Epidemiol. Infect. (2009), **137**, 913–921.
doi:10.1017/S0950268809002295 Printed in the United Kingdom

REVIEW ARTICLE
Giardia and *Cryptosporidium* infections in sheep and goats: a review of the potential for transmission to humans via environmental contamination

L. J. ROBERTSON*

Parasitology Laboratory, Department of Food Safety and Infection Biology, Norwegian School of Veterinary Science, Oslo, Norway

(*Accepted 27 January 2009; first published online 10 March 2009*)

SUMMARY

The public health significance of giardiasis and cryptosporidiosis in sheep is currently unclear. Some research suggests that they are probably not an important zoonotic reservoir, whilst other research indicates this potential exists, and some outbreaks have also been associated with infections in sheep. Actions to limit water supply contamination by sheep have sometimes been severe, occasionally creating problems between farming and public health communities. Here our knowledge on these parasites in both sheep and goats is reviewed; although direct evidence of transmission to humans via water supply contamination is limited, the data accrued indicate that this is a real possibility. As cryptosporidiosis in sheep is generally more prevalent than giardiasis, and species/genotypes of *Cryptosporidium* infections in sheep are likely to be infectious to humans, this parasite may be considered the greater threat. Nevertheless, geographical variation in prevalence and genotypic distribution is extensive and as measures to limit sheep grazing can have a highly negative impact, it is important that cases are judged individually. If water contamination from a particular population of sheep/goats is suspected, then suitable investigations should be instigated, investigating both prevalence and species/genotype, before precautionary measures are imposed.

Key words: *Cryptosporidium*, *Giardia*, goats, sheep, waterborne transmission.

INTRODUCTION

Giardiasis and cryptosporidiosis are intestinal protozoan infections with a global distribution, which may cause diarrhoeal disease in the infected host. Both parasites may be transmitted to humans by ingestion of their infectious stages (cyst and oocyst respectively), which are environmentally robust. Infected hosts may excrete very high numbers of the transmission stages, whilst relatively few are necessary in order to initiate an infection, thus lending themselves to transmission via environmental contamination. Both parasites have been associated with community-wide outbreaks, in which contaminated drinking water has been demonstrated to be, or indicated to be, the vehicle of transmission.

The taxonomy of *Giardia* is complex, and *G. duodenalis*, the only species of *Giardia* which is infective to humans, is subdivided into seven different assemblages or genotypes, which may actually represent different species, and which molecular studies have demonstrated to have distinct genotypic differences, and also show some degree of host specificity. Two of

* Author for correspondence: Dr L. J. Robertson, Parasitology Laboratory, Department of Food Safety and Infection Biology, Norwegian School of Veterinary Science, PO Box 8146 Dep., 0033 Oslo, Norway.
(Email: Lucy.robertson@veths.no)

these assemblages, named A and B, are zoonotic, having been identified in human infections, as well as a range of mammalian infections, including those of livestock and companion animals. However, the other assemblages have a more limited host range, with assemblages C and D limited to canines, assemblage E limited to artiodactyls, including cattle and sheep, assemblage F limited to felines, and assemblage G limited to rodents.

The taxonomy of *Cryptosporidium* also remains unresolved, and species designation has been in a state of flux for several years. There are currently 19 valid named species of *Cryptosporidium* [16 listed in [1], and *C. macropodum* (host: eastern grey kangeroos), *C. fayerii* (host: red kangaroo) and *C. ryanae* (host: cattle)] and over 40 different isolates or genotypes [1], which tend to differ from valid species types by host and/or molecular study results. Insufficient evidence has been accumulated to designate these isolates as species, but it is anticipated that several of these will be eventually described as species as more information is accrued. *C. hominis* is the one species which is host-specific to humans (although a natural infection in cattle has been observed [2], and infections of dugong, primates, sheep, and pig with *C. hominis* have also been reported [3]). Zoonotic species of *Cryptosporidium* which have been identified in human infections are *C. parvum*, *C. andersoni*, *C. meleagridis*, *C. felis*, *C. canis*, and *C. suis*, with the vast majority of zoonotic human infections being attributed to *C. parvum* [4, 5]. Human infections with *Cryptosporidium* of the cervine genotype and the chipmunk genotype have also been reported [4], and the former appears to be relatively widespread, with sporadic symptomatic infections reported from Slovenia [6], England [5], USA [7], and Canada [8, 9].

There has been considerable interest in identifying animal species which may be hosts for those species or genotypes of these parasites which have the potential to be transmitted to humans, in order that suitable measures and initiatives can be implemented which limit the possibilities of faecal contamination of drinking-water sources by host animals.

In considering those animals which may be potential reservoirs of zoonotic species/genotypes of these infections, most attention has been directed towards cattle, particularly calves, as these are well recognized as hosts of *C. parvum*, and an infected calf may excrete many millions of infective oocysts on a daily basis. However, for sheep and goats the case is less clear cut; some argue that these animals may not be an important zoonotic reservoir for these parasites [10, 11], whilst others have recently produced evidence that sheep and/or goats may harbour species or genotypes of these parasites which are potentially infectious to humans, suggesting that sheep and/or goats should be considered to be epidemiologically significant reservoirs [12–14]. A simple, widely used risk assessment for *Cryptosporidium* in water supplies (both surface and ground) gives a significant weighting to catchment areas with a sheep density of >6/ha of forage [15]. The presence of sheep pens and/or lambing in the catchment area also increases the risk weighting. Goats are not mentioned in the assessment schedule, and are presumably included under 'any other farmed animal or bird', which has a lower weighting.

In general the term 'sheep' applies to the domestic sheep, species *Ovis aries*, one of the first animals to be domesticated, of which there are over 200 different breeds. This relatively large range of breeds has been reached by selective breeding to fulfil the various uses of sheep as a domestic animal.

Sheep are an important sector of the global, agricultural economy, although in many parts of the world, other species (particularly pigs, chickens, and cows) have replaced them to a large extent. Although the global sheep population has fallen since its peak around 1990, numbers are still considerable, and in some areas of the world, particularly Asia, sheep stocks are rising steadily [16]. The estimated global sheep population for 2006 has been estimated as 1 101 639 000 head [16] and the largest flocks are currently found in China, Australia, India, and Iran, serving both local and export requirements. Developing countries have over 60% of the global sheep population, although middle-income countries have proportionally larger sheep populations than low-income or high-income countries. In Europe, the largest sheep stocks, by a considerable margin, are to be found in the UK.

Although the demand and price for sheep products is falling in many markets, sheep have distinct economic advantages over many livestock, which make them particularly attractive to nations with limited resources. Sheep are one of the few livestock animals that have never been widely kept in intensive, confined-animal feeding operations, and they do not require expensive housing. This means that sheep are often left to graze in a defined area, with access to drinking water, for a relatively prolonged period before being rounded up and transferred to another area or brought in for slaughter. In many parts of the world the grazing area can be extensive, and may be unfenced rough pasture or hillside, particularly in summer pasturing for herds in which transhumance is practised; a large grazing area reduces pressures for transmission of infection within the herd, but also means that a larger area may be contaminated by their faeces, and also that the sheep have access to sites which would otherwise be considered pristine, including water catchment areas.

Domestic goats are of the subspecies *Capra aegagrus hircus*, and over 300 distinct breeds are recognized. Despite their similarities to sheep, the global domestic goat population is considerably less than that of sheep, with the estimated global head for 2006 being 837 236 000 [16], meaning about 30 % more sheep than goats; however, the general trend in global goat stocks has been a gradual increase, particularly in Asia (excluding Middle East) and South America [16]. As with sheep, the largest goat population is in China; India and Pakistan also have large goat populations. In Europe, the majority of goats are found in Greece, and there are also sizable goat populations in Spain and France.

As with sheep, goats eat a variety of vegetation; however, their grazing habits are generally more similar to that of deer than sheep, preferring to browse on woody shrubs and weeds rather than on grasses. This means that in general they are less likely than sheep to ingest parasites that have been excreted in faeces. As with sheep rearing, goats are generally free-ranging, and therefore, because of the economic advantages of lack of requirement for expensive housing and feed, like sheep, they are particularly attractive to human populations with limited resources. Additionally, goats have a high capacity for adapting to extreme climatic conditions, and are particularly important in arid and semi-arid regions to which sheep are unable to adapt so readily. Whereas sheep tend to stay within the confines decided by the sheep farmer, goats easily escape from fenced areas and are often good climbers; this means that in various parts of the world, domestic goat populations have established themselves in the wild. These feral goat populations may reach a considerable size and have a significant negative effect on the habitat, as well as contributing to contamination of otherwise pristine environments.

As an adult sheep or goat produces between 1–3 kg faeces on a daily basis it is clear that the potential for environmental contamination, particularly water contamination, with faecal parasites is considerable.

In this paper we review and discuss the information available to consider whether sheep and goats should be considered as potentially important reservoirs of *Cryptosporidium* and *Giardia*, and whether there is a necessity for instigating measures to limit contamination of the environment, particularly drinking water sources, by these animals.

Cryptosporidium and *Giardia* infections in sheep and goats

A number of studies of sheep and goat populations for *Cryptosporidium* and/or *Giardia* infections have been conducted from different parts of the world. A summary of many of the publications (from 1989 onwards) is provided in Table 1 (an expanded version of the table is available online). Some publications are surveys and other case reports; however, the majority of studies published to date do not include molecular studies, and therefore lack information on whether the infections identified are zoonotic, with the potential to be transmitted to humans.

From the survey-type studies it can be seen that both parasites are prevalent and widely distributed in sheep and goat populations, although differences between surveys in sample collection variables [age of animal, selection of animals by symptoms such as diarrhoea, individual or pooled samples, etc. and analysis methods (microscopy of wet mounts, microscopy following simple concentration or staining techniques, immunofluorescent antibody staining (IFA), or PCR)] means that inter-survey comparison is difficult. Some studies are outbreak reports and these indicate that in some instances both parasites can cause considerable morbidity and mortality in sheep and/or goat populations [20, 35, 44].

Summarizing the available data, the cross-sectional prevalence of *Giardia* in sheep is reported to range from $<10\%$ to $>40\%$ (mean $\sim 25\%$, $n=10$), and of *Cryptosporidium* in sheep is reported to range from $<5\%$ to $>70\%$ (mean $\sim 30\%$, $n=20$). There are considerably more surveys from sheep populations than goat populations, but summarizing from those cross-sectional prevalence surveys which have been conducted, *Giardia* in goats is reported to range from $<10\%$ to $>40\%$ (mean $\sim 20\%$, $n=7$), and of *Cryptosporidium* in goats is reported to range from $<5\%$ to $>35\%$ (mean $\sim 15\%$, $n=11$). Considering the global distribution of sheep and goat populations, there are very few available publications which report on these infections in places where they are most likely to exert the greatest impact on the human populations; however, in European countries, the predominant

Table 1. *Studies on the occurrence of* Giardia *and* Cryptosporidium *in sheep and goats**

Study	Ref.
Europe	
Belgium (East Flanders)	[12]
Czech Republic	[17]
France (Deux-Sèvres, Western France)	[18, 19]
Italy (Central Italy)	[20]
Italy (Abruzzo region, Central Italy)	[21]
The Netherlands	[22]
Poland (Poznań district, west central region)	[23]
Portugal	[24]
Spain (Aragón)	[13]
Spain (Galicia, NW Spain)	[25, 26]
Spain (Granada Province)	[27]
Spain (Gran Canaria, Canary Islands)	[11]
Spain (Zaragoza, NE Spain)	[28]
Switzerland	[29]
UK	[14, 30–33]
Americas	
Brazil (mountain region of Rio de Janeiro state)	[34]
Brazil (University of Minas Gerais)	[35]
Canada (Alberta, British Columbia, Nova Scotia, Saskatchewan, Yukon)	[36]
Canada (southern Alberta)	[37]
Mexico	[38]
Trinidad	[39]
Trinidad & Tobago	[40]
USA (Maryland)	[41]
Australia	
Narrikup, Western Australia	[10]
Asia	
Iraq	[42]
Iran	[43]
Sultanate of Oman	[44]
Sri Lanka	[45]
Taiwan	[46]
Africa	
Egypt (Qalubia Governorate)	[47]
Zambia (Central, Southern, and Lusaka Provinces)	[48]

* An expanded version of this table containing information on study populations, study methodologies, summarized prevalence data, and the results of gentoyping or molecular studies when conducted, is available online on the Journal's website (http://journals.cambridge.org/hyg).

research is from UK, which has the largest sheep population in Europe, and Spain which has a sizable goat population.

From those studies which have included molecular studies, some trends can be identified although geographical variation is also obvious. Additionally, interpretation of the reports is made more difficult because it is not always clear from the results how many samples were genotyped (either the data were not included or the samples were pooled), and often the number of samples included is very low (sometimes due to samples from a range of animal species being analysed or because the report is of an outbreak rather than a survey, or simply because successful PCR amplification from a limited number of samples was rare).

Nevertheless, among nine studies in which genotyping of *Giardia* isolates from sheep and/or goats was included, assemblage E was demonstrated to be the most frequently detected genotype, being the sole genotype detected in at least three reports. Excluding those reports in which isolate number is unclear, of seven reports from six different countries (Australia, Belgium, Italy, Netherlands, Spain, USA), in samples from sheep and/or goats *Giardia* isolates of assemblage E were detected in 95/126 (75%), assemblage A detected in 34 (27%), and assemblage B detected in three (2%); some animals had isolates from more than one assemblage. Thus, by extrapolation, it may be considered that of *Giardia* isolates from sheep, almost 30% may be zoonotic, with the potential to be transmitted to humans, either directly or by environmental contamination.

Of the publications reporting investigations on *Cryptosporidium* species/genotype/sub-genotype isolated from sheep and goat populations, only *C. parvum* has been isolated from goat samples to date, and from sheep samples, *C. parvum* and cervine genotype predominate. Summarizing results from 11 reports from eight countries (Australia, Belgium, Czech Republic, Portugal, Spain, UK, USA, Zambia) in samples from sheep and/or goats *C. parvum* was identified in 271/406 (67%) isolates, cervine genotype was identified in 93 (23%), *C. bovis* was identified in 21 (5%), whilst the remaining isolates (5%) were of various different species and genotypes, including *C. andersoni, C. hominis, C. fayerii, C. suis* and several unnamed genotypes. Regional variation is apparently marked, with *C. parvum* predominating in Europe, compared with cervine genotype predominating elsewhere, with none of 60 isolates being identified as *C. parvum* in a survey in Australia. Although *C. parvum* is accepted as zoonotic, the potential for cervine genotype to be considered a potential pathogen of humans is less clear cut. However, this genotype is widely spread geographically, and has an apparently extensive host range, infecting not only deer and sheep, but also being identified in a captive primate, a zoo nyala, and several human infections (as listed in [49]), which has resulted in the suggestion that it could emerge as an important human pathogen resulting from contact between humans and animals [49]. Thus, again by extrapolation, from up to 90% (or >65% if cervine genotype is excluded as being of potential public health significance) of *Cryptosporidium* isolates from sheep are zoonotic with the potential to be transmitted to humans either directly or by environmental contamination.

Human outbreaks of cryptosporidiosis and giardiasis associated with sheep or goats

A search of the literature provides scant concrete evidence that human infections of giardiasis and/or cryptosporidiosis have been acquired from sheep or goats, and some reviews suggest that calves are the only major reservoir of *C. parvum* infections in humans [50]. Although there are some publications that indicate the direct transmission of cryptosporidiosis from lambs to humans, particularly during bottle feeding of orphan lambs and/or petting of lambs at farm open days or on educational/recreational farm visits [32, 51–55], transmission of cryptosporidiosis from goats to humans, or transmission of giardiasis from either sheep or goats was poorly reported, although transmission of cryptosporidiosis between sheep/goats and animal handlers was occasionally mentioned [42]. Obviously lack of reporting does not exclude the possibility of such transmission occurring, but it does suggest that if it does occur, the infection itself and/or the transmission route are usually not identified. It should be noted that it is widely recognized that in many countries the prevalences of both giardiasis and cryptosporidiosis in the human populations are under-estimated, and that even during an outbreak situation many infected persons may not attend a doctor for diagnosis. The cultural differences which prompt some persons to seek medical advice, and others not, are little understood and may have an impact even when population groups are considered to be very similar [56]. Additionally, and paradoxically, persons who are persistently exposed to low levels of parasites (e.g. through water supply, or from routine handling of infected animals) may develop immunity, and thus not develop symptomatic infection upon exposure, and therefore not seek medical assistance, although persons who have not experienced this might do so [57].

Reports on contamination of water supplies by *Cryptosporidium* and/or *Giardia* from sheep or goat faeces are even less conclusive. One of the first occasions in which contamination of drinking water by *Cryptosporidium* from sheep was reported was in a mixed outbreak of cryptosporidiosis and campylobacteriosis affecting a total of 43 people, all of whom had drunk unboiled water from an untreated private supply [58]. Three lamb carcasses discovered in a collection chamber associated with the supply were postulated to be associated with this outbreak, although definitive evidence was not found, and slurry run-off from surrounding fields was also considered as a possible source. A small waterborne outbreak involving 24 people was reported in 1998, in which water from a private farmland supply was implicated [59]. In this case *Cryptosporidium* oocysts were identified in a water tank for the supply, which was reported to be vulnerable to contamination by sheep. However, a lack of analysis of sheep samples, and an absence of molecular studies, means that whether sheep were the source of contamination cannot be confirmed.

An outbreak of cryptosporidiosis in North West England in 1999 in which over 200 persons were affected was, at the time, strongly associated with sheep grazing around the implicated reservoir, with 37·5% of the 32 sheep samples analysed positive for *Cryptosporidium* oocysts [60, 61]. However, although molecular analysis of isolates from the human patients demonstrated that they were *C. parvum*, comparable analyses from the sheep samples have not been published. A later publication which reported a 'novel isolate' of *Cryptosporidium* in sheep from a different area of Britain [30], later identified as cervine genotype [62], suggests that the 'evidence' that sheep are contaminating a water supply (the detection of morphologically indistinguishable oocysts in sheep in a particular catchment area and oocysts from human cases), is of doubtful value, unless accompanied by genotyping. The identification of the 'novel isolate' in sheep occurred during part of an investigation into an outbreak of waterborne cryptosporidiosis in Scotland in 2000 [63] in which sheep grazing in the vicinity of the water source (Loch Katrine) were considered as the potential source, particularly as there were very few cattle in the catchment and the sheep had access to the loch side. The 'novel genotype' (cervine genotype) differed from those in clinical human cases during the outbreak, but as the sheep samples were obtained some 3 months after the first case of human illness [30] it is difficult to exclude sheep unequivocally as the source of contamination.

Cryptosporidium and *Giardia* infections in sheep or goat populations as a threat to water sources: measures to limit the potential for contamination of water sources by sheep and goats

Despite the lack of conclusive evidence linking contamination of water supplies by sheep or goats with outbreaks of cryptosporidiosis or giardiasis in human populations, in some instances sheep populations, in particular, are clearly considered as a potential threat and initiatives have been implemented to eliminate or reduce this potential. For example, following outbreaks of cryptosporidiosis in Scotland associated with water supplied by Loch Katrine, although sheep were not definitely implicated as the source of the oocysts, the water authority chose to close one of Scotland's largest sheep farms (a 9500 ha farm with 8000 livestock) as well as a smaller neighbouring farm [64]. Over a year after the removal of sheep from the catchment had begun, but before it was completed, high levels of *Cryptosporidium* oocysts were again detected in water from the same supply (up to 11 oocysts/10 litres) resulting in the implementation of a boil water notice affecting about 170 000 consumers. However, no human cases were reported and subsequent molecular typing of oocysts from the water sampling equipment demonstrated them to be *C. andersoni* and therefore of minimal public health significance [63]. The origin of this contamination event was not unequivocally determined.

The 1999 outbreak of cryptosporidiosis in North West England precipitated another initiative in which, whilst water treatment plants were being upgraded, the supposed 'source of the problem' (sheep) was removed. As lambs were considered to be particularly likely sources of oocysts, pregnant ewes were scanned, and those which were carrying more than one lamb were relocated to alternative grazing land in the Cumbrian salt marshes until the lambing period was over [65]. Less expensive initiatives were also brought in, including fencing off a feeder stream to prevent sheep access [66].

Although it may seem reasonable to restrict sheep grazing in order to ensure the safety of public water supply, it can have a severe impact on the affected sheep farmers. A sheep grazing ban implemented by the Northern Ireland Water Services in the catchment area of a reservoir in the Mourne Mountains, due to fears of contamination with *Cryptosporidium*, caused considerable anger and frustration to local farmers [67], particularly in the absence of any associated disease. Clearly if such preventive measures do not have any good scientific grounding, then not only are they unlikely to provide much, if any, benefit, but they are expensive both in resources for those directly affected, and in terms of goodwill and hopes of future cooperation.

CONCLUSION

Although direct evidence of transmission of *Cryptosporidium* and/or *Giardia* from sheep or goats to humans via contamination of the environment, particularly the water supply, is limited, sufficient evidence has been accrued over the years to suggest that this is a real possibility, which may, indeed, have already occurred. Contamination of water supplies by *Cryptosporidium* from infections in sheep seems to be the most probable threat, not only because cryptosporidiosis in sheep is generally somewhat more prevalent than giardiasis, but also because the species/genotypes of *Cryptosporidium* infections in sheep are likely to be infectious to humans, whilst *Giardia* infections in sheep are more likely to be of assemblage E, which is non-zoonotic. However it should be noted that zoonotic infections of *Giardia* (assemblages A or B) may also occur in sheep.

Nevertheless, geographical variation is extensive, both in terms of prevalence and in terms of genotypic distribution, and as measures to limit sheep grazing are costly, and can have a highly negative impact on those affected, it is important that individual cases are judged upon their own merits. If water contamination from a particular population of sheep and goats is suspected, then considering the evidence reviewed here, it is recommended that suitable investigations are conducted, investigating both prevalence and species/genotype of the parasites, preferably before precautionary measures are instigated.

DECLARATION OF INTEREST

None.

NOTE

Supplementary material accompanies this paper on the Journal's website (http://journals.cambridge.org/hyg).

REFERENCES

1. **Fayer R.** General biology. In: Fayer R, Xiao L, eds. *Cryptosporidium and Cryptosporidiosis*. CRC Press, Boca Raton, FL: Taylor & Francis Group, 2008, pp. 1–42.
2. **Smith HV, *et al.*** Natural *Cryptosporidium hominis* infections in Scottish cattle. *The Veterinary Record* 2005; **156**: 710–711.
3. **Xiao L, Fayer R.** Molecular characterisation of species and genotypes of *Cryptosporidium* and *Giardia* and assessment of zoonotic transmission. *International Journal for Parasitology* 2008; **38**: 1239–1255.
4. **Xiao L, Ryan UM.** Molecular epidemiology. In: Fayer R, Xiao L, eds. *Cryptosporidium and Cryptosporidiosis*. CRC Press, Boca Raton, FL: Taylor & Francis Group, 2008, pp. 119–172.
5. **Leoni F, *et al.*** Genetic analysis of *Cryptosporidium* from 2414 humans with diarrhoea in England between 1985 and 2000. *Journal of Medical Microbiology* 2006; **55**: 703–707.
6. **Soba B, *et al.*** Molecular characterisation of *Cryptosporidium* isolates from humans in Slovenia. *Clinical Microbiology and Infection* 2006; **12**: 918–921.
7. **Feltus DC, *et al.*** Evidence supporting zoonotic transmission of *Cryptosporidium* spp. in Wisconsin. *Journal of Clinical Microbiology* 2006; **44**: 4303–4308.
8. **Ong CS, *et al.*** Novel *Cryptosporidium* genotypes in sporadic cryptosporidiosis cases: first report of human infections with a cervine genotype. *Emerging Infectious Diseases* 2002; **8**: 263–268.
9. **Trotz-Williams LA, *et al.*** Genotype and subtype analyses of *Cryptosporidium* isolates from dairy calves and humans in Ontario. *Parasitology Research* 2006; **99**: 346–352.
10. **Ryan UM, *et al.*** Sheep may not be an important zoonotic reservoir for *Cryptosporidium* and *Giardia* parasites. *Applied and Environmental Microbiology* 2005; **71**: 4992–4997.
11. **Ruiz A, *et al.*** Occurrence and genotype characterization of *Giardia duodenalis* in goat kids from the Canary Islands, Spain. *Veterinary Parasitology* 2008; **154**: 137–141.
12. **Geurden T, *et al.*** Prevalence and molecular characterisation of *Cryptosporidium* and *Giardia* in lambs and goat kids in Belgium. *Veterinary Parasitology* 2008; **155**: 142–145.
13. **Quílez J, *et al.*** *Cryptosporidium* genotypes and subtypes in lambs and goat kids in Spain. *Applied and Environmental Microbiology* 2008; **74**: 6026–6031.
14. **Mueller-Doblies D, *et al.*** Distribution of *Cryptosporidium* species in sheep in the UK. *Veterinary Parasitology* 2008; **154**: 214–219.
15. **The *Cryptosporidium* (Scottish Water) Directions 2003.** (https://www.scotland.gov.uk/Resource/Doc/26487/0013541.pdf). Accessed 11 November 2008.
16. **EarthTrends Databases, World Resources Institute.** (http://earthtrends.wri.org/text/agriculture-food/variables.html). Accessed 11 November 2008.
17. **Ryan U, *et al.*** Identification of novel *Cryptosporidium* genotypes from the Czech Republic. *Applied and Environmental Microbiology* 2003; **69**: 4302–4307.
18. **Castro-Hermida JA, *et al.*** *Giardia duodenalis* and *Cryptosporidium parvum* infections in adult goats and their implications for neonatal kids. *Veterinary Record* 2005; **157**: 623–627.
19. **Delafosse A, *et al.*** Herd-level risk factors for *Cryptosporidium* infection in dairy-goat kids in western France. *Preventive Veterinary Medicine* 2006; **77**: 109–121.
20. **Aloisio F, *et al.*** Severe weight loss in lambs infected with *Giardia duodenalis* assemblage B. *Veterinary Parasitology* 2006; **142**: 154–158.
21. **Giangaspero A, *et al.*** Prevalence and molecular characterization of *Giardia duodenalis* from sheep in central Italy. *Parasitology Research* 2005; **96**: 32–37.
22. **Van der Giessen JW, *et al.*** Genotyping of *Giardia* in Dutch patients and animals: a phylogenetic analysis of human and animal isolates. *International Journal for Parasitology* 2006; **36**: 849–858.
23. **Majewska AC, *et al.*** Prevalence of *Cryptosporidium* in sheep and goats bred on five farms in west-central region of Poland. *Veterinary Parasitology* 2000; **89**: 269–275.
24. **Alves M, *et al.*** Distribution of *Cryptosporidium* subtypes in humans and domestic and wild ruminants in Portugal. *Parasitology Research* 2006; **99**: 287–292.
25. **Castro-Hermida JA, *et al.*** Prevalence and preliminary genetic analysis of *Giardia* isolated from adult sheep in Galicia (northwest Spain). *Journal of Eukaryotic Microbiology* 2006; **53** (Suppl. 1): 72–73.
26. **Castro-Hermida JA, *et al.*** Occurrence of *Cryptosporidium parvum* and *Giardia duodenalis* in healthy adult domestic ruminants. *Parasitology Research* 2007; **101**: 1443–1448.
27. **Díaz V, *et al.*** Aspects of animal giardiosis in Granada province (southern Spain). *Veterinary Parasitology* 1996; **64**: 171–176.
28. **Causapé AC, *et al.*** Prevalence and analysis of potential risk factors for *Cryptosporidium parvum* infection in lambs in Zaragoza (northeastern Spain). *Veterinary Parasitology* 2002; **104**: 287–298.
29. **Taminelli V, Eckert J.** The frequency and geographic distribution of *Giardia* infections in ruminants in Switzerland. *Schweizer Archiv für Tierheilkunde* 1989; **131**: 251–258.
30. **Chalmers RM, *et al.*** *Cryptosporidium* in farmed animals: the detection of a novel isolate in sheep. *International Journal for Parasitology* 2002; **32**: 21–26.
31. **McLauchlin J, *et al.*** Molecular epidemiological analysis of *Cryptosporidium* spp. in the United Kingdom: results of genotyping *Cryptosporidium* spp. in 1,705 fecal samples from humans and 105 fecal samples from livestock animals. *Journal of Clinical Microbiology* 2000; **38**: 3984–3990.
32. **Pritchard GC, *et al.*** *Cryptosporidium parvum* infection in orphan lambs on a farm open to the public. *Veterinary Record* 2007; **161**: 11–14.
33. **Taylor MA, *et al.*** Giardiasis in lambs at pasture. *Veterinary Record* 1993; **133**: 131–133.

34. **Bomfim TC, *et al.*** Natural infection by *Giardia* sp. and *Cryptosporidium* sp. in dairy goats, associated with possible risk factors of the studied properties. *Veterinary Parasitology* 2005; **134**: 9–13.
35. **Vieira LS, *et al.*** Outbreak of cryptosporidiosis in dairy goats in Brazil. *Veterinary Record* 1997; **140**: 427–428.
36. **Olson ME, *et al.*** *Giardia* and *Cryptosporidium* in Canadian farm animals. *Veterinary Parasitology* 1997; **68**: 375–381.
37. **Buret A, *et al.*** Zoonotic potential of giardiasis in domestic ruminants. *Journal of Infectious Diseases* 1990; **162**: 231–237.
38. **Alonso-Fresán MU, *et al.*** Prevalence of *Cryptosporidium* spp. in asymptomatic sheep in family flocks from Mexico State. *Journal of Veterinary Medicine, B: Infectious Diseases and Veterinary Public Health* 2005; **52**: 482–483.
39. **Adesiyun AA, *et al.*** A longitudinal study on enteropathogenic infections of livestock in Trinidad. *Revista da Sociedade Brasileira de Medicina Tropical* 2001; **34**: 29–35.
40. **Kaminjolo JS, *et al.*** Prevalence of *Cryptosporidium* oocysts in livestock in Trinidad and Tobago. *Veterinary Parasitology* 1993; **45**: 209–213.
41. **Santín M, Trout JM, Fayer R.** Prevalence and molecular characterization of *Cryptosporidium* and *Giardia* species and genotypes in sheep in Maryland. *Veterinary Parasitology* 2007; **146**: 17–24.
42. **Mahdi NK, Ali NH.** Cryptosporidiosis among animal handlers and their livestock in Basrah, Iraq. *East African Medical Journal* 2002; **79**: 550–553.
43. **Nouri M, Karami M.** Asymptomatic cryptosporidiosis in nomadic shepherds and their sheep. *Journal of Infection* 1991; **23**: 331–333.
44. **Johnson EH, *et al.*** Atypical outbreak of caprine cryptosporidiosis in the Sultanate of Oman. *Veterinary Record* 1999; **145**: 521–524.
45. **Noordeen F, *et al.*** Prevalence of *Cryptosporidium* infection in goats in selected locations in three agroclimatic zones of Sri Lanka. *Veterinary Parasitology* 2000; **93**: 95–101.
46. **Watanabe Y, Yang CH, Ooi HK.** *Cryptosporidium* infection in livestock and first identification of *Cryptosporidium parvum* genotype in cattle feces in Taiwan. *Parasitology Research* 2005; **97**: 238–241.
47. **Abd-El-Wahed MM.** *Cryptosporidium* infection among sheep in Qalubia Governorate, Egypt. *Journal of the Egyptian Society of Parasitology* 1999; **29**: 113–118.
48. **Goma FY, *et al.*** The prevalence and molecular characterisation of *Cryptosporidium* spp. in small ruminants in Zambia. *Small Ruminant Research* 2007; **72**: 77–80.
49. **Santín M, Fayer R.** Intragenotypic variations in the *Cryptosporidium* sp. cervine genotype from sheep with implications for public health. *Journal of Parasitology* 2007; **93**: 668–672.
50. **Xiao L, Feng Y.** Zoonotic cryptosporidiosis. *FEMS Immunology and Medical Microbiology* 2008; **52**: 309–323.
51. **Dawson A, *et al.*** Farm visits and zoonoses. *Communicable Disease Report. CDR Review* 1995; **5**: R81–86.
52. **Health Protection Scotland.** Weekly report (serial online), 26 April 2005; **39**(16) (http://www.show.scot.nhs.uk/scieh/PDF/weekly_report.pdf). Accessed 20 October 2008.
53. **Communicable Disease Report Weekly.** (http://www.hpa.org.uk/cdr/archives/1994/cdr1694.pdf). 1994; **4**: 73. Accessed 11 November 2008.
54. **Communicable Disease Report Weekly.** (http://www.hpa.org.uk/cdr/archives/back_issues.htm). 2005; 15. Accessed 11 November 2008.
55. **Elwin K, *et al.*** Modification of a rapid method for the identification of gene-specific polymorphisms in *Cryptosporidium parvum* and its application to clinical and epidemiological investigations. *Applied and Environmental Microbiology* 2001; **67**: 5581–5584.
56. **Hajdu A, *et al.*** Investigation of Swedish cases reveals an outbreak of cryptosporidiosis at a Norwegian hotel with possible links to in-house water systems. *BMC Infectious Diseases* 2008; **8**: 152.
57. **Pollock KG, *et al.*** Cryptosporidiosis and filtration of water from Loch Lomond, Scotland. *Emerging Infectious Diseases* 2008; **14**: 115–120.
58. **Duke LA, *et al.*** A mixed outbreak of *Cryptosporidium* and *Campylobacter* infection associated with a private water supply. *Epidemiology and Infection* 1996; **116**: 303–308.
59. **Communicable Disease Report Weekly.** Surveillance of waterborne disease and water quality: January to June 1998 (http://www.hpa.org.uk/cdr/archives/back_issues.htm). 1998; **8**: 305–306. Accessed 11 November 2008.
60. **Communicable Disease Report Weekly.** Outbreak of cryptosporidiosis in north west England (http://www.hpa.org.uk/cdr/archives/back_issues.htm). 1999; **20**: 175–178. Accessed 11 November 2008.
61. **Qamruddin AO, *et al.*** Increased stool sampling during a waterborne outbreak of cryptosporidiosis does not increase the detection of other faecal pathogens. *Journal of Clinical Pathology* 2002; **55**: 271–274.
62. **Elwin K, Chalmers RM.** Contemporary identification of previously reported novel *Cryptosporidium* isolates reveals *Cryptosporidium bovis* and the cervine genotype in sheep (*Ovis aries*). *Parasitology Research* 2008; **102**: 1103–1105.
63. **Reilly WJ, Browning LM.** Zoonoses in Scotland – food, water, or contact? In: Cotruvo JA, Dufour A, Rees G, Bartram J, Carr R, Cliver DO, Craun GF, Fayer R, Gannon VPJ, eds. *Waterborne Zoonoses: Identification, Causes and Control*. IWA Publishing, London, UK (http://www.who.int/water_sanitation_health/diseases/zoonosessect4.pdf). Accessed 11 November 2008.
64. **BBC News Online.** Water authority to end sheep farming, 26 October 2001 (http://news.bbc.co.uk/2/low/uk_news/scotland/1622411.stm). Accessed 11 November 2008.
65. **Health Protection Agency.** Cryptosporidium beaten

by collaboration and 'maternity leave for sheep', 2005 (http://www.hpa.org.uk/webw/HPAweb&HPAwebStandard/HPAweb_C/1195733756380?p=1192454969657). Accessed 11 November 2008.

66. **Edie net news article.** Sheep blamed for Manchester Crypto outbreak, 12 May 2000. Faversham house group (http://www.edie.net/news/news_story.asp?id=2714). Accessed 11 November 2008.

67. **BBC News Online.** Sheep battle over bug at reservoir, 5 September 2000 (http://news.bbc.co.uk/2/hi/uk_news/northern_ireland/910594.stm). Accessed 11 November 2008.