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Update on *Cryptosporidium* and *Giardia* infections in cattle

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Cattle are frequently parasitized with *Giardia duodenalis*, *Cryptosporidium parvum* and *Cryptosporidium andersoni*. These parasites cause diarrhoea and impair gain of body weight. *Giardia* and *Cryptosporidium* from cattle are potential zoonotic pathogens, and contact with animals, manure or contaminated water is believed to lead to infections in humans. Molecular epidemiology has suggested that cattle are not as significant a reservoir for human infections as was once believed. Most *G. duodenalis* from cattle (Assemblage E) are different from those in humans (Assemblages A and B), and *C. andersoni* does not infect humans. However, molecular tools have shown that humans can be infected with zoonotic *C. parvum*, as well as anthroponotic *Cryptosporidium hominis*.

As reports of the common occurrence of *Giardia* and *Cryptosporidium* in cattle have increased, so has concern on the role of cattle as the source of waterborne outbreaks of giardiasis and cryptosporidiosis. It is now clear that the source of infections with these two enteric protozoans in humans is probably more often from other humans, rather than from cattle. By contrast, insufficient attention has been given to the role of cryptosporidial and giardial infections as causes of disease and production losses in cattle, particularly the effects of sub-clinical, chronic infections.

Cryptosporidium

The taxonomy and phylogenetic relationships of *Cryptosporidium* are in a state of flux [1], and there is growing evidence that *Cryptosporidium* has more affinities with gregarine protozoa than with the coccidians [2]. This will have an enormous impact on the biology, epidemiology and control of *Cryptosporidium*, and the infections it causes. At the species level, 13 are currently recognized on the basis of morphological differences, host, site of infection and genetic differences (Table 1). In addition, an increasing number of genetically distinct intraspecific variants, or genotypes, ostensibly of *Cryptosporidium parvum*, have been described, many of which appear to be host specific and could represent distinct species (Table 1). Molecular epidemiological studies have shown that there are at least two distinct life cycles of *Cryptosporidium* involving humans, and a series of other transmission cycles involving what appear to be principally host-adapted species [1]. As a result of the extensive molecular data that have been obtained on the human and cattle genotypes of *C. parvum*, combined with a growing amount of biological information on these two morphologically identical forms, the anthroponotic human genotype has recently been proposed to be recognized as a distinct species, *Cryptosporidium hominis* [3].

Two species of *Cryptosporidium* have been identified in cattle: (i) *C. parvum* (cattle genotype) in the intestine; and (ii) *Cryptosporidium andersoni* in the abomasum. In addition to their site of predilection, the two species have morphologically distinct oocysts and differ genetically [4]. The cattle genotype of *C. parvum* also infects other mammals including humans [1]. Although *C. andersoni* was originally thought to be host specific for cattle, its occurrence in and infectivity to other hosts including rodents and cervids has brought this into question [5,6]. However, whether its occurrence in other livestock represents an active infection or oocysts ingested from pasture contaminated by cattle remains to be determined.

Giardia

The taxonomy of *Giardia* is unsatisfactory with numerous genetic variants from mammals currently in the one species *Giardia duodenalis* [1]. Six species of *Giardia* are recognized on the basis of morphological characteristics and host occurrence (Table 2). The lack of morphological differences between the genetic variants found in mammals has resulted in an informal categorization of these genotypes based on genetic differences (Table 1). Cattle are susceptible to infection with two genotypes of

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Table 1. *Cryptosporidium* and *Giardia* spp. and their hosts

Species	Host
Cryptosporidium[a]	
C. canis	Dog
C. hominis	Humans
C. molnari	Marine fish
C. felis	Cat
C. parvum	Cattle and other mammals
C. muris	Mouse
C. wrairi	Guinea pig
C. andersoni	Cattle, other livestock and rodents
C. meleagridis	Poultry and possibly mammals
C. baileyi	Chickens
C. serpentis	Snake
C. saurophilum	Reptiles
C. nasorum	Fish
Giardia[b]	
G. duodenalis (syn. *G. intestinalis, G. lamblia*)	Most mammals including humans, livestock and pets
G. muris	Mice
G. microti	Voles and muskrats
G. psicatti	Budgerigars
G. ardeae	Heron and ibis
G. agilis	Frogs

[a]Data obtained from Refs [1,3].
[b]Data obtained from Ref. [1].

G. duodenalis: (i) the zoonotic genotype Assemblage A; or (ii) the livestock genotype, Assemblage E.

Life cycles and epidemiology

In cattle, *C. parvum* and *C. andersoni* invade superficial cells of the mucosa in the intestine and abomasum, respectively, but remain extracytoplasmic being surrounded by an invagination of the host cell membrane. Subsequent development involves asexual and sexual phases, but might not be typically coccidial as previously believed, and gregarine-like extracellular developmental stages could play an important role in the life cycle of *Cryptosporidium* within its hosts [2].

Giardia develops in the small intestine where it multiplies by asexual binary fission on the surface of the mucosa as the trophozoite stage. As trophozoites pass through the small intestine, they encyst and are excreted with the faeces.

Transmission from one host to another is achieved by ingestion of an encysted, sporulated oocyst for *Cryptosporidium* or cyst for *Giardia*. Oocysts and cysts are discharged in the faeces of infected cattle, and are of primary importance for the dispersal and survival of the parasites. Transmission can be direct from host to host, by ingestion of fecal contaminated food or water or, as with other fecal transmitted parasites, possibly mechanically via insect vectors [7]. Limiting factors for oocyst and cyst survival are high temperatures and desiccation. Transmission is likely to be direct between infected animals because environmental contamination on farms with oocysts and cysts would be insufficient to account for the high levels of infection seen in cattle, particularly with *Giardia* [8,9].

Table 2. Genotypic groupings of *Giardia duodenalis*[a]

Assemblage (genotypic grouping)	Host range
Assemblage A (Group I)	Humans and other mammals; zoonotic
Assemblage A (Group II)	Mainly humans; zoonotic
Assemblage B (Group III)	Humans and other mammals; zoonotic
Assemblage B (Group IV)	Humans
Assemblage C/D	Dogs
Assemblage E	Livestock
Assemblage F	Cats

[a]Data obtained from Ref. [1].

Veterinary significance

Cryptosporidium parvum

Calves usually become infected with *Cryptosporidium* (Table 3) between one and four weeks of age, and the duration of infection is short, lasting around two weeks [10–13]. Calves begin shedding oocysts as early as two days of age with peak shedding occurring at 14 days of age.

The pathogenesis of *Cryptosporidium* diarrhea is believed to result from parasite invasion and epithelial destruction, resulting in mild to moderate villus atrophy, and microvillus shortening and destruction [14]. This leads to impaired nutrient digestion and transport. The main clinical manifestations of *C. parvum* in cattle are diarrhea, depression, anorexia and abdominal pain [10–14]. Clinical cryptosporidiosis in calves is observed in calves 7–30 days of age, which lasts 4–14 days. The severity and duration are highly variable among calves. The diarrhea, which is pale yellow with mucus, can be mild to severe and can last for up to two weeks. Calves are usually lethargic, anorexic and dehydrated. In severe cases, calves die from dehydration and cardiovascular collapse. Other enteric viral, bacterial and parasitic pathogens such as rotavirus, *Escherichia coli* and *Giardia* could also be observed in calves during the first four weeks of life that could contribute to the severity of cryptosporidiosis [10,14,15]. Calves with severe cryptosporidiosis can take four to six weeks to recover fully, and there could be an initial negative impact on production due to weight loss or impaired weight gain. However, there is no evidence to support or refute that *Cryptosporidium* infections in beef and dairy calves have long-term performance effects [16]. Therefore, an economic analysis of the cost of this highly prevalent protozoan infection to the beef and dairy industry is needed.

Cryptosporidium parvum is less frequently identified in open-range beef calves that are typical to Western Canada and the USA [11,16,17], however, when infection occurs in beef calves, it is usually more severe in these calves than in dairy [11,18]. In the Canadian provinces of Alberta, Saskatchewan and British Columbia, mortality rates of up to 30% have been observed in beef calves. These cases of high *Cryptosporidium* mortalities are usually associated with the introduction of dairy calves to beef herds during the calving season and a lack of herd immunity in certain herds because most dairy animals have been exposed to *Cryptosporidium* and developed natural immunity within the herd following infection. Herds with high mortalities had low levels of serum selenium (0.02–0.05 ppm; normal is 0.08–0.20 ppm), suggesting that certain trace elements might also have a role in the immune status and clinical outcome of the calves [19]. The differences in prevalence and clinical signs between Canadian beef and dairy calves

Table 3. Infection dynamics of *Giardia* and *Cryptosporidium* spp. in cattle

	Giardia duodenalis	*Cryptosporidium parvum*	*Cryptosporidium andersoni*	Refs
Age of oocyst and/or cyst shedding (weeks)	2–10	1–5	>7	[9–11,13,15–17]
Duration of cyst shedding	>30 weeks	1–2 weeks	5 months to years	[9–11,13,15–17]
Age of peak shedding (weeks)	~5	1–2	N/A	[9–11,13,15–17]
Age of onset of diarrhoea (weeks)	3–8	1–2	N/A	[9–11,13,15,16]
Duration of diarrhoea (weeks)	1–2	1–3	N/A	[9–11,13,15,16]
Duration of peri-parturient shedding (weeks)[a]	0–3	0–2	0– > 4	[9,11,12,15]

[a]Peri-parturient refers to the period between two weeks before calving and four weeks post-calving.

are most likely attributable to the industry itself. In the dairy industry, new calves are born and introduced to herds continuously throughout the year, whereas beef calves are born over a period of one to two months in the spring. Continual introduction of dairy calves provides the opportunity for year-round transmission to a new susceptible population. The transmission cycle can be broken in beef calves because the calving season is short. Dairy calves are confined to pens or hutches from birth, whereas beef cows give birth in a large calving area and are released into a range area [20,21]. A distance between the shedding calf and the susceptible calf reduces chances of disease transmission. Neutralizing antibodies in colostrum and milk are believed to reduce infectivity by immobilization of the parasite, blockage of invasion, inhibition of adhesion to host cells or direct cytotoxicity to *Cryptosporidium* sporozoites [22]. Beef calves are consuming mother's milk, which could be protective, provided that the mother has had prior exposure to the parasite. Dairy calves are often fed bulk milk with low antibody concentrations or a milk replacement without any antibodies. The diet itself could have a major role in preventing establishment of infection and reducing the severity of the clinical signs. Indeed, milk from vaccinated cows has been shown to reduce clinical signs [23]. In conclusion, it is believed that the herds that experience high mortalities and severe clinical signs are those where: (i) herd immunity to the parasite is poor; (ii) there is inadequate nutrition; (iii) presence of concurrent enteric infections (e.g. rotavirus, *Giardia*); and (iv) presence of certain management practices.

Cryptosporidium andersoni

Cryptosporidium andersoni was reported to colonize the abomasum of Idaho feedlot cattle that were in poor body condition compared with other pen mates [24]. This parasite has now been identified worldwide [5,24,25]. *Cryptosporidium andersoni* usually infects post-weaned beef and dairy calves, and mature cattle, persisting for years, if not for life [16,25,26]. Abomasal *Cryptosporidium* invades the peptic and pyloric glands causing dilation of the glands, hypertrophy of the gastric mucosa and thinning of the epithelial lining. Functionally, this leads to impairment of protein digestion by increasing gastric pH and inhibition of proteolytic function [24,27]. Infections with *C. andersoni* can cause moderate to severe impairment of weight gain and decreased feed efficiency in feedlot cattle, and a 3.2 kg per day reduction in milk production in diary cows [16,24,27]. The effects of *C. andersoni* on range cattle is not known, but the known nutritional and milk production effects of this abomasal parasite would be expected to affect growth in nursing range calves as a result of reduced milk production in dams.

Giardia

Giardia duodenalis has been found in beef and dairy cattle, worldwide. The prevalence rates can vary, but this is reflected by differences in management, climate and study design. Longitudinal studies have consistently demonstrated prevalence of 100% in beef and dairy [10,11]. *Giardia* infection patterns (Table 3) are similar between beef and dairy cattle [9–11], and *Giardia* transmission occurs readily between infected calves and between chronically infected adults. Indeed, *Giardia* transmission was shown to occur between dairy calves, despite the use of extensive disinfection methods and antiparasitic treatment [28]. Peri-parturient (the period between two weeks before calving and four weeks post-calving) rise in cyst excretion has also been demonstrated and dams might act as an infection source for calves [18].

Giardia has been implicated as an etiological agent alone and in combination with other enteric pathogens in calf diarrhea [9,10]. Concurrent infections with *Giardia* and *Cryptosporidium* were observed as the primary cause of diarrhea in calves <30 days of age, and *Giardia* alone was associated with diarrhea in calves >30 days of age [10]. *Giardia* infection has been shown to influence performance in several animal species. Experimentally infected lambs had reduced rate of weight gain, impaired feed efficiency and decreased carcass weight, but the average daily weight gain, feed intake and feed efficiency were not affected in a small calf feedlot study [16,29]. In conclusion, *Giardia* infections in cattle are clinically important and could have economic significance by impairing performance.

Cattle as reservoirs for other livestock and wildlife

Wildlife and game ranched animals such as deer, buffalo, elk and reindeer are potential reservoirs of *Giardia* and *Cryptosporidium* for cattle. Cattle could also act as a source of these parasites for many wildlife species. Throughout the world, beef cattle and, to a lesser extent, dairy cattle, frequently have direct contact with wild and ranched wildlife species. Many of these wildlife species are susceptible to infection with the same species and genotypes of *Giardia* and *Cryptosporidium* as cattle. Zoonotic *G. duodenalis* genotypes (Assemblages A and B) and *C. parvum* (cattle genotype) have been identified in wild and captive primates (spider monkeys, gorillas), cervids (deer, elk, reindeer, caribou), bovids (bison), felids (bobcat, cougar), pinnipeds (seals), whales and rodents (beaver, ground hog, prairie dog) [30–34]. The transmission

pathway of these infections has not been reported, but *C. parvum* from cattle could potentially be a source of wildlife infections. Chronic infections with *C. parvum* and/or *G. duodenalis* could lead to increased susceptibility of the host to other infections agents, starvation and predation. The role of *Giardia* and *Cryptosporidium* in wildlife health has not been investigated, although prevalence rates might be high in some species.

Ecosystem health

Although the transmission process is complex and the risk is low, there is a definite potential for *Giardia* and *Cryptosporidium* contamination of ground and surface waters from livestock operations. Management of faecal waste is crucial when water run-off can reach receiving surface water or contaminate groundwater. There are major concerns with applying fresh animal manure to fertilize agricultural land because of the potential for faecal pathogens to reach surface and/or groundwater. Rainfall could result in pathogen spread into soil or water directly by run-off from manure or by leaching through soil profiles. Following irrigation with a zero gradient, >70% of *Cryptosporidium* oocysts can be recovered from the top 2 cm of the soil and oocyst recovery from the leachate is minimal, whereas at a gradient of 7.5%, the movement of *Cryptosporidium* in run-off was demonstrated [35,36]. Soil samples collected from New York State dairy farms yielded 17% positive for *Cryptosporidium* and 4% positive for *Giardia* [8]. It is believed that the primary modes by which parasites such as *Giardia* and *Cryptosporidium* are transported to surface water are via: (i) the drainage from manure storage areas; (ii) direct contact by cows with water; (iii) run-off from fields on which manure has been spread; and (iv) wash from manure-laden soil [8,35–39]. Parasites, including *Giardia* and *Cryptosporidium*, have been isolated from irrigation waters [40] and have been subsequently isolated from fruits and vegetables [41]. Application of manure to soil is another way in which bacteria and parasites can contaminate fruits and vegetables. Apples contaminated with *Cryptosporidium* with cattle faeces have been implicated in human infections linked to consumption of non-pasteurized apple juice [42].

Giardia cysts are non-infective in water, cattle feces, and soil following one week of freezing at −4 °C and within one week at 25 °C [43]. At 4 °C, *Giardia* cysts are infective for 11 weeks in water, seven weeks in soil and one week in cattle feces [43]. *Giardia* cysts have been shown to be viable for up to 84 days in cold river and lake water [44]. At 5 °C, cysts survive for >156 days in mixed human and swine manure slurry, whereas, at 25 °C, cysts survive for less than a week [45].

Cryptosporidium parvum oocysts are more environmentally resistant than are *Giardia* cysts. At −4 °C and 4 °C, the oocysts survive in soil, water and feces for >12 weeks with degradation of oocysts accelerating in these environments at 25 °C [43]. In another study, oocysts could survive for several months in temperate climates in agricultural soil [46]. In cattle manure piles, which reach and maintain temperatures between 35 °C and 50 °C, oocyst infectivity declines significantly within 70 days [46]. *Cryptosporidium* oocysts can be inactivated by freezing at −70 °C for 1 h and at −20 °C for 24 h, but remain viable for up to eight weeks when stored at −5 °C [47]. On the other end of the spectrum, *Cryptosporidium* loses its infectivity by heating at 55 °C for 30 s, at 60 °C for 15 s and at 70 °C for 5 s [47,48]. *Cryptosporidium* oocysts are strongly resistant to most of the commonly used disinfectants, and chlorination of drinking water is not sufficient to prevent an infection. *Cryptosporidium* oocysts are also able to endure the silage fermentation process [49]. Cattle manure requires careful management because *C. parvum* oocysts in agricultural soils and in manure pose a threat to surface water.

Public health significance

Cryptosporidium

There is circumstantial evidence of human cryptosporidiosis *associated* with farms and exposure to infected livestock, particularly young cattle, animal manure and contaminated water [1,12,17]. Although farm workers and visitors to farms might have contracted cryptosporidiosis by direct contact, indirect zoonotic transmission of *Cryptosporidium* of cattle origin via water has long been considered to be the most important zoonotic source of human infection. Unfortunately, recent *Cryptosporidium* outbreaks where there was an association of human exposure to infected cattle have not been confirmed using available molecular tools [50]. In the search for sources of waterborne outbreaks of cryptosporidiosis, livestock have often been implicated as the origin of contaminating isolate. However, such conclusions were often only circumstantial, with presumptions being made that run-off from pasture used for cattle was the predisposing factor.

With the advent of appropriate PCR-based molecular tools that could discriminate between different *Cryptosporidium* species and/or genotypes, cattle have not been conclusively identified as the source of any waterborne outbreak within the USA and in Canada. One exception is the waterborne outbreak in Cranbrook, British Columbia, Canada, where oocysts of the bovine genotype have been identified [12]. However, there have been outbreaks caused by the bovine genotype in North America that were linked to direct contact with animals or contaminated food such as the Maine apple cider outbreak in 1995, the Pennsylvania rural family outbreak in 1997 and the Minnesota Zoo outbreak in 1997 [40–42,51].

There has been a steady accumulation of epidemiological data during 1998–2003 in which *Cryptosporidium* isolates from human cases have been genotyped (Table 4). Although *C. parvum* (Type 1, bovine genotype) is the most common zoonotic species, other *Cryptosporidium* species have also been identified, including *Cryptosporidium meleagridis*, *Cryptosporidium canis*, *Cryptosporidium felis* and *Cryptosporidium muris* [18,52–62]. There is a report of a human infection with *C. muris* [56,58,62], but the cattle abomasal parasite, *C. andersoni*, does not appear to infect immunocompetent or HIV-infected individuals. Genotyping *Cryptosporidium* infections in humans has revealed some interesting differences between the situation in Australia and North America,

where most cases appear to be of human origin, and in Europe where zoonotic sources of infection appear to be more common [1]. These can only be general observations at present and more focused molecular epidemiological studies in defined endemic foci are required to gain a better understanding of transmission.

Giardia

Although beef and dairy cattle are commonly infected with *Giardia*, there is no evidence to support their role as reservoirs of infection in humans. Studies that compared the prevalence and genotypes of beef and dairy in different geographical locations indicated that >90% of cattle harbored infections with the non-zoonotic livestock genotype (Assemblage E) of *G. duodenalis* [63,64]. A molecular epidemiological investigation in which cattle were found to be infected with the zoonotic genotype of *G. duodenalis* (Assemblage A) demonstrated that humans were the likely source of infection in both cattle and co-habiting wildlife [34].

Control and treatment

Cryptosporidium

Vaccination has been proposed as a method to control cryptosporidiosis in animal populations [22,65,66]. Immunodominant *Cryptosporidium* antigens have been identified from natural infections, and subunit vaccines have been prepared and vaccination trials have been conducted in calves [22,66]. Using active and passive immunization approaches, vaccines have been shown to reduce clinical signs but, in most cases, have not eliminated or reduced oocyst shedding. Indeed, selection of immunodominant antigen-subunit vaccine candidates is based upon the premise that the T helper cell Type 2 (Th2) response is responsible for eliminating the parasite and for protection from further infection. Although immunoglobulin (Ig) G, IgA and IgM responses are developed following vaccination, the role of antibodies in parasite clearance and prevention of clinical signs is unclear [23,65]. Cellular immunity could be more important for prevention of clinical signs and elimination of the parasite [23,65]. Non-specific agents in milk, such as epidermal growth factor (EGF), have been shown to protect enterocytes from parasite-induced pathophysiological alterations [67].

Many chemotherapeutic agents have been tested *in vitro* and *in vivo* for the treatment of cryptosporidiosis, but few agents have shown promise. Drugs such as paromomycin and decoquinate decrease oocyst shedding, and improve the frequency and severity of diarrhea in calves and lambs [14,68]. Halfuginone lactate (Halocur®, Intervet; http://www.intervetusa.com/) has recently been registered in Europe as a chemotherapeutic agent for cryptosporidiosis in domestic cattle, which has been shown to reduce incidence and severity of diarrhea, but does not prevent oocyst shedding [69]. Currently, there are no studies investigating the treatment of *C. andersoni* in the abomasum of feedlot or dairy cattle. The impact of this infection on performance and production would warrant such studies.

Giardia

Infection with *G. duodenalis* is able to produce humoral immunity that results in self-limiting infection in many animal species [70,71], but it can take >100 days for the host to produce protective antibodies [71]. Lactating cows produce colostrum and milk with anti-*Giardia* activity, thereby protecting young calves from infection. A vaccine could have potential application in beef and dairy cattle [70].

Benzimidazoles (fenbendazole, albendazole) are effective in eliminating *Giardia* from confined and range calves [28,72,73]. Fenbendazole was also able to improve the mucosal microvillus structure and function within seven days of initiating treatment [73]. Although these agents are highly effective, re-infection frequently occurs if the sources of environmental contamination are not eliminated [28]. The use of chemotherapeutic agents for the control of giardiasis in cattle provides the opportunity to enhance performance, reduce clinical signs and prevent environmental contamination.

Conclusion

Cattle are principally of public health significance as a source of infection with *C. parvum*, but the circumstances where pasture run-off could lead to waterborne outbreaks are only recently being identified through the use of molecular typing. By contrast, the fact that cattle are most commonly infected with the non-zoonotic livestock

Table 4. Prevalence of *Cryptosporidium* spp. in immunocompetent and patients with HIV

Location[a]	No. of samples	Prevalence (%)						Refs
		C. hominis	*C. parvum*	*C. meleagridis*	*C. canis*	*C. felis*	*C. muris*	
USA (HIV)	10	5 (50)	1 (10)	0	1 (10)	3 (30)	0	[52]
Various (HIV)	22	7 (31.8)	8 (36.4)	2 (9.1)	0	5 (22.7)	0	[53]
Peru (children)	85	67 (78.8)	8 (9.4)	7 (8.2)	2 (2.3)	1 (1.2)	0	[54]
UK	1711	651 (38.0)	1055 (61.7)	5 (0.3)	0	0	0	[55]
Thailand (HIV)	29	24 (82.7)	0	3 (10.3)	0	1 (3.5)	1 (3.5)	[56]
Northern Ireland	39	5 (12.8)	34 (87.2)	0	0	0	0	[57]
France	57	18 (31.6)	29 (50.9)	3 (5.3)	0	6 (10.5)	1 (1.7)	[58]
Denmark	44	25 (56.8)	18 (40.9)	1 (2.3)	0	0	0	[59]
Thailand (HIV)	34	17 (50)	5 (14.7)	7 (20.6)	2 (5.9)	3 (8.8)	0	[60]
New Zealand	66	1 (1.5)	65 (98.5)	0	0	0	0	[61]
Various (HIV)	63	47 (74.6)	14 (22.2)	1 (1.6)	0	0	1 (1.6)	[62]
Canada	35	19 (54.3)	14 (40)	2 (5.7)	0	0	0	[18]

[a]Patients that were positive for HIV are indicated in parentheses. The patients in other studies were either negative for HIV or their status was not reported.

genotype of *G. duodenalis* probably limits their role as reservoirs of giardiasis in humans. Although the adverse clinical consequences of *C. parvum* in calves are well recognized, the circumstances that could lead to acute disease remain to be determined. Similarly, although seemingly ubiquitous in cattle, very little is known about how *G. duodenalis* and *C. andersoni* affect cattle in terms of disease and productivity. The presence of both organisms probably exacerbates the effects of concurrent infections, nutritional deficiencies and stress, but research data are lacking. Drugs are unlikely to be a practical approach to controlling infection with these protozoa in cattle, whereas vaccination could prove to be the best strategy and warrants research in terms of both candidate identification and delivery.

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