Review

Cell PRESS

Parasites ramble on: Focus on food security

The global burden of foodborne parasitic diseases: an update

Paul R. Torgerson[1], Nilanthi R. de Silva[2], Eric M. Fèvre[3,4], Fumiko Kasuga[5], Mohammad B. Rokni[6], Xiao-Nong Zhou[7], Banchob Sripa[8], Neyla Gargouri[9], Arve Lee Willingham[10,11], and Claudia Stein[12]

[1] Section of Veterinary Epidemiology, University of Zurich, Zurich, Switzerland
[2] Faculty of Medicine, University of Kelaniya, PO Box 6, Ragama, Sri Lanka
[3] Institute of Infection and Global Health, University of Liverpool, Leahurst Campus, Neston, CH64 7TE, UK
[4] International Livestock Research Institute, PO Box 30709-00100, Nairobi, Kenya
[5] Division of Safety Information on Drug, Food, and Chemicals, National Institute of Health Sciences, 1-18-1 Kamiyoga, Setagaya-ku, Tokyo 158-8501, Japan
[6] Department of Medical Parasitology and Mycology, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
[7] National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention, 207 Rui Jin Er Road, Shanghai 200025, People's Republic of China
[8] Division of Experimental Pathology, Department of Pathology, Faculty of Medicine, Khon Kaen University, Khon Kaen 40002, Thailand
[9] Head of Surveillance, Ministry of Health, PO Box 5701, Amman, Jordan
[10] WHO Collaborating Center for Research and Training on Neglected and Other Parasitic Zoonoses, Department of Veterinary Disease Biology, Parasitology, and Aquatic Diseases, Faculty of Health and Medical Sciences, University of Copenhagen, Thorvaldsensvej 57, 1871 Frederiksberg C, Denmark
[11] School of Veterinary Medicine, Ross University, St Kitts, West Indies
[12] Division of Information, Evidence, Research, and Innovation, World Health Organization Regional Office for Europe, UN City Marmorvej, 512100 Copenhagen, Denmark

Foodborne diseases (FBDs) are a major cause of morbidity and mortality in the human population. Accurate information on the burden of FBDs is needed to inform policy makers and allocate appropriate resources for food safety control and intervention. Consequently, in 2006 the WHO launched an initiative to estimate the global burden of FBDs in terms of Disability Adjusted Life Years (DALYs). This review gives an update of the progress on evaluating the burden of foodborne parasitic diseases that has been generated by this study. Results to date indicate that parasitic diseases that can be transmitted through food make a substantial contribution to the global burden of disease.

Foodborne diseases

Foodborne diseases (FBDs) can be defined as those conditions that are commonly transmitted through ingested food (see Glossary). FBDs comprise a broad group of illnesses caused by enteric pathogens, parasites, chemical contaminants, and biotoxins [1]. The full extent and cost of unsafe food is currently unknown. Precise information on the burden of FBDs, however, is needed to adequately inform policy makers and allocate appropriate resources for food safety control and intervention efforts. The WHO is coordinating a major effort to estimate the burden of FBDs. This review will summarize the methodologies used for estimating the burden of FBDs caused by parasites and will also summarize the important results available to date.

Foodborne Disease Burden Epidemiology Reference Group

In 2006, the WHO established the Foodborne Disease Burden Epidemiology Reference Group (FERG) [1]. There are now six specific task forces within the FERG (Figure 1). Disease specific task forces have been organized as Enteric Diseases, Parasitic Diseases, and Chemical and Toxin Task Forces, which identify the FBDs that have substantive impact on human health, based on a qualitative assessment and then coordinate studies to estimate the burden in terms of prevalence or incidence. The other three task forces have different functions. The Source Attribution Task Force is primarily concerned with estimating the relative contribution to the burden of disease of food and nonfood sources; and with regard to the foodborne sources, the types of food that may present the highest risk to human health. The Country Studies Task Force is concerned with developing tools that can be used on a country-by-country basis to estimate the burden of FBDs. Such tools will be cognizant of FBDs that may be important locally but have little impact on the global burden of disease. Country studies may also provide a framework to develop specific projects to fill in missing data gaps. The

Corresponding author: Torgerson, P.R. (paul.torgerson@access.uzh.ch).
Keywords: foodborne diseases; DALYs; global burden; epidemiology.

1471-4922/$ – see front matter
 http://dx.doi.org/10.1016/j.pt.2013.11.002

Glossary

Burden of disease: the term 'burden of disease' in the context of the WHO initiative follows the principles of the Global Burden of Disease Study, and includes the quantification of morbidity, all disabling complications, as well as mortality in a single summary measure (DALY).
Disability Adjusted Life Year (DALY): a measure that combines the Years of Life Lost due to premature death (YLL) and the Years Lost due to Disability (YLD) from a disease or condition, for varying degrees of severity, making time itself the common metric for death and disability. One DALY is a health gap measure, equating to 1 year of healthy life lost.
Disability Weight (DW): a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1. YLD is calculated by multiplying the incident cases by duration and DW for the condition.
Food: according to the definition of the Codex Alimentarius Commission [54], food means any substance, whether processed, semi-processed, or raw, which is intended for human consumption, and includes drink, chewing gum, and any substance that has been used in the manufacture, preparation, or treatment of food but does not include cosmetics, or tobacco, or substances used only as drugs. The definition includes all bottled drinks.
Foodborne diseases (FBDs): can be defined as diseases commonly transmitted through ingested food. FBDs comprise a broad group of illnesses caused by microbial pathogens, parasites, chemical contaminants, and biotoxins.
Incidence: this is the number of new cases of individuals with a disease, in a fixed population, that arise during a fixed time period. The incidence is often given as numbers of new cases per 100 000 population per year.
Prevalence: this is the proportion of individuals in a population found to have a condition at a single point in time. It is estimated by enumerating the number of people found to have the condition divided by the total number of people studied. It is normally expressed as a number between 0 and 1 or as a percentage.
Recall bias: is a systematic error caused by differences in the accuracy or completeness of the recollections retrieved ('recalled') by study participants regarding events or experiences from the past.
The Foodborne Disease Burden Epidemiology Reference Group (FERG): is composed of internationally renowned experts in a broad range of disciplines relevant to global FBD epidemiology. Members were appointed by the WHO Director-General, Dr Margaret Chan, following a transparent selection process. The FERG engages in:
- assembling, appraising, and reporting on the currently existing burden of FBD estimates;
- conducting epidemiological reviews for mortality, morbidity, and disability in each of the major FBDs;
- providing models for the estimation of FBD burden where data are lacking;
- developing cause and source attribution models to estimate the proportion of diseases that are foodborne; and
- developing user-friendly tools for burden of FBD studies at country level.

Computational Task Force is concerned with compiling all the data and developing a consistent approach to making the burden estimates, including developing methods to model uncertainty and missing data.

Parasitic diseases

At the first FERG meeting in 2006, the Parasitic Diseases Task Force identified parasites that could be transmitted by food to humans. From this list, those parasites that could produce a substantive burden of disease were identified and prioritized. These were intestinal protozoa (*Giardia*, *Entamoeba* and *Cryptosporidium* spp.), *Fasciola* spp., *Trichinella* spp., *Toxoplasma gondii*, *Echinococcus* spp., *Opisthorchis* spp., *Clonorchis* spp., *Taenia solium*, *Anisakis simplex*, and *Ascaris lumbricoides* [1]. Disease caused by *A. simplex* was later considered to be an uncommon FBD and was subsequently removed from the priority list. The important pathogens on this list were largely confirmed by the WHO/FAO Joint Expert Meeting on Foodborne Parasitic Diseases [2]. The next stage was to identify potential experts and commission systematic reviews to estimate: (i) the global incidence stratified by age and gender and by WHO region; (ii) frequency of sequelae following infection with these agents; (iii) the proportion of cases where food was the source of infection; and (iv) the burden of disease using appropriate disability weights for each sequelae. Although this project was initiated in 2006 the complexity and size of the task means it is not yet completed, but we aim to summarize the important results with regard to the burden of foodborne parasitic diseases.

Intestinal protozoa

The FERG commissioned a systematic literature review to estimate the global burden of illness caused by *Entamoeba*, *Giardia*, and *Cryptosporidium* spp. by age and sex for all countries and WHO regions, and to assess the proportion of those infections transmitted by food. Information on health effects (e.g., sequelae and mortality) attributable to infection, where available, was also collected. The work on this study has not been published as of the date of this review. However, the findings, as relayed by the study's primary investigator, Dana Schneider, in a personal communication (D. Schneider *et al.*, unpublished) are based on over 10 000 studies that were retrieved using specific search terms.

A literature review was undertaken using databases including PubMed, WHO, CAB Abstracts, SIGLE, and EMBASE. A total of 10 450 studies were retrieved using specific search terms, which included morbidity, mortality, incidence, prevalence, epidemiology, sequelae, food, transmission, outbreak, *Entamoeba histolytica*, Amoebiasis, *Giardia*, Giardiasis, *Cryptosporidium*, and Cryptosporidiosis. Of those, 3504 (33.5%) were reviewed in full, and 495 (4.7%) were included in the analysis. Of the three parasites studied, *Giardia* appeared to have the highest global prevalence (median = 10.8%), followed by *Entamoeba* (median = 4.3%), and *Cryptosporidium* (median = 4.0%). The Americas had the highest median prevalence of *Entamoeba* and *Giardia*, whereas Africa had the highest for *Cryptosporidium* spp. Europe had the lowest prevalence of *Entamoeba*, and the Western Pacific region had the lowest for *Giardia*. Southeast Asia had the lowest prevalence of cryptosporidiosis. Overall, the data indicated that children under 18 years of age, particularly those in the age groups between 1–4 years and 5–14 years, had higher health burdens, due to these parasitic infections. The proportion of people infected, in general, decreased with increasing age. Differences by sex were generally small, although females tended to have a higher median prevalence of *Entamoeba* (most notably in the Americas), whereas males had a slightly higher prevalence of *Giardia* and *Cryptosporidium*.

The authors noted that the vast majority (76%) of published information retrieved came from cross-sectional (prevalence) studies; few long-term follow-up or country-level studies were found. The authors also found limited or no data describing health outcomes, which are needed for calculation of Disability Adjusted Life Years (DALYs). Twenty-four studies (4.8%) were found implicating certain foods with infections by protozoa infection. However, based on the number of outbreak or other studies (e.g., [3,4]), which were able to identify a source with some certainty, the authors noted that the majority of large-scale outbreaks were waterborne, possibly because contaminated drinking water would reach a larger proportion of the community than a particular contaminated food product.

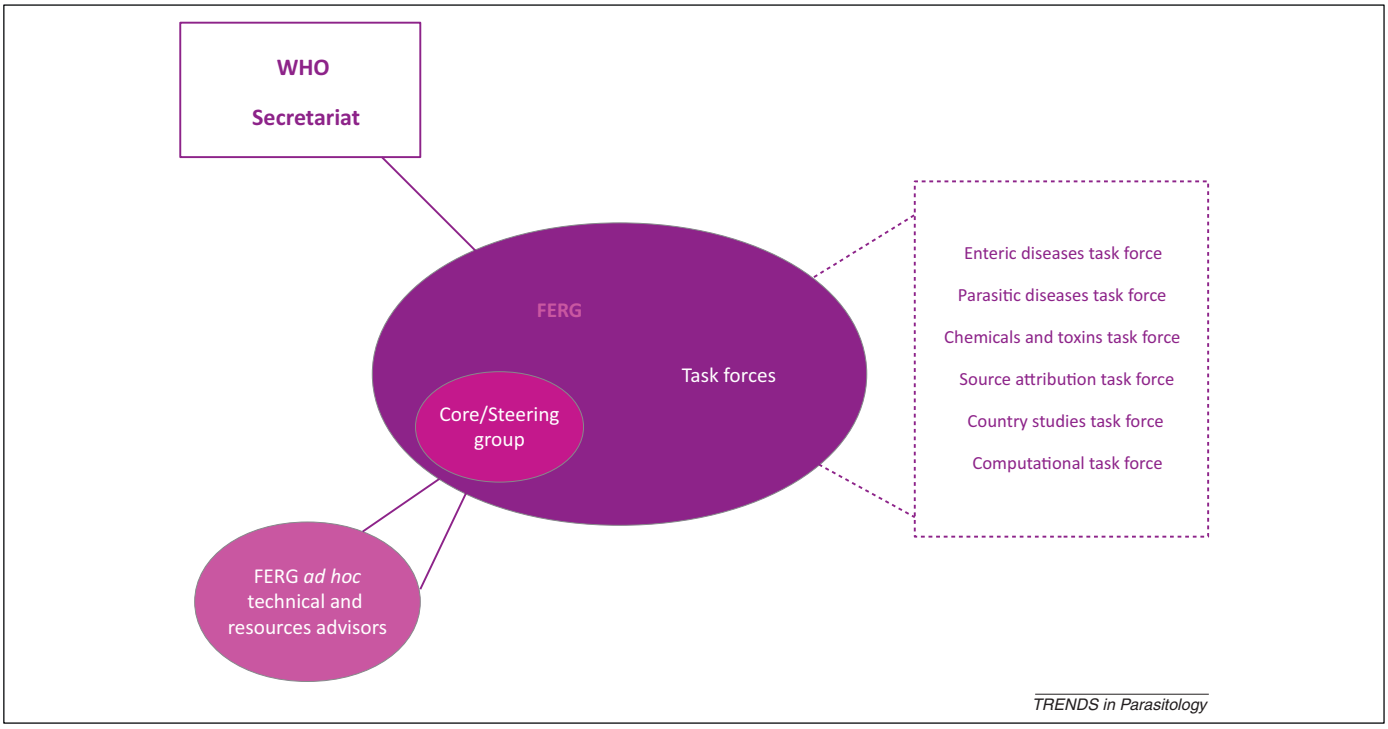

Figure 1. Organization of the Foodborne Disease Burden Epidemiology Reference Group (FERG; reproduced with permission of the Publisher; http://www.who.int/foodsafety/foodborne_disease/ferg/en/index3.html, accessed 25 November 2013). The FERG consists of a Core (or Steering) Group to coordinate and oversee the scientific work, six different Thematic Task Forces advancing the work in specific areas as shown; and external resource and technical advisers who are invited on an *ad hoc* basis to provide specific expertise. The WHO secretariats are members of the WHO who aim to provide support to the activities of the FERG.

Of the food-related outbreaks, investigators often traced the root source back to water, which contaminated fresh produce: unwashed vegetables and unpeeled, unwashed fruit.

It is expected that the DALYs lost due to intestinal protozoan infections, and the proportion that are foodborne will be estimated by the Source Attribution and Computational Task forces and reported when the burden of FBDs is published within the next 2 years.

Toxoplasmosis

Toxoplasma gondii has a complex life cycle with the cat as the definitive host. Many animal species can act as intermediate hosts including humans. Humans can be infected from the ingestion of oocysts contaminating the environment including food contamination, or through consuming undercooked meat containing viable bradyzoites. Human toxoplasmosis has a high prevalence with perhaps one-third of the human population being infected with this parasite [5]. Congenital toxoplasmosis (CT) occurs when a pregnant woman is exposed to *Toxoplasma* for the first time, and the parasite is transmitted to the fetus. This can result in abortion, neonatal death, hydrocephalus and other neurological deficits, and chorioretinitis [6]. In the immunosuppressed, such as AIDS patients, toxoplasmosis can cause fatal encephalitis [7]. In healthy immunocompetent individuals who are exposed to *Toxoplasma*, it is widely believed that following a mild flu-like illness and seroconversion that there are no further adverse effects. However, acquired chorioretinitis is a well-described syndrome that occurs in a number of such individuals [8]. Other important syndromes that are increasingly recognized as being associated with acquired toxoplasmosis include epilepsy [9], schizophrenia [10], Parkinson's disease [11], migraine [12], and psychomotor deficits leading to an increased risk of road traffic accidents [13].

The global burden of CT has now been estimated [14]: 190 000 new cases of CT each year globally, resulting in the loss of approximately 1.2 million DALYs. The distribution of cases not only depends upon the risk of exposure of pregnant women but also the genotype to which pregnant women are exposed: non-type 2 genotypes have more severe sequelae [15]. In addition, the risk of CT increases if women have children when they are young because of the lower probability of being exposed and hence seroconverted prior to the pregnancy. Figure 2 gives the global distribution of DALYs per 1000 births resulting from CT.

The evaluation of the burden due to other toxoplasmosis-associated syndromes has yet to be completed. However, in view of the increasing reports of chronic syndromes with high disability weights associated with acquired toxoplasmosis the burden is likely to be considerable.

The proportion of toxoplasmosis that is foodborne is probably sizable. Consumption of undercooked meat is a well-recognized risk factor [16,17] and perhaps results in 50% or more cases of toxoplasmosis. Further infections will be acquired from consuming other foods, such as salad vegetables that are contaminated with sporulated oocysts.

Foodborne trematodes

The global burden of foodborne trematodiasis and sequelae was published in 2012 [18]. The main conclusion was that there are approximately 56 million people infected with foodborne trematodes. Of these, approximately 7.9 million have severe sequelae with approximately 7158 deaths per annum. *Clonorchis sinensis* and *Opisthorchis viverrini* can induce cholelithiasis, cholestasis, cholangitis, cholecystitis,

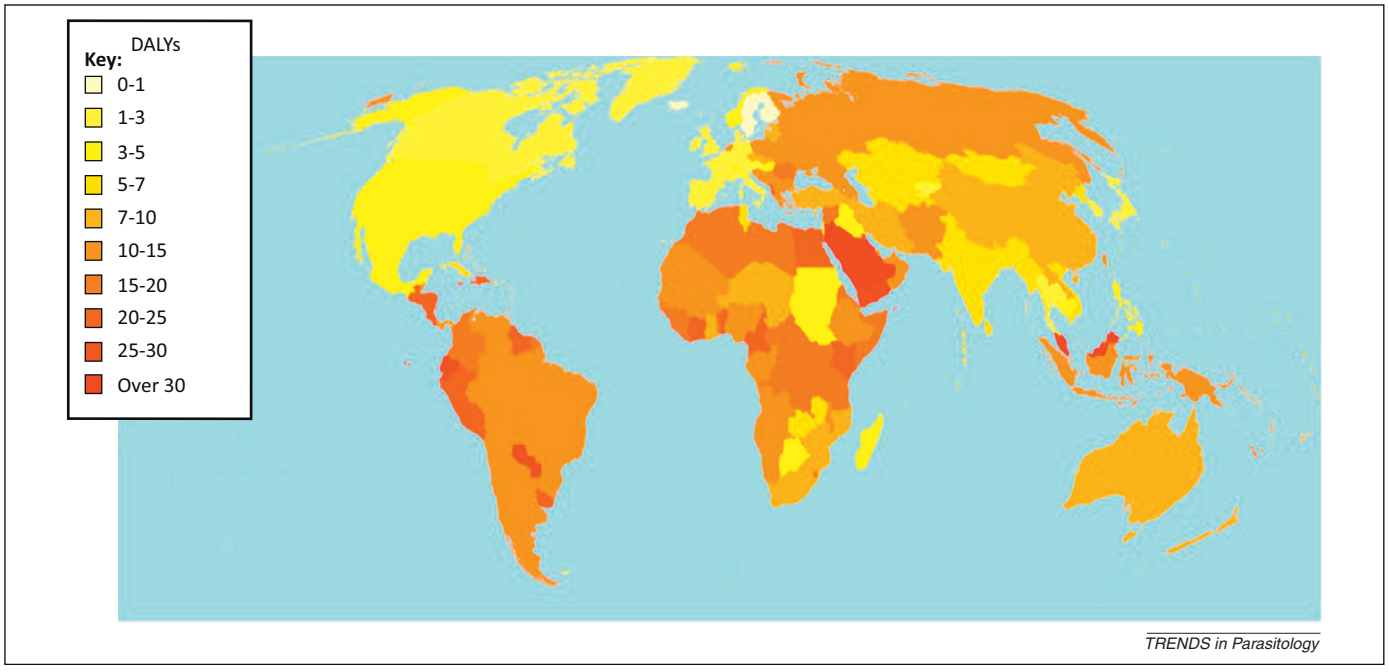

Figure 2. Disability Adjusted Life Years (DALYs) per 1000 births due to congenital toxoplasmosis. Estimates for the burden were made for every country with the reference year of 2008. The data used to construct this map are available in [12] and associated appendices.

biliary and liver abscess and cirrhosis, pancreatitis, hepatitis, and, as a most severe consequence, the bile duct cancer cholangiocarcinoma [19]. Clinical manifestations can be asymptomatic, resulting from mostly light infections. With moderate infections, symptoms such as fever, fatigue, anorexia, and gastrointestinal complaints may occur. In heavy infections, severe diarrhea, sometimes in alternation with constipation, nausea, colicky pain, dyspepsia, malnutrition, and anemia are seen [19]. The main burden of this disease occurs in East and Southeast Asia and the Asia Pacific regions. Cholangiocarcinoma is the most common cause of death attributable to foodborne trematodiasis. Infections with *Opisthorchis felineus*, *Fasciola* spp., and intestinal flukes can present with the same pathological changes and clinical manifestations as *C. sinensis* and *O. viverrini*. However, strong evidence for the carcinogenic potential of *O. felineus* is not available, although in Russia the highest incidence of bile duct cancer in humans was documented in the same area (i.e., Tyumen region) with the highest incidence of *O. felineus* infection in humans [20]. There is no evidence that *Fasciola* spp. can cause neoplasms. Nevertheless, the incidence of human fasciolosis in Egypt, Iran, and Latin America is high. Paragonimiasis causes a significant health impact in China because large numbers of individuals are infected with a proportion developing neurological lesions with consequentially a high disability weight. Globally, foodborne trematode infections are estimated to result in approximately 665 000 DALYs a year (estimated for 2005) [18]. Apart from the possibility that a proportion of fasciolosis cases could be waterborne, virtually the entire disease burden is caused by the ingestion of food contaminated by these trematodes.

Echinococcosis

Human echinococcosis results from infection with the larval stage of a number of species of the genus *Echinococcus*, originating from the consumption of eggs from the canid definitive host. Foodborne transmission is possible through contamination of food with parasite eggs. The global burden of cystic echinococcosis (CE), caused by *Echinococcus granulosus*, was previously estimated at approximately 1 million DALYs [21]; an update of this estimate has been commissioned by the FERG with additional aims to report: (i) the frequency of various sequelae associated with CE; (ii) an estimate of how much of the global burden is associated with contaminated food; and (iii) the types of food involved in transmission.

Meta-analyses of community studies across a number of areas where echinococcosis is endemic have shown the prevalence ranging between 1% and 7% with annual incidences of up to 32 cases per 100 000 in hospital-based studies. Females are more at risk than males, with an increase in prevalence with age [22]. With abdominal CE, 57.3% had symptoms of abdominal pain, 14.1% fever, 9.4% jaundice, 15.6% nausea or vomiting, and 8.6% with weight loss. For pulmonary cases 51.3% had cough, 39.9% chest pain, 14.8% fever, 12.6% hemoptysis, 23.7% dyspnea, 8.8% expectoration of cyst content, with a further 12.8% asymptomatic [22]. These data will be used to obtain updated estimates of the global incidence of CE and the symptomatology to develop disability weights, which have been previously based on hepatic carcinoma [23].

The global burden of the other major form of echinococcosis, alveolar echinococcosis (AE), caused by *Echinococcus multilocularis* had not been previously estimated before the commencement of the work by the FERG. This has now been completed, and approximately 18 000 new cases of AE are possibly occurring globally each year resulting in approximately 660 000 DALYs [24]. Greater than 90% of this burden is in China owing to the extremely high incidences in certain Tibetan communities, although in Europe and Central Asia the diseases appear to be increasing in

incidence [25–29]. In the absence of treatment the disease has a very high case fatality rate [30], thus resulting in a high disease burden. The proportion of this disease transmitted through food has not yet been estimated, although ingestion of certain foodstuffs has been associated with human infection. For example, having a kitchen garden has been associated with an increased risk of AE [31], which might be the result of contamination of homegrown vegetables.

One of the major issues with source attribution of human echinococcosis is the length of time between exposure and the development of clinical signs, which can be several years. This results in considerable recall bias when undertaking epidemiological studies to investigate potential risk factors. However, taeniid eggs have been identified in salad vegetables [32], which clearly indicate that considerable foodborne transmission of echinococcosis is possible. The proportion of human echinococcosis that is foodborne will be estimated by the Source Attribution and Computational Task Forces and reported when the burden of FBDs is published.

Taenia solium

The life cycle of *Taenia solium*, the pork tapeworm, usually involves transmission of eggs to scavenging pigs via human feces, followed by the hatching of these eggs into oncospheres that penetrate the intestinal wall and develop into cysticerci (cysts) in muscle. Humans consume undercooked pork meat infected with the cysticerci, which then develop to adult worms in the gut.

Humans may also become infected by directly consuming eggs, either through the environment or autoinfection. It is this latter element of the life cycle in humans that causes the most severe health issues; whereas adult worm infections in the gut may cause mild discomfort, cysts in tissue, particularly the brain, can cause severe disease such as neurocysticercosis (NCC). In regions with endemic transmission, the disease is a significant cause of acquired epilepsy [33].

Although cysticercosis is often not transmitted directly by food, pork consumption is essential for transmission of *T. solium*, and hence there would be no cysticercosis if pork was not consumed. Therefore, the FERG commissioned two studies [34,35] specifically on NCC, having solicited expert opinion indicating that the burden of disease caused by intestinal tapeworm infection itself was likely to be extremely low. A systematic review on the frequency of NCC worldwide including the prevalence, proportion, incidence rate, or proportion among a specific population considered 565 papers, of which 26 articles met the inclusion criteria. Full selection criteria are given in [34]. These included confirmation of diagnosis through computer tomography (CT), magnetic resonance (MR) or autopsy, and studies with original data with more than 20 participants. As most included studies involved neuroimaging techniques, this left many gaps geographically, especially in Africa, where the technology is only available in a few sites [36].

The proportion of NCC cases among patients with epilepsy, across age groups and from different locations in 12 separate studies, was found to be 29.0% (95% confidence interval: 22.9–35.5%) [34]. The frequencies of different manifestations, complications, and disabilities associated with NCC were estimated in another systematic review with similar methodology [35]. A total of 21 studies met the selection criteria from an initial list of 1569. A diverse range of clinical signs and sequelae associated with NCC seen in the clinical setting were itemized: 79% of NCC patients had epilepsy or seizures, 38% had headaches, 12% had signs of intracranial pressure (such as hydrocephalus or papilledema), 8% had meningitis symptoms, 3% had cranial nerve palsy, 6% had abnormal gait, 16% had focal deficits, ~5.5% had visual changes, and 4.5% had psychiatric symptoms. These data are extremely valuable in breaking down the morbidity associated with NCC infection in calculating burden, given data on the age breakdown of the symptoms (also reported) and the duration of sequelae.

The Global Burden of Disease (GBD) 2010 study published in 2012 [37] has already calculated a global DALY for cysticercosis, summing to a mean of 503 000 DALYs lost per year, largely due to morbidity, although there is lack of clarity over the proportion of epilepsy DALYs that might be ascribed to cysticercosis in this calculation. Thus, the burden due to cysticercosis is probably considerably higher. The FERG Computational Task Force will undertake its own DALY calculation, which will be reported when the burden of FBDs is published.

Trichinella spp.

Human trichinellosis is transmitted through meat and hence is entirely foodborne. There are large investments around the world in veterinary public health services to prevent transmission to humans through the consumption of infected meat. For example, the estimated annual cost of inspecting 167 million pigs in the EU ranges from €25 million to €400 million [38–40]. Despite this, there have been no previous attempts at estimating the global burden of trichinellosis. A systematic review came to the surprising conclusion that the burden is likely to be very small [41]. Between 1986 and 2009 there were 65 818 cases and 42 deaths recorded globally, and all of the cases were from 41 countries. Trichinellosis primarily affects adults (median age of 33.1 years) with no evidence for a gender predisposition. The major clinical signs that were described included myalgia, diarrhea, fever, facial edema, and headaches. Pork was the major source of infection with wild game sources also frequently reported [41]. The proportion of cases or outbreaks acquired from pork or wild game varied with geographical region. In South America, all reported cases were from pork. By contrast, in Canada all cases were from wild game whereas in the USA just over half the cases were from pork with the remainder from wild game. In the Eastern Mediterranean, all cases reported were associated with wild game. In Europe, Asia, and the Pacific regions, there were substantial proportions of cases due to both wild game and pork consumption. Outbreaks due to the consumption of horsemeat were recorded in Mexico, France, and Italy. Outbreaks due to consumption of dog were recorded in Slovakia and China [41]. Although these data may well be an underestimate of the numbers of cases, it clearly

indicates that the burden of disease is low. Consequently, the large investments in *Trichinella* control in its present form can be questioned, particularly as the presently used diagnostic tests have poor sensitivity and hence the meat inspection procedures will be preventing only a proportion of cases [40]. Certainly, a move to risk based surveillance rather than universal surveillance is warranted [42].

Ascaris lumbricoides

Ascaris lumbricoides has a single host life cycle with an obligatory period of development in soil. It is one of the commonest helminth infections of humans, with an estimated 5.2 billion persons at risk of infection in countries with stable transmission [43]. The numbers infected have been estimated to range from 807 to 1221 million [44,45].

In common with most other helminth infections, the morbidity and mortality caused by ascariasis is related to the worm burden. Like the other soil-transmitted helminths, *Ascaris* is 'overdispersed' in endemic communities, such that most individuals have light infections and are clinically asymptomatic, whereas a few individuals harbor most of the worms. The most intense infections are usually seen in children in the 5–15 year age group, with a decline in both prevalence and intensity in adulthood. Acute intestinal obstruction is the commonest sequela of ascariasis, accounting for approximately three-quarters of all complications that result in hospitalization [46]. It usually occurs in heavy infections, is seen largely among children below the age of 10 years, and was associated with a mean case fatality rate of 5.7%. Other recognized acute sequelae include intestinal intussusceptions and volvulus, as well as biliary and hepatic complications, pancreatitis, appendicitis, and other syndromes caused by migrating adult worms in ectopic sites [46]. Ascariasis is also associated with more insidious, chronic effects. Infections with 10–15 adult worms have been shown to be associated with reversible deficits in growth and physical fitness in children [47–49]. Infections have also been implicated in lactose intolerance, malabsorption of vitamin A, as well as impaired cognition and reduced school attendance [34]. Larval migration to kidney, heart, and brain has been reported. Invasion of the brain may result in convulsions. Larvae in ectopic locations are rapidly killed and granulomas are formed [50]. Damage to the lungs occurs during the migration of larvae on their way to the intestine. Larvae cause symptoms from their actual physical presence and the eosinophilic inflammatory responses they elicit. Löffler's syndrome may present, in which eosinophils accumulate in the lungs in response to a parasitic infection. Löffler's syndrome can be potentially fatal, and may be accompanied with fever, cough, sputum, asthma, skin rash, eosinophilia, and radiological pulmonary infiltration [51,52].

In the GBD 2010 estimates published in 2012, ascariasis was estimated to cause 2700 deaths (range 0–13 000) in 2010, and account for 1 315 000 DALYs (range 713 000–2 349 000) in all age groups and both sexes [37,53]. This is a marked reduction from the estimated 3400 deaths (range 0–16 400) and 4 217 000 (range 2 291 000–7 148 000) DALYs for 1990.

Consumption of raw, unpeeled fruits and vegetables that have come into contact with soil contaminated with human feces is a well-recognized form of transmission of ascariasis. The proportion of ascariasis that is foodborne will be estimated by the Source Attribution and the Computational Task Forces of the FERG.

Concluding remarks

Estimating the global burden of FBDs caused by parasites and other hazards is challenging because of complex transmission pathways and the diversity of health outcomes such parasites cause. The work of the FERG to date has indicated that parasites that can be potentially transmitted in food have a major impact on human health. Whereas some parasites such as fishborne trematodes are entirely transmitted through food, others, for example, *Echinococcus* spp., have a variety of potential pathways including food contamination and non-food pathways such as direct animal contact. Unraveling this source attribution continues to be one of the main tasks remaining with the FERG as total estimates of the burden caused by these pathogens have largely been completed.

Acknowledgments

All the coauthors are present or past members of the FERG. All except C.S. have been members of the Parasitic Diseases Task Force. Many of the studies reviewed in this article were supported by grants from the WHO.

References

1 WHO (2007) *First Formal Meeting of the Foodborne Disease Burden Epidemiology Reference Group (FERG), 26–28 November 2007*, WHO
2 WHO and FAO (2012) *Multi Criteria Based Ranking for Risk Management of Foodborne Parasites. Report of a Joint FAO/WHO Expert Meeting on Foodborne Parasites, 3–7 September 2012*, WHO
3 Carnicer-Pont, D. *et al.* (2005) An outbreak of Cryptosporidiosis in Wales, November 2005. *Euro Surveill.* 10, E051208.4
4 Valderrama, A. (2009) Multiple risk factors associated with a large statewide increase in Cryptosporidiosis. *Epidemiol. Infect.* 137, 1781–1788
5 Pappas, G. *et al.* (2009) Toxoplasmosis snapshots: global status of *Toxoplasma gondii* seroprevalence and implications for pregnancy and congenital toxoplasmosis. *Int. J. Parasitol.* 39, 1385–1394
6 Montoya, J.G. and Liesenfeld, O. (2004) Toxoplasmosis. *Lancet* 363, 1965–1976
7 Liesenfeld, O. *et al.* (1999) Toxoplasmosis in the setting of AIDS. In *Textbook of AIDS Medicine* (2nd edn), pp. 225–229, Williams and Wilkins
8 Bodaghi, B. *et al.* (2012) Toxoplasmosis: new challenges for an old disease. *Eye (Lond.)* 26, 241–244
9 Palmer, B.S. (2007) Meta-analysis of three case controlled studies and an ecological study into the link between cryptogenic epilepsy and chronic toxoplasmosis infection. *Seizure* 16, 657–663
10 Torrey, E.F. *et al.* (2012) *Toxoplasma gondii* and other risk factors for schizophrenia: an update. *Schizophr. Bull.* 38, 642–647
11 Miman, O. *et al.* (2010) The probable relation between *Toxoplasma gondii* and Parkinson's disease. *Neurosci. Lett.* 475, 129–131
12 Koseoglu, E. *et al.* (2009) Is *Toxoplasma gondii* a causal agent in migraine? *Am. J. Med. Sci.* 338, 120–122
13 Flegr, J. *et al.* (2002) Increased risk of traffic accidents in subjects with latent toxoplasmosis: a retrospective case-control study. *BMC Infect. Dis.* 2, 11
14 Torgerson, P.R. and Mastroiacovo, P. (2013) The global burden of congenital toxoplasmosis: a systematic review. *Bull. World Health Organ.* 91, 501–508
15 Gilbert, R.E. *et al.* (2008) Ocular sequelae of congenital toxoplasmosis in Brazil compared with Europe. *PLoS Negl. Trop. Dis.* 2, e277

16 Cook, A.J.C. *et al.* (2000) Sources of *Toxoplasma* infection in pregnant women: European multicentre case-control study. *BMJ* 321, 142–147
17 Sakikawa, M. *et al.* (2012) Anti-*Toxoplasma* antibody prevalence, primary infection rate, and risk factors in a study of toxoplasmosis in 4,466 pregnant women in Japan. *Clin. Vaccine Immunol.* 19, 365–367
18 Fürst, T. *et al.* (2012) Global burden of human food-borne trematodiasis: a systematic review and meta-analysis. *Lancet Infect. Dis.* 12, 210–221
19 Keiser, J. and Utzinger, J. (2009) Food-borne trematodiases. *Clin. Microbiol. Rev.* 22, 466–483
20 Mordvinov, V.A. *et al.* (2012) *Opisthorchis felineus* and *Metorchis bilis* are the main agents of liver fluke infection of humans in Russia. *Parasitol. Int.* 61, 25–31
21 Budke, C.M. *et al.* (2006) Global socioeconomic impact of cystic echinococcosis. *Emerg. Infect. Dis.* 12, 296–303
22 Budke, C.M. *et al.* (2013) A systematic review of the literature on cystic echinococcosis frequency worldwide and its associated clinical manifestations. *Am. J. Trop. Med. Hyg.* 88, 1011–1027
23 Budke, C.M. *et al.* (2004) Use of disability adjusted life years in the estimation of the disease burden of echinococcosis for a high endemic region of the Tibetan plateau. *Am. J. Trop. Med. Hyg.* 71, 56–64
24 Torgerson, P.R. *et al.* (2010) The global burden of alveolar echinococcosis. *PLoS Negl. Trop. Dis.* 4, e722
25 Schweiger, A. *et al.* (2007) Human alveolar echinococcosis after fox population increase, Switzerland. *Emerg. Infect. Dis.* 13, 878–882
26 Schneider, R. *et al.* (2013) Unexpected increase of alveolar echinococcosis, Austria, 2011. *Emerg. Infect. Dis.* 19, 475–477
27 Bruzinskaite, R. *et al.* (2007) Alveolar echinococcosis, Lithuania. *Emerg. Infect. Dis.* 13, 1618–1619
28 Nahorski, W.L. *et al.* (2013) Human alveolar echinococcosis in Poland: 1990–2011. *PLoS Negl. Trop. Dis.* 7, e1986
29 Usubalieva, J. *et al.* (2013) Human alveolar echinococcosis in Kyrgyzstan. *Emerg. Infect. Dis.* 19, 1095–1097
30 Torgerson, P.R. *et al.* (2008) Alveolar echinococcosis: from a deadly disease to a well-controlled infection. Relative survival and economic analysis in Switzerland over the last 35 years. *J. Hepatol.* 49, 72–77
31 Piarroux, M. *et al.* (2013) Populations at risk for alveolar echinococcosis, France. *Emerg. Infect. Dis.* 19, 721–728
32 Abougrain, A.K. *et al.* (2010) Parasitological contamination in salad vegetables in Tripoli-Libya. *Food Control* 21, 760–762
33 Coyle, C.M. *et al.* (2012) Neurocysticercosis: neglected but not forgotten. *PLoS Negl. Trop. Dis.* 6, e1500
34 Ndimubanzi, P.C. *et al.* (2010) A systematic review of the frequency of neurocysticercosis with a focus on people with epilepsy. *PLoS Negl. Trop. Dis.* 4, e870
35 Carabin, H. *et al.* (2011) Clinical manifestations associated with neurocysticercosis: a systematic review. *PLoS Negl. Trop. Dis.* 5, e1152
36 Winkler, A.S. (2012) Neurocysticercosis in sub-Saharan Africa: a review of prevalence, clinical characteristics, diagnosis, and management. *Pathog. Glob. Health* 106, 261–274
37 Murray, C.J.L. *et al.* (2012) Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 380, 2197–2223
38 Alban, L. *et al.* (2011) Towards a standardised surveillance for *Trichinella* in the European Union. *Prev. Vet. Med.* 99, 148–160
39 Kapel, C.M.O. (2005) Changes in the EU legislation on *Trichinella* inspection – new challenges in the epidemiology. *Vet. Parasitol.* 132, 189–194
40 Torgerson, P.R. (2013) One world health: socioeconomic burden and parasitic disease control priorities. *Vet. Parasitol.* 195, 223–232
41 Murrell, K.D. and Pozio, E. (2011) Worldwide occurrence and impact of human trichinellosis 1986–2009. *Emerg. Infect. Dis.* 17, 2194–2202
42 Schuppers, M.E. *et al.* (2010) Comparing the demonstration of freedom from *Trichinella* infection of domestic pigs by traditional and risk-based surveillance. *Epidemiol. Infect.* 138, 1242–1251
43 Pullan, R.L. and Brooker, S.J. (2012) The global limits and population at risk of soil-transmitted helminth infections in 2010. *Parasit. Vectors* 5, 81
44 Bethony, J. *et al.* (2006) Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm. *Lancet* 367, 1521–1532
45 De Silva, N.R. *et al.* (2003) Soil-transmitted helminth infections: updating the global picture. *Trends Parasitol.* 19, 547–551
46 De Silva, N.R. *et al.* (1997) Morbidity and mortality due to *Ascaris*-induced intestinal obstruction. *Trans. R. Soc. Trop. Med. Hyg.* 91, 31–36
47 Stephenson, L.S. *et al.* (1993) Physical fitness, growth and appetite of Kenyan school boys with hookworm, *Trichuris trichiura* and *Ascaris lumbricoides* infections are improved four months after a single dose of albendazole. *J. Nutr.* 123, 1036–1046
48 Stephenson, L.S. *et al.* (1993) Weight gain of Kenyan school children infected with hookworm, *Trichuris trichiura* and *Ascaris lumbricoides* is improved following once- or twice-yearly treatment with albendazole. *J. Nutr.* 123, 656–665
49 Thein-Hlaing *et al.* (1991) A controlled chemotherapeutic intervention trial on the relationship between *Ascaris lumbricoides* infection and malnutrition in children. *Trans. R. Soc. Trop. Med. Hyg.* 85, 523–528
50 Pawlowski, Z.S. (1990) Ascariasis. In *Tropical and Geographic Medicine* (2nd edn), pp. 369–378, McGraw-Hill
51 Gelpi, A.P. and Mustafa, A. (1967) Seasonal pneumonitis with eosinophilia. A study of larval ascariasis in Saudi Arabs. *Am. J. Trop. Med. Hyg.* 16, 646–657
52 Geissler, P.W. *et al.* (1998) Geophagy as a risk factor for geohelminth infections: a longitudinal study of Kenyan primary schoolchildren. *Trans. R. Soc. Trop. Med. Hyg.* 92, 7–11
53 Lozano, R. *et al.* (2012) Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 380, 2095–2128
54 WHO and FAO (2007) *Codex Alimentarius Commission. Procedural Manual* (17th edn), WHO/FAO