMed, Research gate), using keywords associated with “reverse zoonosis”, “anthroponosis”, “zoonosis”, “one health”, and “biosecurity” combined with specific pathogens (e.g., “SARS-CoV-2”, “MRSA”, “*Mycobacterium tuberculosis*”. To guarantee relevance and current situation, articles published between 2000 and 2024 were given priority. Zotero was used to manage referencing, and Ms. Word 2016 was used to prepare the manuscript in accordance with journal guidelines. This review is limited by availability of published data, possible underreporting of reverse zoonotic events, variability in diagnostic methods across studies, and absence of standardized surveillance system for human to animal transmission.

3. Factors Contributing

Many factors contribute to reverse zoonosis, including mutation, drug resistant phenomena, urbanization, deforestation, agricultural expansion, pollution, climate change, waste management, host-pathogen interface, cultural practices, vector variation, population density, and others [17]. Mutation is a major factor in reverse zoonosis. Variation in pathogen due to mutation complicates the dynamics of reverse zoonosis. Pathogens such as SARS-CoV-2 virus exhibit high degree of variability because of their high mutation rates, allowing them to adapt to a new host and environment [18]. This ability to mutate which causes variation, possess challenge for prediction and control the spread of disease across different species.[19]. Furthermore, close interactions between humans and animals throughout our history have allowed numerous pathogenic microorganisms to co-evolved, effectively infecting both host types. Cross species transmission may also enhance the genetic diversity in pathogens by providing additional opportunities for genetic reassortment, which can propel the evolution of pathogens [12].

Another major factor is the inappropriate use of antibiotics in human healthcare and animal farming, especially when it comes to those antibiotics deemed critically important for human health by the World Health Organization (WHO) [20]. Overuse and misuse of antibiotics in health sector results in a rise of drug resistant bacteria, which are later transferred to animals through environmental exposure or direct contact. Such drug resistant pathogen transferred from humans poses great challenges for treatment in animal and public health because it limits effectiveness of antimicrobial agents in animals and animals may also serve as reservoir for resistant bacteria which can be later again transmitted to human, a phenomenon called secondary zoonosis. Drug resistant phenomena therefore accelerate risk of reverse zoonosis [21–23]. Human activities and environmental changes also drive reverse zoonosis. Urbanization, deforestation, agricultural expansion, and pollution usually bring wildlife closer to human, thus increases chances of disease transmission [24, 25]. Man-made and environmental pollutants can disrupt ecosystem and degrade health of wildlife, making animals more susceptible to pathogen transmitted from humans [26]. Climate change further accelerate reverse zoonosis by changing animal behavior, distribution change, habitat alteration, disease-transmitting pattern, and so on. Change in temperature and rainfall may influence occurrence and distribution pattern of vector borne disease like malaria and dengue fever [27–30].

Vectors plays very important role in transmission of vector borne disease. Tick, fleas and many insects such as Mosquito, Blackfly, Sand-fly, etc. can transmit pathogen between human and animals, which leads to establishment of new transmission pathways. [31–33]. The increasing trend of pet ownership and greater number of exotic pet entering in household further elevate the risk of disease transmission between human and animal [16]. And with the swift transportation system of today, contemporary public health issues are becoming more intricate. A pathogen that appears today in a nation can swiftly be carried unnoticed by humans, animals, plants, or food items to far-off regions of the globe in under 24 hours [34]. The two persistent dynamics of increasing population and globalization and synergy have come together to broaden options for agents to transition from familiar areas into uncharted territories, frequency with deadly consequences. Neither force is diminishing, and combined they are creating pleiotropic and unmatched effects [4]. Finally, intrinsic and extrinsic factors interact to influence risk of reverse zoonosis. Extrinsic factors influence both host and human population dynamics that determine the rate of transmissible interactions at the human-wildlife and wildlife-livestock boundaries. Intrinsic factors include life history, behavior, competence, and swift evolutionary adaptations in animal hosts and pathogens; as well as variations in host vulnerability, frequency influenced by wealth or destitution in human groups, and by pristine or compromised environments in wildlife hosts. Intrinsic factors (from host, pathogens, and vectors) interact with extrinsic factors to influence disease risk in humans and animals [35].

4. Agents

On the basis of agent's reverse zoonosis can be categorized as bacterial, viral, protozoal/parasitic, and fungal reverse zoonosis. According to one review article there is higher incidence of reverse zoonosis of viral infections, particularly respiratory viruses such as severe acute respiratory syndrome coronavirus-2 and influenza, which is followed by bacterial infections like tuberculosis and methicillin-resistant *Staphylococcus aureus*.[17]. The primary emphasis is on bacterial and viral pathogens, since they primarily play a role in interspecies transmission among animals, including wildlife [13].

4.1 Viral Agents

Viral agents cause disease in wide range of host such as humans, animals, plants, and bacteria. Viral infection has potential for rapid spread, the diversity of diseases, challenges in treatment and prevention, and global impact. Due to all these factors viral infection has significant importance in public health. Viral agents also play important role in shaping public health, economies, and scientific research.[17]. For a viral agent to jump between species several barriers needed to be crossed. Required criteria for jump between species is frequent contact between two species and sufficient compatibility between virus and new host to allow for attachment, entry and replication [36]. Here are some important viral agents that are emerging as cause of reverse zoonosis (Table1).

4.2 Bacterial Agents

According to a systemic review, *Mycobacterium tuberculosis* and Methicillin resistant *Staphylococcus aureus* (MRSA) are reported frequently in cases of reverse zoonosis [17]. Here are some important bacterial agents that are emerging as cause of reverse zoonosis (Table2)

4.3 Fungal Agents

First reverse zoonosis case was reported as fungal reverse zoonosis. It is less studied compared to viral and bacterial reverse zoonosis [17]. Fungal agents reported for reverse zoonosis are: *Encephalitozoon intestinalis* [37], *Cryptosporidium hominis* [38], *Microsporum gypseum* [17] and *Candida albicans* [17].

There are also reports of some protozoal and parasitic reverses zoonosis cases [17].

Table 1. Viral agents emerging as cause of reverse zoonosis

Viral agents	Infected animal	Reference
SARS-CoV-2	Cat, Dog	[39–41]
	Tiger, Lion, Leopard	[42, 43]
	Mink, Pig, Cattle	[44–46]
Human influenza virus (pH1N1, H3N2)	Pig	[47, 48]
Rota virus	Dog	[49]
Mumps virus	Dog	[50]
Arbovirus	Animal	[51]
Chikungunya virus	Non-human primates	[52]
Dengue virus	Wild mammals	[53]
Human adenovirus	Non-human primates	[54]
Meta-pneumo virus	Chimpanzees	[55]

Table 2. Bacterial agents emerging as cause of reverse zoonosis

Bacterial agents	Infected animals	Reference
Mycobacterium tuberculosis	Cattle, Goat	[56]
	Elephants	[57]
Salmonella spp.	Dog	[58]
Methicillin resistant *Staphylococcus aureus* (MRSA) and Oxacillin-resistant *Staphylococcus aureus* (ORSA)	Livestock	[59, 60]
Escherichia coli	Dog, Horse	[61]
Helicobacter pylori	Marsupial	[62]
Campylobacter spp.	Gorilla	[63]
Pseudomonas aeruginosa	Dog	[64]

5. Species Affected

A recent study reported that domesticated pigs (*Sus scrofa domesticus*) (n 31 viruses), cattle (n 31 viruses), horses (n 31 viruses), and dogs (n 27 viruses) are animals with which human exchange highest number of viruses.[65]. Pig, for example, are affected by 3 viruses transmitted from human severe acute respiratory syndrome-related coronaviruses (SARSr-CoV), swine vesicular disease (SVDV), and noroviruses (NoV) [21]. Most affected species in reverse zoonosis are domesticated animals as they are in frequent contact with human being [16]. According to a case report 3 of the findings suggested presence of reverses zoonosis phenomenon in the Southern Ocean. *Salmonella ser. Enteritidis* and *C. jejuni* of human origin are seen in Southern Ocean that is carried by scavenging species. This indicate that any species in contact with human may be susceptible to reverse zoonosis [66].

6. Case Studies

6.1 Viral Cases

Coronaviruses (CoVs) are enveloped, positive sense, single-stranded RNA viruses [67]. Recently in pandemic of 2020 there is detection of SARS-CoV-2 in pet, zoo and certain farm animals, which spark the topic of reverse zoonosis [68]. There are multiple cases suggesting reverse zoonosis of SARS-CoV-2. A report from Hong Kong in February 2020 indicated a potential SARS-CoV-2 infection in two dogs showing no symptom; their owner had been diagnosed with COVID-19 earlier [41]. Transmission of SARS-CoV-2 from humans to dogs, house cats, tigers, and lions has been detected. Pigs, cats, ferrets, and primates are found to be more susceptible to SARS-CoV-2 infection [69]. Another case report also concluded that SARS-CoV-2 replicates poorly in dogs, pigs, chickens, and ducks, but ferrets and cats are more susceptible [70]. At the Bronx zoo, three lions and four tigers were infected with COVID-19 from two separate transmission events, including one from a zookeeper [42]. Humans were recognized as the source of infection in farmed mink, which was subsequently transmitted among the mink [71].

On May 2, 2009, roughly one month after the pH1N1 virus was detected in humans, pH1N1 virus was extracted from pig on a ranch in Alberta, Canada, in what was eventually determined to be the first documented case of human-to-swine transmission of pH1N1 virus [72]. After this incidence there are several reported cases of human to swine viral transmission. One article examine how recently enhanced influenza surveillance for viruses in pigs has shown that influenza the transmission of viruses from people to pigs is significantly more common than swine-to-human zoonosis. Transmission of influenza virus from human to swine represents the largest ‘reverse zoonosis’ of a pathogen documented to date [73]. Case of reverse zoonosis of Influenza A/ H1N1pdm09 virus in captive giant panda in Hong Kong was reported in 2019[74]. Cases of cats with influenza A/ H1N1pdm09 were also documented in Cat Colony in Italy in 2009 influenza pandemic [75]. Subclinical infection of Influenza A(H1N1) pdm09 virus in dogs was reported in Guangdong Province, China [76]. Infections of Influenza A(H1N1) pdm09 virus were also found in domestic bird species such as turkey at two breeding sites in united kingdom (UK) during late 2010 and early 2011 [77].

Measles is a very contagious virus primarily found in humans. The measles morbillivirus typically donot exists in wild monkeys but can become significant as a pathogen when nonhuman primates are kept in captivity and come into direct or indirect contact with humans infected with the measles virus. In similar manner, herpes virus infections frequently occur in humans. Infection from Human simplex herpesvirus has also been documented in various nonhuman primates, as well as in domestic rabbits, chinchillas, and African pygmy hedgehogs [13].

6.2 Bacterial Cases

"*Mycobacterium tuberculosis* is primarily a pathogen of humans" [78]. Most cases of TB in elephants are caused by *Mycobacterium tuberculosis*, the causative agent of the disease for humans [79]. Elephant TB has been known more than 2000 years ago. Recent studies suggest transmission of M. tuberculosis from human to animal and animal to human. And there is no evidence of *M. tuberculosis* infection in wildlife that hasn't been yet in contact with human population [80]. In many domestic and wild animals of various species living in close contact with human population, infection with *M. tuberculosis* has been reported [57]. In one study it is reported that "from 1997 to 2000, *Mycobacterium tuberculosis* was diagnosed in two Asian elephants (*Elephas maximus*), three Rocky Mountain goats (*Oreamnos americanus*), and one black rhinoceros (*Diceros bicornis*) in the Los Angeles Zoo" [81]. There is also reported cases of transmission of *M. tuberculosis* from human to cattle and potential adaptation of this organism in bovine tissue [82]. Case of transmission of M. tuberculosis transmission from dog-owner to the companion dog have been documented [83].

The initial identification of MRSA in domesticated animals globally occurred in the 1970s, with the first strains isolated from mastitic dairy cows in Belgium. Their resistance to antibiotics was akin to that of the methicillin-resistant strains identified in humans [84]. The rampant misuse of antibiotics in veterinary practices leas to rise of MRSA in livestock [85]. Numerous reports indicates that this pathogen can be found in samples form cattle, pigs, and chickens in slaughterhouses, as well as in randomly tested food samples from supermarkets [86].

7. What is Secondary Zoonosis?

According to the World Health Organization (WHO), a zoonosis is "any disease or infection that is naturally transmissible from vertebrate animals to humans" [87]. Secondary zoonosis refers to a situation where pathogen that was originally transmitted from human to animals (Reverse Zoonosis) adapts, establishes itself in the new animal host, and then spills back into humans as a new or modified infection [17]. There are many reported cases of secondary zoonosis. Cases of Methicillin-resistant *Staphylococcus aureus* (MRSA) is on the rise globally. Sometimes, animals are accidentally infected with strains originated from humans. And there is emergence of new strains of MRSA from farm animals that has been previously exposed to human MRSA, especially from pigs and are leading to human infections. MRSA originated from animals are referred to as Livestock Associated - Methicillin-resistant *Staphylococcus aureus* (LA-MRSA) [88]. This indicates that the infected animal serves as a constant reservoir for MRSA, leading to human infections with LA-MRSA [85].

In 2009, reports were received by the Tennessee Department of Health regarding 5 tuberculin skin test (TST) conversions among staff at an elephant refuge, along with the isolation of *Mycobacterium tuberculosis* from a resident elephant [89]. This study suggest that M. tuberculosis is transmitted between humans and elephants. A recent study in Australian zoo presents evidence of *M. tuberculosis* transmission to six chimpanzees and staff members. These findings demonstrate the spread between various animal types [78]. Report of a zoonotic *M. tuberculosis* infection was documented among three veterinary pathologists who conducted the dog's necropsy that was confirmed positive for *M. tuberculosis* [90]. All the mentioned cases indicate there is possibility of transmission of *M. tuberculosis* from animal to human which was originally transferred from human to animals. In summary it can be concluded that the population of the affected animals may develop into a disease agent reservoir, allowing for the reintroduction of the disease agent into people, which ultimately raises a concerning public health issue and secondary zoonosis is major risk factor of reverse zoonosis.

8. Prevention & Control

8.1 One Health Approach

In 1964, veterinary epidemiologist Calvin Schwabe created the phrase "one medicine" to describe the connection between animal and human health and the medical challenges of preventing and managing zoonotic diseases, or "zoonosis". Subsequently, the phrase "one health" was adopted, followed with the incorporation of the wider notion of “one world one health” [91]. According to [92]. One health is defined as “the collaborative effort of multiple disciplines to obtain optimal health for people, animals, and our environment”. Due to the various connection among humans, animals, and environmental health, tackling zoonotic diseases demands a holistic approach. The idea of “One Health” acknowledges the interconnectedness, highlighting the need for cooperation among sectors in managing and preventing zoonotic risks, and promotes a comprehensive strategy for tackling global health challenges [93]. Joint efforts between epidemiologist, veterinarians, ecologist, and public health officials facilitate the identification of disease hotspots, aiding in focused interventions [94]. No single sector, organization, or individual can tackle challenges at the animal-human-environment interface independently [95]. The approach must adjust to local requirements and the current limitations of the health system, while also utilizing them by allowing different stakeholders to work together seamlessly [96]. Essentially, One Health focuses on understanding the relationship among all organisms and the environments we share. One health is frequently depicted as three interconnected pillars: human health, animal health, and environmental health. By acknowledging the common determinants of health (or illness) and the interconnections between these pillars, we emphasize the essential significance of the inherent value of every species and generation, along with necessary mutual care for one another as humans, animals, and the environments we collectively inhabit [97]. Vaccination is one of effective approach to control reverse zoonosis. But aiming to vaccinate all humans is challenging, expensive and lengthy process, making it impossible to guarantee that all individuals interacting with at-risk wildlife will be vaccinated promptly. Moreover, it remains uncertain whether vaccination alone would effectively stop all transmission. So, immunizing non-human animals is a more straightforward, though contentious, defense approach [14].

8.2 Surveillance and Monitoring

Given the globalization of human and animal products, referred to as global express, a pathogenic virus can spread to any location within hours, as seen in recent pandemics (2009 Influenza A (H1N1) and SARS-COV-2). So, there is necessity for ongoing surveillance and monitoring at the interfaces between animals, humans, and the environment, as well as at critical points in animal value chain (especially wildlife, livestock, and pets that have either direct or indirect contact with humans) for pathogen known to have a wide host range, while also considering possibility of unknown pathogen that may have potential to evolve into future epidemic or pandemic. In case of virus proceed with viral genome sequencing to document both zoonotic and reverse zoonotic mutations that could aid in the rapid identification of potentially hazardous viruses [4, 98, 99]. Additionally, machine learning algorithms can detect viruses using minimal research data for prioritized surveillances, enabling faster response that can help prevent future outbreaks [100]. Wastewater-based epidemiology is regarded as an effective method for real-time surveillance of the movement of virus within communities and across international boundaries, and it is suggested for trafficking and managing the spread of potential human disease outbreak [101]. Targeted One Health surveillance would encompass humans, livestock, pets, and instances of wild animals mortality, thereby providing a global early warning system [99]. One of the most extensive initiatives for large-scale sampling and viral discovery is the Global Virome Project (GVP), which was initiated in 2018 AD. The objective of GVP is to identify and characterize 99% of all zoonotic viruses with epidemic or pandemic potential within a decade [102].

8.3 Biosecurity Measures

FAO defines the term biosecurity as “a strategic and integrated approach to analyzing and managing risks to human, animal, and plant life and health, and associated risks to the environment” [103]. Globalization has led to increased trade in livestock and their products, which heightens the risk of diseases affecting both animals and humans [104]. A strong biosecurity program enhances animal welfare by promoting the health and resilience of animals against environmental challenges; it acts as a primary defense mechanism by identifying diseases early and preventing their spread within farm [105]. This approach lowers the expenses related to disease treatment, ensures the production of safe, high-quality, and nutritious goods, and boosts the likelihood of operating a successful enterprise and continuing in agricultural sector [106]. At farm level, biosecurity practices can either aim to prevent the introduction of new pathogen i.e. external biosecurity or focuses on limiting the spread of pathogens within the farm i.e. internal biosecurity. Nevertheless, the way biosecurity measures are implements on farms can differ significantly due to numerous factors, such as geographic location, social demographics, the attitudes of farmers, and their access to information, among others [107]. It is not possible to suggest universal biosecurity practices sue to the differing management approaches present on various farms [108]. A successful biosecurity strategy should adapt to new information and advancements in technology [104]. Suggested on-farm biosecurity measures include: maintaining animal cleanliness, ensuring sanitation, imposing restrictions on sharing equipment, vehicles, and facilities, controlling ticks and pests, implementing vaccination programs, regulating the movement of animals and quarantining newly introduced ones, preventing the mixing of different animal groups, culling infected animals, establishing protocols for care and treatment of sick animals or contaminated products, managing feeds, maintaining facilities and vehicles, and setting guidelines for handling manure and disposing of carcasses[105].

Change is desperately required, starting with a shift in our health strategies and reassessment of our viewpoint to quickly and sustainably achieve harmony with the natural environment. Continuing to do nothing is not a viable option-significant change is urgently needed [97]. Reducing contact with wildlife animals and, when effective vaccines are available, vaccinating the main reservoir-humans and susceptible farm and pet animals-are best ways to prevent animal infections spread by humans. This strategy would shield pets and farm animals from reverse zoonotic diseases and stop it from spreading to people [94].

9. Conclusion

Reverse zoonosis highlights the bidirectional nature of infectious disease transmission and underscores the need for integrated approaches to human, animal, and environmental health. Tackling reverse zoonosis requires an integrated and forward-looking strategy that prioritizes both animal and human health. Strengthening One Health frameworks, expanding surveillance systems, and implementing sustainable biosecurity and antimicrobial stewardship programs are critical to reduce risks. Risk of reverse zoonosis is burning issue in today’s world, despite that there is limited research on this topic especially protozoal and fungal reverse zoonosis. Future research must prioritize neglected pathogen groups, evaluate the ecological consequences of pathogen adaptation, and integrate socio-economic and environmental factors into risk models.

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