Water Disinfection for International and Wilderness Travelers

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Acquisition of waterborne disease is a substantial risk for international travelers to countries with inadequate sanitation facilities. It also poses smaller but still significant risks for wilderness travelers who rely on surface water in developed countries with low rates of diarrheal illness, such as the United States. This article reviews the etiology and risks associated with waterborne disease that might be encountered by both types of travelers. It also summarizes—and makes recommendations for—the various water-treatment methods available to travelers for reducing their risk of contracting waterborne disease.

In certain tropical countries, the influence of a high-density population, rampant pollution, and the absence of sanitation systems means that available raw water is virtually wastewater [1]. Contamination of tap water also must be assumed because of the presence of antiquated and inadequately monitored disposal, water-treatment, and distribution systems. Worldwide, >1 billion people have no access to potable water, and 2.4 billion live in areas without adequate sanitation systems [2]. These inadequacies result in billions of cases of diarrhea among the local inhabitants of these areas every year, creating a reservoir of enteric pathogens that travelers may then encounter. Travelers must take appropriate steps to ensure that the water that they drink does not contain infectious agents. Even in developed countries with low rates of diarrheal illness, wilderness travelers who rely on surface water must be concerned with ensuring the microbiologic quality of the water that they use [3].

ETIOLOGY AND RISK

Infectious agents with the potential for waterborne transmission include bacteria, viruses, protozoa, and parasites (table 1). Although the primary reason for disinfecting drinking water is to destroy microorganisms from animal and human biologic wastes, natural surface water may also be contaminated with (1) organic or inorganic material from land and vegetation, (2) biologic organisms that reside in soil and water, and (3) industrial chemical pollutants (an increasing problem) [6].

Risk of contracting waterborne illness depends on the number of organisms consumed, which is, in turn, determined by the volume of water, the concentration of the organisms, and the efficiency of the treatment system [7]. Additional factors include the virulence of the organism and the defenses of the host. Microorganisms with a small infectious dose (e.g., *Giardia, Cryptosporidium,* and *Shigella* species; hepatitis A virus; enteric viruses; and enterohemorrhagic *Escherichia coli*) may cause illnesses even when a small volume of contaminated water is inadvertently swallowed during water-based recreational activities. Because total immunity does not develop for most enteric pathogens, reinfection may occur.

Estimations of water safety cannot reliably be made on the basis of the look, smell, and taste of water. In fact, travelers have no reliable resources for evaluating the quality of local water systems. Even less information is available for determination of the quality of remote (i.e., wilderness) surface-water sources [8]. *E. coli* and *Vibrio cholerae* may occur naturally in tropical waters and may be capable of surviving indefinitely [9]. Enteric pathogens can also retain viability for long periods in cold water [5]. Most enteric organisms, including *Shigella* species and *Salmonella typhosa,* hepatitis A virus, and *Cryptosporidium* species, can survive for weeks to months when frozen in water [10–12].

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WATER-TREATMENT METHODS FOR TRAVELERS

Safe and efficient treatment of drinking water has been among the major public health advances of the 20th century [13]. Without it, waterborne disease would spread rapidly in most public water systems served by surface water [5, 14]. Individuals and small groups can easily use many of the techniques used in large-scale treatment plants, regardless of whether their travels take them to the wilderness or to a hotel in the developing world. Because travelers may stay in hotels at night and explore remote villages or wilderness parks during the day, they require an understanding of the treatment methods used for a spectrum of water conditions. Although drinking bottled water is convenient and popular, the bottles create ecological problems in countries that do not recycle the plastic used in their manufacture. A report previously published elsewhere provides a more detailed discussion of these techniques [15].

In this article, the term "disinfection" (i.e., the desired result of field-water treatment) is used to indicate the removal or destruction of harmful microorganisms (comparable to the concept of low- to intermediate-level disinfection practiced in a hospital setting). The goal of disinfection is to make water potable—that is, to ensure that, on average and over a period of time, a water source contains only a "minimal microbial hazard," so that the statistical likelihood of illness is acceptable. All standards allow for a small risk of enteric infection, thereby acknowledging the impracticality of eliminating all microorganisms from drinking water. In general, the goal is to achieve a 3–5-log reduction in the level of microorganisms [16]. The term "purification," although frequently used interchangeably with "disinfection," is more accurately used to indicate the removal of organic or inorganic chemicals and particulate matter to improve offensive color, taste, and odor. Purification may not eliminate enough microorganisms to assure microbiologic safety [17]. "Clarification" refers to techniques that reduce the cloudy appearance of river, lake, or pond water, which is caused by the presence of natural organic and inorganic material.

Table 1. Waterborne pathogens, according to type.

Bacterial
Aeromonas species[a]
Campylobacter species[a]
Enterotoxigenic *Escherichia coli*
E. coli O157:H7[a]
Salmonella species
Shigella species[a]
Vibrio cholerae
Yersinia enterocolitica[a]
Parasitic[b]
Ancylostoma duodenale
Ascaris lumbricoides
Clonorchis sinensis
Diphyllobothrium latum
Dracunculus medinensis
Echinococcus granulosus
Fasciola hepatica
Paragonimus westermani
Strongyloides stercoralis
Taenia species
Trichuris trichiura
Protozoan
Acanthamoeba species
Balantidium coli
Blastocystis hominis
Cryptosporidium species[a]
Cyclospora species[a]
Entamoeba histolytica
Giardia lamblia[a]
Isospora belli
Viral
Hepatitis A virus[a]
Hepatitis E virus
Norwalk virus
Poliovirus
Miscellaneous enteric viruses[a,c]

NOTE. Data are from [4, 5].

[a] Confirmed or suspected source of outbreaks of waterborne enteric disease in North American wilderness or recreational water.

[b] Waterborne transmission is possible but uncommon for all these parasites, with the exception of *D. medinensis*.

[c] More than 100 types.

Clarification

Clarification, the process of clarifying water, facilitates disinfection achieved by filtration or chemical treatment.

Sedimentation. Sedimentation is the separation of suspended particles that are large enough to settle rapidly by gravity (e.g., sand and silt). Sedimentation can result in the clarification of water but should not be considered a means of disinfection. Water must be allowed to sit undisturbed for ~1 h or until sediment has formed on the bottom of the container. The clear water should then be decanted or filtered from the top of the container. Microorganisms—especially protozoal cysts—also eventually settle, but the process takes much longer [1].

Coagulation-flocculation. This technique, which has been in use since 2000 B.C., can remove smaller suspended particles and chemical complexes that are too small to settle by gravity (e.g., colloids). Coagulation is achieved by the addition of an appropriate chemical that causes particles to stick together as a result of electrostatic and ionic forces [5, 18]. Flocculation is a physical process that promotes formation of larger particles by gentle mixing. Alum (an aluminum salt) and lime (alkaline

Table 2. Temperature and time required for heat inactivation of microorganisms.

Organism	Lethal temperature and time	Reference
Giardia species	55°C[a] for 5 min	[26]
	50°C for 10 min (95% inactivation)	[27]
	60°C for 10 min (98% inactivation)	
	70°C for 10 min (100% inactivation)	
Cryptosporidium species	64°C within 2 min	[28]
	72°C heated up over 1 min	
E. coli, and *Salmonella, Shigella,* and *Campylobacter* species	65°C[b] for 3 min	[29]
Vibrio cholerae	60°C for 10 min	[30]
	100°C for 10 s	
E. coli	60°C for 5 min	[31]
	70°C for 1 min	
Enteric viruses	56°C–60°C for 20–40 min	[32, 33]
	<1 min at ⩾70°C[c]	[34]
Hepatitis A virus	98°C for 1 min	[35]
	85°C for 1 min	[11]

NOTE. *E. coli, Escherichia coli.*

[a] 131°F.

[b] 149°F.

[c] ⩾158°F.

chemicals that contain calcium, magnesium, or iron salts) are commonly used coagulants. In an emergency, baking powder or even the fine white ash from a campfire can be used as a coagulant [19]. Coagulation-flocculation removes 60%–98% of microorganisms, heavy metals, and some chemicals and minerals from water [20].

The amount of alum added (approximately a pinch, or 1/8 teaspoon, per gallon of water) need not be precise. The water should be stirred or shaken briskly for 1 min, to achieve a mix, and then should be agitated gently and frequently for at least 5 min, to assist flocculation. If the water is still cloudy, more flocculent should be added and mixing repeated. After the water has been allowed to sit for at least 30 min to achieve settling, it can be poured through a fine-woven cloth or paper filter. A final process of filtration or halogenation should be completed to ensure that disinfection has been achieved.

Granular-activated carbon (GAC). GAC purifies water by adsorbing organic and inorganic chemicals, thereby improving odor and taste [21]. GAC is a common component of portable field filters. It may trap but does not kill organisms; in fact, bacteria readily colonize GAC [22]. In field-water treatment, GAC is best used after chemical disinfection, to make water more palatable and more safe by removing disinfection byproducts, pesticides, organic chemicals, and heavy metals [23].

Heat

Heat is the oldest means of disinfecting water. The advantages and disadvantages of using heat for water disinfection are as follows:

1. Heat neither imparts additional taste to nor improves the taste, smell, or appearance of poor-quality water.
2. Heat is a single-step process that inactivates all enteric pathogens.
3. Heat's efficacy is not compromised by contaminants or particles in the water, as is the case with halogenation and filtration
4. Fuel sources may be scarce, expensive, or unavailable.

Heat inactivation of microorganisms is exponential and follows the rules of first-order kinetics [24]. Thus, thermal death is reached in less time when higher temperatures are used; lower temperatures are effective when a longer contact time is used. Pasteurization uses this principle to kill enteric food pathogens and spoiling organisms at temperatures of 60°C–70°C, temperatures that are well below the boiling point [25]. All common enteric pathogens are readily inactivated by heat, although the heat sensitivity of microorganisms varies (table 2).

Bacterial spores, such as *Clostridium* spores, are heat resistant (some can survive for long periods at a temperature of 100°C) and are ubiquitous in the natural environment, but they are not waterborne enteric pathogens [36]. Thus, sterilization—the destruction or removal of all life forms—is not necessary for drinking water.

Because enteric pathogens are killed within seconds by boiling water and are killed rapidly at temperatures >60°C, the traditional advice to boil water for 10 min to ensure potability is excessive. Because the time required to heat water from a temperature of 55°C to a boil works toward disinfection, any water that is brought to a boil should be adequately disinfected. Boiling water for 1 min or keeping water covered and then

allowing it to cool slowly after boiling can add an extra margin of safety [37]. The boiling point decreases with increasing altitude, but this is not significant when compared with the time required to achieve thermal death at these temperatures.

Although heating water to boiling is not necessary, it is the only end point that can be easily recognized without use of a thermometer. The temperature of hot tap water and the temperature of water that is too hot to touch vary too widely to be reliable determinants of pasteurization of water [29, 31]; however, if no reliable method of water treatment is available, tap water that has been kept hot in a tank for some time (at an estimated temperature of 55°C–60°C [140°F] for at least 30 min) is a reasonable alternative [38]. Travelers with access to electricity can boil water with the use of either a small electric heating coil or a lightweight electric beverage warmer brought from home. In austere or desperate situations, an adequate temperature for pasteurization can be achieved in hot, sunny climates by use of a solar oven or simple reflectors [39].

Table 3. Susceptibility of microorganisms to filtration, by size.

Organism	Approximate size, μm	Maximum recommended filter rating, μm
Virus	0.03	NA[a]
Escherichia coli	0.5 × 3–8	0.2–0.4
Campylobacter species	0.2–0.4 × 1.5–3.5	0.2–0.4
Vibrio cholerae	0.5 × 1.5–3.0	0.2–0.4
Cryptosporidium oocyst	2–6	1
Giardia cyst	6–10 × 8–15	3–5
Entamoeba histolytica cyst	5–30	3–5
Nematode egg	30–40 × 50–80	20
Schistosome cercariae	50 × 100	Coffee filter or fine cloth
Dracunculus larvae	20 × 500	Coffee filter or fine cloth

[a] Not applicable to most portable filters; only reverse-osmosis membranes exclude viruses by virtue of pore size.

Filtration

Filtration is both a physical and a chemical process influenced by characteristics of filter media, water, and flow rate [20]. The primary determinant of a microorganism's susceptibility to filtration is its size (table 3). Electrochemical attraction may cause organisms, especially viruses, to adhere to the filter surface.

Filters are simple to operate and require no holding time. They add no unpleasant taste and may even improve the taste and appearance of water. They do add bulk and weight to baggage, however, and will eventually become clogged by suspended particulate matter, thus requiring cleaning or replacement. As a filter clogs, increasing pressure is required to drive the water through it; this increased pressure can force microorganisms through the filter.

Most of the portable filters sold for water treatment are depth filters that are made of various media—commonly, ceramic material, fiber, or compressed GAC—that create irregular labyrinthine passages to trap the organism. A depth filter has a large capacity for holding particles, so it lasts longer than a single-layer membrane filter does before it becomes clogged. Flow can be partially restored to a clogged filter by means of back-flushing or by surface cleaning (e.g., for ceramic filters), which removes the larger particles trapped near the surface. Most filters incorporate a prefilter on the intake tubing to remove large particles, thereby protecting the inner microfilter; if this is lacking, a fine mesh cloth or a coffee filter can be used.

Portable filters can readily remove protozoan cysts and bacteria [40], but they may not remove all viruses, which are an order of magnitude smaller than bacteria. Only the semipermeable membranes in reverse-osmosis filters are inherently capable of removing viruses. The First Need filter (General Ecology) was able to meet US Environmental Protection Agency (EPA) standards for water purifiers, including the standard that a purifier must be able to achieve a 4-log reduction in viruses [41]. In general, mechanical filters can reduce virus loads by 2–3 logs but should not be considered adequate for complete removal of viruses [42].

In pristine protected watersheds, where pollution caused by humans is minimal and for which the main concerns are bacteria and cysts, mechanical filtration alone can provide adequate disinfection. However, for water encountered during foreign travel and for surface water with heavy levels of fecal or sewage contamination, mechanical filters should not be used as the sole means of disinfection [43]. Additional treatment with heat or halogens before or after filtration guarantees effective virus removal.

Reverse-osmosis filtration uses high pressure (100–800 psi) to force water through a semipermeable membrane that filters out dissolved ions, molecules, and solids [5]. This process can both remove microbiologic contamination and desalinate water. Although small hand pump–operated reverse-osmosis units have been developed, their high price and slow output currently prohibit their use by land-based travelers. They are, however, important survival aids for ocean voyagers.

The US EPA does not endorse, test, or approve mechanical filters; it merely assigns registration numbers. Its registration requirements do, however, distinguish between 2 types of filters: those that use mechanical means only and those that use a chemical, which is designated as a pesticide [44]. Performance-based standards were developed as a framework for testing and evaluating water purifiers for US EPA registration [45]. Many companies now use the standards as their testing guidelines. Testing is either done or contracted by the manufacturer. Chal-

lenge water, for which temperatures, turbidity, and numbers of microorganisms have been specified, is pumped through the filter at given intervals within the claimed volume capacity. A 3-log reduction is required for cysts, a 4-log reduction for viruses, and a 5–6-log reduction for bacteria. To be called a "microbiologic water purifier," the unit must remove, kill, or inactivate all types of disease-causing microorganisms in the water, so as to render the processed water safe for drinking. An exception for limited claims may be allowed for units that remove specific organisms to serve a definable environmental need—for example, removal of *Giardia* species only.

Halogens

Worldwide, chemical disinfection with halogens—chiefly chlorine and iodine—is the most commonly used method for improving and maintaining the microbiologic quality of drinking water. The germicidal activity of halogens results from oxidation of essential cellular structures and enzymes [46]. The disinfection process is determined by characteristics of the disinfectant, the microorganism, and environmental factors [47]. "Halogen demand" is the amount of halogen reacting with impurities. "Residual halogen concentration" is the amount of active halogen remaining after the halogen demand of the water is met.

The primary factors that determine the rate and proportion of microorganisms killed are the halogen concentration and the exposure, or contact, time for the organisms; these factors are inversely related. Halogen concentration is measured either in milligrams per liter or its equivalent (i.e., parts per million). Contact time is usually measured in minutes but ranges from seconds to hours. In field-water disinfection, use of concentrations of 1–16 mg/L for 10–60 min is generally effective. Secondary factors are water temperature, pH, and organic contaminants. Halogen reacts with organic nitrogen compounds produced from the decomposition of organisms and their wastes to form compounds with little or no disinfecting ability, effectively decreasing the concentration of available halogen [48]. Although turbidity can be caused by nonreactive sand and silt, in general, halogen demand increases with increased turbidity [49]. For this reason, instructions for use of halogens in the field suggest doubling the dose of halogen for cloudy water; a longer contact time may not be effective. This crude means of compensation often results in a strong halogen taste on top of the taste of the contaminants. A more rational approach is to clarify water first to reduce the halogen demand. Even clear surface water often has a halogen demand of at least 1 mg/L, so it is prudent to use 4 mg/L as a target halogen concentration for clear water and to allow extra contact time for the uncertain halogen residual, especially if the water is cold (table 4). Lower concentrations (e.g., 2 ppm) can be used for additional treatment of tap water.

Cold slows reaction time. Some treatment protocols recommend doubling the dose of halogen in cold water, but, if time allows, exposure time can be increased instead (table 4). The pH of the water affects disinfection by determining the percentage concentration of each halogen compound. The optimal pH for halogen disinfection is 6.5–7.5 [50]. As water becomes more alkaline, approaching a pH of 8.0, much higher doses of halogens are required. Most surface water is neutral to slightly acidic, so compensating for pH is not necessary. Tablet formulations of halogen have the advantage of some buffering capacity.

The final variable is the target microorganism (table 5). Vegetative bacteria (non–spore-forming) are very susceptible to halogens; viruses have intermediate susceptibility, requiring higher concentrations or longer contact times. Protozoal cysts are more resistant than are enteric bacteria and enteric viruses, but they can be inactivated by doses of halogens used in the field [59, 60]. *Cryptosporidium* oocysts, however, are extremely resistant to halogens, and inactivation may not be practical with the common doses used in field-water disinfection [61]. Little is known about *Cyclospora* species, but they are assumed to be similar to *Cryptosporidium* species. Certain parasitic eggs, such as *Ascaris* eggs, are also resistant to halogens, but these are not commonly spread by water [62]. All of these resistant cysts and eggs are susceptible to heat or filtration. Relative resistance between organisms is similar for iodine and chlorine (table 5).

Halogens are inexpensive, readily available in several forms, and easily applicable to large or small quantities of water (table 6). Given adequate concentrations and contact times, both iodine and chlorine are effective disinfectants with similar biocidal activity under most conditions [63]. Of the halogens, iodine reacts least readily with organic compounds and is less affected by pH, indicating that low iodine residuals should be more stable and persistent than corresponding concentrations of chlorine. Taste preference is individual.

Objectionable taste and smell limit the acceptance of halogen use, but taste can be improved by several means. One method is to use the minimum necessary dose with a longer contact time. Several chemical techniques are available to reduce free iodine to iodide or chlorine to chloride, chemicals that have no color, smell, or taste. Because the chemical techniques also have no disinfection action, they should be used only after the required contact time. The best and most readily available agent is ascorbic acid (vitamin C), which is available in crystalline or powder form. A common ingredient of flavored drink mixes, it accounts for their effectiveness in covering up the taste of halogens [64]. Other safe and effective means of chemical reduction are sodium thiosulfate, hydrogen peroxide, and zinc-copper alloys (KDF resins) that act as catalysts to reduce free iodine and chlorine through an electrochemical reaction.

After the required contact time, passing water through GAC

Table 4. Recommended contact time for specified halogen concentration, according to water temperature.

Halogen concentration	Contact time, min		
	At 5°C	At 15°C	At 25°C
2 ppm	240	180	60
4 ppm	180	60	45
8 ppm	60	30	15

NOTE. Contact times are extended from the usual recommendations to account for (1) uncertainty about the presence of residual halogen and (2) the time required to kill *Giardia* cysts in very cold water.

will remove the taste of iodine and chlorine partially by adsorption and partially by chemical reduction. Finally, alternative techniques, such as filtration or heat, can be used in many situations.

Chlorine. Hypochlorite, the major chlorine disinfectant, is currently the preferred means of municipal water disinfection worldwide, so extensive data support its use [46]. Both calcium hypochlorite ($Ca[OCl]_2$) and sodium hypochlorite (NaOCl) readily dissociate in water.

Chlorine has no known toxicity when used for water disinfection. Sodium hypochlorite is not carcinogenic; however, reactions of chlorine with certain organic contaminants yield chlorinated hydrocarbons, chloroform, and other trihalomethanes, which are considered carcinogenic [5, 23]. Nevertheless, if disinfection is not used, the risk of death due to infectious diseases is far greater than any risk associated with the by-products of chlorine disinfection.

Iodine. In low concentrations, iodine is effective for killing bacteria, viruses, and cysts, and, in higher concentrations, it is effective against fungi and even bacterial spores; however, it is a poor algicide [64–68]. Elemental (diatomic) iodine (I_2) and hypoiodous acid (HOI) are the major germicides in an aqueous solution. The main issues associated with iodine are its physiologic activity, potential toxicity, and allergenicity [69]. Currently available data reviewed by Backer and Hollowell [70] suggest the following guidelines as appropriate:

1. Use of high levels of iodine (16–32 mg/day), such as those produced by recommended doses of iodine tablets, should be limited to short periods (≤1 month).
2. Iodine treatment that produces a low residual concentration of ≤1–2 mg/L appears to be safe, even when given for long periods to individuals with healthy thyroids.
3. Anyone planning to use iodine for prolonged periods should have their thyroid examined and should have thyroid function tests performed to ensure that they are initially euthyroid. Consider repeating the tests in 6–12 months.

Certain persons should not use iodine for water treatment because of their increased susceptibility to thyroid problems.

Table 5. Halogen disinfection data from 11 studies.

Halogen type, organism	Concentration, mg/L[a]	Time, min	Temperature, °C	Disinfection constant, Ct	Reference
Chlorine					
Escherichia coli	0.1	0.16	5	0.016	[46]
Campylobacter species	0.3	0.5	25	0.15	[51]
20 enteric viruses	0.5	60	2	30	[52]
Hepatitis A virus	0.5	5	5	2.5[b]	[53]
Entamoeba histolytica cysts	3.5	10	25	35	[54]
Giardia cyst	2.5	60	5	150	[55]
Cryptosporidium oocyst	10	720	20	1440	[56]
Schistosome cercariae	1.0	30	28	30	[57]
Iodine					
E. coli	1.3	1	2–5	1.3	[23]
E. histolytica cyst	3.5	10	25	35	[54]
	6.0	5	25	30	[54]
Poliovirus 1	1.25	39	25	49	[58]
Coxsackie virus	0.5	30	5	15	[58]
Giardia cyst	4	15	30	60[c]	[59]
	4	120	5	480[c]	[59]

NOTE. Most experiments use a 2–3-log (99%–99.9%) reduction as the end point.

[a] Residual concentration of active chlorine disinfectant compounds.

[b] End point of 4-log reduction.

[c] A 100% rate of killing organisms; viability tested only at 15, 30, 45, 60, and 120 min.

Table 6. Dose of halogen for field-water disinfection.

Method of disinfection	Amount of halogen administered (no. of drops[a])			
	For 4 ppm	For 5 ppm	For 8 ppm	For 10 ppm
Iodination added to 1 L or qt of water				
Iodine tablets (tetraglycine hydroperiodide; e.g., EDWGT, Potable Aqua, and Globaline)[b]	1/2 tablet	—	1 tablet	—
2% Iodine solution (tincture)	0.2 mL (5)	—	0.4 mL (10)	—
10% Povidone-iodine solution	0.35 mL (8)	—	0.70 mL (16)	—
Saturated solution (iodine crystals in water; e.g., Polar Pure[c])	13 mL	—	26 mL	—
Chlorination added to 1 L or 1 qt of water				
Household bleach 5%; sodium hypochlorite	—	0.1 mL (2)	—	0.2 mL (4)
Chlorine tablets (sodium dichloroisocyanurate [e.g., AquaClear[d]])	—	—	—	1 tablet
Chlorine plus flocculating agent (e.g., AquaCure, AquaPure, or Chlor-Floc[e])	—	—	1 tablet	—

NOTE. EDWGT, emergency drinking water germicidal tablet.

[a] Measured with a dropper (1 drop = 0.05 mL) or a small syringe.
[b] Manufactured by Coghlan's Ltd., Wisconsin Pharmacal, and Van Ben Industries, respectively.
[c] Manufactured by Polar Equipment.
[d] Manufactured by Gal Pharmaceuticals.
[e] Manufactured by Safesport, World Resources, and Control Chemical, respectively.

These include pregnant women; individuals with known hypersensitivity to iodine; those with a history of thyroid disease, even if it is controlled by medication; persons with a family history of thyroid disease (thyroiditis); and those who are from countries whose inhabitants have chronic iodine deficiency.

Iodine resins. Iodine resins are considered demand disinfectants because they are insoluble in water, with little iodine released into aqueous solution. As water passes through and microorganisms contact the resin, iodine binds to microorganisms, apparently aided by electrostatic forces [71]. Bacteria and cysts are effectively exposed to high iodine concentrations, which allow for reduced contact time compared with that of dilute iodine solutions; however, some contact time is necessary, especially for cysts [72]. Resins have proved effective against bacteria, viruses, and cysts, but they have not proved effective against *Cryptosporidium parvum* oocysts or bacterial spores [71].

The concept of demand disinfectants has great potential for water disinfection in small or individual systems. Small, portable filters that contain iodine resin have been designed for field use. Most incorporate a 1-μm cyst filter to remove *Cryptosporidium* species, *Giardia* species, and other halogen-resistant parasitic eggs or larvae, in an attempt to avoid prolonged contact time. Carbon that removes residual dissolved iodine prevents excessive iodine ingestion in long-term users but may not allow sufficient contact time for cyst destruction [73]. Cloudy or sediment-laden water may clog the resin, as it would with any filter, or it may coat the resin, inhibiting iodine transfer.

The effectiveness of the resin is highly dependent on the product design and function, and more testing of specific products is needed. Two companies recently pulled iodine resins from the market because repeated testing demonstrated virus breakthrough, despite the fact that they passed the US EPA protocol in initial premarketing tests. The companies were not able to determine whether the failure was caused by channeling of water that allowed organisms to avoid contact with the resin, a lack of residual iodine concentration in effluent water, or the need for more contact time.

Miscellaneous Disinfectants

Ozone and chlorine dioxide. Ozone and chlorine dioxide are both highly effective disinfectants that are widely used in municipal water-treatment plants, but, until recently, they have not been available in a stable form for use in the field [46]. These are the only disinfectants that have been demonstrated to be effective against *Cryptosporidium* species in commonly used concentrations [74].

A stabilized solution of chlorine dioxide has been developed and marketed under the names Aquamira (McNett Outdoor) and Pristine (Advanced Chemicals). US EPA registration for its use as a "water purifier" is pending; however, these products are approved for sale in the United States, their safety and bactericidal activity having been proven. A process has been developed that uses an electrochemical process to convert simple salt into a mixed-oxidant disinfectant that contains free chlorine, chlorine dioxide, and ozone [75]. The size of the device (manufactured by Miox) has been reduced to that of a cigar, and the unit is powered by camera batteries.

Silver ion. Silver ion has bactericidal effects when given in low doses, and it has some attractive features, including absence of color, taste, and odor. However, concentrations of silver ion are strongly affected by adsorption onto the surface

Table 7. Summary of field-water disinfection techniques.

Technique	Bacteria	Viruses	*Giardia* species or amebic cysts	*Cryptosporidium* species
Heat	+	+	+	+
Filtration	+	+/−[a]	+	+
Halogens	+	+	+	−

[a] Manufacturers of most filters make no claims with regard to viruses. General Ecology claims virus removal by use of its First Need filter. Reverse-osmosis filtration can remove viruses. +, susceptible; −, not susceptible; +/−, inconsistent.

of any container as well as by common substances in water, and the scant data on its use for disinfection of viruses and cysts indicate a limited effect, even when used at high doses [23]. The use of silver as a drinking-water disinfectant is much more popular in Europe, where silver tablets (MicroPur; Katadyn Products) are sold widely for field-water disinfection. The US EPA has not approved silver tablets for this purpose in the United States, but they were approved as a water preservative to prevent bacterial growth in previously treated and stored water.

Ultraviolet (UV) radiation. UV radiation is widely used to sterilize water used in beverages and food products and for secondary treatment of wastewater. It has not been well adapted to field-water treatment because of requirements for power. To kill, the UV waves must actually strike the organism in sufficient doses of energy. The water must be free of any particles that would act as a shield. The UV rays do not alter the water, but they also do not provide any residual disinfecting power. Recently, a portable battery-operated unit (Hydro-Photon) was marketed for small-quantity disinfection. Although previous data have suggested a limited ability of monochromatic rays to inactivate protozoan cysts, company product testing shows their effectiveness against important waterborne pathogens, including *Cryptosporidium* species.

Preferred Technique

The optimal water-treatment technique to be used by an individual or group will depend on the number of people to be served, the space and weight accommodations, the quality of the source water, personal taste preferences, and fuel availability. Because halogens do not kill *Cryptosporidium* species, and because filtration misses some viruses (table 7), optimal protection for all situations may require a 2-step process of either filtration or coagulation-flocculation, followed by halogenation. Heat is effective as a 1-step process in all situations, but it will not improve the aesthetics of the water. The iodine resins, combined with microfiltration to remove resistant cysts, are also a viable single-step process, but questions have surfaced regarding product effectiveness under all conditions (table 8). New techniques that use chlorine dioxide, ozone, and UV radiation may prove to be effective 1-step techniques.

When water is to be stored for a period of time—for example, when it is to be stored on a boat or in a motor home or when a home has rainwater collection—halogens should be used to prevent the water from becoming contaminated. This technique can be supplemented by filtration either before or after storage. A minimum residual concentration of 3–5 mg/L should be maintained in the water. Because it is a poor algacide, iodine will work for short periods but not for prolonged storage. Silver

Table 8. Choice of filtration method for types of water from various sources.

Primary concern and filtration method used	"Pristine" water in the wilderness	Tap water in developing country	Water in a developed or developing country	
			Clear surface[a]	Cloudy
Primary concern				
Giardia species, enteric bacteria	X	—	—	—
Bacteria, *Giardia* species, small numbers of viruses	—	X	—	—
All enteric pathogens, including *Cryptosporidium* species	—	—	X	—
Unpleasant taste plus microorganisms	—	—	—	X
Method used				
Heat	X	X	X	—
Filtration[b]	X	X	—	—
Halogen	X	X	—	—
Coagulation-flocculation followed by a second step (heat, filtration, or halogen)	—	—	—	X
Filtration plus halogen[c] (done in either order)	—	—	X	—

[a] Found near areas of human and animal habitation; includes agricultural runoff (from cattle grazing) or sewage treatment effluent (from upstream villages or towns).
[b] Filtration alone is adequate for eliminating *Cryptosporidium* species introduced by cattle grazing in high-quality wilderness.
[c] May include iodine resin filters (for considerations, see the "Iodine resins" subsection of the "Halogens" section of the text).

(MicroPur; Katadyn Products) has also been approved by the US EPA for this purpose. For prolonged storage, use of a tightly sealed container is best to decrease the risk of contamination. Narrow-mouthed jars or containers with water spigots prevent contamination from occurring as a result of repeated contact with hands or utensils [76]. Water stored on oceangoing boats traveling a long distance must be desalinated as well as disinfected during the voyage, and only reverse-osmosis membrane filters are adequate to achieve this.

SANITATION

As demonstrated among local communities in developing countries, both good sanitation and potable water are necessary for the prevention of enteric illness [1, 77, 78]. Personal hygiene—in particular, hand washing—prevents the spread of infection that results from contamination of food during meal preparation [76]. Dishes and utensils should be disinfected by rinsing them in water to which enough household bleach has been added to achieve a distinct chlorine odor. The sanitation challenge for wilderness and rural travelers is proper disposal of waste to prevent contamination of water supplies. Human waste should be buried 8–12 in deep (~20–30.5 cm), at least 100 ft (30 m) from any water [19, 79], and at a location from which water runoff is not likely to wash organisms into nearby water sources. Groups with $\geqslant$3 individuals should dig a common latrine to avoid numerous individual potholes and inadequate disposal.

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