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Review Article

Zoonotic Parasite Species and Viral Pathogens of Livestock Associated with Human Morbidity

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Abstract

Infectious diseases caused by an array of pathogenic microbial species remain a constant threat to global public health. Therefore, the emergence and re-emergence of such species which can be potentially fatal are high priority. These pathogens represent a significant hazard to human health and also have high economic impact once an outbreak has occurred. Furthermore, parasitic infections of livestock and domestic animals can have a significant commercial and financial impact, in part due to trade restrictions amongst countries. They can result in losses due to animal mortality, morbidity leading to reduced milk and meat quality and quantity, emaciation and a decreased parity in herds. Zoonotic pathogens are some of the most prevalent agents of disease resulting in approximately 60 percent of infectious disease in humans. Indeed, this is an ongoing issue due to human factors such as socio-economic changes, dietary needs and climate change together with the increasing human population. There is a dire need to control livestock disease due their relationship with food contamination and human health and indeed animal morbidity. This is often problematic however, due to the carrier state of some pathogens in host animals. Whereby, the pathogen persists sub-clinically thus going undetected and untreated for extended periods of time.

Keywords: *Zoonotic; Pathogens; Viral; TB; Bovine; Transmission*

Abbreviations

BSE: Bovine Spongiform Encephalopathy; BRSV: Bovine Respiratory Syncytial Virus; BVD: Bovine Viral Disease; DAFM: Department of Agriculture, Food and the Marine; ELISA: Enzyme Linked Immunosorbent Assay; FAO: Food and Agriculture Organization of the United Nations; FMD: Foot and Mouth Disease; HACCP: Hazard Analysis Critical Control Point; HEV: Hepeviridae; HeV: Hendra Virus; ID: Infectious Dose; MERS-CoV: Middle East Respiratory Syndrome Coronavirus; NiV: Nipah Virus; SRM: Specified Risk Material; TB: Tuberculosis; TSEs: Transmissible Spongiform Encephalopathies; vCJD: Variant Creutzfeldt-Jakob Disease; WHO: World Health Organisation

Introduction

Infectious diseases are one of the foremost causative agents of animal and human morbidity and mortality globally, with many emerging and re-emerging species being identified. The One Health approach which employs the belief that human health is related to the health of animals and the environment advocates that maintaining animal welfare is essential to maintaining human welfare. Parasitic species by definition are those unable to reproduce outside of a host environment, and include species from bacterial, viral, fungal, helminth and protozoal origin. Parasitic species which infect and reproduce in food producing (livestock) and companion animals, can be transmitted to human hosts, frequently resulting in disease. These zoonotic parasites can result in human morbidity and in some incidences mortality, thus posing a high risk to public health safety. Additionally, due to the global dependency on livestock farming as a source of food products and employment, the presence of zoonotic species may lead to financial and economic consequences including reduced international trade. Infection/infestation with zoonotic parasitic species may have detrimental effects on a person's physical and mental health, financial stability and social interactions if chronic morbidity results. A complete list of bovine zoonotic parasite species (including bacterial, fungal and viral) is listed in tables 1, 2 and 3, prions are also listed due to their zoonotic potential and high risk for human mortality. The prevention of zoonotic disease is essential to ensure public health safety and is of paramount importance for animal health and welfare. Studies show that viruses represent the largest group (40%) of infectious organisms emerging as pathogens, especially in relation to zoonosis due to their broad range of hosts and genetic adaptability [1]. Viral infections are particularly important in terms of economic losses and animal welfare following the infection of livestock, as viral species typically spread amongst herds rapidly. For a pathogenic species to cause an infection and successfully reproduce in its host, numerous factors must be overcome. The pathogen must be able to enter the host tissue, avoid host immunity and for viral species the host cell must display the viral receptors and the proteins essential for viral replication [2]. This review highlights the most common species associated with human disease from livestock (particularly bovine) zoonosis, outlining the importance of each species and consequences of infection. Emphasizing the direct link between bovine and human health is of significance as cattle are the primary livestock globally and are therefore a huge risk for human disease transmission. Zoonotic species differ in their infectivity, virulence and pathogenicity for humans and this is influenced by various factors including: increased interactions between people and their environment, increased human population, climate change, antigenic drift and changes in host and vector species.

Protozoan and helminths

Zoonotic parasites are typically grouped based on their mode of transmission into 4 groupings: direct-zoonotic, meta-zoonotic, cyclo-zoonotic, and sapro-zoonotic parasites [3]. Direct zoonotic parasites infect humans directly from animals (*Entamoeba histolytica*), meta-zoonotic parasites can infect humans from invertebrate intermediate hosts (*Babesia bovis, Fasciola hepatica*), cyclo-zoonotic parasites have vertebrate intermediate hosts (*Taenia multiceps, Echinococcus granulosus*) and sapro-zoonotic parasites which are transmitted from soil or water (*Cryptosporidium*). *Cryptosporidium parvum* is the most common parasitic species found in cattle, having a high incidence in young calves. The zoonotic transmission of *Cryptosporidium* is well documented with *C. parvum* and *C. hominis* the predominant species associated with bovine and human infection. As with the protozoan parasite *Giardia*, the *Cryptosporidium* oocyst structure is extremely resilient and survives in the environment for weeks to months. Both species have an extremely low infective dose (ID) contributing its pathogenicity even in incidences of low levels of exposure. Babesia is a parasite species transmitted by tick vectors (Ixodid ticks) which results in babesiosis, an emerging zoonotic disease having numerous wildlife species as reservoir hosts [4]. *B. divergens* is the only species currently transmitted from bovine species to humans in Europe. Zoonotic cases are not common but are often fatal unless treated immediately [5]. *Sarcocystis* are parasitic species that require both an intermediate and a final host. Cattle are recognised as intermediate hosts of *S. cruzi, S. hirsuta* and *S. homini*s, with humans as final hosts. *Toxoplasma gondii* is a multi-host obligate intracel¬lular protozoan parasite, causing zoonotic infections throughout the world [6]. Toxoplasmosis is the most frequently occurring disease with drastic consequences to the host including abortion in both human and various animal species. Host species become infected following ingestion of *T. gondii* oocysts from cat faeces or contaminated soil, water, or foodstuffs e.g. greens and the consumption of infected undercooked meat. *T. gondii* can pass vertically via the placenta to the foetus causing encephalitis, mental retardation, loss of vision in humans and stillbirth and abortions in cattle and other livestock animals. Helminth infestations (*Echinococcus* sp., *Fasciola* sp., and *Trichinella* sp) of livestock such as cattle and pigs are common and result in a loss of productivity; they are the most prominent production-limiting diseases of grazing ruminants [7]. *Dicrocoelium dendriticum* (Lancet liver fluke) is the causative agent of a rare food-borne zoonosis of the human biliary tract (dicrocoeliasis) [8]. This trematode resides in the bile ducts of cattle and sheep which can then be transmitted to humans via the consumption of the field ant which is an intermediary host. A summary of the varying zoonotic helminth species, their routes of transmission and resultant disease manifestations are given in table 1. Outbreaks and horizontal spread of such diseases in endemic areas are influenced by a number of factors including the diversity of livestock production systems, poor contingency planning, low public awareness of the disease, and interaction with wildlife populations.

Parasitic species	Zoonotic disease	Host cell/tissue	Routes of transmission	Reference
Helminths				
Nematodes				
Trichinella spiralis, brevoti	Abdominal discomfort, nausea, diarrhoea, fatigue and fever. Trichinosis	Small intestine - duodenal and jejunal mucosa, muscle tissue	Infected meat, raw meat, undercooked meat.	[9]
Bunostomum phlebotomum	Skin inflammation, skin lesions, Hypoproteinemic oedema			[10]
Moniezia benedeni,	Gastroenteritis, obstruction of intestines, mortality		Soil, faecal contact	
M. expansa,			Infected meat, raw meat, undercooked meat, soil and water contamination.	[11]
Ascaris suum - pigs	Malnourishment	Migration through skin		
	Ascariosis, larva migrans and eosinophilic pneumonia	Gastrointestinal tract	Ingestion of food and water contaminated by A. suum eggs.	[12]
Cestode				
Taenia saginata (Cysticercus bovis – larval form)	Cysticercosis, neurological damage – Alzheimer's disease, Taeniasis, Cysticercosis	Gastrointestinal tract	Infected meat, raw meat, undercooked meat, soil and water contamination	[13]
Taenia solium	Neurocysticercosis, seizures	Central nervous system	Undercooked pig meat	
Echinococcosis spp	Echinococcosis, Alveolar hydatidosis	Lung tissue	Livestock are intermediate hosts – transmission via faeces oral route	[14]
Trematode				
Fasciola hepatica and *Fasciola gigantica*	GIT perforation, liver fibrosis, hepatitis, jaundice and anaemia, fascioliasis	Liver, gall bladder and pancreas (chronic infection)	Contaminated food and water	[14]
Dicrocoelium dendriticum	dicrocoeliasis	Bile duct	Ants – intermediary hosts	[8]
Protozoan				
Cryptosporidium	Cryptosporidiosis, malnourishment, diarrhoea, autoinfection	Small intestine - epithelium of the duodenum and jejunum	Contact to faeces, contaminated water	[15]
Giardia	Giardiasis, diarrhoea, gastroenteritis, weight loss, and malabsorption			[16] [17]
Toxoplasma gondii	Toxoplasmosis, blindness, encephalitis, mental retardation in congenitally infected infants	Any nucleated cell	Contact to faeces, contaminated water	[6] [18]
Entamoeba histolytica	amebiasis	Destruction of host tissue, colitis	contaminated food and water	[19]

Table 1: *Zoonotic parasitic species and manifestations of disease in animal and humans: protozoal and helminth.*

Fungal and bacterial species

Fungal species which cause mycosis (Table 2) can be classed as true or opportunistic pathogens having either an environmental or host to host transmission. Some species can produce parasitic invasive forms which reproduce intracellularly i.e. parasitic in nature. These pathogenic species have an evolutionary advantage by having vertebrate hosts, e.g. *Histoplasma capsulatum* which is zoonotic in cattle [20]. Infection with this fungal pathogen occurs following inhalation of mycelial fragments which accumulate in the host lungs producing yeast cells. The fungus has the ability to enter phagocytes avoiding the host immune system and can therefore, travel systemically entering various organs. The severity of the infection relates to the number of inhaled fungal particles and the immune status of the host. In healthy (immunocompetent) persons, a small number of fungal particles can result in asymptomatic infection or acute pulmonary histoplasmosis. For persons who are immunocompromised or have co-morbidities however, may develop chronic pulmonary histoplasmosis or chronic disseminated histoplasmosis [21]. Bacterial zoonotic species and the re-emergence of such species due to antibiotic resistance is an ongoing issue globally. *Mycobacterium* are parasitic zoonotic species given that they can only reproduce inside the cells (macrophage) of the host e.g. bovine or humans. *Mycobacterium tuberculosis* the causative agent of TB is currently a re-emerging multidrug resistant bacterial species displaying resistance to pyrazinamide and streptomycin, isoniazid and rifampin the currently used drug therapy options. Studies have shown that approximately 510,000 new cases of this multi drug resistant TB occur annually across the globe [22]. Infection with TB manifests with respiratory symptoms (cough, haemoptysis chest pain, respiratory deficiency) and systemic symptoms (faintness, fever, weight loss and night sweats). For a percent of infected persons there are often additional infection sites including the liver, lymph nodes, spleen, the musculoskeletal system, heart, brain, meninges, genital-urinary system and skin. For infections of the brain and meninges the WHO recommends up to 12 months' drug therapy due to its high risk of disability and mortality, with 9 months recommended for bone and joint infections due to difficulty in treatment [23]. Coxiellosis (Q fever) caused by the bacterium *Coxiella burnetti* infects many species including cattle, sheep, goats and humans. Transmission is typically faecal oral but aerosol and milk transmission is also possible. Infection with this pathogen can cause reproductive issued in animal and humans including stillbirths, unviable newborns and abortion [24].

Parasitic species	Zoonotic disease	Host cell/tissue	Routes of transmission	Reference
Bacterial				
Mycobacterium tuberculosis	Tuberculosis (TB)	Bovine/human macrophages - alveolar	Airborne, dairy products (untreated)	[25]
Rickettsia - *Coxiella burnetti*	Q fever, bovine abortion, still birth.	Obligate intracytoplasmic - phagolysosome	Contact to bovine urine, milk or faeces, aerosol	[26] [24]
Fungal				
Histoplasma capsulatum - intracellular yeast	Histoplasmosis, Chronic progressive lung disease, Mycotoxicosis, Hypersensitivity	Lung - alveolar macrophages	Inhalation	[20]
Prion				
PrP (protein)	Creutzfeldt-Jakob disease (CJD) and variant CJD (vCJD), Bovine spongiform encephalopathy (BSE)	CNS tissue	Infected meat	[27]

Table 2: *Zoonotic parasitic species and manifestations of disease in animal and humans: bacterial and fungal.*

Prion disease

Prions are proteinaceous material which causes severe and fatal destruction to the host central nervous system manifesting as bovine spongiform encephalopathy (BSE) in cattle, scrapie in sheep and variant Creutzfeldt-Jakob Disease (vCJD) in humans. Also known as transmissible spongiform encephalopathies (TSEs), these are rare progressive neurodegenerative disorders that cause fatal infection of the host. Prions are transmitted to humans via the consumption of contaminated foods of bovine origin and can spread horizontally through blood transfusions with an extremely low infective dose which is undetectable. The infective agent has a prolonged incubation period making identification and treatment of symptoms difficult.

Zoonotic viral species

The pathogenesis and virulence of viral species with particular infection of livestock is discussed under the relevant headings: the virus, the host and the environment in detail.

The Virus

Viruses are unable to reproduce outside a host cell, having an absolute requirement for host DNA to initiate and complete its life cycle, making them obligate intracellular parasites. Viral morphology consists of a DNA or RNA segment encircled by a protein coat, with or without the presence of a viral membrane. The virus attaches to a receptor on the host cell membrane by use of specific proteins on its protein or membrane coat. This specificity determines which host cell the viral DNA can enter. Replication inside the host cell causes biochemical and structural changes to the host cells resulting in cell damage and biochemical issues. The viral life cycle may be either lytic or lysogenic in nature, with the lytic cycle resulting in cell death following viral reproduction e.g. influenza viruses, and the lysogenic resulting in permanent insertion of viral genetic material into the host DNA (proviruses) e.g. herpes virus. Exposure to pathogenic viral species can result in acute or chronic infection and their transmission may be horizontal (transmission after birth), vertical (mother to developing foetus) or both as seen with bovine viral disease (BVD). Infection is typically via the following routes: the respiratory, gastrointestinal, genital tract or transdermal. Viruses spread extracellularly and systemically via the bloodstream, subsequent excretion is via blood (systemic viruses), the respiratory, gastrointestinal and urogenital tracts [28]. There are many viral zoonotic species as listed in table 3 which are livestock pathogens. Zoonotic transmission from animal to humans occurs by direct contact e.g. handling of faecal matter (enteric viruses e.g. NSDV) or airborne transmission (respiratory viruses e.g. H1N1) from close proximity. Following infection with the viral species the host may be asymptomatic or manifest with mild symptoms or severe disease which may be fatal e.g. Ebola virus or persist for extended periods of time e.g. HIV. Another viral species relevant to both cattle and humans is the picornavirus FMD virus, the causative agent of food and mouth disease. Viral virulence factors are essential for intracellular replication and avoidance of the host immune system following infection. The innate immune response of the host plays an important role in defence from invading viral species, specifically cytokines e.g. interferon and chemokines which initiate the adaptive system. However, in acute respiratory infections e.g. H1N1 influenza an extreme innate response can lead to local tissue damage which in turn hinders the adaptive response [29]. Viruses can be excreted by clinically and sub-clinically infected reservoirs into the environment in large numbers where they reside in a dormant state. Survival in the environment awaiting host transmission is a leading factor contributing to their pathogenicity and virulence. Additionally, due to their ability for genetic change and adaptation, viral pathogens have a wide range of hosts and carrier species. Mutations and re-assortment of their own genomes creates complex and phenotypically varied viral subspecies which are capable of crossing species barriers e.g. H1N1. It is these mutations that allow viruses to move from dead end host species in which they cannot reproduce to suitable hosts often having picked up additional genetic information on route. Infectious dose is an important factor in viral pathogenicity as it varies between species, subspecies and for the varying hosts/reservoirs. Viral reproduction and the spread of viral disease are directly related to the infectious dose resulting in either clinical or subclinical infections. Additionally, knowledge of ID is important as the concentration of viruses in the environment can be diluted by natural die-off and other factors e.g. water. Viral species tend to vary in their infectious dose depending on the route of entry e.g. the faecal oral route of HEV in pigs has a higher infectious dose than via the blood route [30].

The host

Host factors relating to susceptibility to viral infection include the age, sex, immune response, disease status and geographical location of the host. Immunocompromised persons such as AIDs and cancer patients, neonates and pregnant women are more susceptible to viral infection with increased manifestations of symptoms. Additionally, genetic susceptibility has also been shown to contribute to clinical

Viral family	Virus	Livestock	Disease	Zoonotic information	Reference
Hepeviridae	Swine HEV	Pigs	Hepatitis	Emerging zoonotic	[31] [32]
Filoviridae	Ebola virus,	Pigs	Haemorrhagic fever	None recorded	[11]
Paramyxovirus	Nipah virus	Pigs	Encephalitis	Yes Malaysia 1 999	[1] [14]
Picornaviridae	Foot and Mouth Disease virus	Cattle, sheep	Hoof/Foot and mouth disease (Aphthae epizooticae)	Yes UK 1966	[33]
Flaviviridae	Classical swine fever virus (CSFV)	Pig	Swine fever	None recorded	CDC, 2018
	Bovine viral diarrhoea virus (BVDV)	Cattle	Respiratory disease - mucous lining, fertility, still birth	None recorded	
Paramyxoviridae	Peste des petits ruminants virus (PPRV)	Sheep, Goats	Nose and eye ulceration, discharge, dyspnea, necrotic stomatitis	None recorded	[34]
	Bovine respiratory syncytial virus (BRSV)	Cattle	Respiratory tract infections		[35]
	Hendra virus	Horses	Fatal, respiratory or neurological disease	Yes Australia 2008	[14]
Bunyaviridae	Nairobi sheep disease virus (NSDV)	Sheep, Goats	Abortion, fatal, hemorrhagic gastroenteritis	None recorded	
Orthomyxoviridae	Influenza A H1N1 virus	Pigs	Respiratory disease	Potentially zoonotic, Reverse zoonotic	[36]
Poxviridae	Parapoxvirus	Sheep	Orf disease/contagious pustular dermatitis	Yes Iran 2016	[11] [37]
	Bovine papular stomatitis virus	Cattle	Contagious ecthyma and pseudo-cowpox	Yes milker's nodules in humans	[38]
	Paravaccinia virus	Cattle	Pseudocowpox		
	Orthopoxviruses Cowpox virus	Cattle	Cowpox	Yes Human smallpox	[39]

Table 3: *Viral diseases of livestock, zoonosis information and disease manifestations.*

infection. The identification of the genetic factors of individual hosts which influence their susceptibility to infection has allowed for studies on host mechanisms of infection. Similarly, new-born and infant animals are more prone to viral infection with shedding of excessive numbers of viruses. Viral infections of livestock can have a major impact on the general health of the herd from respiratory disease (H1N1, BRSV), encephalitis (Nipah virus) and/or gastroenteritis (NSDV) as well as causing significant economic losses resulting from reduced milk yields, decreased fertility or abortions (BVD virus), growth retardation due to malnutrition and an increased vulnerability to secondary infections. BVDV is a viral species which is having such an on-going impact, partly as it can affect the bovine reproductive system in several ways: transmission in male semen, decreased fertility and ovarian dysfunction in females, stillbirths and the birth of persistently infected immunotolerant calves. Such offspring are undersized and can shed the virus over their entire (albeit shorter) lifespan in all bodily excretions or vertically if they live to reproductive age. Following viral infection and the initiation of the host immune system antibodies are produced and can be used to determine rates of infection for viral species in animals. The presence of antibodies in the absence of clinical symptoms of disease, suggests that the animal is a carrier and this is an important factor to consider in controlling incidents of outbreaks. Host vaccination is available for numerous zoonotic viruses e.g. FMDV however, such animals may still act as carriers if the viruses can still reproduce sub-clinically. The presence of other infections or co-morbidities in the host can also contribute to viral virulence. Co-morbidities or the use of therapeutics can hinder the host immunological response limiting the capability of the host immune system to eradicate pathogenic species. It is vital to understand the effect of multi species interaction (e.g. viral, bacterial or parasite) in the host in order to determine optimal treatment and control strategies. Particularly, as evidence is mounting which suggests that multiple infections contribute significantly to the severity of infections such as HIV [40].

The environment

From an environmental aspect viruses play an important role in killing bacterial species, diatoms and cyanobacteria therefore, maintaining carbon dioxide levels and nutrient recycling [41]. Their presence in the environment varies depending on geological location and its subsequent climate. For example, The Hendra virus (HeV) and Nipah virus (NiV) have materialized as bovine zoonotic species in Australia and south East Asia but are not endemic in Europe. These species are both extremely contagious, virulent and potentially fatal. Having a broad range of host species and a lack of drug therapy and vaccine options means both species are classed as biosafety level 4 pathogens. Viruses which are excreted by the faecal-oral route (amongst others) by their varying reservoirs particularly in stable non-enveloped form can persist in the environment until uptake by a suitable host. Animal management and husbandry practices serve as the best option for control of herd infection rates particularly isolation of sick animals. Viral species tend to be highly resistant to disinfection chemicals and current sewage treatment options. This is important in relation to enteric viruses which are present in wastewater, agri runoff and manure fertilizer as they are more adapted to survive in harsh environmental conditions [42]. While animal husbandry is vital to control viral outbreaks it is important to note that many non-domestic or wild animals are also reservoirs or carriers of these pathogens. Both the Ebola and Nipah virus encephalitis outbreaks are an example of how wildlife carriers are an important risk to global public health safety and security. Temperature is important given that viruses can survive in lower environmental temperatures outside the host. Wind and land topography is also a significant factor in the transmission of viral particles as they can be carried across water bodies and land masses to adjacent or non-adjacent countries. The growing human population and human practices increasing contact between diverse animal hosts [43] has also contributed to the increasing number of viruses having zoonotic potential. Climate change, an increase in agriculture and the need for more food sources and livestock across the globe is also a major factor leading to the emergence of new viruses such as the Middle East respiratory syndrome coronavirus (MERS-CoV) [29].

Routes of transmission of zoonotic pathogens

Typically, the transmission of any pathogenic species to humans may be from one of three general zoonotic routes, depending on the life cycle and environmental survivability of the organisms. Numerous parasitic species are capable of surviving in harsh conditions outside of their host environment for extensive amounts of time e.g. *Giardia, Cryptosporidium, Mycobacterium* sp. The extensive shedding of pathogenic species by numerous and various animal hosts suggests that large quantities of viable and potentially infectious parasites are present in the aquatic environment and soil at any given time. Studies have shown that clinically and sub-clinically infected hosts excrete parasites or their life cycle stages in variable numbers into the environment, depending on the infected animal, the parasitic species and the manifestations of infection [44]. Furthermore, the organism can survive for prolonged periods of time in agricultural slurry, run off and consequently in the wider environment where they exist in a dormant form of some type e.g. *Cryptosporidium* oocysts and nematode eggs. Waterborne transmission is therefore a significant risk following contamination of surface waters including lakes and rivers with a potential for drinking water contamination as a result [15]. Foodborne transmission of zoonotic pathogens occurs primarily from the consumption of contaminated foodstuff e.g. meat containing nematode eggs, but can also occur from washing food with contaminated water which may contain bovine excreted pathogens e.g. *Cryptosporidium*. Foodborne transmission can also occur from the production of food products at any level such as farming, processing and packaging of foods where person become infected from handling contaminated food (Table 1). Animal-to-human transmission can occur in situations whereby people come into close contact with infected animals or their faeces. Such situations include persons in employment where exposure to animal faeces is inevitable such as farmers, zoo workers and persons employed in veterinary practices.

Management of zoonotic disease in the European Union

The European legislation relating to zoonotic disease, zoonotic food pollution and veterinary public health include regulation (EC) No 999/2001 (BSE) and regulations (EC) No 853/2004, No 854/2004 and (EU) No 2015/1375) for meat contamination with parasitic species. In 2003 the legislation was updated to detail measures for the control and monitoring of zoonotic disease and includes regulation (EC) 2160/2003 on control measures and Directive 2003/99/EC on monitoring zoonotic pathogens. The European Food Safety Authority (EFSA) in partnership with the European Centre for Disease Prevention and Control (ECDC) produces annual reports on the incidence of zoonosis. The "farm to fork" food safety approach initiated by the EFSA involves risk assessment, risk management and risk communication measures which are undertaken by all EU member states, the European Commission and Parliament and the ECDC to protect public health safety. As part of the European Union, all members must comply with the legislation as stipulated in these regulations and adhere to European laws relating to the monitoring, control and elimination of zoonotic disease. Globally, the Codex Alimentarius which was set up by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organisation (WHO) to combat food pollution at all levels. The Codex Alimentarius which includes 187 Member States and the EU aims to institute harmonized international standards to protect public health safety and guarantee fair agricultural trade amongst its members. Due to their pathogenicity, contagious nature and huge economic impact many zoonotic diseases are classified as notifiable diseases, meaning that any case of infection must be notified to the relevant authority. Individual countries within the EU have determined which infectious species are relevant and notifiable for that member state, based on risk assessment and risk analysis. The Infectious Diseases Regulations 2016 requires that any medical persons or those responsible for public health safety must notify the relevant authority of an incidence of infection so that data can be gathered, analysed and control measures implemented. Notifiable diseases of bovine parasitic zoonotic origin typically include FMD, BSE/CJD, Cryptosporidiosis, Smallpox, Toxoplasmosis, Trichinosis, Trichinella and Tuberculosis. It is vital to be aware that not all zoonotic pathogens are notifiable in all countries, meaning that it is possible for pathogens to go undetected, particularly important in terms of trade amongst member states within the EU. Prompt detection of infection in all host species is essential to control the transmission of the pathogens. Diagnostic testing for specific parasitic species currently relies on faecal smears, fluorescent staining, PCR detection, antigen based detection systems and enzyme-linked immunosorbent assay (ELISA). Samples can be taken from faecal deposits and by filtering (> 100 litres) of contaminated water to determine if the parasite is present. Control measures to prevent zoonotic outbreaks relate to careful monitoring of food products throughout the food production line. Food production must adhere strictly to Good Manufacturing Practice (GMP) and follow the hazard analysis critical control point (HACCP) guide documents. Effective suitable disinfection procedures must be in place from "farm to fork" to prevent contamination of the food chain. At a farm level proper sewage disposal and control of agricultural runoff is essential (*Cryptosporidium, Giardia*, helminthic eggs) including the use of faecal matter as a fertilizer. At an individual level, adequate hand washing and farm employee's personal hygiene is also critical. As an important route of transmission for many species is contaminated or undercooked food, proper pasteurisation of milk (e.g. TB) and cooking (e.g. helminths in meat) is also an essential control measure. Regular monitoring and risk assessment of herds is essential to determine levels of parasite infections e.g. blood tests conducted by veterinary personnel for TB. Proper diagnosis and treatment of bovine infestations is essential with administration of the best available therapeutic options e.g. triclabendazole for trematode species, nitroimidazoles for giardiasis. In certain situations, isolation or even culling/slaughter of herds and removal of specified risk material (SRM) from markets (e.g. potentially prion infected meat) is required to reduce the risk of zoonotic outbreaks. This is typical in cases where incidents of TB, BSE and foot and mouth are evident, where control measures are also implemented at a national level on the import and export of livestock. In BSE-infected cattle, the prion protein is also found in the nerves of peripheral system (as well as the central nervous system) and so the entire body of the infected animal must be disposed of according to the EU regulation. All culling of herds must adhere to the EU Council Regulation (EC) N° 1099/2009 which was implemented in 2013 to ensure ethical sacrificing of livestock animals.

Summary

Zoonotic disease transmission is significant burden both in terms of economic impact and human health. These infections are caused by a wide variety of organisms including bacteria (e.g. *Mycobacterium*), viruses (e.g. BVD), parasites (e.g. *Cryptosporidium*), helminths (e.g. nematodes) and other agents such as prions (e.g. BSE). Viral pathogens particularly represent a significant challenge due to their varied host range, resilience in the natural environment, genetic adaptability and resistant to chemical disinfection. Viral infections in both human and livestock species present a huge economic burden as well as causing often severe cases of morbidity and/or mortality. The ability of these pathogens to cross species barriers due to genetic adaptability, to interrupt the host immune system and their huge excretion rates allows for their virulence. Host factors such as age, sex and immune status is of significant importance as they directly influence the ability of the host to fight infection. The increasing population and demands for agriculture has influenced the emergence or re-emergence of zoonotic pathogens. Increasing pressure is put on agriculture and aquaculture to supply high protein foods using intensive farming conditions, resulting in the spread of zoonotic disease globally. The impact of climate change on agriculture and the spread of zoonosis is also a concern and is an area needing immediate investigation. Environmental influences such as temperature, wind and land topography also support the transmission of species within countries and across borders. The study of microbial pathogenesis and virulence is essential in a One Health approach to control emerging and re-emerging zoonotic diseases. Microbial evolution, mutation, immune triggers and transmission are all vital topics which must be investigated, to reduce and limit both animal and human incidents of disease.

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