A Review of Current Knowledge

Giardia in water supplies

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Foundation for Water Research
Allen House, The Listons,
Liston Road, Marlow,
Bucks SL7 1FD, U.K.
Tele: +44(0)1628 891589
Fax: +44(0)1628 472711
E-mail: office@fwr.org.uk
Home page: www.fwr.org

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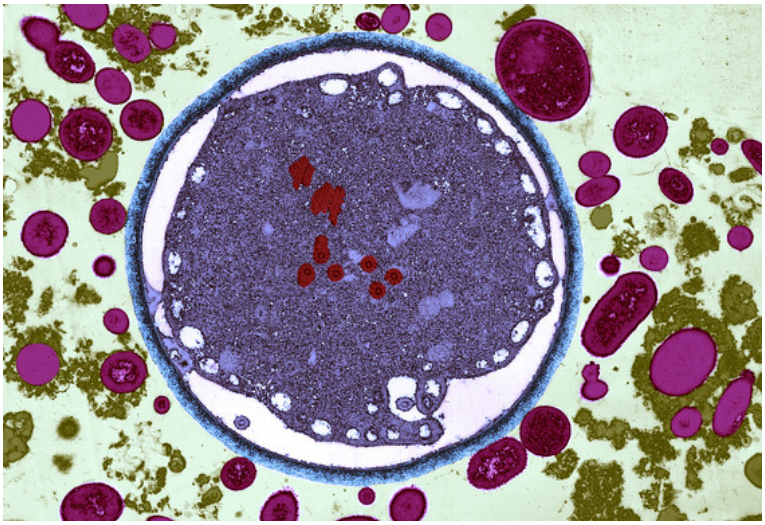
Review of Current Knowledge

Giardia in water supplies



***Giardia lamblia* protozoan**

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Author: R Clayton
Revision: M Waite

Review of Current Knowledge

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"Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g. protozoa and helminths) are the most common and widespread health risk associated with drinking-water."
World Health Organisation, Guidelines for Drinking Water Quality.4th edition p117

1 Introduction

Developed countries have standards for drinking water which are intended to protect public health. In many developing countries satisfactory drinking water quality is an objective still to be achieved. In the EU the quality required in member states for public supplies of drinking water was first specified in 1980 by the 'Drinking Water' Directive. A revised EU Directive was approved in 1998 (EU Council Directive 98/83/EC) which has been implemented in the UK through various Statutory Instruments; the Water Supply (Water Quality) Regulations 2000 for England & Wales, the Water Supply (Water Quality) Regulations 2001 for Wales, both with subsequent amendments, and for private supplies through the Private Water Supplies Regulations 2009. Scotland is covered by equivalent statutory instruments and Northern Ireland by Statutory Rules. The Water Industry Act 1991 in para 68 (1A)(a) requires that water supplied for domestic or food production purposes shall be "wholesome". This is defined in the regulations as "water which does not contain any micro-organism ... or parasite or any substance ... at a concentration or value which would constitute a danger to human health". In the United States of America drinking water quality is set by the Safe Drinking Water Act of 1974 and its many subsequent amendments, and many other countries have their own water quality legislation.

The World Health Organisation in the 4th edition of its Guidelines for Drinking Water Quality (WHO, 2011), advocates the setting of Health-based Targets to include health outcomes, water quality (e.g. guideline values) and performance targets for treatment. It considers that "monitoring finished water for pathogens is not …. a feasible or cost-effective option because pathogen concentrations equivalent to tolerable levels of risk are typically less than 1 organism per 10^4 -10^5 litres".

Despite legislation, waterborne disease still occurs in developed countries and in developing countries it remains a serious problem. The WHO has estimated that 4.0% of all deaths globally are attributable to deficiencies of water, sanitation and hygiene (WHO Facts and Figures on Water Quality and Health). 1.5 million children die each year from diarrhoea and 88% of cases of diarrhoea are linked to poor water, sanitation or hygiene (Pruss-Ustin, 2008.) The main causative agents are waterborne micro-organisms, namely pathogenic viruses, bacteria, and

especially protozoa (Guillot et al., 2009), and the most common pathogenic protozoan is *Giardia duodenalis* (also known as *Giardia lamblia* and *Giardia intestinalis* (see "What is Giardia" below). A wealth of information on waterborne pathogens is available on the Waterborne Pathogens website.

Of all waterborne pathogenic parasites *Giardia duodenalis* is the most common cause of protozoal infections in man with nearly 33% of people in developing countries having had giardiasis (Julio, 2012). Even in a developed country such as the USA (where *Giardia* infection is commonly known as "beaver fever", "hikers' disease" or "campers' disease") it is still the most commonly *identified cause* of waterborne infectious disease although the most *common cause* of waterborne disease in the USA is classified as "unknown agents" (Craun et al., 2006). However, it should be noted that "waterborne" does not mean that the source of the disease was necessarily a treated water supply; in most cases it is not. It should also be stressed that *Giardia* infections also occur from contaminated food and by contact with infected persons or animals. More information on these routes of infection is provided in the section entitled "Giardiasis in the Community".

© John Bavosa/Science Photo Library
Artwork of the human digestive system surrounded by some of the micro-organisms that can cause diarrhoea. Food poisoning can lead to bacterial infection of the colon by *Campylobacter*, *Salmonella*, or *enteropathogenic E coli* leading to acute diarrhoea. The protozoan *Giardia duodenalis* is the face-like image on the top and bottom left.

From 1999 until 2007 the UK had a standard for the specific purpose of controlling and monitoring the presence of the oocysts of the pathogenic protozoan parasite *Cryptosporidium* in water supplies (SI, 1999). This standard specified continuous monitoring at certain water treatment works for oocysts that must not be present at a concentration greater than 1 per 10 litres. This was replaced in 2007 (SI, 2007) by a requirement that water companies carry out risk assessments on all their water supply sites to ascertain the level of risk *Cryptosporidium* poses to the final treated water quality. Those sites at high risk must provide additional treatment in the form of properly controlled coagulation/flocculation filtration systems or membrane or UV treatment systems. The UK regulations also require water companies to design and operate continuously adequate treatment and disinfection. A proven failure to comply with this is now an offence. Although there is no UK legislation which specifically controls *Giardia* in drinking water the *Cryptosporidium* requirements when met should also provide effective control of risk of giardiasis transmission. In the UK the Drinking Water Quality regulations simply require that "the water does not contain any ..... organism …... at a concentration or value which ..... would be detrimental to public health". Thus if *Giardia* cysts are present it may not necessarily be an offence; the problem would be establishing what quantities in drinking water would be detrimental to public health when there is no clearly established minimum infective dose, infection may not necessarily lead to disease, cysts may not be viable, only the species *Giardia duodenalis* can infect humans, and there are sub-types within that species which are not infectious to humans. (see “What is *Giardia*?” below).

IT IS IMPORTANT TO REMEMBER THAT MUCH OF THE INFORMATION AND DATA CITED IN THE REST OF THIS DOCUMENT RELATES TO THE *GIARDIA* GENUS AND NOT SPECIFICALLY TO HUMAN PATHOGENIC TYPES OF *GIARDIA DUODENALIS*.

2 What is *Giardia*?

Giardia (usually pronounced ‘Jiardia’) is a parasite which is found widely distributed around the world, including Europe, and which can cause an unpleasant illness when ingested. The illness is referred to as **giardiasis** and infection is transmitted by tiny spore- or egg-like cells called cysts which are oval in shape with a length of 9-12 µm (a µm is a micrometre or one millionth of a metre). There are currently six recognised species of *Giardia* (Feng & Xiao, 2011) - *Giardia muris* which is found in rodents, *Giardia ardeae* and *Giardia psittaci* which infect birds, *Giardia agilis* which infects amphibians, and *Giardia microti* which infects muskrats and voles - but human infections are caused by just one species, *Giardia duodenalis* (which, as noted above, is also referred to as *Giardia intestinalis* and

Giardia lamblia). *Giardia duodenalis* also causes infections in domestic and wild animals (hence the journalistic apophthegm "beaver fever"). There are also several assemblages (strains) of *Giardia duodenalis*, currently 8 (Xu et al., 2012), although only two are recognised as infecting humans (Thompson, 2009). There is no evidence that species of *Giardia* other than *G. duodenalis* can infect man; efforts to infect laboratory mammals with *G. ardeae* and *G. psittaci* have so far been unsuccessful (AWWA, 2006). The taxonomy (classification) of *Giardia* is not settled and is likely to undergo further changes. The species epithets *duodenalis*, *intestinalis* and *lamblia* are all currently widely used but for the purposes of this review *duodenalis* is used. It is generally accepted that the epithet *lamblia* is not valid although it was historically common and is still widely used by the medical profession including the UK Health Protection Agency.

Giardia was discovered in the late 1600s by Antonie van Leeuwenhoek, often credited with the invention of the microscope, who observed it in a sample of his faeces. *Giardia* cysts can be waterborne and much less commonly foodborne outbreaks have been reported, usually affecting very small numbers of cases (Smith et al., 2007). Infection can also occur through physical contact with an infected person or animal (zoonosis), especially if the normal rules of hygiene are not observed.

The symptoms of giardiasis are acute diarrhoea which is often explosive, abdominal cramps, bloating and excessive flatulence. The severity of the illness can vary considerably and only about a quarter of infected people show symptoms of the illness. Malabsorption of food can lead to considerable loss of weight and in children it can be a cause of failure to thrive. The incubation period can be anything from 1 to 75 days with a median of 7-10 days (USEPA, 1999a). Treatment with drugs can be effective, but if untreated the illness may persist for many years (Robertson et al., 2010).

3 Where is *Giardia* found in the Environment?

Giardia is found in a wide range of vertebrate hosts including mammals, birds, reptiles and amphibians (Kutz et al., 2009) but the range of animals and birds capable of hosting human pathogenic strains of *Giardia duodenalis* is not fully established. It was not formally recognised as a causative agent of illness in man until about 1954 (Rendtorff, 1954; Finch, 1996).

Cysts are passed in the faeces of infected animals, including humans, and infection occurs either by person-to-person contact, zoonosis (animal-person contact) or by the ingestion of food or drink contaminated by *Giardia* cysts.

A number of studies have found *Giardia* cysts in untreated and treated sewage and they are widely found in lakes and rivers especially where there is wildlife which uses these water sources. Reported *Giardia* levels have ranged from 10,000 to 100,000 cysts/L in untreated sewage, 10 to 100 cysts/L in treated sewage, and 10 or few cysts/L in surface water (Nasser et al., 2012); (USEPA, 2000). Cysts have also been detected in cisterns and in wells contaminated by surface water or sewage (USEPA, 2000).

American beaver (Castor canadensis) swimming. Found throughout North America.

The cysts of *Giardia* are passed in the faeces of infected people and animals in large numbers which is why they are found in sewage effluents, lakes and rivers. Cattle slurry can contain *Giardia* cysts as well as the oocysts of the parasite *Cryptosporidium* (see the Foundation for Water Research's complementary ROCK on "Cryptosporidium in water supplies", 2011) and as a consequence the runoff from rainfall can cause an increase in cysts in streams, rivers, lakes and reservoirs. It has been reported that there is an increase in *Giardia* infections during and after heavy rainfall (Atherholt et al., 1998; Curriero, et al., 2001). Studies of the survival of *Giardia* cysts in the environment demonstrate that they can survive for weeks or months in fresh water (Health Canada, 2011), although they are less able to survive than the oocysts of *Cryptosporidium* (Foundation for Water Research, 1998).

4 The life-cycle of *Giardia*

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Scanning electron micro-graph of the parasite *Giardia lamblia* in the human small intestine. Pear-shaped, they have flagellae for motility.

Giardia exists in two forms; the cyst and a trophozoite. A trophozoite is the feeding form of the so-called sporozoan protozoa - namely protozoa which form a non-active spore, cyst or oocyst. The cyst is the infective form which is responsible for the transmission of the parasite and the infection of people and animals.

After ingestion the cyst passes through the stomach to the duodenum where it "ex-cysts" (i.e. hatches) and produces two trophozoites which colonise the small lower intestine. Trophozoites measure about 12µm to 18µm in length and possess a sucking disc which they use to adhere to the surface of the mucous membranes of the small intestine. The trophozoites cause the disease by damaging the membrane and inhibiting the adsorption of nutrient. As trophozoites are passed along the small intestine they may form into cysts which are then passed out with the faeces.

Giardia cysts have relatively thick walls which help them to survive in the environment and to protect them from the action of chemical disinfectants.

5 Giardiasis in the Community

Giardiasis is endemic in all populations studied. The waterborne transmission of *Giardia* was suggested as early as 1946 by an outbreak of amoebiasis caused by sewage contamination of the water supply in a Tokyo apartment building; *Giardia* was isolated from 86% of the occupants who had negative stools for *E. histolytica* and experienced diarrhoea with abdominal discomfort (Davis & Ritchie, 1948; Craun, 1979). Waterborne outbreaks of giardiasis were not reported in the United States until 1965, most likely because the pathogenicity of *Giardia* was still being debated. However, it appears in retrospect that a large outbreak of 50,000 cases of illness in Portland, Oregon, in 1954-55 may have been caused by *Giardia* and may possibly have been associated with drinking water. In this outbreak, an unusual prevalence of *G. lamblia* (sic) cysts was found in the stools of patients, especially among those with a chronic illness of 14.8 days average duration characterized by abdominal discomfort, diarrhea, loss of appetite, nausea, and weight loss. (Veazie, 1969; Veazie et al., 1978). The first well-documented waterborne outbreak of giardiasis in the United States was recognized and investigated primarily because a physician had developed characteristic symptoms of giardiasis after returning from a ski holiday at Aspen, Colorado, in 1965 (Craun, 1990; Moore et al., 1969). Since *Giardia* was recognised as a causal agent of enteric illness a number of waterborne outbreaks of giardiasis have been reported in different parts of the world (an "outbreak" of a disease is defined as a level of disease above the normal background level). For example, the USA has experienced many waterborne outbreaks, over 123 occurring between 1971 and 2006 (Craun et al., 2010). The first reported waterborne outbreak in the UK was in Bristol in 1985 (Jephcott et al., 1985) in which 108 cases were recorded. Outbreaks have also been reported in many other countries including Sweden, Scotland and British Columbia (Hunter, 1997). As noted previously, the term “waterborne” is general and does not necessarily mean the source of disease was a treated water supply; it could be a swimming pool or a natural untreated water body.

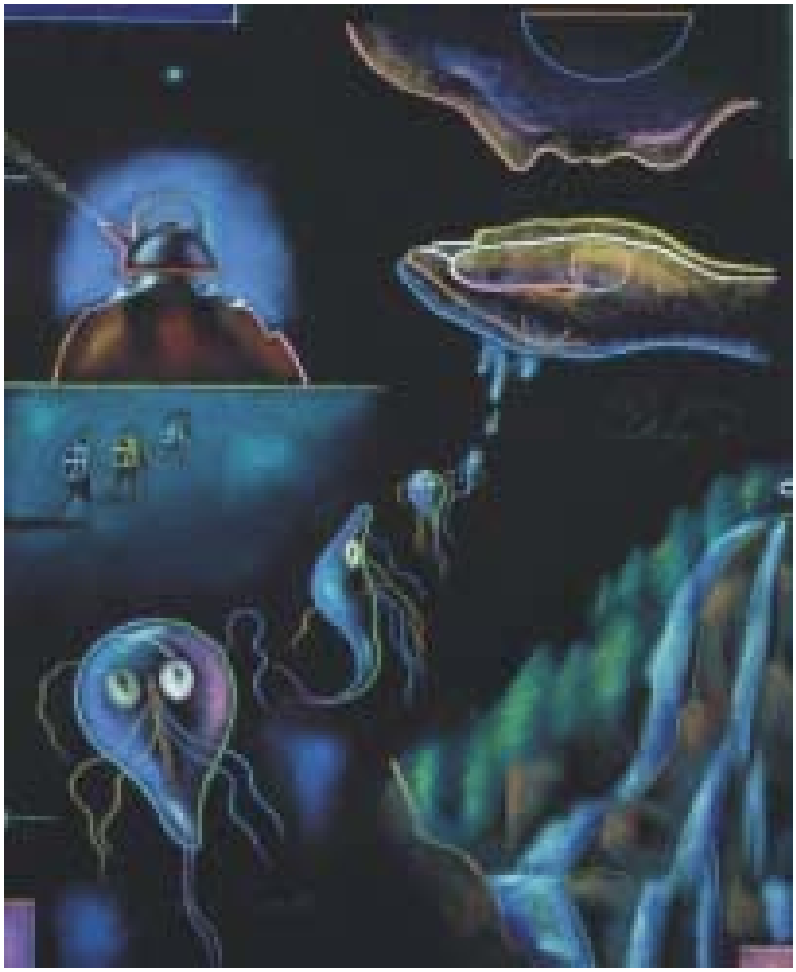
Giardiasis is not a notifiable disease (for a discussion of Notifiable Diseases see the Foundation for Water Research ROCK on "Cryptosporidium in water supplies", 2011) but, like cryptosporidiosis, its symptoms are similar to food poisoning, and it can occur as a result of contaminated foods and drinks and can therefore constitute food poisoning, which is a notifiable disease. As a consequence in the UK the Communicable Disease Surveillance Centre (CDSC), which was part of the Public Health Laboratory Service (PHLS), collected data on giardiasis which was periodically published in the weekly Communicable Disease Reports (CDR Weekly) until 2006. Since 2006 data has been published weekly in Health Protection Reports which can be accessed via the world wide web http://www.hpa.org.uk. Smith et al., (2006) reviewed 89 reported waterborne

outbreaks of disease in England and Wales between 1992 and 2003 affecting 4321 persons. While *Cryptosporidium* was implicated in 62 outbreaks, in only 2 was *Giardia* implicated, one being associated with a private supply and one a swimming pool. The annual totals of notified cases of giardiasis in the UK between 2000 and 2011 are shown below. These are compared with total cases of Campylobacter, the commonest cause of gastrointestinal infections, which helps to put the risk of giardiasis into context.

Year	*Annual Notified Cases of Giardiasis*			*Annual Campylobacter cases notified in England & Wales*
	England & Wales	*Northern Ireland*	*Scotland*	
2000	*4020*	*-*	*-*	*58236*
2001	*3540*	*-*	*251*	*55081*
2002	*3281*	*-*	*207*	*48133*
2003	*3460*	*-*	*191*	*46825*
2004	*3209*	*52*	*188*	*44544*
2005	*2938*	*57*	*197*	*46724*
2006	*2959*	*64*	*200*	*46868*
2007	*3032*	*62*	*220*	*51989*
2008	*3407*	*71*	*221*	*50009*
2009	*3471*	*61*	*209*	*57772*
2010	*3804*	*57*	*217*	*62684*
2011	*3670*	*-*	*195*	*64162*

Person-to-person transmission can occur (Katz et al., 2006) particularly with young children. Investigation of a giardiasis outbreak in a day care facility determined that 47% of ill children transmitted the infection to more than one household contact (Polis et al., 1986).

Unlike cryptosporidiosis, giardiasis is not regarded as a disease which may be fatal although if left untreated the victim may suffer for an extended period of time. Giardiasis can be treated with a wider range of drugs than cryptosporidiosis, for which only nitazoxanide is accepted as effective (Cabada et al., 2010). Wikipedia records that drugs commonly used are metronidazole, nitazoxanide and tinidazole while less commonly albendazole, mebendazole, quinacrine, furazolidone, and paromomycin can be given.



© Giardiasis: the title of an illustration by the artist Andrzej Dudzinski/Science Photo Library.

A significant number of people carry *Giardia* without showing any symptoms of giardiasis. In developed countries between 2% and 5% of stool specimens examined contain cysts whereas in developing countries it can be as high as 30% and up to 35% among children (Furness et al., 2000). One study has shown that although as few as 10 cysts can be sufficient to cause infection as shown by the presence of cysts in the stools of the subjects, many of the infected subjects showed no symptoms. In the same study 40 subjects ingested one million cysts, 21 of whom became infected although none showed any symptoms of giardiasis (Sinclair et al., 1998; Rentdorff 1954). In another study in which 50,000 trophozoites were inoculated into the duodenum, all 10 subjects were infected but only four showed symptoms of the disease (Nash et al., 1987).

A survey in England found that the rate of occurrence of giardiasis in the community was in the region of 0.14 - 0.22 cases per 1000 population (Wheeler et al., 1999).

6 Outbreaks of Giardiasis

As previously stated an "outbreak" of a disease is defined as a level of disease above the normal background level. Data for outbreaks of infectious intestinal disease associated with water in England and Wales for 2004 (CDR, 2006 (a)) and 2005 (CDR, 2006 (b)) show that there were 16 outbreaks of which 11 were caused by *Cryptosporidium*, 3 involved *Vt E coli*, 1 Norovirus and only 1 involved *Giardia*. While 2 of the cryptosporidiosis outbreaks were associated with public water supplies, the only outbreak in which *Giardia* was implicated involved a swimming pool.

Outbreaks in the UK are relatively rare but outbreaks of the disease are more common in North America, possibly because of a larger reservoir of infected wild animals such as beaver in American wildernesses which are popular areas for hiking and camping. Another possible reason is the large number of mountain streams that are used (with minimal treatment) as water supplies in small or remote rural communities in parts of the USA. In the period 1971-1985 18% of outbreaks of waterborne diseases in the USA were caused by *Giardia*. In the period 1991-2002 of the 205 reported outbreaks of waterborne disease 25 were due to *Giardia* (Craun et al., 2006). It is recognised that by no means all outbreaks are recognised or reported. No outbreaks associated with public supplies have been documented by the Drinking Water Inspectorate (DWI) or the Health Protection Agency (HPA). The only recorded public supply related outbreak in England and Wales was in Bristol in 1985. (Jephcott et al., 1986).

Outbreaks of giardiasis in which drinking water was implicated have also been reported in many other countries including Sweden, New Zealand and British Columbia (Hunter, 1997).

As noted above, the first recorded outbreak associated with drinking water in the UK was in Bristol in 1985 since when there do not appear to have been any further outbreaks associated with the public drinking water supply. The general trend in the total numbers of cases of giardiasis in the UK since 1990 has been downwards until 2005 since when there has been a small but steady rise (HPA, 2011).

7 Can all Cysts cause an Infection ?

An infection occurs when the parasite grows in the body of the infected person or animal; this may occur without any symptoms appearing, so the absence of symptoms does not necessarily mean an absence of infection.

With most infective agents there is usually a so-called "infective dose". An infective dose depends on the physical condition of the person who is infected and

the state of their immune system so the size of an "infective dose" will vary. Only cysts from assemblages A and B can infect humans In the case of *Giardia* cysts the infective dose may be as low as 10 viable cysts (Rentdorff, 1954). However, not all cysts are viable (viable means that they are able to "hatch out" and start the reproductive cycle of the parasite) and thus not all cysts can cause an infection. One or two cysts are unlikely to cause an infection unless the individual's immune system is severely compromised as may be the case with the very young, elderly or AIDs sufferers.

8 How are Cysts Detected?

Available analytical methods for detecting cysts in the environment are not very reliable (although they are improving all the time).

The methods for the analysis of a water sample for *Giardia* cysts are broadly the same as for *Cryptosporidium* oocysts (see the Foundation for Water Research's ROCK "Cryptosporidium in water supplies" 2011). The methods consist of three stages: - concentration, separation and detection. There is therefore ample opportunity for cysts to be missed during the collection and analysis of a water sample and there is a wide variation in the results of analyses. Recovery of cysts can vary by as much as 30% to 60%. The Standing Committee of Analysts in the UK has produced an approved methodology for analysis for *Cryptosporidium* and *Giardia* (SCA, 2010).

The concentration stage consists in passing the water sample through one of a range of commercial cartridge filters which have been evaluated and approved for the purpose and then eluting (or washing off) the captured particles from the filter. As an alternative for small volumes a chemical flocculation procedure can be adopted. After subsequent concentration by centrifugation, magnetic beads labelled with antibodies specific for *Giardia* are added to the suspension. Antibody - antigen reactions bind the cysts to the magnetic beads, the sample is magnetised and the cyst -magnetic bead complex can then be separated from the sample debris. The oocysts are then detached from the beads, fixed to slides and stained with immuno-fluorescence assay (IFA) using fluorescein isothiocyanate coupled to monoclonal antibody and examined and counted under the microscope. DAPI stain is then added to stain cell nuclei for viability assessment and the slides re-examined.

Molecular methods including the polymerase chain reaction (PCR) have been used (Baque, 2011). This is a procedure for the detection of organisms in which very small and specific sections of the organism's DNA are replicated in sufficiently large quantity to be detected using an appropriate method. Its main

application is in typing the strain or species of cysts, which cannot be done with the staining procedures described above. Typing can be useful in eliminating possible sources of infections. (Robertson et al., 2006).

When considering data on quantities of *Giardia* cysts found in water samples it should be borne in mind that there is still considerable uncertainty in the techniques used to collect and assay cysts. Experimental recovery rates given in the SCA methodology (SCA, 2010) using filtration range from 5% to 91%!

9 How we prevent *Giardia* entering Water Supplies

Regulation 27 of the Water Supply (Water Quality) Regulations 2000 (SI 2000 No. 3184) requires that risk assessments be carried out on all "water treatment works and supply system to establish whether there is a significant risk of supplying water …. that would constitute a potential danger to human health" DWI in its Guidance on the Water Supply (Water Quality) Regulations 2000 (England) (DWI, 2010) says that "these risk assessments shall be undertaken using the water safety plan approach published by WHO". That approach is re-published in the WHO Guidelines for Drinking Water Quality (2011) and supported by the WHO Water Safety Plan Manual (2009). Having determined whether there are any such risks, appropriate treatment processes are adopted.

The production of drinking water of the right chemical and microbiological quality requires two processes; the physical removal of impurities, including any *Giardia* cysts which may be present in the raw water supplying the treatment works, followed by the inactivation of any micro-organisms still present in the water.

Cysts are particulate and are fairly readily removed by the conventional processes used in drinking water treatment plants such as coagulation, settlement, rapid filtration and slow sand filtration (Betancourt et al., 2004). A well operated treatment plant based on chemical coagulation, sedimentation and filtration should achieve at least 99.9% removal of cysts. Membranes are effectively impervious to particulate matter of the size of cysts and, in theory, can provide an effective barrier in preventing cysts getting into the drinking water supply. However, membranes and the seals in membrane plants can occasionally leak so even a membrane process cannot be regarded as 100% effective. Better than 99.9999% reductions for *Giardia* cysts have been claimed for some membrane processes (Jacangelo et al., 1995).

Since membrane plants and well-run conventional treatment plants may have occasional problems it is prudent to have additional measures to combat the potential break-through of *Giardia* cysts into the drinking water supply. Some sort

of disinfection or inactivation method is therefore desirable. Furthermore, disinfection is, of course, also required for the inactivation of pathogenic viruses and bacteria which are less effectively removed by filtration.

The traditional techniques available for disinfecting drinking water consist of chemical dosing with chlorine, chloramines, chlorine dioxide and/or ozone. Irradiation with ultra-violet (UV) light has also been shown to be effective at inactivating G*iardia* oocysts (Hijnen et al., 2006; Shin et al., 2009) and is particularly useful for small private supplies.

Cysts are protected by a thick wall which is resistant to chlorine. Free chlorine is effective against bacteria and viruses but to be effective against *Giardia* cysts much longer contact times are required at the concentrations which are normally used in drinking water treatment. Chloramine is ineffective against cysts at practicable concentrations for water supplies. Chlorine dioxide has been demonstrated to be reasonably effective in achieving 90% deactivation with practicable dosing regimes. Ozone has also been found to be fairly effective in reducing the viability of cysts. Disinfection effectiveness is usually expressed as the combination of concentration and contact time for a specified log or percentage reduction (CT). Health Canada (2008) has published CT tables which enable comparison of the disinfectant effectiveness of ozone, chlorine, chloramine, and chlorine dioxide against Giardia. For 3 log reduction of *Giardia* at 25ºC CT values

of 0.48 for ozone, 11 for chlorine dioxide, 97 for chlorine and 750 for chloramine are required. Currently irradiation with UV light is the most promising form of disinfection - or inactivation - for *Giardia*. The most effective UV light has a wavelength in the region of 200-300 nanometres with maximum effect at about 265 nanometres. The UV damages DNA in cells, disrupting their replication thereby preventing new cells being created. A detailed description of how UV radiation inactivates micro-organisms can be found in the EPA Ultraviolet Disinfection Guidance Manual (USEPA, 2006). Although early work on UV light suggested that it was not very effective against protozoa a number of recent studies using different techniques to measure inactivation have shown that UV light is effective against cysts at the appropriate intensity. It has been suggested that the use of UV radiation in conjunction with another effective disinfection agent such as ozone should be considered in order to give greater effectiveness in achieving the best levels of deactivation (USEPA, 1999b). For unfiltered supplies the use of 2 alternative disinfectants is a requirement under the US Surface Water Treatment Rule (USEPA, 2010). One reason for suggesting using another disinfectant such as ozone in conjunction with UV is that UV light is absorbed by some of the substances which are sometimes present in water such as iron and various forms of organic matter and this could affect the efficiency of the UV.

10 Summary

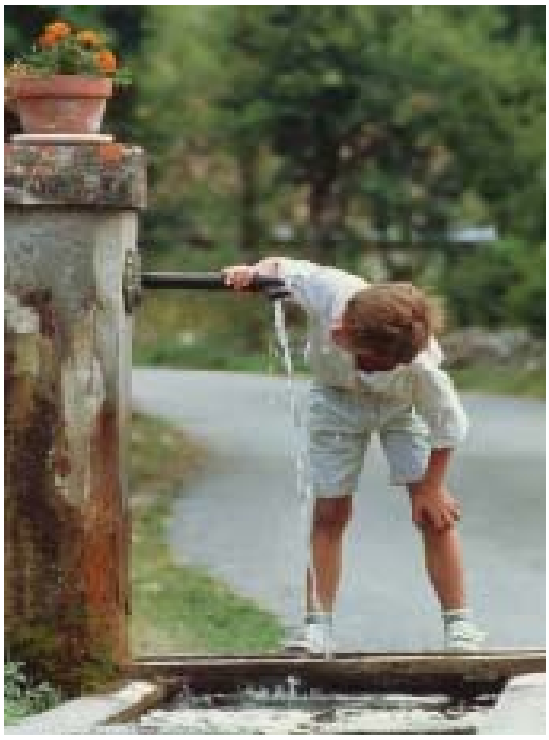
Giardia is a parasite which can produce an unpleasant gastric illness known as giardiasis although some infected people show no symptoms and are unaware that they are infected. The parasite is transmitted in a form known as a cyst. Giardiasis is readily treated by a number of different drugs, but if left untreated it can persist for a number of years.

There are currently 6 recognised species but only one species, *Giardia duodenalis* (also known as *Giardia intestinalis* or *Giardia lamblia*) is known to infect human beings although this species can also infect some other animals as well thus making it possible to pick up the infection from infected domestic pets and farm animals, and from water contaminated by wild animals. *Giardia duodenalis*, the species which infects human beings has possibly 8 different strains of which only two are known to infect humans.

Giardia is frequently waterborne in natural waters and infections have occurred from drinking contaminated water. However, there are many other possible ways of becoming infected with *Giardia* such as person-person contacts, zoonosis (animal-person contacts), contaminated food and contaminated swimming pools and other recreational waters (rivers and lakes), or foreign travel - giardiasis is also known as "travellers' diarrhoea".

A well-operated drinking water treatment plant based on coagulation, clarification and filtration can physically remove over 99.99% of cysts from a polluted raw water. These traditional processes remain the best defence against this parasite entering supplies although membrane technology can also offer an effective method for removing cysts from water.

The effectiveness of standard chemical disinfectants such as chlorine and chloramine against *Giardia* cysts is limited. However, they may present a further barrier to the entry of viable cysts into the supply system. Ozone and UV light can be effective disinfectants against *Giardia.*



In the UK there are regulations to control the risk of pathogens getting into the drinking water supply and these are supported by robust Water Safety Plans. The total numbers of infections of giardiasis in the UK are small. In the year 2011 the total number of reported cases of giardiasis in England and Wales was 3670 out of a total population of c56 million of whom c55.3 million are connected to the public water supply. However, there is no evidence that any of these cases were caused by drinking the public water supply. Furthermore, it seems likely that a number of these cases were contracted by people travelling overseas. Data for Scotland and Northern Ireland suggest that the situation there is little different from England and Wales.

In conclusion one can say that the risk of infection by *Giardia* in the UK is low, and the risk of infection from the public drinking water supply is negligible.

References

(Many of the hyperlinks below do not lead to the actual publication but to a source where it can be obtained as many of the journals etc. require a subscription)

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Some useful discussions on *Giardia* can also be found in "Wastewater Microbiology, 4th Edition" by Gabriel Bitton, pub. by Wiley-Liss, 2010.
http://onlinelibrary.wiley.com/book/10.1002/9780470901243
The Foundation for Water Research ROCK "*Cryptosporidium* in water supplies" (2011) also has some useful additional information which supplements this Report on *Giardia*. http://www.fwr.org/cryptosp.pdf