# Water Disinfection

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## RISK FOR TRAVELERS

Waterborne disease is a risk for international travelers who visit countries that have poor hygiene and inadequate sanitation, and for wilderness visitors who rely on surface water in any country, including the United States. The list of potential waterborne pathogens is extensive and includes bacteria, viruses, protozoa, and parasitic helminths. Most of the organisms that can cause travelers' diarrhea can be waterborne. Many types of bacteria and viruses can cause intestinal (enteric) infection through drinking water. Protozoa that are commonly waterborne include *Cryptosporidium*, *Giardia*, and *Entameba histolytica* (the cause of amebic dysentery). Parasitic worms are not commonly transmitted through drinking water, but it is a potential means of transmission for some.

Where treated tap water is available, aging or inadequate water treatment infrastructure may not effectively disinfect water or maintain water quality during distribution. Some larger hotels and resorts may provide additional onsite water treatment to provide potable water. Travelers can ask the facility manager about safety of their water; however, if there is concern, it may be easiest for travelers to treat the water themselves. Where untreated surface or well water is used and there is no sanitation infrastructure, the risk of waterborne infection is high.

Bottled water has become the convenient solution for most travelers, but in some places it may not be superior to tap water. Moreover, the plastic bottles create an ecological problem, since most developing countries do not recycle plastic bottles. All international travelers, especially long-term travelers or expatriates, should become familiar with and use simple methods to ensure safe drinking water. Several methods are scalable and some can be improvised from local resources, allowing adaptation to disaster relief and refugee situations. Table 2-07 compares benefits and limitations of different methods. Additional information on water treatment and disinfections methods can be found at www.cdc.gov/healthywater/drinking/travel (http://www.cdc.gov/healthywater/drinking/travel).

## FIELD TECHNIQUES FOR WATER TREATMENT

### Heat

Common intestinal pathogens are readily inactivated by heat. Microorganisms are killed in a shorter time at higher temperatures, whereas temperatures as low as 140°F (60°C) are effective with a longer contact time. Pasteurization uses this principle to kill foodborne enteric pathogens and spoilage-causing organisms at temperatures between 140°F (60°C) and 158°F (70°C), well below the boiling point of water (212°F [100°C]).

Although boiling is not necessary to kill common intestinal pathogens, it is the only easily recognizable end point that does not require a thermometer. All organisms except bacterial spores, which are rarely waterborne enteric pathogens, are killed in seconds at boiling temperature. In addition, the time required to heat the water from 60°C to boiling works toward heat disinfection. Any water that is brought to a boil should be adequately disinfected; however, if fuel supplies are adequate, travelers should consider boiling for 1 minute to allow for a margin of safety. Although the boiling point decreases with altitude, at common terrestrial travel elevations it is still well above the temperature required to inactivate enteric pathogens (for example, at 16,000 ft [4,877 m] the boiling temperature of water is 182°F [84°C]). In hot climates with sunshine, a water container placed in a simple reflective solar oven can reach pasteurization temperature of 65°C. Travelers with access to electricity can bring a small electric heating coil or a lightweight beverage warmer to boil water.

## Filtration and Clarification

Portable hand-pump or gravity-drip filters with various designs and types of filter media are commercially available to international travelers. Filter pore size is the primary determinant of a filter's effectiveness, unless the filter is designed to remove microbes by electrochemical attachment to filter media. Filter pore size will be described as being "absolute" or "nominal": absolute pore size filters will remove all microbes of the identified pore size or larger, whereas nominal pore size filters allow 20%–30% of particles or microorganisms of the pore size to pass through. Progressively smaller pore size filters require higher pressure to push water through the filter, often at a slower rate and higher cost. Filters that claim Environmental Protection Agency (EPA) designation of water "purifier" undergo company-sponsored testing to demonstrate removal of at least 106 bacteria (99.9999%), 104 viruses (99.99%), and 103 *Cryptosporidium* oocysts or *Giardia* cysts (99.9%). (EPA does not independently test the validity of these claims.)

Filters with absolute pore size of 1 µm or smaller should effectively remove protozoan parasites like *Cryptosporidium* and *Giardia*. Microfilters with "absolute" pore sizes of 0.1–0.4 µm are usually effective at removing bacteria as well as cysts but may not adequately remove enteric viruses, like norovirus (Table 2-08). Water in remote alpine areas with little human and animal activity generally has little contamination with enteric pathogens, so microfilters with ceramic, synthetic fiber, compressed carbon, or large-pore hollow-fiber filter elements are sufficient to remove bacteria and protozoan cysts, the primary pathogens.

For areas with high levels of human and animal activity in the watershed or developing areas with poor sanitation, higher levels of filtration discussed below or other techniques to remove viruses are preferred. If using a microfilter, one option to remove viruses is pretreatment with chlorine. Progressively finer levels of filtration known as ultrafiltration, nanofiltration, and reverse osmosis can remove particles of 0.01, 0.001, and 0.0001 µm, respectively. All of these filters can remove viruses. Portable ultrafilters are the most commonly available "purifying" filters and may operate by gravity, hand-pump, or drink-through. Ultrafilter-based filters will have a rated pore size of 0.01 µm, and should be effective for removing viruses, bacteria, and parasites. All are effective, although drink-through is least practical because of the negative pressure required to draw water through the filter.

Nanofilters will have rated pore sizes of 0.001 µm and thus will remove chemicals and organic molecules. Reverse osmosis filters (having pore sizes of 0.0001 µm [0.1 nm] and smaller) will remove monovalent salts and dissolved metals, thus achieving desalination. The high price and slow output of small hand-pump reverse osmosis units prohibit use by land-based travelers; however, they are survival aids for ocean voyagers, and larger powered devices are used for military and refugee situations.

In resource-limited international settings, filters may be used in the communities and households that are made from ceramic clay or simple sand and gravel (slow sand or biosand). Gravel and sand filters can be improvised in remote or austere situations when no other means of disinfection is available.

Water can be clarified by using chemical products that coagulate and flocculate (clump together) suspended particles that cause a cloudy appearance and bad taste and do not settle by gravity. This process removes many but not all microorganisms, unless the product also contains a disinfectant. Alum, an aluminum salt that is widely used in food, cosmetic, and medical applications, is the principal agent for coagulation/flocculation, but many other natural substances are used throughout the world. When using alum, a one-fourth teaspoon of alum powder can be added to a quart of cloudy water and the water stirred frequently for a few minutes. The process can be repeated, if necessary, until clumps form. The clumped material is allowed to settle, and then the water is poured through a coffee filter or clean, fine cloth to remove the sediment. Most microbes are removed, but not all, so a second disinfection step is necessary. Tablets or packets of powder that combine flocculant and a chemical disinfectant are available commercially (for example, Chlor-floc and P&G Purifier of Water).

Granular-activated carbon (GAC) treats water by adsorbing organic and inorganic chemicals (including chlorine or iodine compounds) and most heavy metals, thereby improving odor, taste, and safety. GAC is a common component of household and field filters. It may trap microorganisms, but GAC filters are generally not designed or rated for microbe removal and do not kill microorganisms.

## Chemical Disinfection

### LIQUID AND TABLET PRODUCTS

Chemical disinfectants for drinking water treatment, including chlorine compounds, iodine, and chlorine dioxide, are commonly available as commercial products. Sodium hypochlorite, the active ingredient in common household bleach, is the primary disinfectant promoted by CDC and the World Health Organization. Other chlorine-containing compounds such as calcium hypochlorite and sodium dichloroisocyanurate, available in granular or tablet formulation, are equally effective for water treatment. An advantage of chemical water disinfection products is flexible dosing that allows use by individual travelers, small or large groups, or communities. In emergency situations, or when other commercial chemical disinfection water treatment products are not available, household bleach can be used for flexible dosing based on water volume and clarity. Refer to CDC guidelines at www.cdc.gov/healthywater/emergency/drinking/making-water-safe.html (http://www.cdc.gov/healthywater/emergency/drinking/making-water-safe.html).

Given adequate concentrations and length of exposure (contact time), chlorine and iodine have similar activity and are effective against bacteria and viruses (www.cdc.gov/safewater/effectiveness-on-pathogens.html (http://www.cdc.gov/safewater/effectiveness-on-pathogens.html)). *Giardia* cysts are more resistant to chemical disinfection; however, field-level concentrations are effective with longer contact times. For this reason, dosing and concentrations of chemical disinfection products are generally targeted to the cysts. Some common waterborne parasites, such as *Cryptosporidium* and possibly *Cyclospora*, are poorly inactivated by chlorine- and iodine-based disinfection at practical concentrations, even with extended contact times.

Chemical disinfection may be supplemented with filtration to remove resistant oocysts from drinking water. Cloudy water contains substances that will neutralize disinfectant, so it will require higher concentrations or contact times or, preferably, clarification through settling, coagulation/flocculation, or filtration before disinfectant is added.

Because iodine has physiologic activity, WHO recommends limiting iodine water disinfection to a few weeks. Iodine use is not recommended for people with unstable thyroid disease or known iodine allergy. In addition, pregnant women should not use iodine to disinfect water over the long term because of the potential effect on the fetal thyroid. Pregnant travelers who have other options should use an alternative means such as heat, chlorine, or filtration.

Some prefer the taste of iodine to chlorine, but neither is appealing in doses often recommended for field use. The taste of halogens in water can be improved by running water through a filter containing activated carbon or adding a 25-mg tablet of vitamin C, a tiny pinch of powdered ascorbic acid, or a small amount of hydrogen peroxide (5–10 drops of 3% peroxide per quart), then stir or shake. Repeat until taste of chlorine or iodine is gone.

#### CHLORINE DIOXIDE

Chlorine dioxide (ClO2) can kill most waterborne pathogens, including *Cryptosporidium* oocysts, at practical doses and contact times. Tablets and liquid formulations are commercially available to generate chlorine dioxide in the field for personal use.

#### SALT (SODIUM CHLORIDE) ELECTROLYSIS

Electrolytic water purifiers generate a mixture of oxidants, including hypochlorite, by passing an electrical current through a simple brine salt solution. Purifier products sold for personal and group travel use produce an oxidant solution that can be added to water to kill microorganisms. This technique has been engineered into portable, battery-powered products that are commercially available.

### Ultraviolet (UV) Light

UV light kills bacteria, viruses, and *Cryptosporidium* oocysts in water. The effect depends on UV dose and exposure time. Portable battery-operated units that deliver a metered, timed dose of UV are an effective way to disinfect small quantities of clear water in the field. Larger units with higher output are available where a power source is available. These units have limited effectiveness in water with high levels of suspended solids and turbidity, because suspended particles can shield microorganisms from UV light.

### Solar Irradiation and Heating

UV irradiation of water using sunlight (solar disinfection or SODIS) can improve the microbiologic quality of water and may be used in austere emergency situations. Solar disinfection is not effective on turbid water. If the headlines in a newspaper cannot be read through the bottle of water, then the water must be clarified before solar irradiation is used. Under cloudy weather conditions, water must be placed in the sun for 2 consecutive days. (See www.sodis.ch/index_EN (http://www.sodis.ch/index_EN) for further information.)

### Silver and Other Products

Silver ion has bactericidal effects in low doses, and some attractive features include lack of color, taste, and odor, and the ability of a thin coating on the container to maintain a steady, low concentration in water. Silver is widely used by European travelers as a primary drinking water disinfectant. In the United States, silver is approved only for maintaining microbiologic quality of stored water because its concentration can be strongly affected by adsorption onto the surface of the container, and there has been limited testing on viruses and cysts. Silver is available alone or in combination with chlorine in tablet formulation.

Several other common products, including hydrogen peroxide, citrus juice, and potassium permanganate, have antibacterial effects in water and are marketed in commercial products for travelers. None have sufficient data to recommend them for primary water disinfection at low doses in the field.

### Photocatalytic Disinfection

Advanced oxidation processes use UV light or natural sunlight to catalyze the production of potent disinfectants for microorganisms and can break down complex organic contaminants and even most heavy metals into nontoxic forms. Titanium dioxide ($TiO_2$) is the most effective substance, but other metal oxides, chitins, and nanoparticles also have oxidative potential. A $TiO_2$-impregnated membrane incorporated into a portable bag is available commercially.

## Table 2-07. Comparison of water disinfection techniques

| TECHNIQUE | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| Heat | • Does not impart additional taste or color<br>• Single step that inactivates all enteric pathogens<br>• Efficacy is not compromised by contaminants or particles in the water as for chemical disinfection and filtration | • Does not improve taste, smell, or appearance of source water<br>• Fuel sources may be scarce, expensive, or unavailable<br>• Does not prevent recontamination during storage |
| Filtration | • Simple to operate<br>• Requires no holding time for treatment<br>• Large choice of commercial product designs<br>• Adds no unpleasant taste and often improves taste and appearance of water<br>• Can be combined with chemical disinfection to increase microbe removal | • Adds bulk and weight to baggage<br>• Many filters do not reliably remove viruses<br>• More expensive than chemical treatment<br>• Eventually clogs from suspended particulate matter and may require some field maintenance or repair<br>• Does not prevent recontamination during storage |
| Chlorine, iodine, electrolytic solutions | • Inexpensive and widely available in liquid or tablet form<br>• Taste can be removed by simple techniques<br>• Flexible dosing<br>• Equally easy to treat large and small volumes<br>• Will preserve microbiologic quality of stored water | • Impart taste and odor to water<br>• Flexible dosing requires understanding of principles<br>• Iodine is physiologically active, with potential adverse effects<br>• Not readily effective against *Cryptosporidium* oocysts<br>• Efficacy decreases with cloudy water<br>• Corrosive and stains clothing |

| TECHNIQUE | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| Chlorine dioxide | • Low doses have no taste or color<br>• Simple to use and available in liquid or tablet form<br>• More potent than equivalent doses of chlorine<br>• Effective against all waterborne pathogens, including *Cryptosporidium* | • Volatile and sensitive to sunlight: do not expose tablets to air, and use generated solutions rapidly<br>• No persistent residual concentration, so does not prevent recontamination during storage |
| Ultraviolet (UV) | • Imparts no taste<br>• Portable battery-operated devices now available<br>• Effective against all waterborne pathogens<br>• Extra doses of UV can be used for added assurance and with no side effects | • Requires clear water<br>• Does not improve taste or appearance of water<br>• Relatively expensive (except solar disinfection [SODIS])<br>• Requires batteries or power source (except SODIS)<br>• Cannot know if devices are delivering required UV doses<br>• No persistent residual concentration, so does not prevent recontamination during storage |

## Table 2-08. Microorganism size and susceptibility to filtration

| ORGANISM | AVERAGE SIZE (µm) | MAXIMUM RECOMMENDED FILTER RATING (µm ABSOLUTE) |
|---|---|---|
| Viruses | 0.03 | Not specified (optimally 0.01, ultrafiltration) |
| Enteric bacteria (*Escherichia coli*) | 0.5 ×2–8 | 0.2–0.4 (microfiltration) |
| *Cryptosporidium* oocyst | 4–6 | 1 (microfiltration) |
| *Giardia* cyst | 8 × 19 | 3.0–5.0 (microfiltration) |
| Helminth eggs | 30 × 60 | Not specified; any microfilter |
| Schistosome larvae | 50 × 100 | Not specified; any microfilter |

## CHOOSING A DISINFECTION TECHNIQUE

Table 2-09 summarizes advantages and disadvantages of field water disinfection techniques and their microbicidal efficacy. It is advisable to test a method before travel.

## Table 2-09. Summary of field water disinfection techniques

| | BACTERIA | VIRUSES | PROTOZOAN CYSTS (*GIARDIA*/ AMEBAS) | CRYPTOSPORIDIA | HELMINTHS/ SCHISTOSOMES |
|---|---|---|---|---|---|
| Heat | + | + | + | + | + |
| Filtration | + | +/-[1] | + | + | + |
| Halogens | + | + | +[2] | - | +/-[3] |
| Chlorine dioxide | + | + | + | + | + |

[1] Most filters make no claims for viruses. Hollow-fiber filters with ultrafiltration pore size and reverse osmosis are effective.

[2] Require higher concentrations and contact time than for bacteria or viruses.

[3] Eggs are not very susceptible to halogens, but risk of waterborne transmission is very low.

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Chapter 2 - Food & Water Precautions

Chapter 2 - Food Poisoning from Marine Toxins



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