Parasites in Food Chains

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Abstract

While in high-income countries, the majority of people die from non-communicable, chronic conditions, nearly 40% of deaths in developing countries are among children under 15 years. Diarrhoea is among the top 10 leading causes of death and many cases are caused by pathogens transmitted in food and water supplies. This paper introduces major representatives of foodborne parasites and aims to show why they are no longer a public health concern of low-income countries only. Approaches used in assessing and managing the risk of foodborne parasitoses will be presented.

1. Diseases in complex food production systems

In high-income countries approximately 70% of people die above the age of 70 years, mostly due to non-communicable, chronic conditions such as cardiovascular diseases. Foodborne infections caused illness in 12.5% (4 million) Canadians in 2006 and 16.7% (48 million) Americans in 2011. In these countries, the majority of disease cases are caused by unknown agents and the top four identified pathogens are *Norovirus*, non-typhoidal *Salmonella*, *Clostridium perfringens* and *Campylobacter* species [1,2]. In low-income countries, nearly 40% of deaths are among children under 15 years of age. People die mostly of infectious diseases (i.e. lower respiratory infections, HIV/AIDS, malaria, diarrhoea and tuberculosis). Diarrhoea is among the top 10 leading causes of death in lower-middle income countries, killing 1.5 million people in 2012 (Word Health Organization 2014). Many of these deaths are caused by pathogens transmitted to humans in food and water supplies [3].

Human food from both plants and animals is produced, processed and marketed in intricately linked systems of primary producers (i.e. corn or cattle), input and service providers (i.e. pesticides, water and veterinary drugs), transporters, processors, wholesalers, retailers, consumers and end-users of by-products (i.e. manure). Foodborne diseases are conditions that are commonly transmitted through ingested food and comprise a broad range

of illnesses caused by enteric pathogens, parasites, chemical contaminants and biotoxins which are either naturally present in food (i.e. cyanogens in cassava) or contaminate food at different points in the food production and preparation process [4].

Humans harbour about 300 species of helminths and over 70 species of protozoa; many are transmitted by food and water [5]. According to the International Classification of Diseases, eight out of the 21 aetiological causes of death due to potentially foodborne diseases are caused by parasites [4], especially protozoa and cestodes. The complex life cycle involving different development stages inside one or several hosts and/or the environment allows entry of stages infectious to humans at any point of the food chain. Foodborne parasites are acquired by ingesting infectious stages in tissue of infected mammals, fish and even invertebrates as well as contaminated food and water supplies or via contaminated fomites or fingers. Many parasitic diseases have traditionally been considered confined to tropical countries and of little concern to wealthy countries [6] but this perception is slowly changing. *Toxoplasma gondii*, the only parasite in a 2011 ranking of important foodborne pathogens, was identified as the second most important pathogen causing death from foodborne infection in the United States of America in 2011 [2]. In 1993 an outbreak with an estimated 403,000 cases of watery diarrhoea due to cryptosporidiosis from a single source of contaminated water was reported in Milwaukee in the United States of America [7]. Globalized trade [8] and travel [9] increases the risk of imported parasitoses from tropical countries.

2. Selected parasites in food chains

From an initial list of foodborne diseases, a list of priority foodborne parasitic diseases was established [4,10] including protozoa and nematodes (both foodborne and intestinal) as well as foodborne trematodes and cestodes. This section introduces these groups of foodborne parasites. Microsporidia, the topic of this meeting, are known to enter the food chain through waterborne routes but microsporidiosis is also a potential emerging meatborne zoonosis, given that natural hosts of human infective microsporidia can be part of the human food chain. Pleistophora-like microsporidians, may be acquired from raw or lightly cooked fish or crustaceans [11]. The potential of pigs as a reservoir for *Enterocytozoon bieneusi* has been discussed in Czech Republic [12]. Currently, microsporidiosis is not considered a priority foodborne parasitosis.

Intestinal protozoa: The three main representatives of this group are *Giardia*, *Entamoeba* and *Cryptosporidium* spp. with the highest median prevalence of *Entamoeba* and *Giardia* in the Americas, whereas Africa had the highest for *Cryptosporidium* with highest health

burdens in children below 15 years of age [13]. The most important source of infection for humans is attributed to contaminated drinking water [13]. In low- and middle-income countries, approximately 200 million people suffer from symptomatic giardiasis with about 500,000 new cases reported each year [14], while the number of reported human cases in the United States of America remained constant around 20,000 per year [15]. The epidemiology of zoonotic *Giardia* spp. is still under debate [14,16].

Cryptosporidiosis is a major cause of diarrhoea in humans, globally and attributed to water, food and contact with infected animals [11]. It is a particular problem in immunocompromised people. The major zoonotic species is *C. parvum* and main transmission routes include water and fruit and raw vegetables contaminated with infectious faeces from humans or animals, or shellfish such as oysters and mussels [17]. Even though Africa has the highest burden of cryptosporidiosis, the proportion of zoonotic cryptosporidiosis seems to be highest in high-income countries [18].

Intestinal nematodes: *Ascaris lumbricoides*, a gastrointestinal nematode of humans, enters the food chain through contaminated water and soil. The consumption of raw vegetables and fresh fruit contaminated with soil are major sources of infection. Whether *Ascaris lumbricoides* and *A. suum* are identical and/or cross-transmissible between humans and pigs [19] is still being researched. Acute health problems in humans arise from intestinal obstruction but chronic infections may have a much more important impact as they are associated with (reversible) deficits in growth and physical fitness in children and possibly impaired cognition [20].

Foodborne protozoa: Toxoplasmosis, caused by *Toxoplasma gondii*, is a major zoonosis with a global distribution. Humans can become infected by ingesting oocysts (e.g. in contaminated water, food or soil) shed by cats or by consuming undercooked meat containing viable bradyzoites. Perhaps more than 50% of the cases of toxoplasmosis can be attributed to the latter transmission route [13]. Maternal infection for the first time during pregnancy can cause foetal or newborn death or congenital abnormalities such as hydrocephalus or chorioretinitis. Non-congenital toxoplasmosis poses a serious threat to immunocompromised patients but has been considered an asymptomatic or mild flu-like illness in otherwise healthy individuals but with lifelong infectivity. Increasingly, this is debated and seropositivity linked to behavioural changes and mental disorders [21–24].

Foodborne trematodes: The group consists of *Fasciola*, *Opisthorchis* and *Clonorchis* spp. Fasciolosis is a true zoonoses with cattle and sheep being the main reservoir for human

disease but pigs, goats, dogs, alpacas, llamas and rats can also serve as the definite host [14]. Snails are recognized as the intermediate host of *F. hepatica* in temperate climates and *F. gigantica* in tropical climates. Transmission to definite hosts occurs by ingestion of infectious stages in water or on plants. *Opisthorchis* and *Clonorchis* spp. are parasitoses of mammals eating raw or undercooked freshwater fish. Infections in humans are usually asymptomatic but symptoms increase depending on the infection dose and range from fever, fatigue, rash and gastrointestinal disorders to inflammations of the liver and bile duct system, liver abscesses or cirrhosis and pancreatitis with the most serious consequence being cholangiocarcinoma. Approximately 56 million people are infected with foodborne trematodes. Of these, approximately 7.9 million (14%) have severe sequelae with approximately 7158 deaths per year. The highest health burden (i.e. neoplasms) is caused by *Clonorchis sinensis* and *Opisthorchis viverrini* and occurs in East and Southeast Asia and the Asia Pacific regions; it is mostly caused by the ingestion of contaminated food [13].

Foodborne cestodes: Larval stages of the cestodes *Echinococcus* and *Taenia* spp. cause potentially fatal diseases of humans. Taeniasis in humans, the final host of *T. solium*, is caused by ingesting parasite cysts from eating undercooked pork and results in mild non-specific gastrointestinal illness [3]. Neurocysticercosis (NCC) in humans is caused when *T. solium* cysts lodge in the brain, a consequence of autoinfection when humans ingest eggs shed by adult worms in human guts. NCC is responsible for 29% of epilepsy patients [20] and transmission by eating undercooked pork is vital for maintaining the parasite's life cycle. Previously considered a disease of developing countries, neurocysticercosis has increasingly been imported to North America from endemic countries [25]. Larval echinococcosis in humans is caused if they ingest eggs from contaminated water or raw vegetables. *E. granulosus* causes cyst formation in the liver, lungs or other organ system (cystic echinococcosis) in livestock and humans with dogs as definite hosts and is widely endemic [26], while alveolar echinococcosis in humans is caused by the fox tapeworm *E. multilocularis* and causes serious infiltrative growth of metacestodes in the liver with ultimate liver failure as humans are aberrant intermediate hosts [27]. *E. multilocularis* is increasingly found in dogs [28] and strains previously found in Europe have travelled to Canada [29].

Foodborne nematodes: Human trichinellosis, caused by *Trichinella* spp., is found worldwide except for the Antarctic. It is a direct foodborne zoonosis and is acquired by ingesting infectious larvae with raw or undercooked meat, especially pork from organic or extensive farms, and game meat. While asymptomatic in animals, disease symptoms in humans can range from diarrhoea, periorbital and facial oedema, myalgia, fever, photophobia, headache, conjunctivitis and skin rash to life-threatening conditions such as

myocarditis or meningoencephalitis [30]. While control measures in industrialized countries seem to be disproportional considering the relatively low burden on human health, data on the human health burden from potential hotspots in Asia and Africa are still lacking.

3. The global burden of foodborne parasitic diseases

The full extent and cost of unsafe food, especially the burden from chemical and parasitic contaminants, is largely unknown but estimates are improving [4]. In 2013, one million deaths were caused by parasitic diseases, approximately 60,000 through potentially foodborne parasitic diseases [31]. With more reliable data on the burden of disease, policymakers can prioritize government action and assess the effectiveness of interventions, in both monetary and non-monetary terms. In 2006, the World Health Organization mandated a Foodborne Disease Burden Epidemiology Reference Group (FERG) including a parasitic diseases taskforce which is assessing health burden using the Disability-Adjusted Life Year (DALY). DALYs express the years of life lost due to premature death and the years lived with disability for varying degrees of severity, making time the common metric for death and disability [4]. The most recent update on the global burden of foodborne parasitic diseases was compiled by Torgerson and colleagues [13,14]; an adapted summary is given below (Table 1) and a comprehensive final report will be published by the end of 2015.

Table 1: Possible magnitude of annual global burden of selected foodborne parasitic diseases

Foodborne parasitic disease	Possible global burden (DALYs)	Animal health costs	Trends/ remarks	Reference
Intestinal protozoa: *Giardia*, *Entamoeba* and *Cryptosporidium* spp.	? x 10^5-10^6	Unknown, but likely to be high		[14]
Intestinal nematodes: *Ascaris lumbricoides*	1.3 x 10^6	Likely high if infective for pigs	Highest burden on children aged 5-15 years	[13,19,35]
Foodborne protozoa: *Toxoplasma gondii*	2-8 x 10^6	Possibly substantial	New sequelae are being assigned to toxoplasmosis; highest burden in South America, some Middle Eastern and low-income countries	[14,36]
Foodborne trematodes: *Fasciola*, *Opisthorchis*, *Clonorchis* spp.	>0.5 x 10^6	Animal fasciolosis is very high	Increasing reports; highest health burden (i.e. neoplasms) is caused by *Clonorchis sinensis* and *Opisthorchis viverrini* and occurs in East and Southeast Asia and the Asia Pacific regions. The major proportion is caused by ingestion of contaminated food	[13,14,37]
Foodborne nematodes: *Trichinella* spp.	?	Control programs are a large financial burden	Data on burden on human health in developing countries are lacking	[38]
Foodborne cestodes: *Echinococcus* spp. *Taenia solium*	2-5 x 10^7 2-5 x 10^6	US$2 x 10^9 Unknown	Burden AE highest in China with rising incidence in Central Asia and Europe Assumes ca. 30% of epilepsy in low income countries due to NCC	[13,14,26,27] [13]
For comparison: HIV Malaria Tuberculosis	 59 x 10^6 34 x 10^6 34 x 10^6			[39]

Adapted from Torgerson et al. (2011) [14]

4. Approaches in assessing and managing the risk of foodborne parasitic diseases

The International Livestock Research Institute (ILRI) makes use of three approaches in researching parasites in food chains: One Health/ecohealth concepts, integrated livestock and fish value chain assessments and participatory epidemiology. The One Health and ecohealth concepts acknowledge that the health of humans is connected to the health of animals and the environment, which is particularly true for zoonotic diseases, and prompts us to work interdisciplinarily with veterinarians, physicians, ecologists, statisticians and economists. We are attempting to understand zoonotic disease transmission patterns and predict and manage disease in the face of global challenges such as population growth, migration of people into new ecological regions, changes in husbandry practices, globalized trade and tourism, all of which increase the frequency of interfaces between parasite reservoirs and hosts which are particularly complex with parasitic life cycles. The CGIAR Research Program on Livestock and Fish, led by ILRI, sees value chain assessment and innovation as a key strategy [32]. ILRI's food safety research under the CGIAR Research Program on Agriculture for Nutrition and Health integrates risk analysis tools for food safety into the program's value chain transformation approach. Participatory epidemiology is a branch of veterinary epidemiology based on the principles and methods of participatory rural appraisal, discussing animal health problems in a given community [33]. In veterinary public health it has proven to be a fast and relatively affordable way of identifying zoonotic and foodborne risks to public health, a methodology developed by ILRI and partners and dubbed 'participatory risk assessment' (ILRI Safe Food, Fair Food project 2008-2011) [34].

Concluding remarks and future directions

Foodborne parasitic diseases are no longer mainly confined to low-income countries but are emerging with globalized migration, trade and tourism. The lack of human health data in developing countries, under-reporting and difficulties in source attribution due to the nature of parasitic diseases (time between exposure and clinical signs) make it difficult to comprehend the true extent of the burden and may lead to under-estimation and under-prioritization of parasitoses. Assessment and management of foodborne parasitoses warrant a One Health and food chain systems approach in developing countries supported by means of participatory epidemiology.

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