Cryptosporidium In Water Supplies - Updating the Expert Group Report

Summary of Additional Evidence Since 1989
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1. BACKGROUND

The report of the Group of Experts published in July 1990 brought together information available at that time to provide advice to the water industry on the minimisation of the risks of water-borne cryptosporidiosis. The Group recognised gaps in some areas which limited the advice which could be given. The National Research Programme has been running since 1990 to provide answers to some of the questions raised.

It is timely to review whether the results from this research and other studies materially change or consolidate the advice given. This paper attempts to address that question.

2. THE NATURE OF THE PROBLEM

Passage of time and further water-borne outbreaks since 1990 have served to provide perspective both on the scale of the problem and possible causative factors. However, the low frequency of incidents has inhibited the drawing of firm conclusions on the causes of water-borne outbreaks, although there has been much speculation based on circumstantial evidence.

The Expert Group Report and the interim Research Report published in July 1992 made it clear that it is unlikely that the risk of water-borne cryptosporidiosis can be eliminated and that the exercise is essentially one of risk reduction. This is achieved by maximising the barriers to the transmission of disease. The principal barriers are pollution prevention, and source protection coupled with effective removal/inactivation in treatment.

3. MEASUREMENT

All aspects of work on Cryptosporidia are hampered by the current methods of measurement which are inaccurate, time consuming and therefore expensive. Research so far has failed to produce a rapid method which can be applied to environmental samples. Some progress has been made in speeding up the later stages of the method but recovery efficiency has not been increased significantly.

An effective test for viability has been developed but attempts to produce a method which is specific for Cryptosporidium parvum have not been successful. Development of gene probes for these purposes is said to be promising but work has not been included in the National Programme due to studies already in progress in the UK and USA. A review of this area has been commissioned and a final report is awaited.

Other developments outside the National Programme include use of an electron rotation assay, which is still under development and application of flow cytometers to the final stages of evaluation.

Published recovery efficiencies for the standard cartridge filter method range from 9% to 59%. In spiked sample tests mean recoveries have been shown up to lie between 24% and 42% depending on the quality of the water tested.
4. SOURCE CONTAMINATION AND PROTECTION

The balance of evidence suggests that water-borne outbreaks occur as a result of contamination of sources with large numbers of oocysts, probably from animal sources. However, such contamination levels have not been recorded even during outbreaks. The 15 month UK National Survey produced a maximum result of 4 oocysts litre\(^{-1}\) for river waters with means for the different sites between 0.12 and 1.09 oocysts litre\(^{-1}\). Results from 'industrial' US rivers gave consistently higher figures with maxima ranging from 0.3 to 484 oocysts litre\(^{-1}\). Data provided by UK water companies have indicated surface water maxima of between 0.36 and 76.7 oocysts litre\(^{-1}\). The higher figure is interesting since it was measured in 1992 on a river which gave largely negative results except for a period in July and August. In fact the same site produced values of 74.6 oocysts litre\(^{-1}\) and 76.7 oocysts litre\(^{-1}\) on successive weeks, indicating the possibility of a sustained concentration over this period. The recent intensive survey of the River Torridge where a total of 42 samples were taken from 7 sites yielded 17 positive samples. Most of these were in the range of 0.08-2.27 oocysts litre\(^{-1}\) although levels of 15.6 and 66.4 were recorded. Although there was a correlation between positive samples and indices of faecal pollution this was more likely to be a result of diffuse run off during the prevailing storm conditions than from discrete pollution incidents.

Although the origin of oocysts in raw waters has not been established clearly, published work and more recent studies funded by MAFF and SOAFD demonstrate that large numbers can be shed by cattle and sheep usually in the first 2-3 weeks after birth. Seasonal peaks in cases have been shown, in the case of cattle from November to April/May and for sheep February to May. These studies are continuing and will assess the partitioning between slurry and water and mechanisms of release to water courses. Studies of viability in storage and after treatment will provide additional data from which guidelines can be developed to allow farmers to minimise potential hazards. Water suppliers would wish to know whether such pollution prevention measures could help to ease the challenge on water treatment works.

Water suppliers will need to include cryptosporidium in their studies of the strategic use of raw water storage for surface supplies. In a few cases alternative supplies may provide an option when contamination of a source occurs, but this is unlikely to be a solution for large supplies.

There has been no systematic study of the occurrence of oocysts in sewage effluents. Available data are conflicting, but it may be significant that there is no epidemiological evidence that outbreaks have occurred in communities receiving water from sources downstream of infected communities.

5. TREATMENT

It is becoming increasingly clear that the provision and effective operation of water treatment processes is the single most important factor in risk minimisation. This is also the message coming from the United States following the Milwaukee and other smaller water-borne outbreaks. The US approach is to propose amendments to the Surface Water
Treatment Rule which requires treatment for surface waters and groundwaters under the influence of surface waters. With a proposed goal of zero cryptosporidium oocysts in supply, exacting removal/inactivation requirements are proposed for treatment plant which, as they stand, are far beyond those which have been demonstrated in conventional processes.

5.1 Treatment provision

It is unlikely that a case can be sustained for an untreated supply from a water with contamination or potential contamination from cryptosporidium oocysts. Indications are that a well-operated two-stage chemical treatment or slow sand filter plant can result in a 3 log removal of oocysts. On the other hand there seems no proven case for enhancing treatment specifically for oocyst removal, although the provision of additional barriers, for example, activated carbon adsorbers, for other purposes will give additional removal. The introduction of single-stage membrane treatment as an alternative to conventional plant would need evaluation in terms of the risk of oocyst penetration.

5.2 Treatment operation

There is some circumstantial evidence that poorly operated treatment plant may have played a role in water-borne outbreaks, but the case is not proven. Nevertheless, water suppliers must assume that effective operation is important and attention needs to be given to a number of factors, many of which have been discussed in the Expert Group Report.

5.2.1 Coagulation control

Effective particle separation in a chemical treatment plant depends crucially on the formation of good flocs which can be removed subsequently in settlement and filtration. Raw water quality following heavy rainfall, which could be the time when oocyst challenges are high, is often the most difficult to treat because of the presence of high solid concentrations and varying quality, which makes the achievement of optimum coagulation conditions difficult.

5.2.2 Filter start-up

The period following the backwashing of a filter is proving to be a time of increased particle penetration. Water suppliers are examining ways in which effects can be minimised including slow start mechanisms or filtration to waste. These measures, and others to reduce flow changes on filters when one or more is off-stream for washing, may require the provision of additional plant capacity.
5.2.3  Plant monitoring

The provision of turbidimeters on individual filters was recommended in the Expert Group report. More attention is now being paid to the use of particle size monitors, although a strategy has yet to be developed in terms of triggering of backwashing. Although turbidimeters are not thought to be sensitive to particles in the cryptosporidium size range, and particle counters do not differentiate between different types of particle, both instruments have value in detecting breakthrough on filters which provides some warning that oocysts might be present.

5.2.4  Recycling of supernatant

The practice of recycling supernatant water from sludge and backwash water separation plant has been much discussed. Initial calculations indicate that the impact of this practice depends crucially on the separation efficiency achieved in the settlement system receiving the washwater and sludge. Further practical and theoretical work is planned or in progress on this subject. Some companies are already installing treatment of backwash water to reduce the chance of cryptosporidium oocyst being returned to the plant inlet.

6.  DISINFECTION

No further evidence has been produced which would indicate that conventional chlorination is effective against cryptosporidium. The effectiveness of ozone is still a matter of debate. The published work shows that comparison of results is difficult because different ozonisation conditions, methods of measuring inactivation and temperatures have been used. It is clear that effectiveness is less at lower temperatures and that the interpretation of results from animal studies is not uniform and leads to significant differences in inactivation rates. Furthermore, the relationship between the different inactivation tests and the risk of human illness has yet to be established. Ozone is undoubtedly more effective than other disinfectants but it is unlikely that, at present, it would be installed solely for dealing with cryptosporidium. However, use for other purposes, such as pesticide removal, taste and odour and disinfectant by-product minimisation, would lead to some inactivation. In view of the spread of published results it is difficult to define how effective the modest doses and contact times in normal practice would be. For example, a residual of 1 mg l\(^{-1}\) for a period of 4-6 minutes at temperatures between 15 °C and 25 °C give reported inactivations ranging between 0.24 log 4 log depending on the study chosen. Other chemicals and UV treatment appear not to be effective but some studies are in progress on the use of ultrasound, although no detailed results are available. At present it seems unlikely that disinfection will provide a barrier as robust as conventional disinfection is in relation to other pathogens.

7.  MONITORING

The nature of the present method of measurement for oocysts restricts the amount of routine monitoring which can be done by water companies. The cost of analysis limits the
number of samples which can be taken and the analysis time does not allow real-time control of treatment. The seminar held by DWI/DH in June 1993 concluded that some raw water monitoring was justified but only on sources where oocysts are likely to be present and that routine monitoring of treated waters for protection of consumers was not justified. However, some work relating the presence of oocysts to levels of illness in the community would be helpful. Consideration should therefore be given to a study in which treated-water is continuously filtered for cryptosporidium oocysts, as in the Lomond Study, in conjunction with epidemiological studies in the receiving community on a supply where oocysts are known to occur in the raw water. This would require the collaboration of the water company and the appropriate health authority.

8. OTHER FACTORS AFFECTING OUTBREAKS

It has been established in a number of studies, e.g. Rose, LeChevallier and Ongerth in the United States and in the UK water company surveys, that oocysts can be found in treated water without producing detectable levels of illness in the community supplied. A number of factors have been put forward to explain this.

8.1 Viability

Using the viability test developed at Stobhill figures are now becoming available for the viability of oocysts found in water. Fresh oocysts prepared from bovine or human isolates have viabilities in excess of 70%. Loch Lomond results showed viabilities of between 0 and 40% for individual samples of water at the intake. The figures were: one at 40%, two at 19% and eight at 0%. In controlled studies exposure to the aquatic environment has resulted in a reduction in viability of almost two thirds. At present water companies have to assume that all oocysts found are viable.

8.2 Species

In the absence of a test for specificity it has to be assumed that all oocysts are C. parvum which may not be the case. However, it has not been established beyond doubt that C. parvum is the only species infective to humans.

8.3 Infective dose and numbers present in treated water

The work on infective dose completed to date is inconclusive. The results from Moredun on gnotobiotic lambs indicated that a dose of one oocyst could cause infection whereas doses up to $10^5$ did not infect vervet monkeys in the Kenya trials. This latter result contrasts with work in the United States where infection occurred with the lowest dose of 10 oocysts using 25-50 day old Macaque monkeys. Two differences between the primate studies were noted by the authors of the Kenya report. Firstly, their youngest animals were older (8 months) than the animals in the American study and secondly, oocysts were obtained from diseased humans in Kenya and from symptomatic Macaques in the USA.
Possible reasons for the differences between the results from the studies include: passage of immunity from adults to the captively bred infants in Kenya, lack of cross-host infectivity and differences in oocyst virulence.

Various rodent models have been used in disinfection studies. These indicate that infective dose depends upon the type of animal and age. In French studies immuno-suppressed Sprague-Dawley rats were shown to have a minimum infective dose of $10^4$ oocysts. Experiments with mice show that not all were susceptible to infection by oocysts. Using 3-4 day neonatal mice threshold infection has been obtained at doses of 25 oocysts with an ID$_{50}$ between 60 and 80, although with Swiss mice the ID$_{50}$ was between 100 and 500. However, the true relevance of such figures to human infection has been questioned.

Of greater interest will be the results from the human feeding trials in the USA. There will undoubtedly be questions about the protocol but the results should be informative. The latest available information is that 15 of 21 antibody-negative volunteers become infected, 5 at doses as low as 100 oocysts. The water supplier, however, will be interested in the threshold infective dose.

It is unlikely that a precise infective dose figure for humans will be obtained. Nevertheless, an idea of the likely range would be helpful to compare with the possibility of consumers receiving such a dose. In this respect calculations could be made on the probability of consumers receiving an infective dose at various levels of treated water contamination, bearing in mind the proportion of water taken as cold drinks. To support these calculations, data could be used from surveys of treated water which indicate the range of concentrations found. As indicated in the July 1992 interim research report, concentrations of oocysts in filtered water, excluding outbreak situations, ranged from 0.001 oocysts litre$^{-1}$ to 0.48 oocysts litre$^{-1}$, the latter result coming from a raw water with high oocyst concentration. More recent figures from water company surveys in the UK indicate a range of positives between 0.002 oocysts litre$^{-1}$ and 0.4 oocysts litre$^{-1}$, the latter being a one-off result. It should be noted that the returns on treated water indicate that of 297 samples tested 7 were found positive (2.4%) an order of magnitude lower than the previously reported results.

### 8.4 Immunity

The evidence on immunity is still limited, as concluded in the Expert Group report. Since in immuno-competent individuals the disease is self-limiting at least short-term protection must be developed. Whether this protects through life is uncertain. Person-to-person infection is concentrated in the young (1-5 years) but this could relate as much to exposure as immunity. Water-borne infections affect a wider age range which could suggest that exposure is an important factor. Attack rates in populations in water-borne outbreak areas are always less than 100% but exposure could still be a factor. In sheep and calves it is mostly young animals affected even though adults and young are likely to be equally exposed, suggesting immunity.
In the absence of systematic human feeding trials which include repeated infection it is difficult to assess the importance of immunity on controlling water-borne outbreaks. The human trials in the USA are to continue with antibody-positive volunteers in the next phase.

8.5 Virulence

One possible explanation of the fact that water-borne outbreaks occur in some cases whereas in others oocysts can be present in supplies without illness, is a variation in virulence of oocyst. This phenomenon is found in other pathogens and there is no scientific reason why cryptosporidium should be different. One theory is that variations in surface properties of the oocysts could account for differences in virulence but, as with immunity, there is no firm evidence in terms of human feeding trials, or detailed examination of oocysts from outbreak situations. There is some evidence of different levels of infectivity between strains of oocysts. This may be a function of virulence or may indicate that immunity from previous exposure is strain specific.

8.6 Effects of stress on oocysts

It has been suggested by LeChevalier and others that environmental factors could weaken oocysts thus making them less infective or more susceptible to inactivation. Experiments have shown that some factors will lead to oocysts becoming non-viable but results from laboratory and pilot plant work do not suggest differences in behaviour in treatment between ‘fresh’ and ‘stressed’ oocysts although the stressed oocysts are less likely to be viable and may be slightly more sensitive to disinfection.

9. CONCLUSIONS

1. Absence of a quick, easily applied and accurate method of detecting and enumerating oocysts continues to impede progress on all aspects of Cryptosporidium in drinking water.

2. There is still no clear-cut evidence in the conditions which lead to outbreaks of water-borne cryptosporidiosis.

3. There is sufficient evidence to suggest that oocysts from infected animals represents a potential significant source of oocysts and that pollution prevention measures could be an important barrier to disease transmission.

4. Effective removal of oocysts in treatment continues to be the most important barrier in controlling potential waterborne outbreaks.

5. Specification and control of treatment processes are important elements in reducing risk.
6. Effective monitoring of filtration for breakthrough conditions is important and both turbidimeters and particle size analysers have potential. It is important that an effective strategy is developed for using particle size analysers.

7. There is no clear-cut evidence that oocysts which have been subjected to environmental stress are significantly more susceptible to treatment, although numbers of viability decrease in the environment. Stressed oocysts appear to be more susceptible to chlorine but not to the extent that conventional application levels lead to effective inactivation.

8. Evidence on the effect of ozone is not uniform with some studies showing a higher degree of inactivation than others. The method of test and the temperature of treatment are both important. The balance of evidence is that some inactivation can be achieved but, unless high doses and contact times are used the effect will be limited.

9. Important factors affecting outbreaks may well be numbers passing treatment, viability, strain, virulence and immunity in the population.

10. Although there are no important new factors which have emerged to guide water companies since the report of the Group of Experts, many of the recommendations can be more fully supported by the data acquired in studies both within the UK and overseas. It is therefore recommended that plans are drawn up to reconvene a representative Expert Group to consider this further advice, although it is unlikely that this would need to involve a committee of the size of the previous Group.