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Changing dietary habits in a changing world: Emerging drivers for the transmission of foodborne parasitic zoonoses

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ABSTRACT

Changing eating habits, population growth and movements, global trade of foodstuff, changes in food production systems, climate change, increased awareness and better diagnostic tools are some of the main drivers affecting the emergence or re-emergence of many foodborne parasitic diseases in recent years. In particular, the increasing demand for exotic and raw food is one of the reasons why reports of foodborne infections, and especially waterborne parasitosis, have increased in the last years. Moreover increasing global demand for protein of animal origin has led to certain farming practices (e.g. aquaculture) increasing in emerging or developing countries, where health monitoring may not be sufficiently implemented. Therefore, high quality epidemiological data are needed which together with biological, economic, social and cultural variables should be taken into account when setting control programs for these increasingly popular production systems in emerging economies. This review focuses on the dietary, social, economic and environmental changes that may cause an increase in human exposure to foodborne parasites. Some examples illustrating these new epidemiological dynamics of transmission foodborne parasitic disease are presented.

1. Introduction

Disease emergence or re-emergence is often the consequence of societal and technological change and manifests frequently in an unexpected and unpredictable manner. It has been estimated that among emerging diseases, 75% has zoonotic characteristics (Slingenbergh et al., 2004). In 1992, the Institute of Medicine (IOM) identified six groups of factors influencing the emergence of zoonoses: changes in demographics, changes in technology and industry, increasing international travel and commerce, environmental change and land use, breakdown of public health measures, and microbial adaptation and change (IOM, 1992). Many of these factors may increase the susceptibility of populations to infectious diseases or the exposure to or transmission of infectious agents (Cohen, 2000). Thus, the same six factors can be considered important for zoonotic foodborne diseases, and have received increasing attention over the past few decades. Some of these diseases have been designated as emerging or re-emerging based on either an increase in true prevalence (WHO, 2002), better reporting or improved diagnostics (Dorny et al., 2009).

Prior to 1960, the majority of foodborne gastrointestinal diseases were referred to bacteriological etiological agents; *Salmonella*, *Clostridium botulinum* and *Staphylococcus aureus*. During the 1960s, *Clostridium perfringens*, and *Bacillus cereus* were reported, and during the 1970s, rotavirus and norovirus. In the 1980s and 1990s, *Campylobacter*, *Yersinia*, *Listeria monocytogenes*, new strains of *Escherichia coli* such as O157:H7 and, in particular, parasites such as *Cryptosporidium* and *Cyclospora* were added to the list (Newell et al., 2010). While parasitic infections have received less attention than those caused by

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bacteria, it is known that foodborne parasitic infections such as toxoplasmosis, giardiosis, cysticercosis affect many millions of people worldwide and they are often characterised by having fatal consequences. Although humans may serve as host of around 300 species of parasitic worms and over 70 species of protozoa (Cox, 2002), only around 100 species are known to be foodborne (Orlandi et al., 2002).

Several foodborne helminths and certain protozoa are considered emerging issues and are receiving increasing attention. Improvements in the performance of diagnostic tests may have led to recognition that several foodborne parasites have been underestimated and thereby neglected, but it is also possible that new dietary habits, alternative food production systems, changing global food trade and profound changes in mobility of people might have changed the risk scenarios.

As an example, the globalisation of USA food supply increased substantially during the 1990s, and so did the risk of US consumers to acquire foodborne parasitic infections. In 1990, about 13 species of foodborne parasites were of concern to US authorities, while today, that figure has increased to over 100 (Orlandi et al., 2002).

A range of parasites are well adapted and have coevolved with their hosts so to persist in relationships which may be sub-clinical or even mutualistic in their nature: this would guarantee the survival both of the host and of the parasite populations. This may be true if a population is constantly exposed to a parasite, where young individuals acquire tolerance gradually by, for example, consumption of the “local” contaminated food. Such balance between a foodborne parasitic disease and a host population was usually confined to specific environments and host populations or geographic areas. Nowadays, due to the increased globalisation and movement of people and food commodities, this geographical segregation is not necessarily evident any more (Orlandi et al., 2002).

Human and society behaviour plays a fundamental role in the epidemiology, emergence and spread of parasitic zoonoses. Host-parasite relationships are intricately linked; each component is important and may determine the dynamics and outcome of disease transmission and control (Azim et al., 2008).

During the last decades there have been changes in food preferences and eating habits; there is a growing market for more ready-to-eat fresh and healthy food, as well as novel, ethnic food products, which have created new situations where pathogens may be introduced into food and then to populations (Murphy, 1999). Changes in dietary practice have been recently implicated as a reason for the emergence of several helminth zoonoses including capillariasis, anisakiasis and gnathostomiasis (McCarthy and Moore, 2000). In the past, the consumption of raw or undercooked meat and fish was associated with specific cultures and practices, but with shifting consumer habits, increased international travel, globalisation of food supplies and cosmopolitan eating habits, what once were regarded as rare diseases of discrete geographical distribution are now becoming increasingly more widespread (Slifko et al., 2000).

The multiple drivers that have contributed or are contributing to changing trends in foodborne parasitic diseases include:

- changing eating habits, such as the consumption of raw or lightly cooked food, and the demand for exotic foods, such as bush meat;
- rapid population growth, concentrating in urban areas;
- an increasingly global market in vegetables, fruit, meat, ethnic foods, and even farm animals, some of which originate from countries without appropriate food safety procedures;
- improved transport logistics and conditions, which enable agents to survive on food products and reach the consumer in a viable form;
- an increasingly transient human population carrying its parasitic fauna worldwide;
- the shift from low- to high-protein food consumption as nations develop economically with a concomitant and global greater dependency on meat and fish products;
- higher proportion of immunologically compromised individuals either as a consequence of increasing elderly population or the generation of highly susceptible groups with immunosuppressive diseases or treatments;
- changing farming practices, for example intensification to produce cheaper food or a shift to free-range/organic animal production to respond to consumer welfare concerns;
- social and political upheavals leading to a disorganization of veterinary control and modes of production (Cuperlovic et al., 2005);
- the increasing intrusion of man on native wildlife habitats;
- climate change, for example favouring distribution of intermediate hosts, bringing novel vectors into temperate regions or temperature-associated changes in contamination levels (FAO, 2008).

This paper aims to focus on the dietary, social, economic and environmental changes that may cause an increase in human exposure to foodborne parasites, providing some examples that may shed some light on these new epidemiological dynamics of transmission of parasitic diseases.

2. Changing food habits

In addition to the fundamental availability of a food resource, customs, traditions, cultural and religious beliefs all have significant impact on the choice and preparation of food and consequently the potential exposure to foodborne parasitic agents.

Throughout history, different societies have exhibited great variations in diet. Nevertheless, during the 20th century, the relative high level of welfare in certain countries, the profound increase in world trade and improved means of communications have facilitated major changes in the variety of local diets and food preparation. At the same time, both human population growth and rising incomes have driven increasing demand for animal source foods and exotic foods.

There are nowadays, mainly in the high-income regions, some emerging food fashions and trends that may favour the transmission of foodborne parasites. An increasing number of consumers is now searching for exotic products (e.g. crocodile meat in Scandinavia), or season products all year round, which are now easily available on our tables because of global trade (e.g. strawberries during winter). The media play a role in increasing the exposure to 'exotic foods' and their growing popularity has broadened national eating habits. During the 1950s, the average supermarket in the USA had about 300 food items available on display, whereas over 3000 choices are exhibited today, originating from many different parts of the world where different species of parasitic zoonoses may be common (Macpherson, 2005). Even in some low-income regions, transition into new food production systems (e.g. rapid growth of pig production in Africa, aquaculture in Asia) may favour the transmission of foodborne parasites.

In addition, people more often consume raw or undercooked foods in the so called street-food restaurants or take-away, that do not always respect food safety standards (WHO, 2002). At the same time, there is an increasing interest for healthy and ready-to-eat products, such as ready-to-eat salads. Soft fruit and salad vegetables increase both the likelihood of surface contamination and the survival of the infective stages of parasites pathogenic to man (Slifko et al., 2000).

Moreover, the increased awareness of healthy dietary regimes to prevent cardiovascular disease and cancer has raised fish consumption (including fish oil, omega-3 fatty acids), which has led to more aquaculture products from Asian markets (where many fishborne parasites are endemic) being now globally traded and consumed.

Fish meat may indeed be the vehicle for different parasite species, and the new dietary habits linked to the higher demand for fish in many countries, in particular for saltwater fish, have favoured the exposure to fishborne parasites. Considering saltwater fishborne parasites, an important example is represented by anisakids (parasites of the genera *Anisakis*, *Pseudoterranova*, *Phocascaris*, and *Contracaecum*, with the species of major public health interest being *Anisakis simplex* and *Pseudoterranova decipiens*), which are the main marine fishborne parasite of public health importance. Human infection occurs through ingestion of raw fish containing infective larval stages that invade the gastrointestinal tract and lead to eosinophilic granuloma formation in the mucosa with potentially severe symptoms of disease, including anaphylaxis.

Although the first case of anisakid infection was described by Leuckart in Greenland in 1876, the disease was more widely described in the 1950s and 1960s when epidemics of anisakiasis occurred in the Netherlands following ingestion of "green" (i.e. lightly salted) herring (154 proven cases between 1955 and 1968 (Van Thiel et al., 1962)). Of the approximately 20,000 cases of anisakiasis reported to date worldwide, over 90% are from Japan (where approximately 2000 cases are diagnosed annually), with most of the rest from Spain, the Netherlands and Germany (Audicana et al., 2002; Bouree et al., 1995).

Over the last 30 years, there has been a marked increase in the reported prevalence of anisakiasis throughout the world. This increase is probably due to more widespread application of diagnostic techniques, particularly endoscopy (previously many cases of gastric anisakiasis were probably misdiagnosed (Oshima, 1987)), but also to the increasing global demand for seafood, a growing preference for raw or lightly cooked food, especially in many Western countries, with increased risk of parasite exposure (McCarthy and Moore, 2000). For this reason the European laws require a compulsory freezing treatment at −20 °C for not less than 24 h for fishery products to be consumed raw (Reg. EC No 853/2004).

The amount of raw fish dishes consumed in Western countries has increased dramatically in recent years, e.g. in the USA, sushi consumption at restaurant increased 40% in the past five years according to the US National Restaurant Association. This has led to the recognition of *Anisakis* infection in ethnic groups who otherwise would not have been exposed. As noted in other settings, the skill and vigilance of those preparing the fish for consumption along with awareness of food safety regulations (freezing for defined periods of time) has a marked impact on the danger of eating the food. It has been suggested that sushi prepared commercially is safer than the same food prepared at home by an inexperienced cook (Schantz, 1989), but most likely this relates to awareness of regulations.

Typically, sushi and sashimi are spiced up by different ingredients (ginger, wasabi, etc.) which are traditionally believed to inactivate anisakids larvae. Shogaol and gingerol extracted from ginger (*Zingiber officinale*), as well as components of *Perilla* leaves are able to kill *A. simplex* under experimental conditions (Goto et al., 1990; Hierro et al., 2004, 2006). In soy sauce the larvae may resist up to 18 h (Sakanari and McKerrow, 1989). The commercial paste of wasabi (*Eutrema wasabi*) or a 5% solution may destroy the larvae in 2 h (Jofre et al., 2008). Although such spices may have a direct effect on the parasite in an experimental setup, the minute quantities deposited on the surface of the sushi may not have any effect on the larvae inside the fish flesh.

Some authors argue that the risk of infection with fishborne parasites by dining at Japanese restaurants and sushi bars is low. In these, raw fish based foods are preferentially, although not exclusively, prepared from relatively expensive marine fish such as tuna, yellow tail, red snapper, and flatfish/flounder which have lower prevalence of *Anisakis* larvae than other popular marine fish, such as cod, herring, mackerel. Except for *Anisakis* and *Dyphillobothrium latum*, marine fish do not usually harbour a broad range of parasite species of public health importance (Nawa et al., 2005).

Apart from sushi and sashimi, the increased interest in traditional European raw fish preparations may also contribute to the spread of anisakiasis. Examples of different specialities in European countries which, if not adequately treated, may be at risk for *Anisakis* infection are salted herring, marinated anchovies (It. *alici marinate*; Sp. *boquerones en vinagre*), gravlax (fermented salmon), *Rollmops* (marinated herring), *nieuwe* (herring), bloater and kipper (whole, salted in brine, cold smoked herring) (EFSA, 2010).

In Latin American counties, such as Mexico and Chile, the source of infection may be mainly "ceviche", a very popular dish in Central and South America, typically made from fresh raw fish marinated in lemon or lime juices and spiced with chilli peppers (Laffon-Leal et al., 2000), whereas in Brazil it seems to be more linked to consumption of smoked fish (Mercado et al., 1997, 2001).

Some food habits that may increase exposure to fishborne parasitic infection through fish can be also related to superstitious credence. In Asia attention should be paid in consuming local ethnic dishes prepared from local freshwater or brackish-water fish and wild animal meats, which are often consumed raw as sashimi (Nawa et al., 2005).

In Greenland, where mostly saltwater fish is consumed and often semi-dried, a seroepidemiological survey in an Inuit community for anisakid infection, suggested an age-related effect, with an overall 4.7% prevalence, but a prevalence over 10% in people over 40 years of age (Moller et al., 2007).

An important issue related to food habits and anisakiasis is that in recent years it has been recognised that the infection may be followed by a food allergic response. The onset of allergic urticaria and anaphylactoid syndromes associated with gastrointestinal infection by *A. simplex* was first described in Japan (Kasuya et al., 1990). Subsequently, this parasite was identified as an etiological agent of other allergic reactions mediated by IgE (Audicana et al., 1995). Following these initial descriptions, Spanish allergists became aware of this newly described syndrome and a series of reports after 1995 described cases involving clinical symptoms ranging from isolated angioedema and urticaria to life-threatening anaphylactic shock (Audicana and Kennedy, 2008).

The antigenicity of the larvae is preserved even after freezing, cold smoking or marinating and may explain why some sensitized patients develop symptoms after ingestion of infested frozen fish and cold-cured dishes (Rodriguez-Mahillo et al., 2008).

Aside from fish eating habits, significant differences of sensitization occurrence between regions could be explained not only by different fish eating habits, but also by different parasite prevalences in the fish consumed. A recent study of anisakids in anchovies revealed a higher prevalence of *A. simplex* in fish from the Atlantic than from the Mediterranean, whereas within the Mediterranean a higher prevalence was found in the Ligurian Sea compared with the Catalan sea (Rello et al., 2009).

The same variation can be found comparing herrings from the North Sea and the Baltic Sea, where the low salinity of the Baltic Sea does not allow the presence of the crustacean intermediate host (*Euphausiacea*) of *Anisakis* and thereby prevents the lifecycle of the parasite (Fagerholm, 1982).

Considering freshwater fish, it is estimated that more than 50 million people are infected with fishborne trematodes worldwide, as a result of the consumption of raw or undercooked freshwater fishery products (Chai et al., 2005). The highest prevalence of these infections is in Southeast and East Asia, but increasing numbers of infections are also being recognised in areas previously considered non-endemic, due largely to increased trade of contaminated fishery products and travel to endemic regions.

A range of trematodes may cause fishborne human disease. Among them, liver flukes belonging to the family Opisthorchiidae are of the highest public health concern (among these *Clonorchis sinensis* and the trematodes belonging to the genus *Opisthorchis* and *Metorchis*).

The prevalence of human liver fluke infections is related to the consumption of raw fish, and the prevalence of infection may vary by age and sex in endemic areas. Examples of major dietary risk factors for liver fluke infection include consumption of rice gruel with slices of raw freshwater fish in southern China and Hong Kong; slices of raw freshwater fish with red pepper sauce in Korea; half roasted or undercooked fish in Guangdong Province; raw shrimps in Fujian Province China (Chen et al., 1994); 'Koi pla' dish consisting of chopped raw fish and local vegetables in north-eastern Thailand and Laos (Rim, 1982).

Recently in Italy there have also been two outbreaks of *Opisthorchis felineus* infection caused by the consumption of tench filets (*Tinca tinca*) from a lake in Italy in 2007 and other four outbreaks between 2003 and 2005. In Italy, raw fish consumption has become more popular in recent years, including some freshwater fish preparations, and these outbreaks reflect this change in eating habits (Armignacco et al., 2008).

The change in eating habits may also be a risk factor for the transmission of *D. latum*, a cestode which is most often reported from humans from the holoarctic region. In Europe, the incidence has declined except in Switzerland, Sweden, Finland and Estonia (Dupouy-Camet and Peduzzi, 2004). Infections by the closely related species *Diphyllobothrium nihonkaiense* have also been linked to the consumption of raw pacific salmon (Arizono et al., 2009). Consumption of raw or insufficiently cooked or marinated fish is the main source of infection with *Diphyllobothrium* spp. for humans. Wild-caught fish prepared in a variety of ways such as for sushi or sashimi may pose a high risk of exposure (Deardorff, 1991). Contamination sources include marinated fish filets in northern Europe, '*carpaccio di persico*' in northern Italy (slices of raw perch fish), and perch (*Perca fluviatilis*) and charr (*Salvelinus alpinus*) consumed raw or undercooked around Lake Leman in Switzerland. Another important factor in introducing or sustaining this parasite is the contamination of the local aquatic environments, e.g. through improperly treated sewage (Dupouy-Camet and Peduzzi, 2004). However, since human diphyllobothriosis is often characterised by mild symptoms, it is not systematically reported and this fact may lead to an underestimation of the prevalence.

The so called minute intestinal flukes of the family Heterophyidae and Echinostomatidae are also parasites transmitted through freshwater fish but also by ingesting snails, frogs, snakes, and even aquatic plants, foods that may be found on the tables in countries of the developed world as a consequence of the shifting of food habits towards "unusual foods". Infections in humans with intestinal flukes are of less clinical importance than diseases caused by liver flukes, but heavy infections occasionally cause serious gastrointestinal symptoms. In Japan it is considered a relevant problem: infection with *Metagonimus yokogawai* is still prevalent because people prefer to eat sushi and sashimi of the locally famous freshwater fish "Ayu" (*Plecoglossus altivelis*). Thus eggs of *M. yokogawai* are the most frequently (10–20%) observed parasite eggs in stool samples of inhabitants of Tokyo (Yamakado, 2004).

Seafood, such as molluscs, crabs, shrimps, is becoming more and more popular in home preparation and for street vendors and it is often consumed raw or slightly marinated. The EU is a big importer of seafood from Asia, in particular from Vietnam. In the first nine months of 2010, the EU imported more than 259,800 tonnes of seafood products from Vietnam, valued over US$ 826.7 million, an increase of 6.3% compared to the previous year (Vietnam Business News, 2010). Seafood may be also a candidate for parasite transmission, although drug residues and bacterial contamination are considered greater health problems in frozen seafood exported to western countries originating from Vietnam. Among the seafood-transmitted parasites, the lung fluke *Paragonimus* spp. may cause severe damage of the lung tissue (EFSA, 2010). Humans, dogs, cats and wild carnivores all act as definitive hosts by eating undercooked or pickled crabs, crayfish or shrimp in which the larval stages (metacercariae) are present. Twenty million people worldwide are infected with *Paragonimus* spp. especially in Asia, Nigeria, Cameroon, Peru and Ecuador. In some areas, particular food preparations of crabs such as pickling, salting, or soaking in wine or brine lead to increase risk of infection (Liu et al., 2008). The complete life cycle is not known to occur in Europe, but it has been estimated that in parts of South East Asia, up to 80% of freshwater crabs are infected with the parasite (Pachucki et al., 1984). Paragonimiasis is still endemic in Japan and 30–50 new cases are discovered annually (Nawa et al., 2005).

Among seafood, many bivalve mollusc species such as oysters and mussels that are often eaten raw may also act as carriers, concentrating waterborne protozoa as *Cryptosporidium* oocysts and *Giardia* cysts (and probably other zoonotic transmissive stages found in faecally contaminated fresh, estuarine and marine waters). These mollusc species have been suggested to play the role of reservoirs for zoonotic transmission of the above mentioned protozoa (Schets et al., 2007; Smith et al., 2007; Tamburrini and Pozio, 1999).

Among the changing dietary habits, the increased consumption of raw vegetables and undercooking to retain the natural taste and preserve heat-labile nutrients and vitamins may be linked to increased risk of foodborne transmission of zoonoses. Fruits and vegetables may be subject to surface contamination through water, which is a major vehicle for many environmental stages of parasites, particularly protozoa such as *Cryptosporidium*, *Giardia*, and *Cyclospora*.

Cryptosporidium and *Giardia* are major causes of diarrhoeal disease in humans worldwide, and are considered major waterborne diseases (Smith et al., 2007). They are typically linked to poor hygienic conditions or to contamination of water sources. The (oo)cysts of these parasites may also contaminate soft fruits and salad vegetables and hence cause foodborne infections in humans (Smith et al., 2007; Vuong et al., 2007).

The increasing demand of "healthy" drinks or smoothies containing exotic fruit juice in bars and street vendors may be also a driver for new routes of foodborne transmission of parasites. Recently, some cases of orally transmitted Chagas disease (American trypanosomiasis) have been attributed to consumption of açai fruits, an exotic berry originating from Brazil (Pereira et al., 2009). The etiologic agent of Chagas disease, which chronically infects more than ten million persons in Latin America, is *Trypanosoma cruzi*, and it is transmitted by bloodsucking triatomine insects. The most important route for oral transmission of Chagas disease in Brazil is the ingestion of food contaminated with infected triatomines and/or faeces (with *T. cruzi* in metacyclic forms).

During 1968–2005, a total of 437 cases of acute Chagas disease were reported in the Brazilian Amazon. Of these cases, 311 were related to 62 outbreaks in which the suspected mode of transmission was consumption of açaí (Nobrega et al., 2009). Açai is an exotic and now trendy fruit consumed as juice in many "organic" or "healthy" bars in most big European cities, because of its healthy properties linked to the high content of antioxidants. It is often prepared from frozen açai thick paste. Whether residual infectivity or survival of *Trypanosoma* stages remains in frozen fruit pulp is still unknown, and the lack of proper pathogen inactivation treatments of this product may therefore pose a risk for health consumers.

Among the raw and undercooked foods that may pose a risk for parasitic infection to humans, meat preparations play a major role. Meatborne parasitic zoonoses remain an important cause of illness and economic loss, globally (Slifko et al., 2000). Of well known importance are toxoplasmosis, sarcocystosis, cysticercosis and trichinellosis.

Meat consumption is strongly influenced by religious and cultural factors. Pork meat, which may be a source of infection with *Trichinella* spp., *Toxoplasma gondii* and *Taenia solium*, is avoided by Jews, Orthodox Christians in Ethiopia and Muslims due to religious beliefs. Beef, which contains cysticerci of *Taenia saginata*, is not used by Hindus as cows are sacred in their culture. This has a major impact on distribution of infections in various societies throughout the world.

The role of animals as source of food in different societies varies widely and many animal species, which are viewed in some cultures as just companion, work, wild or domestic animals, are viewed by others as important food sources. Well known examples include differing attitudes towards eating guinea-pigs, dogs and a huge range of wildlife species (Macpherson, 2005).

In Western Europe, human trichinellosis caused by consumption of pork, is extremely rare, mainly due to the improved observance of standards and regulations in the commercial pig industry. However, *Trichinella* infection is occasionally found in pigs raised under traditional rural outdoor practices in some European countries (e.g. Spain, Finland) and are also a recurrent source of human infections in Eastern Europe (Malakauskas et al., 2007).

Besides the re-emerged domestic cycle in Eastern Europe, where up to 50% of pigs have been found to be infected in rural areas (Pozio, 2001; Pozio et al., 2009), cases of *Trichinella spiralis* in Western Europe have occurred in Italy and France in the 1990s due to consumption of raw horse meat from horses imported from Eastern Europe (Murrell et al., 2004). Consumption of wild boar is the one of the most common route of human *Trichinella britovi* infection in Western Europe, and the high prevalence in boars is probably due to uncontrolled garbage dumps including remnants of infected pig and wild game carcasses (Macpherson, 2005).

The consumption of "unusual" animal species is also an increasing trend possibly linked to foodborne parasitic infection. The public health risks related to the consumption of reptile meat have been recently reviewed by the European Food Safety Authority (EFSA, 2007). The increasing demand for reptile meat (e.g. from crocodiles, caimans, alligators, iguanas and turtles) in many areas of the world has resulted in the development of national breeding programs in more than 30 countries in North, Central and South America, Africa, Asia and Australia. For this reason, the infection of reptiles with pathogens, which are potentially infective for humans, has become more important (Hutton and Webb, 2003). Among them, trichinellosis and human sparganosis have to be considered. *Trichinella* has been found to be very prevalent in farmed crocodile in Zimbabwe (40% of all farms infected with *Trichinella zimbabwensis*), which has lead to a change of the European legislation of *Trichinella* control to include reptile meat (Pozio et al., 2002, 2007).

Sparganosis is a disease caused by the ingestion of plerocercoid larvae from reptiles or procercoid larvae from unfiltered water contaminated with copepods harbouring the parasite (Cho et al., 1975). Infection with the plerocercoid larvae is acquired by eating raw or insufficiently cooked meat or by traditional medicine remedies, e.g. by topically applying snake or frog skin to sore eyes. In fact, in Vietnam and Thailand frogs and snakes are popularly believed to have an anti-inflammatory effect, and their muscles are applied as poultices. This custom has been blamed for ocular sparganosis (Cho et al., 1975; Min, 1990). Human sparganosis cases are reported world-wide, but they are more common in Asia, particularly in Korea, China, Japan, Taiwan, Vietnam, and Thailand (Beaver et al., 1984). In Korea, three human cases were reported for the first time in 1924 (Kobayshi, 1925), but more than 100 cases were subsequently documented before the end of the 1980s in the Republic of Korea (Min, 1990). Reported foodborne sparganosis cases were traced to consumption of snakes and frogs but never to meat from crocodiles, lizards or turtles.

Unusual or very special meat preparation may also serve as transmission route for foodborne parasites: *Fasciola* infections have occurred by ingesting raw or undercooked bovine liver contaminated with juvenile worms. Sashimi of bovine liver is served in "Yakitori" bars in Japan (Taira et al., 1997).

Similarly accumulating evidence suggests consumption of raw or undercooked meat, especially poultry, as a source of human toxocariosis (Mitsugi et al., 1988; Nagakura et al., 1989; Nishikata et al., 1991; Morimatsu et al., 2006; Yoshikawa et al., 2010). Recently, Taira et al. (2011) demonstrated that *Toxocara cati* larvae persist as highly infective in meat of experimentally infected chickens.

3. Evolution of food production systems

Food and agriculture systems constitute a major artificial ecosystem in which diseases can emerge or re-emerge according to many factors. As result of demographic growth and an increase in quality of life in developed countries, in order to meet rising demand for products of animal origin, agriculture has been intensified and the number and concentration of livestock is increasing rapidly, especially poultry and pigs. FAO estimates that the number of food animals being processed each year will increase from about 21 billion currently to about 28 billion in 2030. The major share of this growth will be supplied by developing countries, where, between 2001 and 2050, meat production is expected to rise 1.8% annually (FAO, 2009), and where biosecurity regimes may be not always sufficient in preventing livestock from disease.

On the other hand, with increasing ecological awareness of the high carbon footprint of industrial agriculture and animal welfare standards, the food industry is leading to the evolution of food production towards organic farming and more sustainable agriculture. The European organic consumer market, worth about 26 billion USD in 2008, is the biggest in the world, still with an increasing trend. This may also have food safety implications, including parasitic infections.

Parasite-free farming implies strict indoor housing of animals including pest control, proper feed preparation and storage, and general hygienic measures. Such an approach is effective to prevent *Trichinella* infections in swine and might also be effective to prevent other foodborne infections such as *Toxoplasma*. However, the emerging trend is for more extensive and outdoor livestock rearing to comply with increasing public demand for organic production and management practices to improve animal welfare. Such free-ranging livestock in close contact with both the environment and wildlife may constitute an opportunity for emerging parasitic infections (Van der Giessen et al., 2007).

Also the awareness about problems linked to overfishing and sea depletion of wild caught fishery products is leading to higher demand of aquaculture products. The continuously growing aquaculture in Asia, which offers almost 90% of the world's freshwater fishery products, may be one of the drivers leading to the increasing impact of fishborne zoonotic trematodes (Keiser and Utzinger, 2005).

Although some studies from Asia have reported that the link between the transmission of liver fluke infections and aquaculture is still uncertain, in China where most of its fish are produced through pond culture, the high rates of *C. sinensis* infection are difficult to account for by consumption of wild fish alone (Dorny et al., 2009). Moreover, some recent studies conducted in Vietnam recognised freshwater aquaculture as a significant source of human infections (Phan et al., 2010a,b,c,d). This evidence is of utmost importance for prevention and control planning considering the expansion of fish farming in Asia, and deserves a higher research priority in the endemic countries (Chai et al., 2005).

The changing use of water in modern agriculture, the food industry and by human communities may also lead to an increased spread of waterborne parasitic diseases, mainly protozoa such as *Cryptosporidium*, *Giardia* and *Cyclospora* spp. Water is a major conduit for these parasites, and contaminated water is an important source of human infection either by direct consumption or by the use of contaminated water in food processing or preparation. Water transports transmissible stages into public water supplies, recreational sites (including fresh and marine waters, and irrigation waters), which can contaminate the food supply through agricultural and food industry practices along the whole food chain. In addition to the use of water for irrigating crops, the food industry uses large volumes of water for its manufacturing processes (Slifko et al., 2000).

Because of their biological characteristics the above mentioned protozoa can be extensively transmitted by contaminated water. Their infective stages (oocysts or cysts), which have low infectious dose, are usually highly resistant in the environment and often tolerant to disinfectants such as chlorine currently used for water potabilisation. Moreover infected animal hosts usually eliminate a very high number of oocysts (in case of *Cryptosporidium* millions of oocysts may be eliminated by a single host, for example bovine), and this is a key factor for environmental contamination. For example in Marrakech, where raw sewage has been used to irrigate a variety of vegetable crops, potatoes irrigated with raw waste water were contaminated with *Giardia* sp. cysts (Amahmid et al., 1999).

Another example where farming systems may influence the increase or emergence of foodborne diseases is human fasciolosis by *Fasciola hepatica* and *Fasciola gigantica*. Fasciolosis is primarily a parasitic infection affecting livestock: economic losses caused by this parasite are estimated at more than US$ 2000 million (McManus and Dalton, 2006). The importance of human fasciolosis has only been recognised in the last decades. Prior to 1992, the total number of reported human fasciolosis cases was estimated to be less than 3000, but more recent studies provide figures of between 2.4 and 17 million (Dorny et al., 2009). In most cases, the organism is acquired by eating wild watercress of *Nasturtium* and *Roripa* species (which are a common staple food in various cultures) on which the metacercariae have settled or direct ingestion of metacercariae in water (Esteban et al., 2002). Farm management practices and the growing of edible aquatic plants in greenhouses have limited the extent of human infection in industrialized regions, but in some developing countries wild aquatic plants grown in fields where infected animals can roam freely form a regular part of the daily diet (Mas-Coma et al., 2005).

Fasciolosis is an emerging foodborne disease in rural regions of Bolivia and Peru, Iran, Egypt and other Asian countries such as Vietnam, due to several risk factors such as sharing of water sources by animals and humans, and the contamination of edible aquatic plants and rice with infective fluke metacercariae. In these countries the rate of underreporting is likely to be high (Dorny et al., 2009).

A similar epidemiology is attributed to fasciolopsiosis a serious intestinal trematodiases caused by *Fasciolopsis buski* which is also associated with proximity between animals and humans and to agricultural practice. In this case, pigs are the animal reservoir. This parasitosis is endemic in remote rural areas and semi-urban areas in South-eastern Asian countries, such as some Chinese provinces and Bangladesh. (Mas-Coma et al., 2005).

4. Global demand and food trade

As a result of urbanisation (more than 50% of the global population now lives in urban areas), demographic increase and market forces, food (including contaminated food) is now moving on a global scale, carried rapidly from continent to continent. The deployment of more efficient and rapid means of transporting perishable goods worldwide enable fresh products to be available nearly year round. Together, these factors have influenced the emergence and recognition of some foodborne parasites (Orlandi et al., 2002).

The outbreaks of *Cyclospora cayetanensis* in the 1990s, which only recently was recognised as a cause of foodborne illness, are an example of these changes. This coccidian parasite that causes protracted, relapsing gastroenteritis, has been in the North American news since 1996, when it was associated with an outbreak of over 3000 cases arising from importation of Guatemalan raspberries (Herwaldt, 2000; Herwaldt and Ackers, 1997). The leading hypothesis is that the raspberries were contaminated through exposure to water, when the berries were sprayed with insecticides, fungicides, and fertilizers that were mixed into it. Raspberries are not the only food vehicle linked to illness; two outbreaks in the USA (Florida and in Maryland) involved mesculun lettuce (CDC, 1997) and basil in a basil-pesto salad (Hoge et al., 1995).

New technologies for food trade and transportation have allowed the spread of parasitic diseases in areas where they were not present before, both at global and local level. As an example diphyllobothriosis in Japan, once limited to coastal areas, is spreading now all over the country thanks to the development of chilled transportation (Nawa et al., 2001). Salmon and trout have been commonly served as sushi and sashimi, and 1100 cases are now recorded annually in the northern part of the country.

In South America, anisakiasis is associated with the increased consumption of "ceviche" not only in the coastal communities but also in internal mountain regions, following the improved logistics in refrigerated transport of fresh products. Similarly in some cold internal region of Peru some cases of diphyllobothriosis by *Diphyllobothrium pacificum* have been registered, due to the consumption of *ceviche* in this area (Cabrera et al., 2004).

5. Changing tourism habits

One of the most impressive changes of the twentieth century has been in the increased ease of international travel. Travel that once required months has been reduced to hours, converting the world into a global village (Cohen, 2000). From a global perspective, tourism contributes to changes in land cover and land use, energy use, biotic exchange and not least exchange and dispersion of diseases. In 2008, the World Tourism Organization reported that international tourist arrivals reached 924 million, and this number was expected to increase to 1.6 billion by the year 2020 (World Tourism Organization, 2009).

It is globally acknowledged that travelling to tropical and subtropical countries is responsible for a substantial increase in the incidence of tropical diseases in industrialized countries (Gossling, 2002). Furthermore, a growing proportion of tourist activities are nature-based, adventure-oriented and bound to remote areas (Ahlm et al., 1994). Adventure travel, involving activities such as safaris, tours, adventure sports and extreme travel, is the largest growing segment of the leisure travel industry, with a growth rate of 10% per year since 1985 (Chomel et al., 2007). This type of travel increases the chances that tourists participating in such activities will enter into contact with pathogens uncommon in industrialized countries.

Giardia cysts or the oocysts of *Cryptosporidium* are important contributors to traveller's diarrhoea and are common waterborne parasites both in developing and developed countries (Macpherson, 2005). *Giardia* spp. has been identified more often than any other pathogen in waterborne outbreaks in the USA (Fayer, 1994). Such outbreaks have occurred mostly in camps, parks, resorts, and institutions, including day care centres and swimming pools.

Travellers dining in street restaurants can be expected to have much higher risks of infections with various parasites, especially in Asia where frogs, land snails, snakes and wild boar are also served as sushi and sashimi, especially in the mountainous areas (Nawa et al., 2005). The increased number of people travelling to remote areas of, e.g. Southeast Asia should be aware of the risk linked to traditional food preparations. The growing trend for adventure tourism, trekking and mountaineering bring more and more people in touch with wildlife habitats, where sylvatic life cycle of many parasites takes place. In this context the habit of collecting mushrooms and wild berries is a risk factor for transmission of *Echinococcus multilocularis*, a cestode whose life cycle in Europe predominantly involves red foxes (*Vulpes vulpes*) as definitive hosts and several rodent species as intermediate hosts (Hegglin et al., 2008).

Hunting and other outdoor activities may also be an exposure factor to eating inadequately cooked game (e.g. bear, wild boar, warthog), during or after hunting and shooting expeditions (Ancelle et al., 2005; Dupouy-Camet et al., 2009; Houzé et al., 2009). Infection with sylvatic species of *Trichinella* are recurrently being associated with hunting activities in endemic areas (Pozio et al., 2001), e.g. infection acquired during hunting trips in the Arctic or tropical areas are diagnosed after return to mainland Europe. It is estimated that 4.5 million tonnes of bushmeat are extracted from the Congo basin each year, and this meat is often consumed only partially cooked, thus acting as a potential source of zoonotic pathogens (Wolfe, 2005). Apart from the most common parasitic infections that are typically linked to this route such as toxoplamosis, trichinellosis and cysticercosis, there are also some other potential and less known meatborne parasitic diseases. An example of these is alariosis, caused by an intestinal parasite of some carnivores *Alaria alata*, whose mesocercarial stage is known to cause lesions in its paratenic hosts, in particular, in wild boars, and from these to humans as secondary paratenic host. Recent incidental background findings of *A. alata* mesocercariae in meat of wild boars during official *Trichinella* inspection initiated a re-assessment of the potential human health risk as posed by this parasite (Mohl et al., 2009).

Hunters and those who consume raw, traditionally cured, or undercooked meat from a wide range of carrion feeding wild animals, including birds and crocodiles are at risk of being infected with a diversity of parasites different geographical areas (Macpherson, 2005).

6. People migration and demographic change

There are emerging patterns of movements of irregular migrants from less-developed parts of the world to developed countries in search of better opportunities. This mobility implies also importing different cultures, health beliefs, food preferences, and hence risk factors (Apostolopoulos and Sonmez, 2007).

For this reason the barriers for human infection with parasites, which was considered to be geographically limited because of parasites' adaptations to specific definitive and intermediate hosts, and particular environmental conditions, are slowly being breached (Orlandi et al., 2002).

Immigration and demographic changes are associated with emerging patterns of infection as occurs in immigrants, for example from the former Soviet Union to Germany and infected with *O. felineus*. Such cases do present challenges to clinicians unfamiliar with diagnosis and treatment of these parasites (Günther et al., 2006).

Further examples are the cases of *Paragonimus* spp. infections which are now being reported in the USA in immigrants arriving from endemic areas. Infection risk in Europe may arise from the consumption without proper handling or preparation of infected freshwater crabs from endemic areas (EFSA, 2010).

Immigration trends are often followed by import of traditional food product from the country of origin. With increasing numbers of people from South East Asia and Japan settling in Europe, and the increasingly widespread consumption of imported crustaceans that are raw, undercooked, or otherwise insufficiently treated to kill the metacercariae, an increased risk of infection in the EU by *Paragonimus westermani* must be considered a possibility (EFSA, 2010).

Moreover traditional and local food markets in many parts of the world can be associated with emergence of new foodborne parasitic diseases. Live animal markets, also known as wet markets, have always been the principal mode of commercialization of poultry and many other animal species. Such markets, quite uncommon until some decades ago in developed countries, are emerging as a new mode of commercialization within specific ethnic groups for whom this type of trade assures freshness of the product but raises major public health concerns (Chomel et al., 2007).

A significant example of changes in transmission of parasites linked to demographic and socioeconomic change is represented by China where control programs for soil-transmitted helminths, such as hookworms, *Ascaris* and *Trichuris*, have reduced human prevalence by five times (Zhou et al., 2008). However, at the same time, there has been a significant increase in the total number of people suffering from foodborne parasitic disease such as clonorchiasis, trichinellosis, paragonimiasis and angiostrongyliasis. The most striking example is clonorchiasis, for which the average national prevalence has increased by 75%, with an increase in some provinces of 630% (Xu et al., 2005).

Several factors are considered to contribute to the increase of foodborne parasitic infection in China: (i) the increase in income and living standard that offers more opportunities for people to eat foods of animal origin typically consumed raw or undercooked and (ii) the insufficiency of comprehensive and inclusive control strategies for several important foodborne parasitic zoonoses. The latter aspect is characterised by the relatively slow development in the detection and quarantine of meat and fish for zoonotic pathogens, which cannot match the rapid development of livestock and fishery industries.

7. Ecological change and foodborne parasites

Ecological changes may influence and modify the population dynamics of intermediate and definitive hosts of parasites, thus increasing the prevalence of parasites in animal species destined for human consumption.

An example of fishborne parasitic disease could be anisakiasis. It has been speculated that the currently prevailing regulatory measures limiting the exploitation of marine mammals for food has led to an increasing population of some mammalian definitive hosts to *Anisakis* and *Pseudoterranova* (Audicana, 2002; Audicana et al., 2002, 2003; Audicana and Kennedy, 2008; McCarthy and Moore, 2000; Oshima, 1987; Sakanari and McKerrow, 1989). Several observations indicate that a relationship exists between *A. simplex* population size and definitive host population size. For example, the abundance of *P. decipiens* in Norwegian cod markedly declined in the early 1990s, probably due to the phocine distemper virus epidemics, which killed about 70% of the common seal (*Phoca vitulina*), the definitive host of *Pseudoterranova* (Des Clers and Andersen, 1995). However these relationships are likely to be complex, depending on multiple biotic and abiotic factors such as climatic, trophic and ecological variables, on the population dynamics of intermediate and definitive hosts and on human impact. Moreover to date neither scientific nor empirical data exist regarding the long-term effects of strict hunting regulations for marine mammals on the total biomass of anisakid nematodes in any waters (EFSA, 2010).

Abiotic factors such as climate may also favour transmission of foodborne parasites. There is some evidence that anisakiasis caused by *Anisakis physeteris* emerged in Peru during the climatic phenomenon El Niño during the period 1997–1998 (Cabrera et al., 2004). Because of the increased temperature, an increased migration towards the coastal areas of the population of *Coryphaena hippurus* (a fish species of the southern pacific coasts that harbour the parasite) was registered. This increased consequently its fishing rate, thus leading to more human cases (Cabrera et al., 2004).

As another example, increased rainfall and run-off intensity may lead to outbreaks of waterborne protozoa, such as *Cryptosporidium.* In Milwaukee (Wisconsin, US), the largest reported *Cryptosporidium* outbreak occurred, with an estimated 403,000 cases of intestinal illness and 54 deaths. The severity of the outbreak has been attributed to the heavy spring rainfall and runoff from melting snow with a subsequent turbidity load, compromising the efficiency of the drinking water treatment plant (MacKenzie et al., 1995).

8. Conclusions

Foodborne parasitic diseases are indicators of a complex system of interconnected biological, economic, social and cultural variables, and ideally they should be addressed by considering the interfaces between animal (domestic and wildlife), human and ecosystem (natural and agricultural). Nevertheless, this holistic approach would require a large amount of high quality data and wide-ranging collaboration across sectors and disciplines, which would make the setting of control programs and the decision-making process particularly complex. In fact, in comparison to other classes of foodborne pathogens, particularly bacteria, the health impact of parasites is difficult to assess primarily due to the lack of a uniform standard for monitoring the incidence of foodborne illness directly attributed to parasitic infections. As such, statistical data relating parasitic foodborne illness and economic sequelae are either approximations or lacking (Orlandi et al., 2002).

In the future the attention should focus on developing or emerging economies which will represent the main global food supplier, namely Asian, Latin America and African countries, where most foodborne parasites are endemic and where control and monitoring programs are often scantly developed. Particularly in these contexts, the development of rational and targeted disease control programs which are based on strategic research is of utmost importance.

Indeed, reducing the risk of parasitic infection from food relies on several levels of intervention. For meat products, for example, parasitic foodborne infections are traditionally controlled at the end of the meat production chain, e.g. simple low-tech and relatively inexpensive monitoring of individual swine carcasses may detect *Trichinella* infected carcasses, but in countries with highly confined and industrialized pig production systems the risk of infection is negligible (Newell et al., 2010). The major challenge will be designing quality assurance systems in order to ensure a risk based monitoring approach. These should be cost-effective in comparison to low-tech individual carcass inspection, although they may not be appropriate in developing regions with higher prevalence.

In this framework, more research and data about foodborne parasites are needed and should be collected in targeted way in order to properly “feed” risk assessment studies.

Conflict of interest statement

The authors do not have any financial and personal relationships with other people or organizations that could inappropriately influence this work.

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