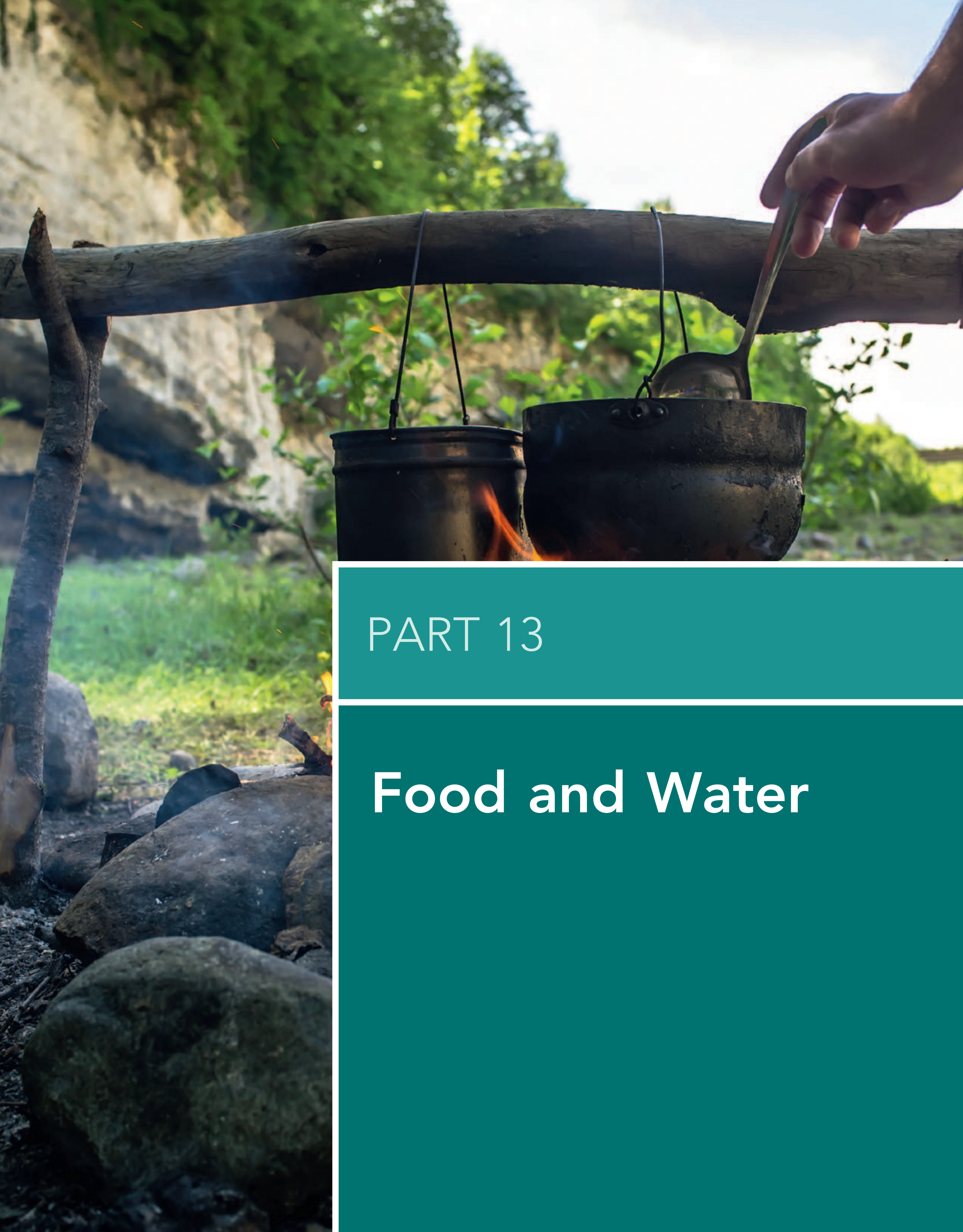

PART 13

Food and Water

CHAPTER 87

Nutrition, Malnutrition, and Starvation

STACIE L. WING-GAIA AND E. WAYNE ASKEW

How does it feel to starve?

> *I am hungry. I am always hungry. … At times I can almost forget about it but there is nothing that can hold my interest for long. … I am cold. … My body flame is burning as low as possible to conserve precious fuel and still maintain my life processes. … I am weak. I can walk miles at my own pace in order to satisfy laboratory requirements, but often I trip on cracks in the sidewalk. To open a heavy door, it is necessary to brace myself and push or pull with all my might. I wouldn't think of throwing a baseball and I couldn't jump over a twelve inch railing if I tried. This lack of strength is a great frustration. It is often a greater frustration than the hunger … and now I have edema. When I wake up in the morning my face is puffy. … Sometimes my ankles swell and my knees are puffy. … Social graces, interests, spontaneous activity and responsibility take second place to concerns about food. … I lick my plate unashamedly at each meal even when guests are present. … I can talk intellectually, my mental ability has not decreased, but my will to use my ability has.*
>
> Observations by a test participant, Minnesota Starvation Study, After 24 weeks of semistarvation (1570 kcal/day, 24% weight loss) (In *The Biology of Human Starvation*, vol. II)[75]

IMPORTANCE OF NUTRITION IN STRESSFUL ENVIRONMENTS

Nutrition has a profound underlying importance to human physiologic homeostasis and functioning in everyday life; it becomes even more important when humans work or recreate in particularly challenging or "extreme" environments.[10] The central role of nutrition is often underappreciated in wilderness expedition planning. Many wilderness enthusiasts do not consider food as critical as gear and equipment, medical supplies, physical fitness, and other logistical considerations. In temperate environments, where food and water are plentiful and resupply is feasible, the importance of nutrition may seem to diminish compared with other aspects of wilderness medicine. However, when a stressful physical environment is superimposed on the physically demanding tasks associated with wilderness activities, the role of nutrition rapidly becomes of prime importance for maintenance of performance and prevention of disease and injury, as evidenced from the description of Napoleon's disastrous 1812 winter retreat from Moscow:

> *The ice and deep snow with which the plains of Russia were covered, impeded … calorification in the capillaries and pulmonary organs. The snow and cold water, which the soldiers swallowed for the purpose of allaying their hunger or satisfying their thirst … contributed greatly to the destruction of these individuals by absorbing the small portion of heat remaining in the viscera. The agents produced the death of those particularly who had been deprived of nutriment.*
>
> Baron D. J. Larrey, inspector general, Napoleon's military medical staff (In *Hypothermia and Warfare: Napoleon's Retreat from Moscow, 1812*)[113]

Fortunately, situations encountered in wilderness activities are usually less "grim" than those faced by Napoleon's army. There is usually some food available, and few enter these environments completely unprepared. However, misfortune, combined with suboptimal or haphazard nutritional planning, can spell disaster for even the best-prepared adventurer. A wrong turn on the trail, injury, unanticipated terrain, unexpected storm, or downed airplane can deplete or isolate a victim from anticipated food sources. Food becomes an overriding consideration in a survival situation, particularly as the supply is exhausted. Although a shortage of food is certainly of concern, it does not necessarily imply impending disaster. Humans are remarkably adaptable and can subsist on poor dietary patterns for prolonged periods without disastrous effects on health and performance. As long as some baseline level of energy intake is present, at least a minimal intake of vitamins and minerals will be ensured, forestalling the eventual onset of malnutrition and clinical nutrient deficiency states. Hunger is not comfortable; optimism wanes, weight loss results, and physical and cognitive performances suffer, but a food-deprived individual can still function for an extended time. One purpose of this chapter is to review some of the physical and mental consequences of suboptimal nutrition that might be anticipated under varying degrees of food restriction. The medical planner can use this information to anticipate limitations in expedition progress or capabilities and to recognize the state of health of rescued victims of starvation or food restriction. Equally important is the proper way to re-aliment a patient after a prolonged period of unintentional starvation. This can be critically important in a rescue situation, where transport of a patient to a medical facility requires several days of refeeding en route.

Although the goal of expedition food planning is to meet daily energy and micronutrient requirements, it is not always possible to provide optimal nutrition because of logistic or situational constraints. Three nutritional states or situations may be anticipated or encountered in the wilderness: (1) ideally, optimal nutrition for effective functioning in environmental extremes; (2) frequently, suboptimal nutrition, potentially leading to malnutrition; and (3) in some instances, complete lack of nutrition or starvation. Dietary planning for wilderness expeditions and emergencies is discussed in the following sections, along with some specific food and nutrient items that may be particularly useful in wilderness environments and expeditions.

ENVIRONMENTAL STRESS AND NUTRIENT REQUIREMENTS

The physical and physiologic conditions of an individual (e.g., body weight, strength, coordination, fluid and electrolyte balance, core temperature) play a significant role in determining nutritional requirements to maintain physiologic homeostasis. These conditions also directly influence survival time, especially when humans are deprived of food or water. The most important nutrient is water.[9] If an adequate supply of water is not available, all discourse on the physiology of starvation and malnutrition is pointless, because death from dehydration will occur before depletion of energy stores. Humans can survive food deprivation for extended periods—weeks or even months—depending on their level of body fat. A nonobese adult may live as long as 60 to 70 days while fasting in a clinical setting.[66] At the end of this time, almost all body fat and one-third of lean body mass would

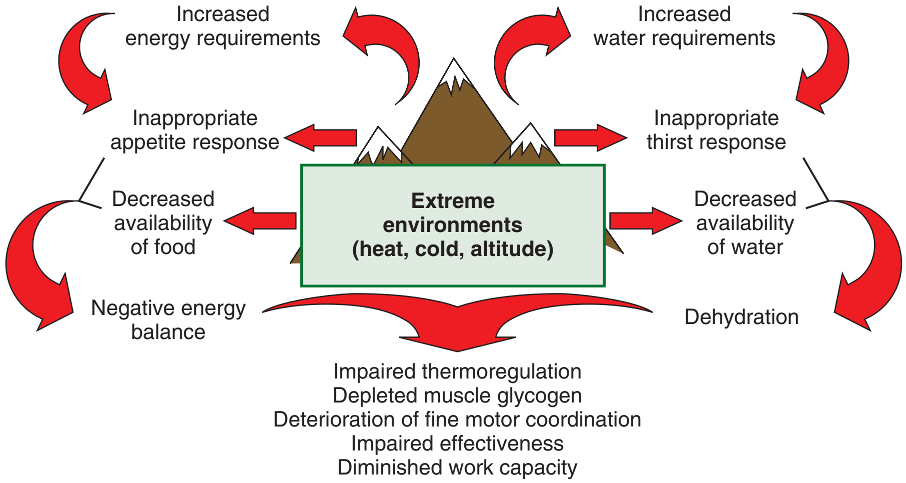

FIGURE 87-1 The influence of extreme wilderness environments on food and fluid intake and on physical and mental performance. *(Redrawn from Askew EW: In Hickson JF Jr, Wolinski I, editors:* Nutrition in exercise and sport, *Boca Raton, Fla, 1989, CRC Press, pp 367-384.)*

be lost.[65] James Scott, a victim of unintentional situational starvation, was marooned in a snow cave in the Himalayas with water but no food. He survived 43 days without food while losing one-third of his body weight, although he was near death at the time of rescue.[129] Death from starvation in nonobese individuals is imminent when approximately 50% of body weight has been lost. This usually corresponds to a body mass index (BMI) of 12 kg/m^2, although under some circumstances, a BMI of as low as 11 may be encountered before death.[37]

Unlike food deprivation, time to death after complete water deprivation is measured in days; estimates range from 6 to 14 days, depending on the rate of body water loss, which is influenced by environmental temperature, humidity, and activity level.[65] Water is critical because more so than any other nutrient, water is responsible for maintaining homeostasis of the internal environment.[9] It provides an aqueous medium to transport heat from cells to blood, to solvate and pass nutrients between blood and cells, to serve as a medium for intracellular reactions, and to transfer metabolic products for redistribution or excretion via urine. Both the quantity of reactants and the volume of fluid in which they are dissolved influence cellular chemical reaction rates; thus, imbalances in hydration status can alter cellular and tissue function, such as the body's ability to regulate temperature. Muscle contraction depends on transformation of chemical energy (ATP) to mechanical energy. Almost three-fourths of the energy used for muscle contraction is released as heat. Unless localized heat production from metabolism and muscle contraction is dissipated, the heat burden can be structurally damaging to enzymes or other proteins. Water absorbs heat produced at the cellular level and transfers it to the surface of the skin, where it can be dissipated to the external environment. Moreover, hypohydration can impair neuromuscular control, which is associated with increased risk of injury during demanding physical tasks in an extreme environment.[42] The importance of water is discussed in greater detail in Chapter 89. The focus of this discussion is energy restriction and assumes an adequate supply of water. For planning purposes, most wilderness expeditions require 3 to 5 L (about 3 to 5 qt) of potable water per person per day.

The environment has a primary role in determining survival under food and fluid restriction circumstances. Advances in food processing, preservation, and nutrient fortification have resulted in development of modern camping foods and the military equivalent, field rations, that can support health and performance in a variety of temperate environments, even if they are not consumed to complete caloric adequacy.[91] However, nutrition that was marginally adequate in a temperate environment may rapidly become inadequate in wilderness environments characterized by extreme temperatures, terrain, and physical demands.[90,92] Rodahl and Issekutz[124] observed, "While short-term nutritional deficiencies in men at room temperature appear to have little or no detrimental effect on the capacity to do short-term, heavy work, there is a marked reduction in physical work capacity when a nutritional deficiency or nutritional stress is superimposed on a cold stress." Superimposed stressors, such as extreme heat, cold, altitude, sleep deprivation, physical exertion, and food restriction, influence nutrient requirements[7] and can jeopardize performance.[10,50,86,90,92,95] Figure 87-1 shows the complex interrelationship between environment and nutrition, and its effect on human physiology and performance. Stressors in the form of environmental extremes can have serious consequences on health and performance. Proper nutrition can help counter detrimental environmental influences on physical and mental performance.[2-7]

Energy and fluid deficits arising from the interaction of environment and nutrition can negatively impact physical[50] and mental[95] performance. Volitional physical activity and mood can suffer under caloric deprivation, depending on the magnitude and duration of the restriction. Motivation may be more acutely influenced by undernutrition than is actual physical performance.[95] Nutritional deficits may have a greater effect on what individuals are *willing to do* (i.e., on their perceived mood, symptoms, and self-motivation) than on what they *can do* (psychomotor performance).[134]

Nutritional Considerations in Planning for Wilderness Activities

Current American national nutritional recommendations are revised periodically and can be found in the most recent dietary reference intakes (DRIs) published by the Institute of Medicine, National Academies.[69] The DRIs are reference values for nutrient intakes that can be used to assess and plan diets for healthy people.[111] Publications that list DRIs can be obtained through the National Academies website (http://www.nap.edu/catalog.php?record_id=11767) and the National Institutes of Health website (http://ods.od.nih.gov/Health_Information/Dietary_Reference_Intakes.aspx).

The DRIs include four categories: estimated average requirement (EAR), recommended dietary allowance (RDA), adequate intake (AI), and tolerable upper limit (UL). EAR is the nutrient intake level estimated to meet the needs of 50% of healthy individuals in a particular life stage or gender group. RDA, calculated from the EAR, is the nutrient intake level sufficient to meet the needs of 97% to 98% of healthy individuals in a particular life stage or gender group. AI is an estimate of adequate intake based on observation or experimentally determined estimates when an EAR cannot be established. AI and RDA are similar but not identical. The UL is the highest daily consumption level of a nutrient; when UL is exceeded, the nutrient poses a risk of adverse health effects. In general, for nutritional planning for wilderness expeditions, the basic daily diet should meet or exceed the DRI recommendations, especially for prolonged wilderness excursions or expeditions. In the short term (<10 days), adequate energy provision is likely to be the predominant dietary concern. In the long term (>10 days), certain nutrients (vitamins and minerals) may assume more critical or primary roles in environmental extremes than they might normally fulfill in everyday life.

The effect of environmental stressors, such as cold, heat, and altitude, on vitamin and mineral requirements have been a focus of considerable military and civilian research.[8] Research conducted primarily in the post–World War II era and the Korean conflict established that vitamin and mineral requirements are not significantly increased by cold exposure, although caloric requirements for thermogenesis and work may be elevated to varying degrees, depending on the cold challenge, clothing ensemble, and level of physical exertion.[92] Work in cold environments can be adequately supported by various combinations of fat, carbohydrate, and protein, although certain combinations of macronutrients may be more beneficial than others in helping a person withstand cold exposure.[4] As an example, Mitchell and colleagues[101] demonstrated that cold tolerance (the length of time body core temperature could be defended during a controlled cold challenge) was favored by previous diets high in fat as opposed to diets higher in carbohydrate or protein. Subsequent research has indicated that the macronutrient source is less important in the cold than consuming enough total daily calories to support activity and thermogenesis.[4,57] In fact, humans demonstrate great versatility in fuel selection for physical work, including shivering thermogenesis.[31] This “metabolic flexibility” is important for sustaining both voluntary and involuntary muscular contraction. Although humans are physiologically engineered to utilize various combinations of macronutrients in the diet, in some cases a particular calorie source may possess some degree of metabolic advantage. Specific nutrient recommendations for optimal performance in specific environments are discussed under the section on tailoring diet to a specific environment.

Food and Adaptive Thermogenesis. When environmental temperature declines, the body must compensate to maintain homeostasis by reducing heat loss and increasing heat production. Mild cold exposure, even without increased physical activity, elevates energy expenditure (i.e., heat production) in warm-blooded mammals, including humans.[76,88,155] This process, called *adaptive thermogenesis,* or regulated production of heat by the body, is influenced by environmental temperature and diet.[88] Figure 87-2 depicts the major sources of metabolic heat production in mammals. Heat can be generated from both shivering thermogenesis (ST) and nonshivering thermogenesis (NST) through synthetic, oxidative, and metabolic uncoupling processes. Mitochondria, the organelles that convert food to carbon dioxide (CO_2), water (H_2O), and adenosine triphosphate (ATP), are fundamental in mediating these effects on energy dissipation in response to an energy-demand stimulus.[61] The greatest contributor to heat production is ST, which is supported by oxidation of carbohydrate, protein, and fat. Historically, NST, fueled primarily by brown adipose tissue (BAT), was thought to be a minor source of heat production. In recent years, however, the contribution of NST to cold-induced thermogenesis has been demonstrated and represents an area that may be susceptible to dietary manipulation, unlike ST.[26] The role of nutrients and BAT is discussed further in the following section on thermogenic nutrients.

Adaptive thermogenesis is a complex cascade of cell-signaling events primarily regulated by two major hormonal effectors: β-adrenergic agents and thyroid hormone. Thyroid hormones are major endocrine controllers of energy expenditure.[61] Thyroid hormones are critical in providing a vigorous response to cold exposure and sustaining that response by providing glucose and fatty acids to fuel energy production and thermogenesis.[136] Thyroid hormone acts synergistically with catecholamines of the sympathoadrenal system during cold adaptation and high energy output and, conversely, with low energy output when energy demands should be reduced, such as during starvation.[136] Physiologic stimuli, such as cold exposure, elicit these thermogenic hormones, which in turn interact with specific cellular tissue ligand-activated nuclear receptors called peroxisome proliferator-activated receptors (PPARs) in brown and white adipose tissue, liver, heart, and skeletal muscle. PPARs act as fatty acid sensors to control many metabolic pathways essential for energy homeostasis.[153] PPARs are mainly expressed in white and brown adipose tissue, where they control expression of several proteins involved in upregulation of lipid metabolism, subsequent energy generation, and thermogenesis. Peroxisome proliferator-activated receptor gamma coactivator-1α (PGC-1α) is a tissue-specific transcriptional coactivator protein that interacts with the nuclear receptor PPAR-γ. This permits interaction of this protein with multiple transcription factors, thus serving as a coactivator that enhances the activity of many nuclear receptors and coordinates cellular transcriptional programs important for energy metabolism and energy homeostasis. PGC-1α can interact with, and regulate the activities of, cyclic adenosine monophosphate (cAMP) response element binding protein and nuclear respiratory factors involved in energy metabolism and thermogenesis. Uncoupling protein-1 (UCP1) is found in the mitochondria of BAT and is used to generate heat by NST. Adrenergic and thyroid hormones have an impact on energy dissipation and subsequent heat production by the mitochondria in BAT and skeletal muscle through a complex signaling mechanism involving PGC-1α, PPAR-γ, and UCP1.[119] PPAR-γ is a nuclear receptor, subject to transcriptional coactivation by PGC-1α, which plays a central role in regulation of cellular energy metabolism. PGC-1α is induced

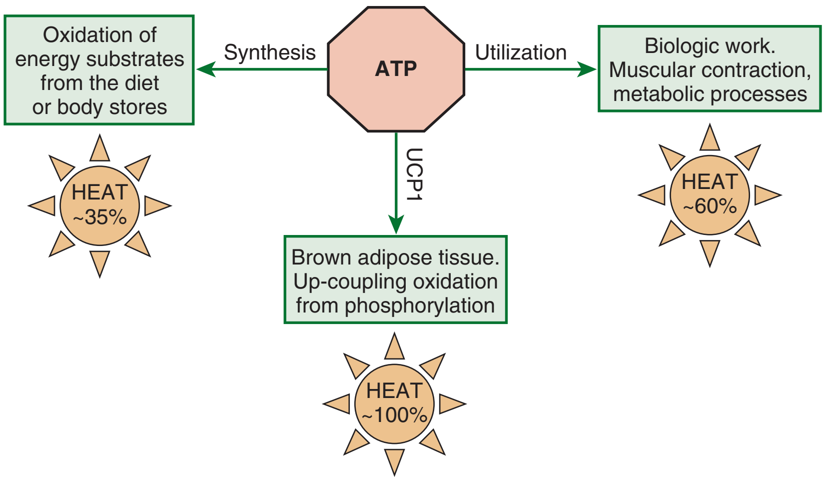

FIGURE 87-2 Energy-transforming pathways and heat production.

FOOD AND WATER

PART 13

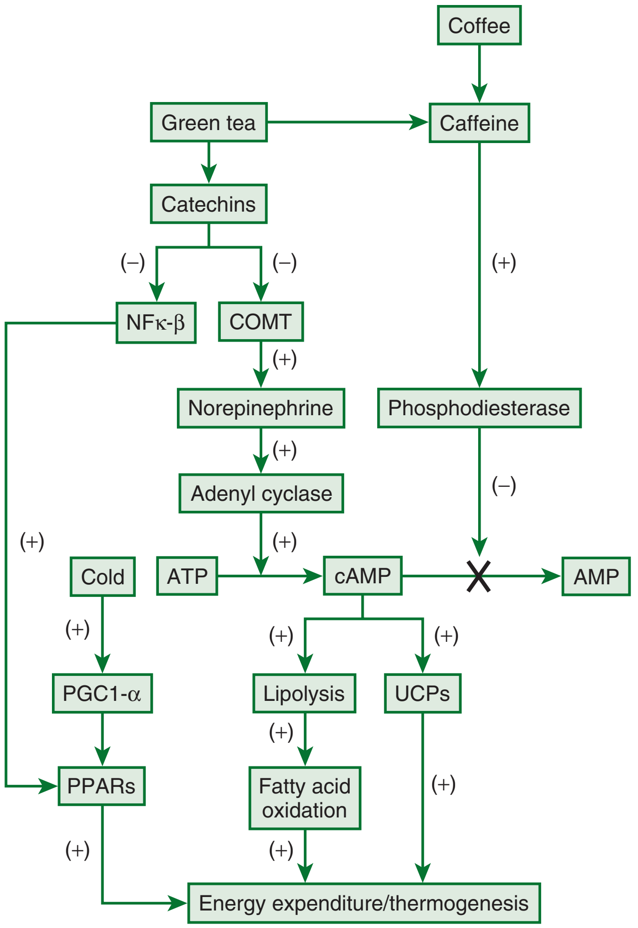

FIGURE 87-3 Cell signaling, activation of thermogenesis, and mechanism of green tea and coffee stimulation of thermogenesis. *NFκ-B*, Nuclear factor kappa B; *COMT*, catechol *O*-methyltransferase; *PGC1-α*, peroxisome proliferator-activated receptor gamma coactivator-1α; *PPAR*, peroxisome proliferator-activated receptors; *UCP*, uncoupling protein; *ATP*, adenosine triphosphate; *cAMP*, cyclic adenosine monophosphate; *AMP*, adenosine monophosphate. *(Modified from Hursel R, Westerterp-Plantenga MS: Thermogenic ingredients and body weight regulation,* Int J Obes *34:659, 2010.)*

by cold exposure, linking this environmental stimulus to adaptive thermogenesis.[84] Induction of increased mitochondrial activity through activation of PGC-1α results in an increase in oxidative-type muscle fibers, which in turn leads to enhanced resistance to muscle fatigue and increased tolerance to cold.[81] PGC-1α is expressed at high levels in tissues where mitochondria are abundant and oxidative metabolism is active, such as BAT, heart, and skeletal muscle.[119] Figure 87-3 shows the schematic relationship of these cell-signaling and response elements and their potential interaction with cold, caffeine, and catechins.

Potential Thermogenic Nutrients. Although considerable research has been conducted on the effects of basic cell-signaling mechanisms on gene activity in response to thermogenic stimuli, less applied research has been conducted on thermogenic nutrients and whole-body cold tolerance. Older studies of food and cold tolerance have largely used core temperature responses to actual cold exposure along with dietary intervention; more recent cold tolerance research has incorporated aspects of basic cell signaling in response to specific food-derived components. Most notably, resveratrol, a plant polyphenol found in abundance in sources such as grapes and Japanese knotweed, has been shown in rat models to induce mitochondrial activity through activation of PGC-1α, which increases oxidative-type muscle fibers, thus increasing resistance to fatigue and cold tolerance.[81] Unfortunately, human resveratrol cold tolerance studies are lacking. However, if the rat model research has applicability to human cold tolerance, resveratrol may be potentially beneficial for facilitating strenuous cold-weather activities. It is unlikely that the food products containing resveratrol could be consumed in quantities adequate to exert a similar effect to that seen in the supplemented rat model. However, numerous concentrated resveratrol supplements, and even food bars containing as much resveratrol as 50 glasses of wine, are commercially available, making a comparable dose level of resveratrol perhaps feasible for human ingestion.

More research has focused on manipulation of macronutrients—carbohydrate, protein, and fat—to enhance cold tolerance by increasing shivering thermogenesis. However, predicting significant effects of macronutrients on cold tolerance based on the thermic effect of food (specific dynamic action of carbohydrate, fat, and protein) has not proved to be a reliable indicator of ability of the body to resist cold exposure. Cold tolerance and diet studies are often complicated by interactions of energy depletion, exertional fatigue, and sleep deprivation. Although partitioning the relative contributions to thermoregulation impairment under multistressor environments is not possible, it is clear that the frequently encountered conditions of negative energy balance, fatigue, and sleep deprivation can impair thermoregulation, and that this impairment can be corrected relatively rapidly by rest and adequate feeding.[159] Dietary approaches involving adjusting the amount and frequency of meals in the cold, amount of total fat in the diet, and inclusion of caffeine/ephedra, capsaicin, and green tea seem to be the most practical approaches to augmenting thermogenesis in the cold. Blondin and associates[25] suggested that coingestion of carbohydrate sources utilizing different metabolic pathways (e.g., glucose, fructose) may be a practical dietary method to facilitate carbohydrate oxidation during cold exposure to support ST. An applied dietary application of these findings might be to put honey (high in fructose) on other high-carbohydrate foods that release glucose, such as a biscuit, bagel, or oatmeal.

Research on the NST properties of green tea seems to provide support for tea as a historically favored hot beverage for cold-weather and high-altitude expeditions. In obesity research investigating the possible thermogenic role of green tea in conjunction with caloric restriction for weight loss, green tea was found to stimulate thermogenesis in a manner that cannot be completely attributed to its caffeine content, which is relatively low.[45,46,59] The exact mechanism by which green tea stimulates NST is not clear but may involve several mechanisms, such as increased recruitment of BAT and/or enhanced BAT activity following recruitment.[26] The two primary active compounds in green tea are caffeine and catechin polyphenols, with the most active catechin being epigalocatechin gallate (EGCG). Both caffeine and catechins have separate but distinct roles in promoting thermogenesis. Caffeine inhibits the enzyme phosphodiesterase, which prevents degradation of cAMP. Cyclic AMP increases lipolysis, which provides additional fatty acids for eventual oxidation.[68] Catechins inhibit the enzyme catechol *O*-methyltransferase (COMT), which degrades catecholic compounds such as norepinephrine. COMT inhibition results in higher, more sustained levels of norepinephrine, which in turn produces a more sustained lipolytic response to support increased energy expenditure. Catechins also inhibit nuclear factor kappa B (NF-κB), a transcription factor that normally regulates PPARs. Upregulation of key enzymes involved in fatty acid oxidation by PPARs increases energy expenditure and enhances stimulation of fatty acid release afforded by elevated cAMP. Finally, catechins have a direct effect on expression of several uncoupling proteins that also can influence thermogenesis by uncoupling or decreasing the efficiency of oxidative phosphorlyation.[78,88] Caffeine potentiates these catechin effects. The role of green tea and coffee in enhancing energy expenditure (thermogenesis) is shown schematically in Figure 87-3.

Other thermogenic "nutrients" may also have application in cold tolerance. Capsaicin is the major pungent compound found in certain pepper species and a common spice in many food products. It has been studied with mixed results for its thermogenic properties and influence on increasing fat oxidation.[138] Capsaicin is believed to increase thermogenesis by enhancing catecholamine secretion from the adrenal medulla through activation of the central nervous system (CNS), resulting in β-adrenergic stimulation.[68] It may also upregulate certain uncoupling proteins in response to catecholamine release.[94] Polymorphisms in the receptor and promoter regions of genes of individuals may explain variability in capsaicin stimulation between individuals[68] and equivocal results reported in the literature.[58,64,138]

Another thermogenic "nutrient" to consider is brown adipose tissue. BAT has been extensively studied in infants and animals under a variety of conditions. It helps maintain body temperature. It was formerly thought that this energy-rich and heat-generating tissue regresses with age.[82,83] Discovery that humans contain more BAT than previously thought,[40,151] and that cold exposure activates BAT thermogenic activity in humans,[150] has stimulated BAT research in adult humans. The unique uncoupling properties of BAT that make it such an efficient heat-producing organ may also be shared by other tissues, such as skeletal muscle. Wijers and colleagues[155] found that mitochondrial uncoupling in skeletal muscle during cold exposure may be one mechanism facilitating cold-adaptive thermogenesis in humans. Blondin and associates[26] found that daily cold exposure increases both the amount and the metabolic activity of BAT in humans, suggesting a potential nonshivering contribution to cold-induced thermogenesis. Dietary or pharmacologic approaches to stimulating BAT activity may be a promising way to turn on heat production during cold exposure. Future research on metabolic and dietary control of adaptive thermogenesis may have particular relevance to diverse metabolic outcomes, such as obesity and weight loss research, as well as human cold tolerance. Identifying ways to potentiate the NST activity of BAT through cold acclimation and pharmaceutical or dietary compounds may prove to be an important mechanism to improve cold tolerance.[26]

Tailoring Fat, Carbohydrate, and Protein to Different Environments. Although the most important nutritional concern in challenging environments, aside from water, is total energy intake, when wilderness activities shift from a cold-weather environment at sea level to cold-weather environment at moderate or high altitude, the macronutrient balance in the diet should be reconsidered. Although fat is an efficient and well-tolerated energy source during sustained, but relatively low-power-output, cold-weather activities at sea level, it is not as well tolerated at high altitude, at least in non–fat-adapted sojurners.[5] Substituting carbohydrate for fat and, to a certain degree, for protein can theoretically provide metabolic advantages to the individual's critical oxygen economy when working at altitude.[3] Carbohydrate is a more efficiently metabolized fuel at altitude than is fat because it is already partially oxidized (i.e., it contains a higher ratio of oxygen atoms to carbon atoms) and therefore requires less oxygen to combust its carbon skeleton to CO_2, H_2O, and energy. Metabolizing carbohydrate for energy requires approximately 8% to 10% less inspired oxygen than is required to obtain a similar amount of energy from fat. A high-carbohydrate diet can reduce symptoms of acute mountain sickness, enhance short-term high-intensity work and long-term submaximal efforts, and lower the effective "felt" elevation by as much as 300 to 600 m (984 to 1969 feet) by requiring less oxygen for metabolism.

Initial altitude exposure frequently results in anorexia and subsequently reduces energy and carbohydrate intake.[30] Anorexia (and thus food intake) usually improves with time and acclimatization (3 to 7 days at altitude), but, depending on the altitude, may never match that at sea level. Weight loss and performance decrements are quite common under these conditions. Carbohydrate supplementation of the diet at elevations exceeding 2200 m (7218 feet), particularly with carbohydrate-containing beverages, is usually an effective method to increase carbohydrate and total energy intakes.[3,30,48,110] Some,[39] but not all,[145] studies of carbohydrate supplementation at altitude have demonstrated a decrease in adverse symptoms resulting from acute altitude exposure. Enhancement of short-term, high-intensity performance,[31] as well as long-term, submaximal performance,[3,14,110] by carbohydrate supplementation has also been noted in some studies involving altitude exposure. The beneficial effects of carbohydrate at altitude most likely depend on the type of exercise performed (intensity and duration) and the degree of prior muscle glycogen depletion experienced by the test participant, because of varying degrees of anorexia.

Muscle glycogen is related to the caloric adequacy of an individual's prior diet; carbohydrate intake usually parallels the overall dietary intake of the antecedent diet.[3] It is a good plan to consume a mixed diet with snacks high in carbohydrate. The most effective form of carbohydrate supplementation in environmental extremes is usually liquid beverages; people will drink when they are reluctant to eat.[3,14,30,48] Increasing fluid intake along with carbohydrate intake is also beneficial at altitude, where increased fluid losses occur as the result of diuresis and of respiration in the dry (low-relative-humidity) atmosphere.[9]

Recently, the "dogma" of high-carbohydrate diets being superior in all cases to high-fat diets, particularly in the case of sea level endurance exercise, has been challenged. Noakes and colleagues[108] questioned why the almost universal recommendation for athletes engaged in prolonged submaximal endurance exercise is a high-carbohydrate diet, particularly since work at less than 50% maximum oxygen consumption ($\dot{V}O_2max$) is well supported by fat oxidation. Furthermore, work at higher intensity can be accomplished without penalty if the athlete is already adapted to a high-fat diet.[116] Similar to the carbohydrate recommendations for athletes, the recommendation for work at high altitude is, with few exceptions,[116] for a high-carbohydrate diet.[14,39,100] Although direct comparisons of the beneficial or detrimental effects of high-fat to high-carbohydrate diets at altitude are lacking, theoretically at least, fat seems to be at a disadvantage. Recent comparisons of a high-fat versus a high-carbohydrate diet at rest and exercise at sea level suggest that pulmonary oxygen uptake kinetics associated with high-fat diets may attenuate microvascular blood flow and subsequent oxygen delivery.[121] If this is the case, one might expect the oxygen delivery problem to be even more magnified at altitude. It could be speculated that prior adaptation to a high-fat diet might lessen the microvascular blood flow attenuation, but for now, this is conjecture, and the high-carbohydrate diet remains the "most reliable" recommendation for work at altitude.

The "Right" Macronutrient Mix for Work at Altitude. There are two schools of thought regarding the most advantageous mixture of dietary macronutrients for work at altitude. Some believe that food preferences change greatly as elevation increases during the climb, and that carbohydrate becomes more palatable to the anorexic appetite. Others believe that once appetite recovers from the initial period of altitude acclimatization, the relative proportions of carbohydrate and fat in the diet are not as important as eating to energy demands to prevent loss of lean body mass. Early work published by Teasdale[147] and later advocated by Pugh[120] and Consolazio[39] favored carbohydrate for work at altitude largely because of its structural oxygen content; carbohydrate is more highly oxidized than is fat or protein and therefore theoretically should require less atmospheric oxygen (which is, in effect, reduced with the decreased barometric pressure at altitude) for its metabolism to CO_2 and ATP. This line of reasoning also agrees with what we know about the need for glycogen replenishment. Glycogen stores would be important energy providers for intense physical climbing work at altitude if one was working at a high percentage of $\dot{V}O_2max$. However, as Teasdale[147] aptly noted in "The Diet Problem for Mountaineers in the Himalayas," the actual amount of work in foot-pounds done at altitude is usually self-limited and may be relatively low compared with that at sea level; the real problem is not the amount of energy expended, but rather oxygen availability. Teasdale[147] recommended that climbers should seek a diet "demanding as little oxygen as possible," accomplishing this by ingestion of carbohydrate at frequent intervals. He also was one of the first to point out the oft-encountered "vicious" cycle of human physical deterioration at altitude: loss of appetite–partial starvation–metabolism of climbers' fat stores for energy–ketoacidosis–further anorexia and loss of appetite–loss of weight–deteriorated physical performance. This cycle of events, along with dehydration, is depicted schematically in Figure 87-1. Many of these situational/physiologic turning points leading to physical performance decrements can happen in other extreme environments, but the climber at high altitude seems to experience these adverse factors sooner and to a more significant degree than do workers in other environments. Washburn[154] emphasizes that dietary carbohydrate becomes particularly more critical as altitude increases above 3048 m (10,000 feet), and Consolazio and associates[39] identified carbohydrate as an important factor in lessening the initial severity of altitude illness. Although early observations by Pugh[120] and subsequent research by other investigators seem to indicate that carbohydrate is better "tolerated" or preferred at altitude, other studies in normobaric[125] and hypobaric hypoxic conditions[123] have failed to show a carbohydrate "preference" at altitude.[12] In a study of climbers on Mt Everest, Reynolds and co-workers[123] expected carbohydrate consumption to increase with increasing altitude but surprisingly found that retort pouch packages of high-fat sausages seemed to be preferred under cold, high-altitude conditions. This preference could be caused by a true preference for fat or simply the ease of utilization of the heat in a pouched food product. However, just because high-fat foods gain some acceptance in the cold, and perhaps even at high altitude, does not necessarily mean that carbohydrate loses its importance for glycogen repletion and maintenance of blood glucose levels needed for periods of high-power energy output. The most important consideration regarding fueling heavy physical work in the cold or in combination of cold and altitude is, as Washburn[154] stated, "Plenty of good food is of vital importance." "Good food" that is appetizing and served warm is likely to be consumed and therefore subsequently beneficial. Perhaps the real advantage of carbohydrate at altitude is more evident early in the ascent and, as climbers become more acclimated to the altitude, the exact macronutrient composition of the diet may be of lesser importance than individual climber food preferences.

ENERGY: HOW CRITICAL IS IT?

When planning for a prolonged wilderness outing, the following question should be asked: "If we run short on food, will we suffer severe consequences in our progress along our route and experience difficulty carrying our heavy packs?" For optimal performance, *total energy intake,* especially carbohydrate intake, is the key for sustaining high-level work capacity for extended periods. However, performance across a broad spectrum of backcountry tasks, including load-bearing work, is not always severely degraded by *short* periods of suboptimal energy and carbohydrate intake. A review of the effect of energy restriction on military work performance indicated that soldiers can maintain relatively normal work capacities for short periods (<10 days) of food restriction.[50] The Minnesota starvation studies conducted during World War II demonstrated that energy deficits resulting in loss of less than 10% of body weight did not greatly impair physical performance; however, underconsumption of calories for longer periods producing continued loss of body weight created significant deficits in physical performance,[146] as evidenced by observations of one participant in the 1570-kcal/day, 24-week semistarvation study, resulting in 24% body weight loss: "Then came February twelfth, the starting date of semi-starvation … only two meals a day from now on. For the first two weeks the new life was fun. I was losing weight, of course, but I still had lots of energy. Then came the day when I lost my 'will to activity'—I no longer cared to do anything that required energy."

The degree of reduction of work capacity depends on the degree of caloric restriction, carbohydrate content of the food available, and power output demanded by the work. Studies of food restriction in military scenarios have revealed that restricted energy and dietary carbohydrate content over a 30-day period supported light to moderate activity level without evidence of greatly impaired physical performance capabilities.[15] On the other hand, longer periods (8 weeks) of caloric restriction coupled with higher levels of energy expenditure (U.S. Army Ranger training) have been associated with significantly reduced physical performance capacity.[107]

Because experimental conditions and performance measures differ between research studies, it is difficult to draw conclusions about the relationship between energy deficit and performance. Some indicators of performance, such as grip strength, appear to be well preserved until nutritional status is severely compromised. Other measures, such as maximal lift test, maximal jump height, isometric leg extension, and maximal oxygen uptake, appear to be more sensitive predictors of impaired performance.[71] In general, in nonobese individuals, strength seems to be rather well maintained at a hydrated body weight loss of up to 5%. This may be good news for wilderness travelers who are concurrently on a gradual weight loss program. Shedding fat actually "lightens the load" without diminishing strength. However, when dieting or restricting food results in loss of *lean* body mass, performance decrements result. Aerobic capacity and strength are reduced when loss of body weight exceeds 10% in a hydrated individual over 4 or more weeks, although this could occur sooner depending on the degree of caloric restriction, rate of weight loss, and initial body composition. Friedl[50] reviewed the influence of reduction in body weight resulting from reduced food intake on muscle strength and aerobic capacity and concluded that changes in $\dot{V}O_2$max in response to modest caloric restriction generally influence performance to a lesser degree than do reductions in muscle strength in response to weight loss. The primary concern of weight loss from inadequate energy consumption occurring during extended wilderness activities appears to be loss of muscle strength, which is influenced by an individual's initial body composition, rate of weight loss, composition of weight loss, and health status. Significant loss of muscle strength can be expected after a 5% to 10% body weight loss over 3 days (primarily from low glycogen or fluid loss) to 12 weeks (primarily from loss of lean body mass) under conditions of severe energy deficit. Significant declines in aerobic capacity can also occur after weight losses of this magnitude, but the decline in aerobic capacity appears to have relatively little effect on individual performance at moderate (<50% $\dot{V}O_2$max) sustainable workload levels.[50] In practical terms, this may mean that a gradual trek to the summit may not be precluded by a prior food restriction accompanied by significant loss of body weight, but that a short-term, all-out push for the summit to avoid impending severe weather would most likely be compromised.

Factors other than strength and aerobic capacity should also be considered when evaluating the effects of energy restriction on performance. Although weight losses of 6% or less over periods of 10 to 45 days generally do not produce significant degradations in cognitive performance,[134] mood may be adversely affected by caloric restriction.[36,97] However, long-term reduced consumption resulting in a 50% caloric deficit may significantly degrade cognitive performance.[95] Reduced food intake, when coupled with other stressors such as high rates of energy expenditure and sleep deprivation, can impair immune function.[69,80,86]

Carbohydrates: Critical for Performance of High Work Output

Both the length of time provided for dietary adaptation to carbohydrate restriction and the amount of carbohydrates in the diet can influence the level of aerobic endurance performance.[2] Aerobic endurance performance can be reduced by 40% after only 4 days on a calorically adequate but low-carbohydrate diet (i.e., with carbohydrates providing 10% of the kilocalories).[53] When a diet that was calorically adequate, but only 5% carbohydrates, was fed for 2 weeks, performance was also reduced, but only by approximately 15%, presumably because of metabolic adaptations to the shift in energy sources that occur with time.[118] Carbohydrate is important to performance, but the impact of any reduction in dietary carbohydrate intake depends on (1) period of time during which it is reduced, (2) absolute level of carbohydrate in the diet, and (3) power output ($P = F \times D / T$) needed to accomplish the task at hand. The latter point regarding power output requirements is an important consideration in provision of food for wilderness activities. Since much wilderness activity is usually recreational and not competitive, self-paced work and lowering of power requirements by increasing the time over which the work is accomplished is a feasible approach that can result in less reliance on carbohydrates and more reliance on a "slower-burning" fuel, such as fat.

Reduced carbohydrate intake, more than reduction of any other macronutrient (with the exception of water), can negatively influence muscle glycogen levels and endurance.[2] There is abundant evidence in the sports nutrition literature to permit extrapolation to similar wilderness activities and to conclude that certain types of performance, such as backpacking, cross-country skiing, and climbing, may be influenced by an acute shortage of carbohydrates in the diet, depending on the intensity of the workload (% $\dot{V}O_2max$) in which the individual is engaged. Inadequate carbohydrates in the diet, coupled with successive days of intense prolonged exercise, results in gradual reduction of glycogen stores, deterioration of performance, and increased perception of fatigue. Perceived or "felt" exertion for certain wilderness activities, such as load-bearing work, may reasonably be assumed to be a function of the dietary carbohydrate intake and its subsequent effect on muscle glycogen levels. To avoid fatigue and extend or enhance performance, carbohydrates may be ingested before, during, and after moderate- to heavy-intensity aerobic exercise.[70] This requires daily consumption of a minimum of 5 g of carbohydrate per kg body weight,[130] with ultralong (>4 hours), moderate-intensity exercise requiring as much as 8 to 12 g carbohydrate/kg/day.[28] For a 77-kg (170-lb) person, this equates to approximately 620 to 924 g of carbohydrate per day. To put this into perspective, a review of typical dietary carbohydrate intakes of male soldiers fed a variety of rations during 18 field studies in temperate, hot, and cold environments revealed intakes ranging from 244 to 467 g/day.[18] Similar data are not as well documented for nonmilitary wilderness activities, but a recent study of Mt Everest base camp trekkers revealed a carbohydrate intake of only 3 g/kg/day (325 g/day), far below the level needed for optimal glycogen stores and physical performance.[156] Most people do not selectively consume low-carbohydrate diets during wilderness activities, but total carbohydrate intake is often low because of its relationship to total energy intake and because of limited high-carbohydrate food choices. Some backpackers seek to maximize food and caloric density because of the weight of, and space available in, their packs. Calorie-dense food item choices that achieve this goal are often high in fat and relatively low in carbohydrates. Inadequate food consumption in military field exercises has been ascribed to poor ration palatability and variety, menu boredom, not enough time to eat or prepare meals, anxiety, and intentional dieting to lose weight.[91] Similar factors may be operative in wilderness expeditions. Countermeasures to reduce the effect of these factors should be taken into consideration during ration planning. To sustain short-term performance, a shortfall of energy (calories) is not as significant a concern as the lack of carbohydrate.[50] Table 87-1 lists current carbohydrate recommendations for daily fueling and recovery.

Field studies of carbohydrate intake and performance are difficult to conduct because of the many uncontrolled variables encountered outside the laboratory. Therefore, definitive field studies demonstrating a positive effect of dietary carbohydrate supplements on wilderness performance are limited.[6] However, existing field studies suggest a benefit of carbohydrate intake on performance. In one field study, participants in the Medical Expedition 2008 Hidden Valley Expedition to Nepal ingested either a 10% carbohydrate solution ad libitum (+3.5 g carbohydrate/day) or a placebo at 5152 m (16,900 feet) throughout the 22-day expedition. During the expedition, study participants completed a mountaineering time trial and multiple submaximal exercise, incremental-step tests. The carbohydrate-supplemented group was 17% faster than the placebo group during the time trial, with 18% reduction in perceived exertion.[110]

Although data from actual field studies are limited, data from studies conducted in well-controlled laboratory settings suggest that carbohydrate supplementation benefits performance. To test whether soldier performance would benefit from carbohydrate supplementation under simulated field operations, 18 physically fit U.S. Army Special Operation Forces soldiers were fed a controlled diet designed to simulate a "typical" daily dietary intake of carbohydrate and protein encountered during field operations (327 g carbohydrate/day, 201 g fat/day, and 118 g protein/day, 3657 kcal/day). The soldiers exercised daily (11 days total) under conditions designed to simulate field energy expenditure patterns (intermittent- and sustained-activity patterns of varying intensity levels). Each study participant received one of three beverage supplements during the program: placebo (0 g carbohydrate), carbohydrates (180 g carbohydrate) ingested once a day immediately after exercise, or carbohydrates divided into several doses ingested after the morning exercise session and at intervals during the afternoon exercise session. A decrease in respiratory exchange ratio in all treatments was observed, indicating that the soldiers were experiencing a carbohydrate shortage in response to the field simulation and were consequently utilizing fat to sustain energy expenditure. However, provision of supplemental carbohydrates permitted a higher level of physical performance or aerobic power to be attained. Run times to exhaustion were increased approximately 6% with the single carbohydrate feeding and 17% with the divided-dose administration. The ingestion pattern of the carbohydrate supplement as well as the carbohydrate itself appeared to influence performance, indicating that a supply of easily consumed carbohydrates (supplement or food) ingested before, during, and after field activities is an effective method to sustain or boost physical performance.[104]

TABLE 87-1 Carbohydrate Recommendations for Fueling and Recovery

Daily Fueling	Amount Of Carbohydrate
Moderate exercise (1 $h \cdot day^{-1}$)	5-7 $g \cdot kg^{-1} \cdot day^{-1}$
High exercise (1-3 $h \cdot day^{-1}$)	6-10 $g \cdot kg^{-1} \cdot day^{-1}$
Very high exercise (4-5 $h \cdot day^{-1}$)	8-12 $g \cdot kg^{-1} \cdot day^{-1}$
Acute Fueling Strategies	
Carbohydrate loading (events >90 minutes)	10-12 $g \cdot kg^{-1} \cdot day^{-1}$ for 36-48 hours
1-4 hours before exercise	1-4 $g \cdot kg^{-1}$
During sustained exercise (>1-2.5 hours)	30-60 $g \cdot h^{-1}$
During ultralong exercise (>2.5-3 hours)	Up to 90 $g \cdot h^{-1}$
Recovery (<8 hours between exercise bouts)	1-2 $g \cdot kg^{-1} \cdot h^{-1}$ for 4 hours

From Burke LM et al: Carbohydrates for training and competition, *J Sports Sci* 29(Suppl):S17-S27, 2011.

Fat: A Special Place in Wilderness Exploration?

Historically, wilderness explorers and expeditions have relied heavily on foods higher in fat content than recommended by current sports nutrition and healthy dietary guidelines. One early 20th-century explorer, Vilhjalmur Stefansson, became such a strong advocate of meat-based high-fat diets that he volunteered himself for an unusual experiment in 1928.[85,141] Stefansson consumed an all-meat diet for 1 year with no detectable adverse medical consequences. Stefansson's championing of high-fat diets for work in cold regions led to a World War II–era U.S. Army and Canadian test of a high-protein and high-fat pemmican diet (low in carbohydrate) for work in the cold, but results were not encouraging.[73] Predictable fatigue occurred when the high-fat, low-carbohydrate diet was abruptly thrust on the soldiers. At the time, this study was offered as an argument against including pemmican in the cold-weather military diet. Despite the military's lack of enthusiasm for high-fat food, Arctic explorers have relied on pemmican for nutritional support during cold-weather polar expeditions.[142]

Although we now know that a period of time is required for metabolic adaptation to a high-fat diet,[115,116] the dispute continues concerning suitability of high-fat diets.[108,121] A review of numerous studies and the composition of diets and experimental conditions under which they were conducted indicates that two factors are critical to satisfactory utilization of high-fat diets: prior adaptation to fat in the diet and the power or exertion level at which individuals were required to work.[114] Humans permitted to adapt gradually to increasing levels of fat in the diet for approximately 3 weeks can function much better than if the dietary change is abrupt. High-power outputs require the capacity for repeated bursts of anaerobic metabolism, which is best fueled by carbohydrates (i.e., via glucose and glycolysis). Efficient fat metabolism depends on readily available oxygen; the ability for oxygen uptake necessary for fat oxidation becomes limiting at high-power outputs. Military studies of dietary fat content confirm that a subcaloric, relatively high-fat diet (1976 kcal/day; 46% fat) can maintain moderate physical performance (including load-bearing work) for up to 30 days.[15,86] Practical physical and situational constraints, such as caloric density, weight-per-volume considerations, prior experience, work level intensity, and local availability of food, seem to affect usefulness of relatively high-fat provisions used in support of wilderness expeditions.[3,49]

Although not an ideal energy source for high-power-output competitive sporting events, fat can serve admirably as a concentrated energy source for outdoor activities requiring low-power but sustained work performance over longer periods. This is because low-power but sustained work, such a carrying a loaded backpack along a trail at a comfortable pace, can usually be accomplished aerobically at a moderate % $\dot{V}O_2max$ effort that can be energetically powered largely by fat oxidation without dipping deeply into glycogen reserves. Although fat has received a somewhat tarnished health image over the past 40 years by an imperfectly understood relationship with atherosclerosis and coronary heart disease, we have gradually come to understand that there is significant interaction between the type of fat (fatty acid composition) and the individual's habitual level of physical exertion. Simply put, fat intake becomes particularly problematic when highly saturated fat (e.g., C-16:0 palmitic acid) is habitually consumed without accompanying daily high rates of energy expenditure. Anthropologic support for this concept can be found by examining cardiovascular disease in early Arctic populations that subsisted on a largely meat diet, where fat was a highly prized commodity. No one would consider classically made pemmican a "health" food, because of its high-saturated-fat content. Although pemmican is historically considered to be an ideal trail food for cold-weather expeditions because of its caloric density and resistance to spoilage, no one advocates a long-term habitual diet based on pemmican. Pemmican consumption is largely self-limited—acceptable for its purpose in the backcountry for defined periods but not acceptable as a staple in daily life. There is little scientific evidence that short periods (usually <1 month) of a high-fat diet has an irreversible effect on cardiovascular health, although a single high-fat meal can acutely influence endothelial response to the meal ingestion, causing narrowing of the arteries supplying blood to the extremities.[106] From such observations and epidemiologic studies linking long-term high dietary fat intakes to increased incidence of heart disease, we project that repeated insults of this nature may ultimately lead to increased deposition of lipid in the intima of arteries.[22,137] All indications, however, lead to the conclusion that we really do not know the time course required for high-fat diets to take a toll on our arteries, particularly if the periods of high fat consumption are intermittently imposed and further complicated by the level of caloric expenditure during these periods, as well as the type of fat consumed. Existing wilderness studies indicate that ingestion of high-fat diets do not adversely affect blood lipids and may in fact improve them.[41] The amount and type of fat in wilderness provisions remains largely a personal choice balanced against logistic constraints and the requirement for caloric density.

Washburn[154] stated that diets consisting of high levels of fat can be tolerated well by individuals doing heavy exercise in extreme, cold environments. He also wrote that diets for work in cold weather at low altitude can rely heavily on fats for energy. Because the usual diet of most humans now is generally higher in carbohydrates than fats, it is advisable that a gradual transition to a higher proportion of calories in the diet from fat be accomplished over a few weeks before embarking on an expedition. Enzyme adaptation to a higher-fat diet can help prepare the individual to optimally metabolize and utilize increased fat in the diet. Drury and associates[44] studied the metabolic effects of a diet high in fat and protein under cold-weather field conditions and found distinct adaptation to diets of this nature. Initially, blood glucose drops sharply because of the low amount of carbohydrate in the diet, but levels out in the low-normal range after 2 to 3 days. Ketone excretion rises over the same period in response to the high levels of fat being oxidized for energy, peaking about the same time (3 days) as when glucose decrease levels out, returning to normal levels after about 9 days. Two weeks should be considered the minimum amount of time to adapt to a high-fat, low-carbohydrate diet before utilizing it as the main daily food routine during expeditions.[115]

Early explorers utilized pemmican and other high-fat, high-protein foods as staples for their expeditions, partially from observations of the dietary patterns of native people and partially from logistic considerations of weight/volume and perishability. Evidence that pemmican is not just an "antiquated dietary anachronism" has been demonstrated by current use of pemmican by Arctic adventurers Several food supply houses still manufacture and supply various versions of pemmican to outdoor enthusiasts. Persons desiring to prepare their own pemmican can do so quite easily using a kitchen food processor and readily available supermarket products. Numerous Internet guides to pemmican making can be easily accessed (e.g., http://www.traditionaltx.us/images/PEMMICAN.pdf). Pemmican is energy dense, well preserved without refrigeration, and can be a versatile energy source, especially during long days on the trail when little time or daylight is available for leisurely food preparation. It lends itself well as a cold snack on the trail. When added to a pot of hot water and mixed with a nutritious grain such as quinoa or brown rice, pemmican becomes a hot, filling meal (generically referred to by Arctic explorers as "hoosh") that can provide protein, fat, and carbohydrate at the end of a difficult day. Table 87-2 lists some nutritious carbohydrate grains that compliment a meal of pemmican "hoosh."

Protein and Maintenance of Lean Body Mass and Performance

Considerable discussion of the proper amount of protein to maintain muscle mass, prevent wasting, and sustain performance under conditions of physical stress exists in the literature. However, despite all the controversies, recommendations concerning the amount of protein in the diet have changed little since the World War I era, as evidenced by the 1919 report by Murlin and Miller[103]:

> The amount of protein … sufficient to repair all of the wastes of the body and to supply an adequate reserve is 13% of the total energy intake. It seems a matter of indifference to the muscles whether they receive their energy from carbohydrate or from fat. … Hard muscular work therefore can be done on a diet high in carbohydrate or on a high fat diet. It is of general experience, however, that muscular work is done with less effort if there is a plentiful supply of carbohydrate.

Thirteen percent of the energy intake translates to an intake of 65 g of protein per day on a modest energy intake of 2000 kcal/day, or 130 g of protein per day on a more strenuous 4000-kcal/day energy intake. Quantities of dietary protein in the range of

TABLE 87-2 Nutrient Contents of Some Common Grains to Add to a Pemmican "Hoosh"*

Grain	Energy (kcal)	Protein (g)	CHO (g)	Fat (g)	Fiber (g)
Quinoa	374	13	69	6	6
Amaranth	374	14	66	7	15
Rice (white)	379	8	84	0	2
Rice (wild)	357	15	75	1	6
Oats (oatmeal)	375	10	78	4	7
Wheat (couscous)	376	13	77	1	5
Corn (grits)	347	9	79	1	5

Values from http://www.elook.org/nutrition/grains/.
CHO, carbohydrate.
**Note*: Serving size = 100 g = 3.5 oz = approximately 1/2 cup.

TABLE 87-3 Protein Requirements Based on Activity	
Activity Level	**Recommended Daily Protein Intake**
Sedentary adult	0.8 g/kg
Recreational athlete (low to moderate training volume and intensity)	1.0 g/kg
Endurance athletes	1.2-1.4 g/kg
Ultraendurance athletes	1.2-2.0 g/kg
Strength athletes	1.2-1.7 g/kg

From Dunford M, Doyle JA: Proteins. In *Nutrition for sport and exercise*, 3rd ed, Stamford, Conn, 2015, Cengage Learning, p 174.

65 to 135 g/day are rather easy to obtain, even for the most casual ration planner (e.g., one stick of beef jerky or one serving of peanut butter contains 6 to 8 g of protein).

Protein and Maintenance of Muscle Mass When Energy Intake Is Inadequate. The current RDA for daily protein intake for a sedentary adult is 0.8 g/kg body weight. For moderately active individuals, the recommendations are slightly higher at 1.0 g/kg and continue to increase for highly active individuals (Table 87-3). Even at the proposed maximum amount of 2.5 g/kg,[23] protein intake is relatively easy to obtain under normal conditions (i.e., adequate food availability, temperate climate). Protein considerations seem to be subordinate to the metabolic "jockeying" of fat and carbohydrate for prominence in energy provision during cold-weather and high-altitude operations. Protein is generally assumed to be of less nutritional importance from an energy standpoint. However, protein becomes of greater metabolic importance when energy demands are not being met (caloric restriction). Such situations are often encountered in wilderness settings in physically challenging environments. Recent studies of maintaining lean body mass during caloric restriction suggest that increasing protein intake may be helpful in maintaining muscle protein synthesis and muscle mass despite low-energy and relatively low-carbohydrate intakes.[19,112,117] Diets providing 80% of the energy actually expended (20% caloric shortfall) for periods up to 10 days have been shown to decrease muscle protein synthesis by 19% and, perhaps more importantly, to reduce levels of cell-signaling proteins specific to protein synthesis.[112] Further, a caloric deficit of 40% for 21 days has been shown to upregulate the ubiquitin proteasome system, which is the primary stimulus for protein catabolism.[33] Current research indicates that if prolonged energy deficits cannot be avoided, such as during several days of inadequate food intake, nitrogen retention and maintenance of lean body mass are better preserved with accompanying protein intakes approximately twice the usually recommended RDA of 0.8 g/kg (1.6 g/kg/day). This adds retrospective credibility to the customary use of high-protein food items, such as pemmican and jerky, as ration staples by early wilderness explorers, who often found themselves in situations where it was not possible to eat a full day's ration (adequate kcal) for extended periods.

In situations where it is difficult to consume large amounts of protein, it may be more beneficial to focus on the amino acid profile of the food consumed. Branched-chain amino acids (BCAAs), in particular leucine, are important for muscle protein synthesis and may be good nutritional tools to help preserve lean body mass under energy restriction.[19] Leucine serves both as a substrate for protein synthesis and as an important signaling nutrient for regulating protein metabolism. Leucine has been shown to stimulate protein synthesis through the mammalian target of rapamycin (mTOR) and, at the same time, decrease protein degradation through inhibition of the ubiquitin proteasome pathway.[54] The unique metabolic property of leucine to prevent muscle protein loss under catabolic situations suggests that whey protein products high in leucine and other BCAAs may have application in wilderness nutrition during food preparation. The efficacy and human tolerance of leucine-rich proteins, such as whey, in support of maintaining or increasing muscle mass suggest that efficacy of leucine depends in part on the presence of other BCAAs. Indeed, leucine-rich proteins have been shown to be more efficient than leucine supplementation alone.[19] Extension of the beneficial leucine-specific effects reported in the literature involving exercise, malnutrition, weight management, and prevention of the sarcopenia of aging may apply to the situation of inadequate energy intakes in wilderness activities. Leucine may be of particular importance for activities at high altitude, where the combination of caloric restriction, low protein intake, and hypoxia work together to suppress mTOR activation and thus protein synthesis (Figure 87-4). Limited research suggests that

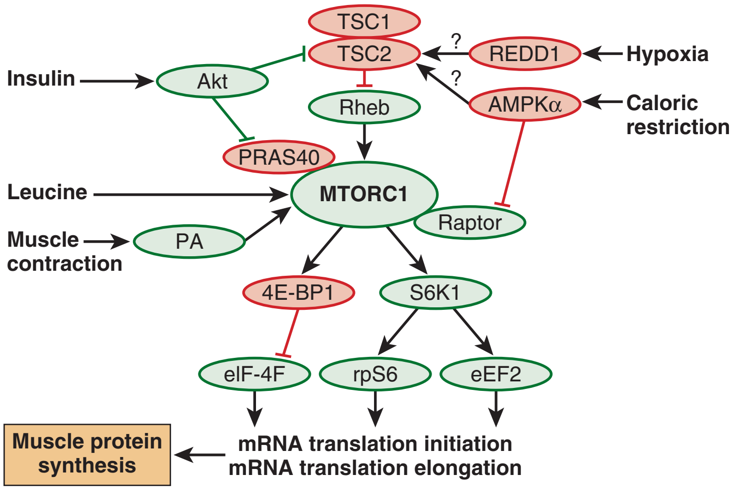

FIGURE 87-4 A simplified schematic diagram of the mammalian target of rapamycin complex 1 (mTORC1) signaling pathway and proposed cellular regulation of muscle protein synthesis in response to hypoxia, caloric restriction, insulin, muscle contraction, and leucine. Proteins in *green ovals* are positive regulators of mTORC1 and muscle protein synthesis, and proteins in *red ovals* are negative regulators of mTORC1 and/or muscle protein synthesis. *TSC1*, Tuberous sclerosis complex 1; *TSC2*, tuberous sclerosis complex 2; *Rheb*, Ras-homologue enriched in brain; *REDD1*, gene regulated in DNA damage responses and development; *AMPKα*, AMP-activated protein kinase alpha; *PRAS40*, proline-rich Akt substrate 40; *Raptor*, regulatory-associated protein of mTOR; *S6K1*, p70 ribosomal S6 kinase 1; *rpS6*, ribosomal protein S6; *eEF2*, eukaryotic elongation factor 2; *4E-BP1*, 4E binding protein 1; *eIF-4F*, eukaryotic initiation factor 4F; *PA*, phosphatidic acid; *Akt*, protein kinase B. *(From Wing-Gaia SL: Nutritional strategies for the preservation of fat free mass at high altitude.* Nutrients *6(2):665-681, 2014.)*

TABLE 87-4 Pemmican Fortified with Unflavored Whey Hydrolysate Powder

Food Item	Grams	Energy (kcal)	CHO (g)	Saturated Fat Content (g)	Total Fat Content (g)	Protein (g)	Leucine (g)
Pemmican Standard Recipe Without Whey Protein							
Beef jerky	255	390	7	2.4	5	79	5.8
Beef tallow	60	2232	0	26.9	59.1	0	0
Cranberries, dried	115	354	95	0.1	1.6	0.1	0
Total	430	2976	102	29	65.7	79.1	5.8
Per 1000-kcal meal	144	1000	34.3	9.7	22.1	34.4	1.95
Pemmican Modified Recipe With Whey Protein							
Beef jerky	255	390	7	2.4	5	79	5.8
Beef tallow	60	2232	0	26.9	59.1	0	0
Cranberries, dried	115	354	95	0.1	1.6	0.1	0
Whey protein powder	56	220	4	2	4	42	4.6
Total	486	3196	106	31.4	69.7	121	10.4
Per 1000-kcal meal	152	1000	33.2	9.8	21.8	37.9	3.25

CHO, Carbohydrate.

BCAA and in particular leucine may be helpful for attenuating loss of body weight and lean body mass.[128,156] (See review[157] for a full discussion of muscle wasting at altitude.)

As a practical matter, a powdered whey protein supplement rich in leucine would take up little room in the pack and might be useful to incorporate into the diet on days that eating to caloric demand is not possible. Excess leucine and other BCAAs ingested beyond those required for protein synthesis and cell-signaling roles would also serve a beneficial role as an alternate supply of glucose through their conversion by gluconeogenesis to glucose. Food sources of leucine include brown rice, beans, meat, nuts, soy flour, milk, and whole wheat, although these food products might not elevate plasma leucine levels efficiently if consumed in small quantities. Whey protein supplements high in leucine are more practical and commercially available in powdered (flavored and unflavored) and food bar form. Food bars containing whey protein are particularly convenient items to increase protein and leucine intakes throughout the day. Unflavored powdered whey protein can be added to other food preparations, such as stews, soups, or pemmican, to arrive at a high-protein, high-leucine food product. Some sports gels also have leucine and BCAA, but often the dose is fairly low. Recommended supplemental doses of leucine generally range from 2 to 3 g of leucine/day. Balage and Dardevet[19] summarized human clinical trials involving as much as 7.9 g of leucine supplement/day for up to 4 months without adverse effects. Gleeson[56] observed that acute intakes of BCAA supplements of as much as 10 to 30 g of BCAA were associated with no adverse effects. Table 87-4 provides a recipe and nutrient content for whey-fortified pemmican containing approximately 3 g of leucine per 1000 kcal compared with pemmican prepared without whey powder. Consistency of the pemmican can be varied as desired by adjusting the amount of melted fat added to the pemmican. The unflavored whey protein flavor is largely masked by the customary pemmican ingredients. It should be noted that pemmican itself, by virtue of its endogenous leucine content from the dried meat (jerky), is an excellent dietary source of leucine even before whey protein supplementation. Pemmican, aside from its concentrated calorie source and adaptability to various nutritional modifications, also has the added advantage of a favorable weight/volume consideration for packing for extended backpacking trips. Figure 87-5 shows a visual comparison of the volume of 1 day's ration of 4000 kcal from pemmican versus typical commercial dehydrated backpacking food products.

VITAMINS AND THEIR RELATIONSHIP TO HEALTH AND PHYSICAL PERFORMANCE

Vitamins are complex essential organic micronutrients that function in growth, maintenance, and metabolism. Vitamins act as coenzymes in metabolic reactions, and vitamins E and C and β-carotene (the precursor of vitamin A) act as protective antioxidants. Considerable oxidative stress may be experienced while working in environmental extremes.[7,11] High rates of energy expenditure, ultraviolet (UV) light exposure, and reduced dietary availability of foods containing antioxidants can cause excessive oxidative stress. Supplementing the diet with a vitamin and mineral mixture containing antioxidants to combat these stresses may be a more immediate concern than supplementation to prevent vitamin deficiencies (e.g., scurvy), which take a relatively long time to develop.

Prevention of vitamin deficiencies is one of the most misunderstood aspects of short- and long-range nutrition planning. Body stores of some vitamins (primarily the water-soluble vitamins) are limited, and under prolonged periods (i.e., weeks, not days) of dietary restriction, vitamin deficiencies can be manifested. This is rarely the case, however, for individuals consuming a mixed diet supplying close to the daily energy requirement. Although not routinely encountered, it is possible to develop a state of tissue depletion of thiamine, riboflavin, and pyridoxine in as short a time as 11 weeks by consuming a calorie-adequate, but vitamin-deficient, experimental diet composed of common food products.[149] Deficiencies of this nature do not develop over

FIGURE 87-5 Comparison of volume and weight of 1 day's selection of food (~4000 kcal) in the form of typical dehydrated backpacking food items, compared with a bar of pemmican (sugar packet shown for reference).

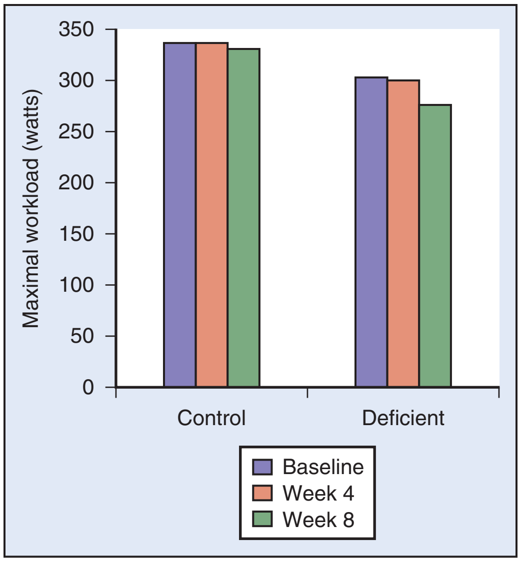

FIGURE 87-6 Impact of restricted vitamin intake on functional performance in humans. Experimental conditions: diet, 3070 kcal; thiamine, 28% RDA; riboflavin, 31% RDA; vitamin B_6, 16% RDA; vitamin C, 10% RDA. Performance test is workload achieved during incremental cycle ergometer testing. *(Data from van derBeek EJ, van Dokkum W, Schrijver J, et al: Thiamin, riboflavin, and vitamins B-6 and C: Impact of combined restricted intake on functional performance in man,* Am J Clin Nutr *48:1451, 1988; and van derBeek EJ, van Dokkum W, Wedel M, et al: Thiamin, riboflavin and vitamin B-6: Impact of restricted intake on physical performance in man,* J Am Coll Nutr *13:629, 1994.)*

the short term; they are not caused by a few days of suboptimal vitamin intake. Van der Beek and colleagues[148,149] studied the maintenance of human physical performance with varying degrees of vitamin restriction. Dietary vitamin deficiencies in persons consuming restricted vitamin intakes significantly less than the RDAs were manifested slowly, particularly in terms of physical performance impairments. Diets containing restricted intakes of thiamine (28% RDA), riboflavin (31% RDA), pyridoxal phosphate (16% RDA), and ascorbate (10% RDA) resulted in less than a 20% decrement in cycle ergometer performance (maximal workload) after 8 weeks at this level of restriction (Figure 87-6).

The relatively small change in performance decrements in response to vitamin restriction can be contrasted with more immediate effects of acute or long-term dietary carbohydrate restriction on physical performance. Manifestation of physical performance impairment is much more sensitive to the amount of carbohydrates in the diet in the short term (1 to 3 days) than it is to the vitamin, protein, or fat content of the diet (6 to 8 weeks).[2]

It can be generalized that development of a vitamin deficiency has four stages (Box 87-1), which involve a continuum of physiologic manifestations.

The possibility that certain nutrients (in particular, vitamins) might help people adapt to, or function more efficiently in, stressful environments has long intrigued explorers and scientists. Perhaps the most thorough study of the interaction between nutrients and the environment was conducted in the 1953 field study "Medical Nutrition Laboratory Army Winter Project: Vitamin Supplementation of Army Rations under Stress Conditions in a Cold Environment—The Pole Mountain Wyoming Study." The objective of this study was to determine if supplementation with large quantities of ascorbic acid and B-complex vitamins would influence the physical performance of soldiers engaged in high levels of physical activity in a cold environment, both with and without caloric restriction.[8] The investigators concluded that supplementing the mixed diet of men engaged in high levels of physical activity in the cold, with or without caloric restriction, did not result in significantly better physical performance.

Thus, it appears reasonable to conclude (at least from a performance standpoint) that vitamin supplementation in the wilderness environment is not nearly as critical as are total energy and carbohydrate provision. This does not mean, however, that dietary vitamin intakes should be ignored. Including a multivitamin and mineral supplement is a practical preventive measure, particularly in high-altitude environments, where considerable oxidative stress is induced. Box 87-2 summarizes conditions under which vitamin supplementation may be recommended.

BOX 87-1 Four Stages in the Development of a Vitamin Deficiency

1. Preliminary Stage
- Inadequate amount because of poor dietary patterns or altered availability in the diet.
- Commonly encountered after short-duration (<30 days) wilderness activities with poor nutritional planning.
- *Consequence*: None except danger of progressing to stage 2.

2. Biochemical Deficiency Stage
- The body's pool of the vitamin is decreased.
- May be encountered after long-term (>30 days) wilderness activities accompanied by suboptimal daily nutrient intakes.
- *Consequence*: Rates of enzyme catalyzed reactions may be slightly altered.

3. Physiologic or Subclinical Deficiency Stage
- Can be detected by functional tests.
- May be encountered after extended periods of consuming foods low in vitamins or periods of food restriction.
- *Consequence*: Performance may be impaired slightly.

4. Clinical Deficiency Stage
- Specific symptoms manifested; physical signs clinically detectable.
- May be encountered after starvation or extended periods of food deprivation.
- *Consequence*: Possible impairments of both health and performance.

Antioxidant Nutrients

Certain vitamins, such as vitamins E and C, may have important functions beyond their conventional essential roles, such as preventing degradation of the immune response, attenuating oxidative stress, and maintaining red blood cell flexibility and oxygen delivery under conditions of increased oxidative stress. In general, prolonged exposure to elevated levels of oxidative stress should be avoided because of its association with chronic disease and cellular organelle damage. In this context, it is worth noting that oxidative stress biomarkers are not only elevated while at altitude, but also can remain elevated for up to 3 days on return to sea level.[62] Although increased oxidative stress is a concern for prolonged sojourns at altitude,[11,62,99] little research can be found to support antioxidant supplementation to enhance performance or to lessen functional decrements (e.g., muscle fatigue) at altitude.[55,67] Consuming balanced meals that contain antioxidant nutrients should be adequate to control excessive free radical production because exercise itself leads to adaptations that suppress free radical production.[43] Because oxidative stressors may be encountered during wilderness activities, and because the quantity and antioxidant content of the foods are often uncertain, it seems prudent to include a multivitamin supplement with antioxidant properties among the food supplies. This nutritional

BOX 87-2 Conditions That Might Warrant Vitamin Supplementation

- Energy intake is below 1200 to 1600 kcal/day.
- Meals are routinely missed.
- Extremely poor or bizarre eating habits are practiced.
- Oxidative stressors (ultraviolet light exposure, high rates of energy expenditure, lack of fruits/vegetables in diet) are high.
- Under physiologic conditions requiring increased nutrient needs, such as pregnancy or lactation.

Supplement Facts

Serving Size 1 softgel

Amount Per Softgel	% Daily Value
Vitamin A 10,000 I.U. 100% as Beta Carotene	200%
Vitamin C 250 mg	417%
Vitamin E 200 I.U.	667%
Zinc 7.5 mg	50%
Selenium 15 mcg	21%
Copper 1 mg	50%
Manganese 1.5 mg	75%

FIGURE 87-7 Antioxidant supplements can contain a variety of nutrient components designed to act as sacrificial antioxidants (e.g., vitamin C) or as cofactors in antioxidant enzyme systems (e.g., selenium). The supplement shown is typical of many basic antioxidant formulations containing vitamin and mineral antioxidant components. *(Copyright 2007 by Mosby, Inc., an affiliate of Elsevier Inc.)*

insurance is inexpensive and takes up little space. Figure 87-7 shows the composition of a typical antioxidant vitamin and mineral supplement. A popular alternative to the typical antioxidant supplement is a food (fruit and/or vegetable)–based extract (Figure 87-8).

MINERAL SUPPLEMENTS: ELECTROLYTES, HEMATOPOIESIS, AND BONE HEALTH

The mineral content of the diet is usually not a primary concern, provided that a mixed diet that meets energy requirements is consumed daily. Supplemental calcium and iron are considerations for female travelers, as discussed in the next section. Sodium in hot environments is an exception, because it is lost during activities producing excessive sweating (see Chapter 89). Hyponatremia can occasionally be encountered in unanticipated scenarios such as a cold environment.[160] With appropriate acclimatization to heat (and resultant renal sodium conservation), the amount of sodium required in the diet for work in the heat is reduced. Laboratory studies have shown that heat acclimatization

Supplement Facts

Serving Size 1 Capsule

	Amount Per Serving	% Daily Value
Acai Berry Extract (Euterpe oleracea) (standardized to 10% phenolic acid)	125 mg	-
Noni Fruit Extract 8:1 (Morinda citrifolia)	125 mg	-
Pomegranate Fruit Extract 5:1 (Punica granatum)	125 mg	-
Wolfberry (goji) Fruit (Lycium barbarum) (freeze-dried concentrate typically containing 60% polysaccharides)	125 mg	-
Mangosteen (Garcinia mangostana) (fruit)	125 mg	-

*Daily Value not established.

Supplement Facts

Serving Size 1 Tablet

	Amount Per Tablet	% Daily Value
Vitamin C (as ascorbic acid)	100 mg	167%
Resveratrol (from 200 mg Polygonum cuspidatum 8% total resveratrols) (Tiger cane)	16 mg	-
Grape Seed Extract (Vitis vinifera) (95% polyphenols)	50 mg	-
Grape Skin Extract (Ancellota lambrusco) (30% polyphenols)	100 mg	-
Green Tea 5:1 Extract (Carmellia sinensis) (45% polyphenolics)	200 mg	-

*Daily Value not established.

FIGURE 87-8 Examples of phytochemical antioxidant supplements containing naturally occurring polyphenols that can be effective free radical quenchers. Many of these fruit- or vegetable-extract antioxidant formulations can have higher ORAC (oxygen radical absorption capacity) values than do conventional vitamin/mineral antioxidant supplements.

can occur when as little as 4 to 8 g of salt (NaCl) is ingested per day.[1] The amount of NaCl required for safe work in the heat depends on the degree of prior heat acclimatization and amount of sweat loss.

Altered dietary patterns or excessive sweating can influence sodium balance. Starvation can lead to plasma volume depletion when sodium in the circulation is insufficient to allow osmotic forces to retain water.[65] When nonacclimatized humans are exposed simultaneously to acute food restriction and high sweat rates, the resulting excessive loss of sodium can lead to dizziness, syncope, and collapse. These problems can be avoided by ensuring that extra salt is included in the food provisions for wilderness expeditions and that salt is available to season food during and after high sweat losses.

Another form of sodium deficit is dilutional hyponatremia caused by overhydration with fluids in conjunction with lower-than-normal sodium intake or excessive sodium loss in sweat. Hyponatremia caused by overconsumption of fluids is extremely rare when regular meals are consumed. Hyponatremia is a complication of overhydration in wilderness environments where food is neglected and water overzealously emphasized. It has been described for hot,[16,17] cold,[160] and high-altitude[140] environments. Calorie deprivation can alter sodium intake. In addition to reduced intake of sodium with food, severe caloric restriction leads to marked natriuresis.[114] Increased loss of sodium in turn leads to depletion of fluid volume, impaired cardiovascular function, and reduced work capacity, further exacerbating the effects of energy restriction. Increased aldosterone levels in response to reduced plasma volume can also lead to accelerated potassium wasting.[114]

For insurance and safety considerations, include 5 g (about two typical restaurant serving packets) of table salt for every day in the field packed with the food supplies. If necessary for fluid replacement after excessive sweating, this extra salt can be used to make a dilute electrolyte beverage by adding 0.5 tsp (2 to 3 g salt) to 1 qt of water. Excess sodium should be avoided because its excretion increases metabolic water demands.[5]

SPECIAL NUTRITIONAL REQUIREMENTS FOR FEMALE WILDERNESS TRAVELERS

Although our understanding of the differences between male and female nutritional requirements is incomplete, gender differences exist for certain nutrients, such as iron, calcium, folate, and vitamin B_6, under normal environmental living conditions.[102] Differences are particularly notable for women using oral contraceptives[93] and those who are pregnant or lactating.[34] The health implications for pregnant travelers planning a trip to altitude are beyond the scope of this chapter; they should consult a knowledgeable pediatrician or obstetrician.

Investigations of nutritional requirements at environmental extremes have been conducted on men, but comparatively little research has been directed toward women. The few studies that have been done suggest that dietary nutrient intakes of women at moderate altitude are similar to those at sea level,[77] implying that specific gender requirements that exist at sea level may be even more important at altitude, particularly if there is scarcity of nutrient-dense foods or if appetite is blunted. Some gender-specific nutrient requirements are known. For example, research in the late 1960s found that female military service members deployed to locations at moderate to high altitude required supplemental dietary iron for optimal support of the hematopoietic response to hypoxia.[60] Subsequently, research on iron requirements and the thermogenic response to cold have also identified iron as a key micronutrient for women in cold environments.[21,89] Because of their smaller body size, women usually consume fewer total food calories than men and thus are at increased risk for reduced vitamin and mineral intake. Fortunately, the need for these vitamins and minerals (with the exception of iron) is related to lean body mass, and women usually have a lower lean body mass than men.

Because the choice of available foods may be limited during expeditions into the wilderness, female travelers should include a multivitamin supplement in their provisions. It should contain

Supplement Facts
Serving Size 1 tablet

Amount Per Tablet	% Daily Value	Amount Per Tablet	% Daily Value
Vitamin A 3,000 I.U.	100%	Iodine 150 mcg	100%
Vitamin C 120 mg	200%	Magnesium 100 mg	25%
Vitamin D 400 I.U.	100%	Zinc 15 mg	100%
Vitamin E 50 I.U.	167%	Selenium 25 mcg	36%
Vitamin K 100 mcg	31%	Copper 2 mg	100%
Thiamin 1.5 mg	100%	Maganese 2 mg	100%
Riboflavin 1.7 mg	100%	Chromium 120 mcg	100%
Niacin 20 mg	100%	Molybdenum 25 mcg	33%
Vitamin B6 2 mg	100%	Chloride 36 mg	1%
Folic Acid 400 mcg	100%	Potassium 40 mg	1%
Vitamin B12 6 mcg	100%	Boron 150 mcg	*
Biotin 30 mcg	10%	Nickel 5 mcg	*
Pantothenic Acid 10 mg	100%	Silicon 2 mg	*
Calcium 250 mg	10%	Tin 10 mcg	*
Iron 18 mg	50%	Vanadium 10 mcg	*
Phosphorus 77 mg	8%	Lutein 250 mcg	*

*Daily Value (DV) not established

10-02

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1. **% of the Daily Value:** The amount of the nutrient recommended for one person for one day based upon a daily energy requirement of 2000-2500 kcal. The DV is a simplification of the RDA; it doesn't take into account age and gender.
2. **Serving size:** The number of tablets needed to reach the % DV on the label.
3. **Scientific units:** Quantitative amount of the nutrient per tablet. May be in international units (IU), mg, or mcg. For example, 1 IU of Vitamin A activity would be equivalent to 0.3 g retinol or 6 mcg of beta carotene.
4. ***(no DV available):** Necessary (essential) nutrients for which quantitative guidelines have not been established.
5. **Expiration date:** After this date the supplement may contain somewhat less than the amount shown on the label.
6. **Lot number:** For tracking specific supplement batches.
7. **Suggested use:** Directions for usage.
8. **Warning alerts:** Potential adverse effects.
9. **Quality statements:** Consumer assurance that product meets quality standards.
10. **Dietary Supplement Verification Program:** The United States Pharmacopeia (USP) assurance that product contains what is stated on the label.

No Artificial Colors * No Artificial Flavors * No Preservatives * No Chemical Solvents or Yeast
SUGGESTED USE: Take one tablet daily with a meal. Keep bottle tightly closed.
Store in a cool, dry place.

Do not use if imprinted seal under cap is broken or missing.

WARNING: Accidental overdose of iron-containing products is a leading cause of fatal poisoning in children under 6. Keep this product out of reach of children. In case of accidental overdose, call a doctor or poison control center immediately.

DIETARY SUPPLEMENT USP VERIFIED

AMERICAN MEDICAL AMA ACCEPTED

Essential Balance tablets made to Nature Made's guaranteed purity and potency standards.

FIGURE 87-9 Annotated multivitamin and mineral supplement label showing some key components and pertinent information. Nutrients are expressed as a percentage of the daily value (DV), which is the amount of nutrients recommended for daily consumption by most adults needing 2000 to 2500 kcal/day.

at least 50% of the female RDA for iron, zinc, folate, vitamin B_6, and calcium. Antioxidant nutrients (see Vitamins and Their Relationship to Health and Physical Performance, earlier), including extra vitamins C and E and perhaps certain carotenoids, such as lutein and zeaxanthin, provide additional insurance against oxidative stress. Figure 87-9 shows the composition of a typical multivitamin and mineral supplement. The values shown reflect the daily value (DV) of the nutrients, that is, the recommended daily amount for most adults needing 2000 to 2500 kcal/day.

Multivitamins often contain relatively low amounts of calcium compared with the female RDA of 1000 to 1300 mg/day, so it may be beneficial for female travelers to include an additional bioavailable calcium supplement containing 250 to 500 mg of calcium per dose. Commercially available chocolate- or caramel-flavored calcium "chews" are convenient and contain a small amount of carbohydrate, as well as "bone-friendly" nutrients such as vitamins D and K. The U.S. RDA for calcium intake for adults younger than 50 is 1000 mg daily, and people older than 50 should ingest 1200 mg daily. Calcium supplements are best taken in small (no more than 500 mg) divided doses throughout the day. If an iron supplement is being taken in a multivitamin or by itself, it is best not to take it at the same time as the calcium supplement, because absorption of each is unpredictable and may be less than optimal in the presence of the other.[122] If an individual is traveling to high altitude, it is recommended that serum ferritin be measured to determine iron status. If iron status is low, supplementation should be implemented before departure.

Nutrients in a vitamin-mineral supplement should be close to the DV level (≤100%). This ensures adequate intake of major micronutrients with minimal risk of adverse nutrient interactions. Synthetic vitamins are structurally the same as, and cost less than, so-called natural vitamins, with the exception of vitamin E. Generic brands are also generally less expensive and equally effective. Addition of herbs, enzymes, or amino acids accomplishes little but adds cost. Some supplements containing phytonutrients extracted from plants may be appropriate when the logistics of the trip offer little or no chance to secure fresh fruits and vegetables. A source of information on vitamin and mineral supplements is ConsumerLab, which provides independent test results and information to help consumers and health care professionals evaluate health, wellness, and nutrition products. The results of its tests, including brands that have passed testing, are available at www.consumerlab.com.

Supplements can lose potency over time, so check the expiration date on the label. Figure 87-9 provides guidance for reading and interpreting supplement labels. The initials USP (for the testing organization U.S. Pharmacopeia) or words such as "release assured" or "proven release" indicate that the supplement is easily dissolved and absorbed.

NUTRITIONAL DEPRIVATION: MALNUTRITION AND STARVATION

DEFINITIONS

There is little uniformity in the terminology used to describe the physiology of human starvation. Hoffer[65] has suggested the following definitions:

Fasting: Total absence of food intake.

Starvation: Physiologic condition that develops when macronutrient content is inadequate for a prolonged period.

Semistarvation or food restriction: The more commonly encountered condition of some food intake, but of insufficient energy and protein provision.

Malnutrition: General term for the condition resulting from long-standing inadequate consumption of nutrients, abnormal absorption of nutrients, or unusual demands on certain nutrients; usually involves suboptimal food intake or consumption of food of poor nutrient density, resulting in micronutrient and macronutrient deficiencies.

Protein-energy malnutrition (PEM): Result of inadequate intake of energy, protein, or both for prolonged periods. Two related types of PEM are *marasmus* (primarily energy deficiency) and *kwashiorkor* (primarily protein deficiency). Both forms occur across a spectrum of situational and environmental conditions and exhibit many of the same symptoms. PEM is frequently a consequence of starvation, but all starvation does not necessarily lead to PEM. Development of PEM depends on body energy reserves, length of the fast, age, and presence or absence of disease. PEM is unlikely to be encountered by most wilderness travelers; a possible exception is within indigenous populations in certain Third World locations. When malnourished indigenous people are encountered in wilderness travels, caution should be exercised about sharing food. These individuals may not be accustomed to ingesting large quantities of food replete with sodium, and there may be consequences to overeating (see Feeding Victims of Starvation, later).

Cachexia: Wasting that results from metabolic stress and loss of appetite. It is sometimes called *cytokine-induced malnutrition* to distinguish it from simple food deprivation in the absence of stress. Inanition of advanced-stage cancer patients is an example of cachexia.

MALNUTRITION IN A WILDERNESS SETTING

This discussion is limited to the metabolic and physiologic consequences of starvation or energy restriction that might be encountered in wilderness settings, including unplanned emergencies that result in shortage of food, and wilderness rescue operations of victims of unintentional starvation. In these settings, duration of food restriction is usually, but not always,[129] of shorter duration than that associated with hunger encountered during famine, war, crop failure, and disease.

Solomons[139] has stated that malnutrition simply means "bad" nutrition and has listed six possible causes of nutrient deficiencies leading to malnutrition: reduced intake, decreased absorption, decreased utilization, increased destruction, increased wastage, and increased requirement. Primary malnutrition is caused by reduced intake of food. This is the most frequently encountered cause of malnutrition in wilderness settings. Reduced food intake, along with increased nutrient requirements, can contribute to development of nutrient deficiencies during expeditions under extreme environmental conditions. Secondary causes of nutrient deficiencies are less frequently encountered but can contribute significantly if disease or illness strikes the wilderness traveler.

Malnutrition develops in stages that usually require considerable time to manifest. As seen in cases of vitamin deficiency, the first changes reflect diminished dietary intake, with resultant reduced blood and tissue levels of nutrients, followed by intracellular changes in biochemical functions. Eventually, if the malnutrition is unrelieved, physical symptoms develop. These effects can include oral lesions, rashes, petechial hemorrhages, ecchymoses, pigmentation changes, and edema. People who undergo prolonged semistarvation experience hunger, weakness, lack of drive, mood changes, osteoporosis, hypoalbuminemia, edema, decreased muscle mass, alopecia, hypotension, and poor wound healing. Impaired immune function, decreased resistance to infection, and prolonged recovery from injury are all consequences of long-term food restriction.[35,51,80,132,133]

STARVATION

Starvation is the physical condition brought about by inadequate consumption, absorption, or retention of protein and dietary energy from carbohydrate and fat.[66] Starvation can be acute or chronic, as well as total or partial. Different forms of starvation are similar but not identical. Starvation can result from disease or simply from lack of food. It can ultimately manifest as a disease (PEM) or, if not prolonged, as nonpathologic weight reduction. The metabolic adaptations that occur in the progression of starvation depend on whether there is acute energy restriction or chronic undernourishment as a result of long-term low-energy intake.[131]

Acute Energy Restriction

The rapid progression of events that occur in response to acute energy inadequacy (e.g., a 50% shortfall of food during the second week of a 2-week backpacking trip) is shown in the first three steps in Figure 87-10. The body reacts quickly to energy shortage by utilizing readily available muscle and liver glycogen stores. Progression to the final steps of organ decompensation and death would be encountered only after complete starvation for several weeks. Following food restriction when the body's carbohydrate stores have been depleted, glucagon level rises, insulin level falls, and the process of gluconeogenesis accelerates, converting noncarbohydrate precursors, such as lactate, glycerol, and amino acids, to glucose in order to maintain blood glucose level and prevent hypoglycemia (Figure 87-11).

These metabolic principles are expressed in more detail in Figures 87-12 and 87-13. Data used to prepare this classic scheme of carbon flux during starvation are based largely on the work of Cahill,[31] who studied metabolic aspects of starvation in humans. Reduction in carbohydrate intake and resultant reduced glucose provision during food restriction is in large part compensated for by accelerated gluconeogenesis. The carbon skeletons of 100 g of protein from endogenous tissue sources can ultimately provide approximately 55 g of carbohydrate after metabolic transformations. The glycerol from 100 g of mobilized fat can yield 10 to 15 g of carbohydrate by gluconeogenesis.[29] As glycogen is depleted, catecholamine production rises simultaneously, facilitating fatty acid mobilization from adipose depots. Once mobilized, fatty acids are taken up by muscle in proportion to their concentration in blood and are oxidized for energy. The

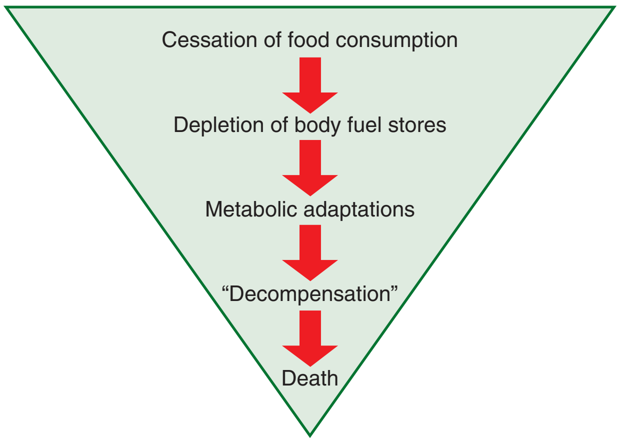

FIGURE 87-10 Sequence of events during prolonged starvation. If the fast is not terminated and energy reserves are depleted, internal organ systems ultimately used for energy will fail (decompensation), resulting in death. *(Copyright 2007 by Mosby, Inc., an affiliate of Elsevier Inc.)*

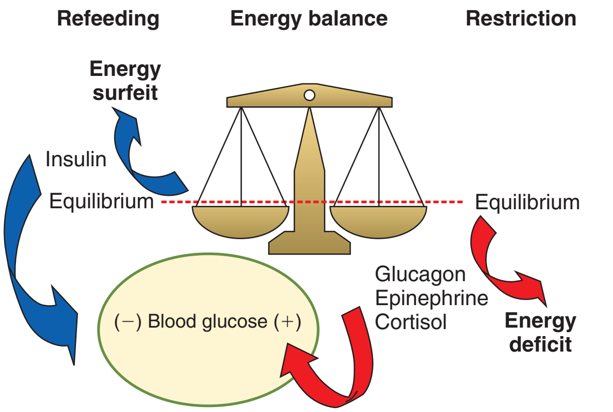

FIGURE 87-11 Influence of energy balance on hormonal control of blood glucose. When food is consumed after ingestion, insulin is released, lowering blood glucose. When no food is consumed and blood glucose drops, gluconeogenic hormones are released, and endogenous sources are used to raise blood glucose levels. *(Copyright 2007 by Mosby, Inc., an affiliate of Elsevier Inc.)*

metabolic events of a short-term fast are shown in Figure 87-12. The major difference between short- and long-term fasts is in the shift of carbon source for energy production. As the duration of the fast increases, the amount of glucose oxidized decreases and the amount of ketone bodies oxidized increases.

Long-Term Energy Restriction

Prolonged fasting is characterized initially by increased protein catabolism for gluconeogenesis, followed by increased production of ketone bodies as a consequence of fat mobilization for energy demands. A fast longer than 2 to 3 days exhausts liver glycogen and uses up about half the muscle glycogen stores.[65] Thereafter, glucose utilized by the body (in the absence of food consumption) must be synthesized from endogenous precursors through gluconeogenesis. The appearance of large amounts of ketone bodies in the blood, breath, and urine results from a low insulin-to-glucagon ratio accompanying a prolonged fast and massive fatty acid mobilization from adipose tissue.

Ketone bodies are a metabolic consequence of vigorous fatty acid oxidation engendered by starvation in the absence of significant carbohydrate intake. Production of acetoacetate and β-hydroxybutyrate increases significantly during the first 7 to 10 days of fasting and stabilizes after 2 to 3 weeks.[24] Ketone bodies can be increasingly used for energy by muscle and brain as energy restriction becomes prolonged. Even a short-term fast elicits significant production of ketone bodies (see Figure 87-12); however, ketone body production may be virtually abolished if a minimum of 150 g of carbohydrate is ingested daily to supply the brain with glucose for energy.[29,65] Normally, in the fed state, ketone body oxidation accounts for provision of less than 3% of the total energy requirement. Longer periods (7 to 10 days) of fasting are accompanied by a greatly increased level of circulating ketone bodies, which can provide as much as 40% of the total energy expenditure and greater than 50% of the brain's energy requirement.[29,65] The switch to using ketone bodies for energy in the brain is believed to be controlled by the concentration of ketone bodies in the blood rather than being a direct hormonal effect on the brain.[24] Metabolic changes during a long-term (e.g., a 30-day) fast are depicted in Figure 87-13.

With increasing duration of the fast and depletion of muscle and liver glycogen, ketones and glucose derived from gluconeogenesis from amino acid carbon skeletons contribute to energy requirements of the brain. As starvation is prolonged and ketone bodies become the predominant fuel, less and less glucose is used, thereby reducing the amount of protein that must be catabolized to support gluconeogenesis. Blood levels of BCAAs (leucine, isoleucine, valine), which are preferred amino acid substrates for muscle energy metabolism, double by 3 to 5 days of fasting but fall during prolonged fasting. These BCAAs are believed to augment gluconeogenesis until fat metabolism has adapted to fasting.[24] The amino acid glutamine has special importance during fasting. It assumes the roles of energy source as a precursor of glucose and as a transporter of amino acid nitrogen in the form of ammonia (NH_3) from tissues to the kidneys for excretion. Urea is the major nitrogen excretory product in the urine during the fed state, but it becomes much reduced as the

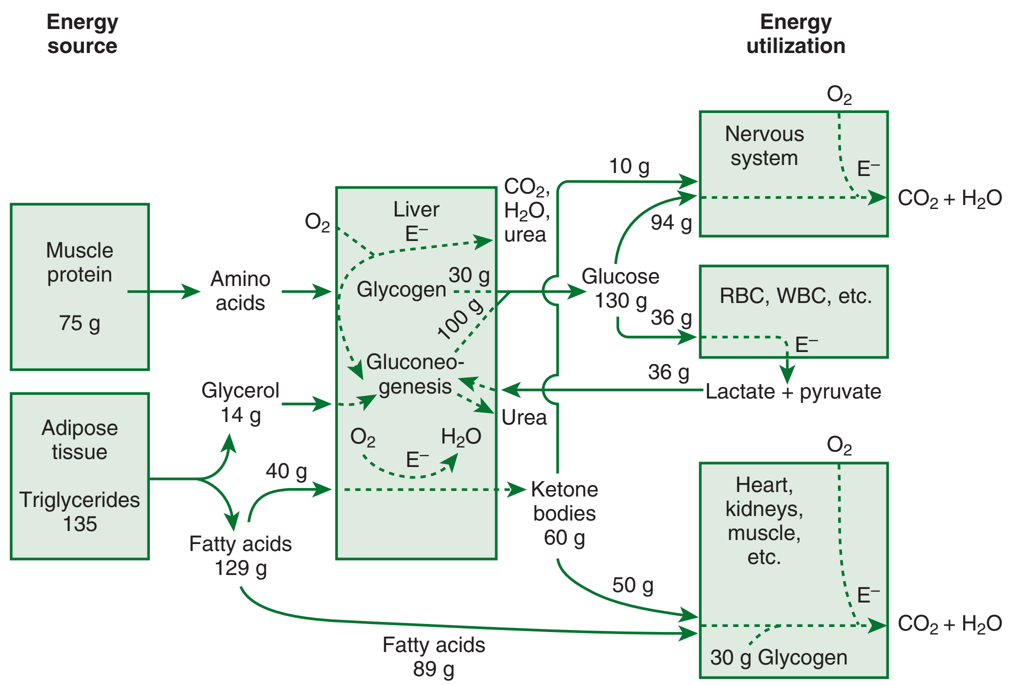

FIGURE 87-12 Fuel utilization in short-term starvation. Metabolic rates in grams per day after a 24-hour fast. Energy expenditure, 1800 kcal/day (7.53 MJ/day); respiratory quotient, 0.76. *E⁻*, Oxidative formation of energy (ATP). *(Original data from Cahill GF Jr: Starvation in man,* N Engl J Med *282:668, 1970. Algorithm redrawn from Bursztein S, Elwyn DH, Askanazi J, Kinney JM:* Energy metabolism, indirect calorimetry, and nutrition, *Baltimore, 1989, Lippincott Williams & Wilkins.)*

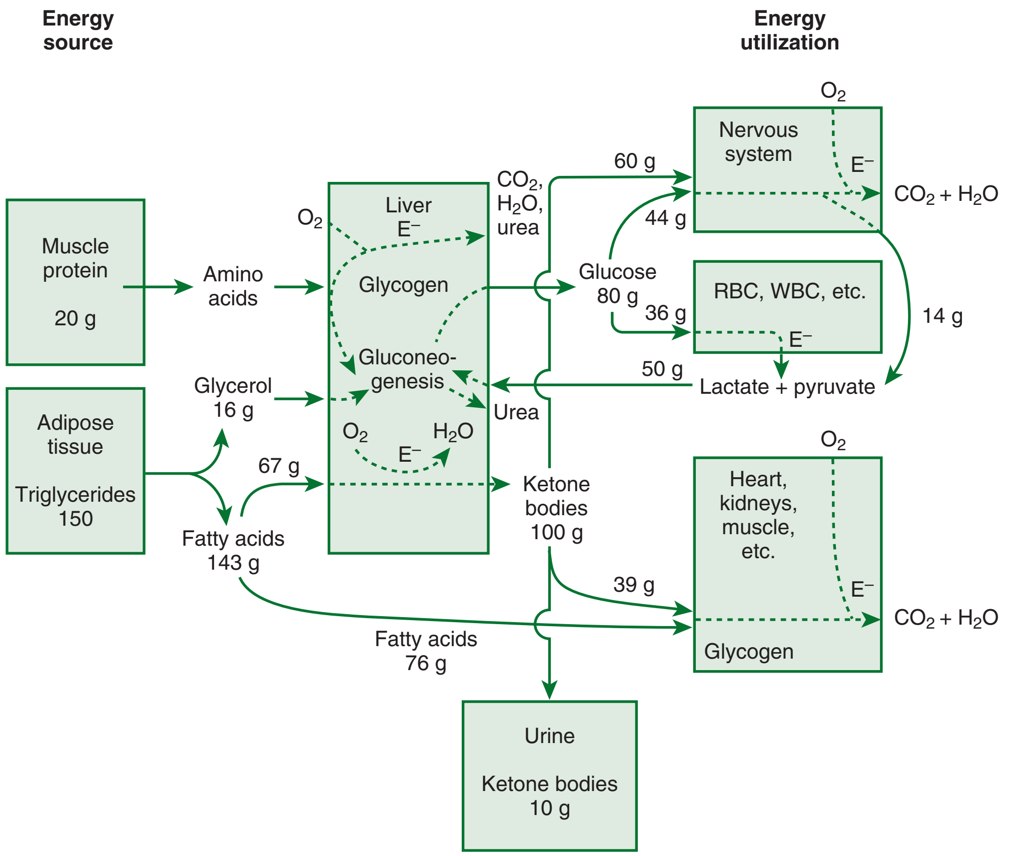

FIGURE 87-13 Fuel utilization in long-term starvation. Metabolic rates in grams per day after a prolonged fast of 5 to 6 weeks. Energy expenditure, 1450 kcal/day (6.07 MJ/day); respiratory quotient, 0.74. *E*⁻, Oxidative formation of energy (ATP). *(Original data from Cahill GF Jr: Starvation in man,* N Engl J Med *282:668, 1970. Algorithm redrawn from Bursztein S, Elwyn DH, Askanazi J, Kinney JM:* Energy metabolism, indirect calorimetry, and nutrition, *Baltimore, 1989, Lippincott Williams & Wilkins.)*

fast progresses and ammonia nitrogen increases. The increase in ammonia nitrogen serves to buffer ketoacids during their excretion via the urine, as well provides an excretory route for nitrogen. Glutamine is released from muscle during fasting (NH_3 formed from amino acid deamination by muscle is subsequently transaminated to glutamate to form glutamine) and serves as both a special energy source for the gut and a gluconeogenic substrate for the kidney. With increasing ketone body production, the liver reduces its rate of gluconeogenesis, and the kidney becomes the major organ of gluconeogenesis, producing more than one-half the body's glucose requirement.[24] Glutamine is the predominant substrate for kidney gluconeogenesis and provides the NH_3 required to buffer ketoacid excretion produced by ketogenesis from fat oxidation.[24]

Fortunately, muscle proteolysis does not continue at the typically high initial rate of negative nitrogen balances (10 to 12 g/day during the first 7 to 10 days of fasting). After 7 to 10 days of fasting, adaptation in the nitrogen economy of the body reduces nitrogen loss in the urine to less than one-half the initial rate.[65] Although the signal that causes muscle to reduce its catabolic rate is not well understood, it is probably related to the shift to ketone body utilization in the brain and to fatty acid oxidation in muscle during this same period. When adaptation to food restriction is not successful or food restriction is too severe, nitrogen can be lost from both central (visceral) and peripheral (skeletal muscle) sites. Development of central protein deficiency can lead to anergy and hypoalbuminemia. Reduced plasma albumin lowers plasma oncotic pressure, which permits fluid to migrate out of the vessels into the extracellular space, resulting in edema of the extremities. Edema is not present in all cases of starvation, but the presence of edema indicates severe metabolic stress and central protein deficiency and is a potentially dangerous condition.[65]

The net result of short- and long-term metabolic adaptations in energy restriction is increased efficiency of the body's metabolism. When body weight decreases 8% to 10% over a 14-day period, basal metabolic rate (BMR) can decrease about 21%. This short-term decrease in BMR is greater than would be predicted if it were caused solely by the loss of metabolically active lean tissue mass. Reduction in BMR during energy restriction occurs in two different phases.[24] Initially, there is decrease in BMR not attributable to changes in body weight or body composition. This is presumably an attempt by the body to conserve energy by increasing its metabolic efficiency despite reduced energy intake. Then, with continued energy restriction, BMR decreases further because of loss of metabolically active tissue. Several physiologic mechanisms operate to downregulate metabolic activity in the active tissue mass and to increase its metabolic efficiency. The decreased energy flux reduces activity of the sympathetic nervous system and lowers secretion and activity of three thermogenic hormones: catecholamines, T_3 (triiodothyronine), and insulin. Other energy-requiring activities, such as the sodium-potassium pump and futile metabolic cycling (e.g., phosphorylating and dephosphorylating metabolic intermediates), may also be reduced during starvation, further conserving energy.

HIERARCHY OF TISSUE UTILIZATION DURING STARVATION

There is a hierarchy of fuel source utilization during starvation. During an extended period of fasting, the mass of muscle and adipose tissue is more likely to be reduced than that of the viscera.[131] Important internal organs, such as the liver, show no evidence of dysfunction after 7 days of fasting,[126] whereas muscle cell mass decreases linearly with severity and duration of a fast.[131] Adipose mass decreases along with muscle, but not as rapidly

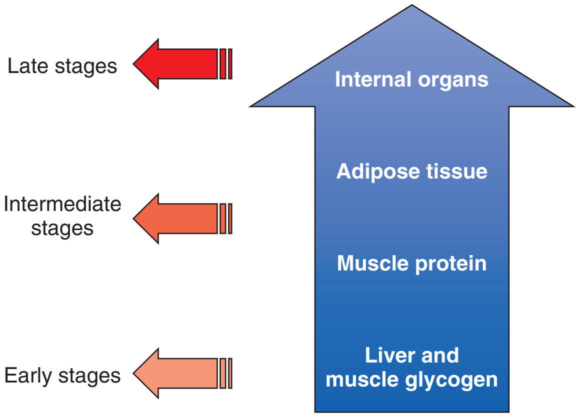

FIGURE 87-14 Energy sources during progressive stages of starvation. Note the hierarchy of the progression of utilization of energy sources.

initially, because of the caloric density of the energy of the fat depot and low amount of associated water. Hoffer[66] has estimated that during a typical 3-week fast that elicits a weight loss of 350 g/day, the shed tissues are composed of approximately 125 g of lean tissue and 200 g of adipose tissue. The body defends a certain amount of body fat as essential for nerve sheath insulation, brain neurolipids, cell membrane integrity, and hormone synthesis. Figure 87-14 shows the general hierarchy of energy-source utilization during progressive starvation.

The largest energy reserves are found in the largest organs of the body: muscle (~28 kg) and adipose tissue (~15 kg). Critical internal organs, such as the liver, brain, heart, and kidneys, have a collective mass of less than 9 kg and are not good fuel-source candidates, because they begin to lose critical functions when they become energy sources during starvation (decompensation). Table 87-5 shows the body reserves that can be drawn on for energy during fasting for a sedentary 70-kg (154-lb) man.

SEQUENCE OF EVENTS DURING STARVATION

Sex hormone synthesis is depressed during extended periods of food restriction,[51,52] because reproduction is not a high priority during starvation. As the fast progresses, eventually even visceral organs begin to be used for energy as the body decompensates or "feeds on itself." During a prolonged fast, the body initially undergoes the series of events depicted in Figure 87-15.[24] The initial steps are similar to those of short-term energy deficiency (see Figure 87-10), but if starvation continues, metabolic adaptations ultimately fail, leading to a grim conclusion: the body has expended its reserves and enters the decomposition, or final stage, of metabolic self-destruction. Organ failure and death are the ultimate outcomes of starvation unless nutritional intervention occurs before decompensation (internal organ catabolism, loss of integration of function of bodily systems, and deterioration of homeostasis).

TABLE 87-5 Utilizable Energy Stores in a Sedentary 70-kg (154-lb) Man

Energy Source	Mass (kg)	Energy (kJ)
Fat	15	590
Protein (muscle)	6	100
Glycogen (muscle)	0.15	2.51
Glycogen (liver)	0.075	1.25
Plasma glucose	0.020	0.33
Plasma free fatty acids	0.0003	0.012
Plasma triglycerides	0.003	0.125

Data from Cahill GF Jr: Starvation in man, *N Engl J Med* 282:668, 1970.

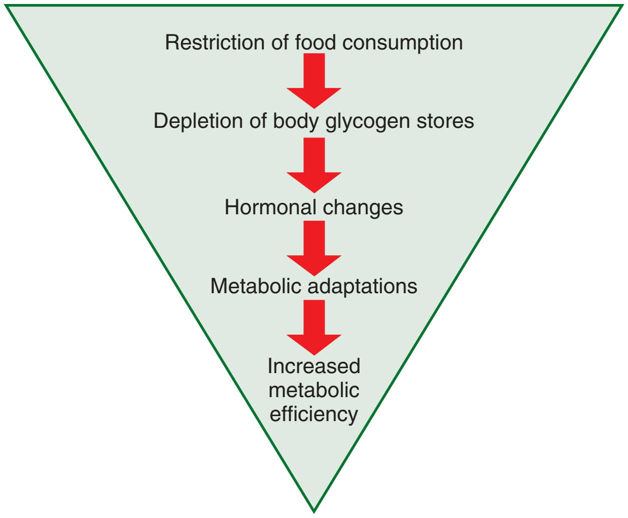

FIGURE 87-15 Sequence of metabolic events during short-term energy restriction or starvation. In the short term, metabolic efficiency increases to compensate for an energy deficit.

THE LIMITS OF HUMAN STARVATION AND FACTORS INFLUENCING SURVIVAL

There were horrific changes in my body. My buttocks were bones jutting against skin. I could no longer warm my hands by nestling them between my thighs. Now I could push a clenched fist between my legs without touching either thigh. I continually felt nauseated. The nausea became so severe I retched uncontrollably. This went on night after night. Death was closing in. My body was conceding defeat.

James Scott's observations near the end of a 43-day period of starvation while lost in the Himalayas[129]

Loss of Fat and Lean Body Mass

The body fat of humans can be considered beneficial when viewed in the context of surviving starvation.[87] A decreasing level of body fat approaching 6% loss is a harbinger of impending lean body mass deterioration in the fasting individual.[3,87] Essential fat stores (in bone marrow, heart, lungs, liver, kidneys, intestine, muscle, cell membranes, and central nervous system) are necessary for maintenance of life and prevention of decompensation. Essential fat stores constitute 3% to 4% of body weight.[109] Total body fat depletion in previously nonobese individuals occurs at approximately 50% body weight loss. In fasting uncomplicated by disease, the time until death is largely determined by the size of fat stores and the time to reach the 3% level of essential fat. Fat stores protect function.[109] Low fat stores per se are not the cause of death, but their diminution contributes to breakdown of homeostasis and impairment of physiologic function. Typical fat stores in humans vary but are typically between 10 and 15 kg (including 2.1 kg of essential fat), or approximately 27% of body weight. A well-nourished adult has sufficient fat energy stores to sustain life for 60 to 70 days. Death has been reported sooner in voluntary hunger strikers and may be related to simultaneous fluid restriction and lack of the will to live. A loss of greater than 50% of the lean body mass is also predictive of death. From a practical standpoint, the remaining body fat and protein reserves in a starving individual are difficult to measure accurately. A more practical measurement is the body mass index (BMI), calculated as body weight (kg)/height^2 (m^2). BMI is easy to obtain and a convenient method to assess risk of mortality in severely starved individuals. Before the war and famine in Somalia, the lowest BMI compatible with life was thought to be 13 in males and 11 in females.[63] Collins[37] collected data at Baidoa, Somalia in 1992 at the Concern Worldwide Adult Therapeutic Centre, where many victims of starvation were treated. He found that a BMI of 10

TABLE 87-6 Demographics and Mortality Rates in the Donner Party, 1846-1847

	Frequency: *N* (%)	Mortality Rate: *n/N* (%)
Total party	90 (100)	42/90 (47)
Age (yr)		
<5	19 (21)	11/19 (58)
6-14	21 (23)	2/21 (10)
15-34	34 (38)	16/34 (47)
>35	14 (16)	11/14 (79)
Gender		
Male	55 (61)	32/55 (58)
Female	35 (39)	10/35 (29)

Data from McCurdy SA: Epidemiology of disaster: The Donner party, *West J Med* 160:338, 1994.

could be compatible with life under conditions of specialized hospital care, possibly explained by somatotype and the warm climate. However, other races in colder climates may face death before reaching the low BMI level noted in Somalia.[37]

Age and Gender Differences in Survival From Starvation

Persons possessing the most limited body reserves, such as older adults and very young children, are at increased risk for early mortality during extended periods of starvation. Children have increased nutrient requirements for growth and develop deficiency symptoms rapidly when faced with severe food restriction.

Starving women have not been studied in the same controlled manner as men. However, observational evidence of unintentional situational starvation involving both men and women seems to indicate that women may possess certain metabolic or cultural advantages over men, which may lead to a reduced incidence of mortality from severe starvation. Such evidence comes from wartime and famine, when there has been disproportionate survival of women over men.[50,109] Although situational circumstances have been suggested to account for these differences, studies of the Mormon handcart trek[20] and the Donner party[143] support the conclusion that women are at lower risk for mortality under nutritionally stressful situations. McCurdy[96] examined the mortality pattern in the Donner party, which became trapped with inadequate food supplies in the Sierra Nevada Mountains during the winter of 1846-1847. The demographic mortality data derived by McCurdy indicate that in general, very young children and males had the highest risk for mortality during starvation (Table 87-6).

The influence of gender on starvation may be attributable, at least in part, to certain metabolic advantages possessed by women, such as a higher initial level of body fat and subsequent reduced loss of protein and lean body mass during fasting. Lowell and Goodman[87] proposed that protein sparing in skeletal muscle during prolonged starvation depends on availability of lipid fuels that may provide energy and attenuate the rise in catabolic hormones during starvation. They also suggest that fatty acids may specifically modulate breakdown of myofibrillar protein, independent of their oxidation as a fuel, thus causing a direct muscle-sparing effect during prolonged starvation. Other factors may contribute. Women generally have lower body mass and less lean body mass to maintain than do men, as well as more subcutaneous fat, which may have insulation value during cold exposure. Gender-related cultural behavior, such as performance of strenuous and high-risk tasks (e.g., the men usually pulled the handcarts during the Mormon pioneer trek west from Missouri to Utah), may also play an important role.

FEEDING VICTIMS OF STARVATION

With modern sophisticated means of communication, highly trained search and rescue teams, and air evacuation resources, rescue of a lost or injured person in a wilderness environment usually is relatively rapid. One study reported that 50% of search and rescue missions were completed within 3 hours, 81% within 12 hours, and 93% within 24 hours.[79] Whereas the rescue of the starving Donner party from the Sierra Mountains in 1847 took 4 months,[96] evacuation of the nutritionally depleted Mike Stroud and Ranulph Fiennes from Antarctica in 1993 took 1 day.[144] Although Stroud and Fiennes voluntarily prolonged their period of starvation before requesting evacuation, most individuals do not have to spend more than a weekend, or at most a few days longer than anticipated, in uncomfortable circumstances. Some food likely will be available to the stranded person because most people do not enter the wilderness totally unprepared. The individual may have consumed the initial food supply and then fasted for several days before rescue or, if disciplined, may have restricted or rationed food intake for several days. Helicopter evacuation can place the rescued individual in a hospital within hours of rescue. The worst-case scenario might be the rescue of a severely injured or ill person who could not or would not eat for an extended period and could not be evacuated by helicopter.

Refeeding victims of short-term starvation is less complicated and dangerous than refeeding victims of prolonged starvation (e.g., James Scott, who was stranded in the Himalayas for 43 days without food[129]). Victims of prolonged starvation subsisting in a catabolic state have dramatically altered blood mineral and protein levels, which can be rapidly perturbed by refeeding large quantities of a normal mixed diet. The flood of nutrients with osmotic properties can lead to dangerous fluid compartment shifts. Among the numerous complications, cardiovascular and pulmonary overload caused by a rapid increase in plasma volume after fluid and nutrient ingestion can result in pulmonary edema and multisystem organ failure. The most common cause of death from refeeding is cardiac arrhythmias.[27]

The specific physiologic and metabolic effects induced by refeeding (the refeeding syndrome; Table 87-7) depend on the individual's existing metabolic state and body composition, as well as the composition of the refeeding diet.[65] Because the refeeding syndrome typically is not recognized, the National Institute for Health and Clinical Excellence (NICE) developed guidelines for identifying high-risk patients[105] (Box 87-3). Refeeding syndrome must be avoided in severely wasted individuals, particularly during the first week of nutritional repletion.[66] Hypophosphatemia, the predominant perturbation of refeeding syndrome, can occur within a few hours of reintroducing food, particularly carbohydrate, to a starved person. In addition, hyponatremia, hypocalcemia, hypomagnesemia, severe anemia, and impaired membrane and cardiovascular function are all possible complications.[27] The priority for re-alimentation of individuals lost in the wilderness for an extended time at risk of refeeding syndrome is first to correct fluid and electrolyte imbalance and to curtail ongoing protein catabolism. Ideally, electrolytes (particularly phosphorus, potassium, calcium, magnesium) would be assessed and normalized before refeeding and then monitored. However, this is an unlikely option in the wilderness setting. After assessing the risk for refeeding syndrome (see Box 87-3),

BOX 87-3 NICE Guidelines for Identification of Patients at High Risk of Refeeding Syndrome

The patient has one or more of the following:
- Body mass index (kg/m^2) <16
- Unintentional weight loss >15% in the past 3-6 months
- Little or no nutritional intake for >10 days
- Low levels of potassium, phosphate, or magnesium before feeding

Or the patient has two or more of the following:
- Body mass index <16
- Unintentional weight loss >10% in the past 3-6 months
- Little or no nutritional intake for > days
- History of alcohol misuse or drugs, including insulin, chemotherapy, antacids, or diuretics

From National Institute for Health and Clinical Excellence (NICE): Nutrition support in adults: Clinical guidelines CG32, 2006. www.nice.org.uk/page.aspx?o=32.

TABLE 87-7 Suggested Refeeding Strategy for Individuals at Risk for Refeeding Syndrome

Day	Calorie Intake	Supplements
1	10 kcal/kg/day (5 kcal/kg/day for extreme cases: BMI 14 or no food for 15 days) Carbohydrate: 50%-60% Fat: 30%-40% Protein: 15%-20%	Prophylactic supplement: PO_4^{2-}: 0.5-0.8 mmol/kg/day K^+: 1-3 mmol/kg/day Mg^{2+}: 0.3-0.4 mmol/kg/day Na^+: 1 mmol/kg/day (restricted) IV fluids restricted (maintain zero balance) Oral or IV thiamine: 300 mg 30 minutes before feeding; maintenance dose: 100 mg/day during feeding
2-4	Increase by 5 kcal/kg/day. If low or no tolerance, stop or keep minimal feeding regimen.	Monitor vital signs, ECG, electrolytes, glucose, prealbumin, body weight, urine output. Administer thiamine + B complex orally or IV until day 3.
5-7	20-30 kcal/kg/day	Monitor as above. Maintain zero fluid balance. Consider iron supplement from day 7.
8-10	30 kcal/kg/day, or increase to full requirement.	Monitor as above.

Compiled from Boateng AA, Sriram K, Meguid MM, Crook M: Refeeding syndrome: Treatment considerations based on collective analysis of literature case reports, *Nutrition* 26:156-167, 2010; and Khan LUR, Ahmed J, Khan S, MacFie J: Refeeding syndrome: A literature review, *Gastroenterol Res Pract* 2011:1-7.
BMI, Body mass index; *ECG*, electrocardiogram; *IV*, intravenous(ly).

the rescuer should administer 200 to 300 mg of oral or intravenous (IV) thiamine (B_1) before feeding the victim any food. Some rescue workers carry this vitamin with them. If unavailable, a multivitamin may suffice, although the thiamine dose would most likely be lower than the recommended refeeding prophylactic dose. Food should not be introduced at a rate greater than 10 kcal/kg/day, and for the critically malnourished victim, no more than 5 kcal/kg/day. The NICE guidelines recommend that refeeding begin at no greater than 50% of the victim's energy requirements if significant weight loss has occurred and if no food has been consumed in more than 5 days.[105]

Fortunately, most rescues happen quickly, and the rescuer need not be reluctant to offer normal food to most victims of short-term (3- to 5-day) starvation without significant weight loss. The most common problem may be that the individual wants to eat too much too soon. This problem is usually self-correcting. The individual may be very hungry, weak, and dehydrated. The victim should first be reassured and then checked for injuries, illness, and dehydration. Juices, soups, instant oatmeal, granola bars, and small pieces of jerky slowly chewed along with the fruit juice are all good choices to return the digestive system to processing food while simultaneously supplying fluid, sodium, potassium, protein, and carbohydrate. Frequent small feedings are best. Sports drinks (if available) are a good choice for simultaneous rehydration, because they provide carbohydrates for energy and electrolytes that may be needed for plasma volume expansion.

It is not uncommon to encounter waterborne or food-borne illness in a backcountry rescue scenario.[16] Rescued victims may be suffering from diarrheal disease as well as starvation. Oral rehydration solutions similar to those used to treat diarrheal disease can be used in wilderness rescue for extremely dehydrated individuals.[16] IV saline and dextrose may be needed for those unable to eat because of shock, injury, or vomiting. IV normal saline should be administered to maintain a "zero" fluid balance (fluid intake and output are equal), starting with 20 to 30 ml/kg and adjusting as necessary.[27] Caution should be used with IV dextrose administration in persons at risk for refeeding syndrome because of the increased risk of hyperglycemia. If in doubt, a lower concentration (10%) of IV dextrose solution should be given.[158] Table 87-8 shows the composition of the World Health Organization's oral rehydration solution.

It is important to ensure that the kidneys are capable of normal function. Fluids should continue to be offered until the victim is able to urinate every 2 to 3 hours, and then a more aggressive re-alimentation program can be followed. If the individual does not seem to be especially dehydrated and at low risk for refeeding syndrome, dilute fruit juices or sports drinks containing 5% to 10% carbohydrate and about 20 mEq (about 1.2 g) Na^{2+} per liter are reasonable rehydration fluids. Water is appropriate. Additional sodium can be provided by liberally salting the solid food offered. A simple rehydration solution can be made by adding 1 tsp of table salt and 8 tsp of sugar to 1 L of boiled water (http://rehydrate.org/solutions/homemade.htm). Sports drinks usually contain 10 to 25 mEq of Na^{2+} and 2 to 5 mEq K^{2+} per liter. Bouillon cubes are a good source of sodium and convenient to carry. One bouillon cube contains about 1000 mg of Na^{2+} (44 mEq). Although providing sodium to a moderately depleted individual is beneficial and desirable for restoring plasma volume, this should be approached much more cautiously in victims of prolonged and severe malnutrition, to avoid overly rapid expansion of plasma volume that could lead to congestive heart failure.[65] Bananas are excellent sources of K^{2+} (450 mg per banana), but because they are perishable, are seldom available to a rescue party. Dried banana chips are a good alternative (152 mg K^{2+}/oz), easily included in the rescue provisions.

Depending on the severity of malnutrition and risk of refeeding syndrome, after being corrected for hydration status and electrolyte balance, the victim should be placed on a moderate-protein, high-energy diet for an ideal weight gain of 2-3 pounds per week.[98] Although there is no consensus on the "best" re-alimentation diet, some diets are likely more appropriate than others for re-alimenting starvation victims.[65] For example, a diet high in sodium and carbohydrate fed to a severely malnourished individual may cause a rapid and large increase in extracellular volume, resulting in peripheral edema as well as fluid accumulation in the heart and lungs. A low-protein, high-energy diet may make sense initially, but if continued, may cause an increase in

TABLE 87-8 Composition of World Health Organization Oral Rehydration Solution*

Solution	Glucose (g/L)	NaCl (g/L)	KCl (g/L)	Trisodium Citrate† (g/L)	Osmolality
WHO oral rehydration	20.0	3.5	1.5	2.9	310

*Preparation information available at http://rehydrate.org/ors/the_salts_of_life.htm#ORS%20Formula (commercially available from Jianas Brothers Packaging Co, 2533 SW Blvd, Kansas City, MO 64108).
†If trisodium citrate is not available, 2.5 g of common baking soda can be substituted.[16]

fat mass without the desired increase in lean tissue mass. A high-protein diet may arrest nitrogen loss, but will not lead to simultaneous replenishment of fat stores. High-protein diets are also not appropriate (at least initially) for severely starved individuals encountered during relief work in famine-stricken areas. Collins and associates[38] reported decreased mortality and increased weight gain in malnourished, edematous adults in Somalia ingesting an 8.5% protein diet compared to the higher, 16.5% protein diet. Guidelines for patients recovering from anorexia nervosa that may also apply to malnourished rescue victims suggest an energy intake of less than twice an individual's basal energy expenditure (and less than 70 to 80 kcal/kg/day) and a protein intake of less than 1.5 to 1.7 g/kg/day, with a typical range of 1.0 to 1.5 g/kg/day.[98] As stated by Mehler and colleagues,[98] the best course of action when re-alimenting a starved victim is to "start low and advance slow."

NUTRITION PLANNING FOR WILDERNESS ACTIVITIES

PRACTICAL CONSIDERATIONS

Nutrition planning is an important aspect of wilderness logistics. One difficulty is that the amount of food carried is often constrained by the space it occupies and its weight. A daily food ration of 4000 kcal for men and 3500 kcal for women will adequately encompass most moderate- to high-energy expenditure situations. If it is known that the task will be hard physical work in the cold, 4000 to 6000 kcal/day may be needed. Generally, an energy allowance of 45 to 55 kcal/kg/day will cover energy needs for most moderate to moderately heavy levels of exertion (e.g., for a 70-kg individual [154-lb] anticipating moderate work levels, 50 kcal/kg/day × 70 kg body weight = 3500 kcal/day).[10] Table 87-9 lists some typical energy targets for food planning appropriate for temperate-weather backpacking activities.

These are only approximate guidelines because it is impossible to establish energy requirements that cover all genders, body sizes, workloads, and environments. More specific nutrient guidelines for food planning can be adapted from the U.S. military target nutrient content for operational rations, which can be viewed in its entirety at www.apd.army.mil/pdffiles/r40_25.pdf. Military field ration nutrient content has been established to meet the needs of a relatively young, active population and is applicable in most circumstances to nutritional support for many wilderness outdoor activities. The standards for daily ration content shown in Table 87-10 are based on current RDAs and can be used by wilderness planners to ensure a reasonably balanced and nutrient-adequate diet to support high levels of physical activity on any particular trek.

The macronutrient composition of food is usually less important than the total energy content, except when heavy efforts are required over short (2- to 3-day) periods, during which carbohydrate content may be the most important nutritional consideration. If a high level of performance (sustained or repeated high levels of power generation, such as working at greater than 60% $\dot{V}O_2max$ for prolonged periods) is anticipated, carbohydrate should be emphasized over fat (see Table 87-1 for carbohydrate recommendations). If weight of the provisions is an overriding consideration, maximal caloric density may be important, and fat may be emphasized over carbohydrate, particularly in cold environments. Lower levels of power generation (working at a slow and steady sustained rate at less than 50% $\dot{V}O_2max$) can usually be adequately supported by higher levels of dietary fat. Individuals who intend to subsist on diets containing greater than 50% of the energy from fat usually require a metabolic adaptation period of approximately 2 weeks to adjust to the higher level of dietary fat.[114,115] Most trail rations consisting of a typical mixed macronutrient content (50% carbohydrate, 35% fat, 15% protein) weigh approximately 1.4 to 2.7 kg (3 to 6 lb) (food for 1 day), depending on the degree of dehydration of the food. Thus, a 7-day backpacking trip may require 9.5 to 19 kg (21 to 42 lb) of food (excluding potable water). An acceptable level of protein content of the diet should provide 1.0 to 2.0 g/kg/day, depending on activity level (see Table 87-3 for protein recommendations). Protein beyond the required amount may be an inefficient source of energy, requiring more water for urea excretion as amino acids are deaminated, nitrogen is excreted as urea, and carbon skeletons are used for energy. The water burden of excess protein is not an overriding consideration if water is abundantly available, but is an important factor in arid environments.

Palatable and nutritious backpacking foods are available at most outdoor stores specializing in camping gear. Some thought (and label reading) must be put into selecting and combining these individual food items. A simple approach is to purchase packaged military food such as the meal, ready-to-eat (MRE), which contain a balanced macronutrient, vitamin, and mineral profile. A typical MRE packet supplies approximately 1250 kcal (13% protein, 36% fat, and 51% carbohydrate) and weighs about 0.6 kg (1.25 lb). MREs require no special handling or preservation and can be eaten cold or hot; their shelf life is 3 years at

TABLE 87-9 Daily Calorie (kcal) Guidelines for Hikers*

		Backpacking	
Body Weight (lb/kg)	Light Hiking	Light	Heavy
100-120/45-59	2000	2500	3500
130-150/59-68	2500	3000	4000
160-180/73-82	3000	3500	4500
190-200/86-91	3500	4000	5000

*Modify according to work level and prior experience.

TABLE 87-10 Nutritional Planning Guide for Field Rations

Nutrient	Unit of Measure*	Daily Ration
Macronutrients		
Energy	kcal	3600
Protein	g	91
Carbohydrate	g	494
Fat	g	140
Vitamins		
Vitamin A	mcg RE	1000
Vitamin D	mcg	5
Vitamin E	mg	15
Vitamin K	mcg	80
Vitamin C	mg	90
Thiamine (B_1)	mg	1.2
Riboflavin (B_2)	mg	1.3
Niacin	mg NE	16
Vitamin B_6	mg	1.3
Folic acid	mcg DFE	400
Vitamin B_{12}	mcg	2.4
Minerals		
Calcium	mg	1000
Phosphorus	mg	700
Magnesium	mg	420
Iron	mg	15
Zinc	mg	15
Sodium	mg	5000-7000
Potassium	mg	3200
Selenium	mcg	55

Based on reference dietary intakes for active military personnel (AR 40-25 Nutrition Standards and Education, Headquarters, Department of the Army, Washington, DC, 2001).
*Units: 1 mcg RE = 1 mcg retinol (3.33 IU) or 6 mcg (10 IU) β-carotene; 1 mcg cholecalciferol = 40 IU vitamin D; 1 mg vitamin E = 1 mg RRR-α-tocopherol; 1 mg NE = 1 mg niacin or 60 mg dietary tryptophan; 1 mcg DFE = 1 mcg food folate or 0.5 mcg synthetic folate.

80° F (27° C). Information about military rations can be found at www.dscp.dla.mil/subs/rations/rations_book.pdf. Further information regarding practical aspects of backcountry and expedition food planning can be found in the publications *NOLS Backcountry Nutrition*[126] and *Nutritional Support for Expeditions.*[13]

FOOD BARS

Some outdoor minimalists choose to ignore nutritional planning and travel with their favorite, easily consumed snack foods. This haphazard approach to nutrient requirements may work for a time but could dispose the individual to potentially important nutrient deficiencies over time or at the very least to palate fatigue. Commercial food (sports) bars are generally a better choice than candy bars and other junk food items, because they are usually nutrient fortified and less prone to melting in the pack.

Food bars might be considered the modern equivalent of the early explorer's pemmican (dried meat pulverized with fat and sometimes berries). Food bars are not as energy dense as pemmican but are certainly more palatable and nutritious. Food manufacturers have combined the camper's old standby of candy bars and trail mix into conveniently packaged and easily carried bars that usually have a good nutrient profile and may be fortified with selected vitamins, minerals, and protein. Most commercial food bars designed for sports nutrition or meal replacement are suitable for wilderness activities, although the low-carbohydrate bars may not be an appropriate choice. For unanticipated wilderness rescue operations, food bars are a good no-preparation, eat-on-the-move energy source for both rescuers and the rescued. Some companies target outdoor activities in their marketing, but the composition of their products is similar to that of others, so their claims may not be meaningful. The main considerations in food bar selection should be stability in the pack or pocket, palatability, and protein and carbohydrate content. If they are fortified with vitamins and minerals, food bars can supplement other foods. The advantages of food bars as nutrition supplements are that they consume little pack space, are a quick energy source, and are convenient when no time is available for a meal on the trail or severe weather precludes food preparation.

Most food bars contain significant amounts of carbohydrate, protein, and fat (Table 87-11). A bar containing 45 g of carbohydrate, 9 g of protein, and 4 g of fat provides approximately 240 kcal of energy. Most are rather low in fat, because they are aimed at replenishing glucose and glycogen supplies during and after sports performance. The food bar market is very competitive, so some manufacturers include "unique" nutrients or herbal compounds to appeal to the buyer. The nutritional merit of some of these additions is questionable. Additions include vitamins, minerals, and other potentially beneficial nutrients such as phytochemicals (antioxidant nutrients); medium-chain triglycerides (as an alternate energy source); branched-chain amino acids (as fuel for muscle); soy protein (an anticancer agent); ginseng (to combat stress); ginkgo biloba (to improve circulation); and choline (to improve concentration).

TABLE 87-11 Food Bar Standards for Wilderness Activities

	Amount	Comments
Nutritional Content		
Carbohydrate	40-50 g/bar	To replenish glycogen stores
Fiber	3-5 g/bar	To prevent constipation
Protein	10-25 g/bar	High-quality protein such as casein or soy may be useful in emergencies when other protein sources are not available.
Fat	Variable	Usually not critical; higher-fat bars are more calorie dense.
Vitamins	Approximately 30% RDA	Not normally needed, but can provide insurance; antioxidant vitamins E and C are most important.
Minerals	Approximately 30% RDA	Ca^{2+}, Mg^{2+}, and Zn^{2+} are the most important, although women may benefit from supplemental Fe^{2+}, especially at altitude.
Other		
Stability	—	Low melting point in heat is determined by trial and error.
Palatability	—	Provide variety to avoid taste fatigue and increase food intake.

RDA, Recommended dietary allowance.

Selecting Food Bars

A typical energy or nutrition bar weighs about 60 g and contains 40 to 45 g of carbohydrate, 10 to 15 g of protein, and about 5 g of fat. Food bars are not dehydrated but usually have low water content, approximately 25% water by weight. Check labels for calorie and nutrient content, because these vary.

Food bars claiming to be "energy bars" tend to have more carbohydrates, whereas "low-carb" and diet bars contain fewer carbohydrates. This reduced calorie claim is usually based on net carbohydrate content, such as fiber and sugar alcohols, which may not contain caloric value. Generally, these carbohydrates do not provide as much energy as do normal food carbohydrates, and they elicit a smaller insulin response. Sugar alcohols (i.e., polyols, such as maltitol and lactitol) that impart a sweet taste are technically carbohydrates and are common in low-carbohydrate bars because, compared with sugars such as glucose, they have fewer calories and less impact on blood sugar and insulin levels. These elements of low-carb dieting do not necessarily support high-level performance on a backpacking trip. Unlike other sugars, sugar alcohols are digested primarily in the large intestine by bacterial fermentation and, consequently, may promote gas or have a laxative effect, not a desirable attribute on the trail or in the tent. If the wrapper of a bar states that net carbohydrates are only 2 g but the Nutrition Facts panel shows 20 g of carbohydrates, there are 18 g of sugar alcohols, glycerin, or fiber in the bar. High-protein bars are designed to be higher in protein. Look at the label for protein sources. High-quality casein, whey, egg, and soy protein are desirable "boosters" of the natural protein content of the basic ingredients in a food bar. Meal-replacement bars have a balance of carbohydrates, proteins, and fats similar to that of a typical mixed meal. Before hitting the trail, be sure to taste-test food bars. Some are more palatable than others.

Typically, food bars may have the vitamins and minerals or other ingredients found in a dietary supplement. Nutrition bars can provide many nutrients needed on a daily basis and may be eaten as an energy boost or a vitamin/mineral supplement, but are not recommended as a total substitute for food except in certain situations, such as a rainy day on the trail or a late camp. They are best eaten as a quick-energy snack along the trail. If fortified with the vitamins and minerals found in a multivitamin pill, food bars can also be considered a multivitamin supplement. However, it is advisable to keep track of the amounts of nutrients being ingested from the bars in addition to the amounts from other foods and supplements, to avoid exceeding recommended upper limits. Some products contain ingredients a consumer may not want in a food bar. A product that claims to be a "dietary supplement," or that provides a Supplement Facts panel instead of a Nutrition Facts panel, may contain ingredients not normally expected in food. Supplementary ingredients are not necessarily undesirable, but consumers should be aware of vitamins, minerals, herbs, or other special ingredients. For example, some products include caffeine in the form of coffee extract, guarana, or green tea. Even cocoa and chocolate contain some caffeine. Caffeine may be desirable in some circumstances, but it can enhance the action and increase the side effects of other stimulants, such as bitter orange (*Citrus aurantium*). An independent evaluation of the nutritional properties of many current commercially available food bars can be found at https://www.consumerlab.com/reviews/High_Protein_Bars_Low-Carb_Diet_Bars_Energy_Bars_and_Meal-Replacement_Bars/NutritionBars/ (subscription required for full report).

EMERGENCY FOOD SUPPLIES

Emergency food supplies of 250 to 350 kcal per person per day should be included in addition to the calculated caloric needs. These should be packed or carried separately from the main food items in case the main food supply is lost or destroyed. A stash of individually packaged food bars, jerky, dehydrated soup mixes, and hard candy provides an energy buffer that is reassuring even if it is not used. A bottle of multivitamins, extra salt packets, and water disinfection supplies are also advised. These small items may not seem important at the time of preparation, but that perception changes rapidly in an emergency. Finally, the most carefully planned food supply does little good unless it is eaten. Include foods that are palatable and comforting to the traveler. Do not overlook the morale-boosting aspects of a hot meal prepared on the trail.

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Complete references used in this text are available online at expertconsult.inkling.com.

CHAPTER 88

Field Water Disinfection

HOWARD D. BACKER

Waterborne disease is a risk for international travelers who visit countries that have poor hygiene and inadequate sanitation and for wilderness users or travelers drinking surface water in any country, including the United States. Natural water may be contaminated with organic or inorganic material from land erosion, dissolution of minerals, decay of organic vegetation, biologic organisms that reside in soil and water, industrial chemical pollutants, and microorganisms from animal or human biologic waste.[71,118] The main reason for treating drinking water is to prevent gastrointestinal illness from fecal pollution with enteric pathogens.[309] Appearance, odor, and taste are not reliable to estimate water safety. Natural organic and inorganic material may not cause illness but can impart unpleasant turbidity, color, and taste to the water (Box 88-1).

Of the 1700 million square miles of water on Earth, less than 0.5% is potable.[336] Global warming is accelerating deterioration of the remaining potable supplies,[184] and emerging waterborne pathogens create the need to reevaluate detection and disinfection methods.[227,309,345] Chemical contamination of groundwater is increasing at an alarming rate in the United States and worldwide from industrial, agricultural, and individual sources. Except for certain pristine alpine or other remote water sources, virtually none of the surface water in the United States is drinkable without treatment.[184] According to the *National Water Quality Inventory Report* by the U.S. Environmental Protection Agency (EPA), as of 2004, bacterial contamination was the leading cause of river and stream impairment; mercury contamination was the leading cause of impairment in lakes, ponds, and reservoirs. Overall, about 40% of surveyed U.S. rivers, lakes, and estuaries are too polluted for basic uses such as fishing and swimming.[2] Disasters, such as floods and hurricanes, often overwhelm treatment facilities and contaminate groundwater, requiring point-of-use disinfection.[286] The World Health Organization (WHO) reports that 780 million people still lack access to an improved drinking water supply, and 2.4 billion people lack access to improved sanitation.[227,338]

BENEFITS OF WATER TREATMENT

Methods for treating water are found in Sanskrit medical lore, and pictures of apparatus used to purify water appear on Egyptian walls from the 15th century BC. Boiling and filtration through porous vessels, sand, and gravel have been known for thousands of years. The Greeks and Romans also understood the importance of pure water.[214] Sanitation, including water treatment, is considered one of the 10 great public health achievements that helped conquer infectious disease as a main cause of mortality in the United States.[48] As the percentage of the U.S. urban population served by water treatment utilities increased after 1900, the annual death rate from typhoid fever decreased.[284]

Drinking-water treatment processes provide enormous benefits with minimal risk. Without filtration and disinfection, waterborne disease would spread rapidly in most public water systems served by surface water.[79,322] The combined roles of safe water, hygiene, and adequate sanitation in reducing diarrhea and other diseases are clear and well documented. WHO estimates that 94% of diarrheal cases globally are preventable through modifications to the environment, including access to safe water.[346] Recent studies of simple water interventions in households of developing countries clearly document improved microbiologic quality of water, 30% to 60% reduced incidence of diarrheal illness, enhanced childhood survival, and reduction of parasitic diseases; much of this progress is independent of other measures to improve sanitation.* Several excellent evidence-based reviews analyze the recent large body of work in this area.[22,68,227]

From a global health perspective, water and sanitation improvements are cost-beneficial in all developing regions in the world.[132,150] Although the combination of improved water quality and sanitation has the greatest effect, improvement in water quality alone has a beneficial effect on health and can reduce incidence of diarrheal disease by more than one-third.[68,69,297,298]

In contrast to extensive evidence from developing areas of the world, there are few data to demonstrate benefits of water disinfection in the U.S. wilderness. Boulware[31] demonstrated that drinking untreated water correlated with higher rates of diarrhea among Appalachian Trail hikers.

*References 10, 68, 82, 105, 109, 149, 191, 192, 212, 250, 251, 259, 260, 297, 298.

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BOX 88-1 Chapter Outline and Shortcuts

- For summary of each technique, see boxes in specific sections.
- For comparison of various techniques, see text and Tables 88-16 to 88-18.
- For details of products, see the appendices.

RISK OF WATERBORNE DISEASE TRANSMISSION

The long list of pathogenic microorganisms capable of waterborne transmission is similar to that of potential etiologic agents of traveler's diarrhea (see Chapter 82); almost all enteric pathogens and opportunistic pathogens that are transmissible by the fecal-oral route can be transmitted through water (Box 88-2). Separating the contribution of waterborne transmission of these pathogens from food-borne and person-to-person transmission is impossible; the latter two are probably more common. In developing countries, 15% to 20% of diarrhea is estimated to be waterborne. Surprisingly, this is similar in developed countries, where as much as 15% to 30% is attributed to municipal drinking water.[113,309]

Risk for waterborne illness depends on the number of organisms consumed, which is determined by the volume of water, concentration of organisms, and treatment system efficiency.[38,77,148] Additional factors include virulence of the organism and defenses of the host (Table 88-1). Infection and illness are not synonymous; the overall likelihood of illness for all three categories of microorganisms (bacterial, viral, protozoan) is 50% to 60%. Death from enteric pathogens is unlikely in healthy, well-nourished persons, except with a few specific organisms (e.g., *Escherichia coli* O157:H7, *E. coli*: 0104:H4, or, in pregnant women, hepatitis E). In malnourished individuals, especially young children, many other pathogens, including *Vibrio cholerae* and *Cryptosporidium,* can lead to infectious causes of death. Total immunity does not develop for most enteric pathogens, and reinfection may occur.[148] Several nonenteric waterborne organisms have high case fatality rates. These include *Legionella* (respiratory) and *Acanthamoeba* (neurologic).

Waterborne outbreaks do not give a complete picture of the potential for waterborne illness. Most outbreaks of waterborne diseases are not identified because not enough people become ill, providing an insensitive mechanism for detecting water contamination. When an outbreak is identified, it is very difficult to prove conclusively that the source was waterborne. The supply may have been only transiently contaminated, water samples from the time of exposure are seldom available, some organisms are difficult to detect, and almost everyone has some exposure to water.[313,349]

The data on concentration of microorganisms in surface water show widely varying values, but the testing is insufficient for risk assessment and dose-response models. Instead, infectious dose data and statistical techniques have been used to devise models for determining risk.[148] These models cannot be applied unless the microbial content of water is known. Pathogenic microorganisms clearly exist in most raw source waters, especially in surface waters.[322] Most microbiologic testing is done on community water intake sources and sewage treatment effluent. Less information is available for more remote water sources.[78,274,343]

Improved detection techniques using enzyme immunoassay (EIA) and polymerase chain reaction (PCR) may give a much more accurate picture of the specific microbes and degree of water contamination.[309] Testing may not be representative, however, because excretion and loading of microbial contaminants are dynamic and change over time.

TABLE 88-1 Estimated Infectious Dose of Enteric Organisms

Organism	Infectious Dose
Salmonella	10^5
Shigella	10^2
Vibrio	10^3
Enteric viruses	1-10
Giardia	10-100
Cryptosporidium	10-100

Data from Hurst C, Clark R, Regli S: Estimating the risk of acquiring infectious disease from ingestion of water. In Hurst C, editor: *Modeling disease transmission and its prevention by disinfection*, Melbourne, 1996, Cambridge University Press, pp. 99-139.

BOX 88-2 Waterborne Enteric Pathogens

Bacteria
Escherichia coli
Shigella
Campylobacter
Vibrio cholerae
Salmonella
Yersinia enterocolitica
Aeromonas

Viruses
Hepatitis A virus
Hepatitis E virus
Norovirus
Poliovirus
Miscellaneous viruses (>100 types; e.g., adenovirus, enterovirus, calicivirus, echovirus, astrovirus, coronavirus)

Protozoa
Giardia lamblia
Entamoeba histolytica
Cryptosporidium
Blastocystis hominis
Isospora belli
Balantidium coli
Acanthamoeba
Cyclospora

Parasites
Ascaris lumbricoides
Ancylostoma duodenale (hookworm)
Taenia spp. (tapeworm)
Fasciola hepatica (sheep liver fluke)
Dracunculus medinensis
Strongyloides stercoralis (pinworm)
Trichuris trichiura (whipworm)
Clonorchis sinensis (Oriental liver fluke)
Paragonimus westermani (lung fluke)
Diphyllobothrium latum (fish tapeworm)
Echinococcus granulosus (hydatid disease)

Data from references 113, 118, 262, 284, and 319.

TABLE 88-2 Water and Spread of Disease

Type	Mechanism	Examples	Prevention
Waterborne	Fecal contamination of drinking water by infectious organisms	Typhoid fever, cholera, campylobacteriosis, giardiasis, hepatitis A	Sanitation and disinfection of water
Water-washed	Person-to-person fecal-oral spread via direct contact, food, and water (all these are also waterborne)	Shigellosis, amebiasis, ascariasis, eye (trachoma) and skin infections	Handwashing and personal hygiene
Water-based	Organism or agent that lives in water	Schistosomiasis, dracunculosis, parasitic worms	Prevention of exposure from bathing
Water-related	Spread by insects that breed in water or collecting water	Malaria, sleeping sickness, yellow fever, dengue	Insect protection and piped water

Data from Bradley D: Health aspects of water supplies in tropical countries. In Feachem R, McGarry M, Mara D, editors: *Water, wastes and health in hot climates*, New York, 1977, Wiley, p 3; and Steiner T, Thielman N, Guerrant R: Protozoal agents: What are the dangers for the public water supply? *Annu Rev Med* 48:329, 1997.

Surface water is subject to frequent, dramatic changes in microbial quality as a result of activities on a watershed. Storm water causes deterioration of source water quality by increasing suspended solids, organic materials, and microorganisms. Some of these contaminants are carried by rain from the atmosphere, but most come from ground runoff. In water sources downstream from towns or villages, storms may overload sewage facilities and cause them to discharge directly into the receiving water. Some organisms (e.g., *Legionella pneumophila, Vibrio cholerae*) exist as natural organisms in water.[301]

The source of fecal contamination in water may be either human or animal. Some bacterial pathogens (*Shigella*, *Salmonella typhi*) occur exclusively in human feces, whereas others (*Yersinia*, *Campylobacter*, nontyphoid *Salmonella*) may be present in wild or domestic animals. No enteric viruses excreted by animals have been shown to be pathogenic to humans.[256] Derlet and colleagues[94,95] found that wilderness water sources in the California Sierra Nevada with significant amounts of human or animal activity are more likely to be contaminated with bacteria.

DEVELOPING COUNTRIES

In tropical areas and developing countries, water has a complex relationship with spread of disease. Bradley[32] presents a useful classification (Table 88-2), and Steiner and associates[302] proposed adding the category "water carried" for infections resulting from accidental ingestion in recreational water. Globally, 88% of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene. About 2 million people, most children under 5 years of age, die annually from illnesses associated with unsafe drinking water or inadequate sanitation.[113,135,334,346] Other estimates put the disease burden from water-related diseases, sanitation, and hygiene at 4% of all deaths and 5.7% to 7% of the total disease burden occurring globally.[36,249]

Substantial progress has been made in the past 20 years toward the goal of safe drinking water and sanitation worldwide, particularly in Asia and Latin America. Two billion people gained access to improved water from 1990 to 2010, but 780 million (11%) still lack a safe water source. Also, access to improved sanitation increased from 49% to 63% of the global population, but 2.5 billion people still lack this public health infrastructure. Africa and Oceania are the regions with the greatest need for improvement. More than 750 million persons still practice open defecation, the largest number residing in India and Africa.[227,337]

In certain tropical countries, the influence of high-density population, rampant pollution, and absence of sanitation systems means that available raw water is virtually wastewater.[60] Only 30% of waste from India's cities is treated before disposal, the rest flowing into surface or ground waters. More than 800 million Indians lack a household water connection, relying on public taps, wells, or surface sources.[66] Contamination of tap water in many urban areas should be assumed because of antiquated and inadequately monitored disposal, disinfection, and distribution systems.[80] Recent studies of household point-of-use water treatment in developing countries and refugee camps provide evidence of extensive coliform contamination in these settings.[62,82,97,127,152,259] Rai and associates[252] found coliforms in almost 90% of 506 samples in Nepal, similar for tap, well, or natural tap water. Kravitz and colleagues[171] found that water in Lesotho villages was nonpotable because of bacteriologic contamination, whether taken from unimproved or improved sources. In Sierra Leone, more than 75% of stored water in the household had high levels of coliform contamination, even when initially drawn from an improved source.[70] Gil and associates[127] found coliforms in almost 50% of water samples in the highlands of Peru and diarrheagenic *E. coli* in 33%.[127]

Water from springs and wells and even commercial bottled water may be contaminated with pathogenic microorganisms.

UNITED STATES AND DEVELOPED COUNTRIES

Developed countries such as the United States still face substantial challenges to ensure potable water in households and to maintain quality of water sources.[113,184,284,309] Improved community water supplies are still responsible for some outbreaks of gastrointestinal (GI) illness. Based on studies comparing rates of diarrheal illness in households with and without effective water filters, Colford and associates[72-74] have estimated that 4 to 11 million cases of acute GI illness annually are attributable to public drinking water systems in the United States.

The etiology of waterborne disease outbreaks from treated drinking water is different from untreated sources, with more respiratory disease caused by *Legionella* and a mix of bacterial, virus, and protozoan pathogens resulting in gastroenteritis.[349] Waterborne pathogens account for most outbreaks of infectious diarrhea acquired in U.S. wilderness and recreation areas (Box 88-3).[79] In both public and surface water supplies, there has been

BOX 88-3 Enteric Pathogens in U.S. Wilderness or Recreational Water

Commonly Reported
Giardia
Cryptosporidium

Occasionally Reported With Firm Evidence for Waterborne
Campylobacter
Hepatitis A
Hepatitis E
Enterotoxigenic *Escherichia coli*
Escherichia coli O157:H7
Shigella
Enteric viruses (especially norovirus, enteric adenovirus)

Unusual Occurrences, Waterborne Suspected
Yersinia enterocolitica
Aeromonas hydrophila
Cyanobacteria (blue-green algae)

an increase in the number of outbreaks caused by protozoan pathogens. *Giardia* is one of the most common waterborne infections, but *Cryptosporidium* epidemics have been identified with increasing frequency.[79,134,136,273] Enteric bacteria are responsible for a relatively small but consistent proportion of waterborne outbreaks in the United States,[275] but less frequently than are protozoa. Bacteria linked to water ingestion include *Salmonella*, *Campylobacter*, *Shigella sonnei*, *Plesiomonas shigelloides*, and *E. coli* O157:H7.[46,47,50,349]

In recreational areas, a distinct seasonal variation is seen, with the majority of cases from recreational areas occurring during summer months.[79] This is probably a result of both increased contamination and increased number of persons at risk.

Risk for GI disease to wilderness users is determined primarily by indirect evidence based on surveys.[31,349] Derlet and colleagues[90-95] have performed extensive testing for bacterial contamination of wilderness waters in the California Sierra Nevada. Human pathogenic bacteria were uncommon, but other enteric bacteria as indicators of contamination were found and associated with animal grazing, pack animals, and high levels of human activity.

RECREATIONAL CONTACT

Inadvertent ingestion during recreational activities of water not intended for drinking is a risk for swimmers and white-water boaters. The microorganisms that cause infection are those that require only a small dose. Recreational water activities have resulted in giardiasis, cryptosporidiosis,[45,49,52,350] typhoid fever, salmonellosis, shigellosis, *E. coli* O157 infection,[107] viral gastroenteritis, and hepatitis A, as well as in wound infections, septicemia, and aspiration pneumonia from *Legionella*.[79] Between 2005 and 2006, a total of 78 outbreaks associated with recreational water were reported, involving 4412 persons and resulting in 116 hospitalizations and five deaths.[350] Most outbreaks occurred in treated water venues such as pools and water parks. Of these, the majority were caused by parasites, predominantly *Cryptosporidium,* and a only few by *Giardia,* reflecting *Cryptosporidium* resistance to chlorine disinfection.[52] Bacterial contamination in treated water sources (including hospitals and hotels) most often resulted in respiratory disease caused by *Legionella* rather than in GI illness. In untreated recreational water, most often lakes and ponds, bacteria (*Shigella* and *E. coli* O157:H7) and norovirus were much more common than protozoa. These were predominantly small, inland water bodies without external sources of contamination, suggesting swimmers were the source. At least one case of usually fatal neuroinvasive disease caused by *Naegleria fowleri* is reported each year from untreated recreational water.

SPECIFIC ETIOLOGIC AGENTS

Viruses

The infectious dose of enteric viruses is only a few infectious units in the most susceptible people.[200,333,343] The risk for infections from enteric viruses is estimated to be 10 to 10,000 times higher than bacteria at the same level of exposure.[309] Hepatitis A virus (HAV), norovirus, and rotavirus are the main viruses of concern for potable water supplies. Norovirus may be the most infectious of all enteric viruses.[308] Not surprisingly, norovirus was the most commonly identified enteric virus in waterborne outbreaks in Finland.[199] All serotypes of adenovirus (besides enteric alone) are excreted in feces, so contaminated water could be a source of exposure for any type, through ingestion, inhalation, or direct contact with the eyes. Outbreaks of adenovirus have been associated with drinking water and contact with recreational water, including swimming pools.[208] In addition to HAV, waterborne transmission of hepatitis E is suspected in outbreaks among travelers from Asia.[42,162,289] Many other viruses are capable and suspected of waterborne transmission, and more than 100 different virus types are known to be excreted in human feces.[124,274] The most frequent waterborne illness (acute infectious nonbacterial gastroenteritis of unknown etiology) in the United States may be caused by undetected viruses; estimates of viral waterborne illness are 6.5 million cases annually.[79,113,200,293] Enteroviruses have been detected, even in finished water from sewage treatment plants, with measurable levels of free residual chlorine.[125]

All surface water supplies in the United States and Canada contain naturally occurring human enteroviruses.[336] Even remote surface lakes and streams tested in California showed disturbing levels of viral contamination.[124] Widespread enteric viral contamination was found at multiple sites in a popular recreational canyon in Arizona. Viruses included poliovirus, echovirus, coxsackievirus, rotavirus, and other unidentifiable viruses and exceeded the recommended state level for recreational water use in several areas. Virus levels correlated with human activity but not with excess levels of standard coliform indicators.[274] In 2002, a series of outbreaks involving more than 130 individuals was reported on 17 different Colorado River rafting trips. Laboratory evaluation of effluent from portable toilets found norovirus, which was also isolated from river water at Lee's Ferry. No specific risk factors were identified in individuals or trips, and it was concluded that risk was likely from the river water.[139] Outbreaks have continued to occur regularly in Grand Canyon river trips, many linked conclusively to norovirus.[158,195]

No evidence exists of human immunodeficiency virus (HIV) transmitted via a waterborne route, and no epidemiologic evidence exists of casual transmission by fomites or by any environmentally mediated mode.[266] There has never been a documented case of influenza virus infection associated with water exposure, although hygiene may be a factor in transmission. Free chlorine levels of 1 to 3 mg/L are adequate to disinfect avian, H1N1, or other influenza viruses.

Protozoa

Six protozoa that cause enteric disease and may be passed by waterborne transmission are *Giardia lamblia*, *Cryptosporidium parvum*, *Entamoeba histolytica*, *Cyclospora cayetanensis*, *Isospora belli*, and the microsporidia.[113,198] The first two are the most important for wilderness travelers. *Cryptosporidium* is an emerging enteric pathogen that has overtaken *Giardia* as the most common waterborne protozoa.[43,113,350] Many aspects of *Cryptosporidium* epidemiology and transmission appear similar to *Giardia*. Ten *G. lamblia* cysts may result in infection, and the infectious dose of *Cryptosporidium* is on the order of 10^2 oocysts.[99,261] Waterborne transmission of *E. histolytica* is common in developing countries. *Cyclospora* has been epidemiologically linked to waterborne transmission in the United States and Nepal, but the reservoir and host range are not known. Unlike *Giardia* and *Cryptosporidium*, *Cyclospora* is not infectious when passed in feces and requires up to 2 weeks in the laboratory to sporulate.[291] Surface water is a common environmental source for microsporidia; however, the route of infection is unknown. *Naegleria fowleri* is a waterborne protozoan that enters the body through the nasal epithelia during swimming in contaminated surface water and causes meningoencephalitis.

***Giardia* and *Cryptosporidium*.** *Giardia* cysts have been found as frequently in pristine water and protected sources as in unprotected waters.[137,153,267,275,276,299] Repeated sampling of "negative" sources invariably produced positive results.

A zoonosis with *Giardia* is known, with at least three different species; the extent of cross-species infection is not clear.[16,341] Many of the species apparently capable of passing *Giardia* cysts to humans, including dogs, cattle, ungulates (deer), and beaver, are present in wilderness areas. Forty percent of beavers in Colorado were infected and shedding 1×10^8 cysts per animal per day. All 386 muskrats found were infected. Up to 20% of cattle examined were infected.[137] Beaver have been implicated in multiple municipal outbreaks of giardiasis. Samples from Rocky Mountain National Park[175,215]and the California Sierra Nevada[299,304] show a direct correlation between numbers of cysts and levels of human use or beaver habitation. In Yukon, Canada, 13 of 61 scat samples from various wild animals yielded *Giardia* cysts.[269]

Even with a low infectious dose, environmental cyst recovery data indicate that the risk for ingesting an infectious dose of *Giardia* cysts is small.[352,353] However, the likely model that poses a risk to campers is pulse contamination—a brief period of high cyst concentration from fecal contamination. Beaver stool and human stool may contain 1×10^6 cysts/g. Stream contamination from a beaver has been calculated to reach 245 cysts/gallon.[153] This is consistent with outbreaks in recreational water caused by human contamination.[51,52,242] In this instance, small amounts of water may cause infection, similar to an outbreak among lap swimmers from inadvertent water ingestion in a fecally contaminated pool.

Cryptosporidium oocysts are found widespread in surface water, and the cyst is durable in the environment. A large zoonosis is evident. Environmental occurrence appears ubiquitous.[182,272,273] *Cryptosporidium* is now found more frequently than *Giardia* in surface water, although in smaller numbers; it is the most common contaminant in treated recreational water and has resulted in large outbreaks in municipal water systems.[41,87,134,194,350]

Parasitic Organisms

Parasitic organisms other than protozoa are seldom considered in discussions of disinfection. Infectious eggs or larvae of many helminths are found in sewage, even in the United States.[258,287] The frequency of infection by waterborne transmission is unknown, because food and environmental contamination or skin penetration is more prevalent.[344]

The most obvious risk is from nematodes, with no intermediate hosts, that are infectious immediately or soon after eggs are passed in stool. *Ascaris lumbricoides* (roundworm) is transmitted by ingestion of the eggs in contaminated food or drink. In endemic areas, 85% of the population is infected; this leads to daily global environmental contamination by 9×10^{14} eggs.[344] *Ancylostoma duodenale* (hookworm) usually infects as larvae penetrate the skin of the foot, but it also may be acquired by mouth. Oral entry of the larvae causes pulmonary (Wakana) disease. *Necator americanus* (hookworm) does not appear to be infectious by the oral route.

Taenia solium (pork tapeworm) is infectious to humans in cyst or egg form. Eggs passed in stool are ingested in food or water and develop into tissue cysts, often in the brain, resulting in cysticercosis.

Echinococcus granulosus (dog tapeworm) can use humans as intermediate hosts. Eggs from the feces of an infected dog or other carnivore are ingested in food and water. Hydatid disease generates cysts in the liver, peritoneum, and other sites.

Fasciola hepatica (liver fluke of herbivores and humans) is normally acquired by ingestion of encysted metacercariae on water plants or free organisms in water.

Cercariae of schistosomiasis, which live in fresh water and normally enter through skin, can enter through the oral mucosa. The cercariae are killed by stomach acid.

Dracunculus medinensis (guinea tapeworm) is a tissue nematode of humans and causes the only such disease transmitted exclusively through drinking water.[334] *Dracunculus* larvae are released in water from subcutaneous worms on the legs of infected bathers or water-gatherers. Larvae are ingested by a tiny crustacean (*Cyclops* spp.), which acts as the intermediate host and releases infectious larvae when ingested by humans. Worldwide eradication of dracunculosis has nearly been accomplished.

Bacterial Spores

Bacterial spores can cause serious wound and gut infections but are not likely to be waterborne enteric pathogens. *Clostridium* is ubiquitous in soil, lake sediment, tropical water sources, and the stool of animals and humans.[135,282] *Clostridium botulinum* and *Clostridium perfringens* type A food poisoning are not waterborne because they require germination of spores in food by inadequate cooking, then production of an enterotoxin, which is ingested. *C. perfringens* type C causes enteritis necroticans, probably through in vivo production of an enterotoxin, and thus has the potential for waterborne transmission in the tropics. However, the epidemiology of these infections in the United States, as in infant botulism, is related to food-borne sources.

Algae

Cyanobacteria, formerly known as *blue-green algae,* grow rapidly in water rich in organic matter during warm weather and produce toxins that pose a health risk to humans, pets, and wildlife. Effects depend on the type of cyanobacterium and level of exposure through dermal contact or aspiration, as well as ingestion. Adverse effects include skin and eye irritation or GI upset. At higher levels, exposure can result in serious illness, including hepatotoxicity (from microcystin toxins) or neurotoxicity. The algae are readily visible and would dissuade most humans from drinking, so it poses more of a threat to animals or small children from recreational ingestion.[37]

Chemical Hazards

Chemical hazards are also an alarming source of pollution in surface water. Wilderness users must consider removal of chemical, as well as microbiologic, contaminants. The greatest risks to wilderness travelers are pesticides from agricultural runoff and heavy metals from old mine tailings. "Fracking" (hydraulic fracturing) to recover shale oil poses a new risk.[145] Industrialization proceeds worldwide without adequate environmental protection. A vast array of toxins are sold with little concept of safe use and no means of safe disposal. Inorganic chemicals in drinking water include common salts, heavy metals, asbestos, fluorides, nitrates, radionuclides, and heavy metals (arsenic, copper, iron, lead, selenium). Natural organic chemicals predominate from soil runoff, forest canopy aquatic biota, and human and animal wastes. Synthetic organic matter includes pesticides, herbicides, and chemicals from industrial or human activities.[322] Major underground aquifers are becoming contaminated. Streams and rivers in rural areas are contaminated by individual carelessness, leaching landfills, and agricultural runoff. Numerous pesticides have been found in runoff and rivers in agricultural areas of the U.S. Midwest.[211] Atmospheric spread has resulted in pesticides being found in remote wilderness lakes and in acid rain.

Persistence of Enteric Pathogens in the Environment

Once environmental contamination has occurred, a natural inactivation or die-off begins. However, enteric pathogens can retain viability for long periods[276,322] (Table 88-3). Factors promoting survival of microorganisms are pH near-neutral (between 6 and 8) and cold temperatures, which contribute to the risk for transmission in mountain regions. In temperate and warm water, survival is measured in days, with densities of infectious agents decreasing by 90% every 60 minutes. However, tropical water differs from temperate water because it contains nutrients that create a microbiologically rich environment. Coliform bacteria can survive several months in natural tropical river water and may even proliferate. Survival of other bacteria is also prolonged: about 200 hours in tropical compared with 30 hours in temperate water. *E. coli* and *V. cholerae* may occur naturally in tropical waters and are capable of surviving indefinitely.[80,135,238] As a rule, viruses persist longer than enteric bacteria in water.[331] Norovirus remained infectious in room-temperature water stored in the dark for 61 days, and virus RNA remained detectable in water for more than 3 years.[285]

Most enteric organisms, including *Shigella,* resist freezing.[96] *Salmonella typhi* can survive for up to 5 months in frozen debris and ice.[336] HAV survives 6 months at below-freezing temperatures.[312] *Cryptosporidium* may be able to survive 1 week or more in home freezers.[302] Viruses persist well on chilled, acidified, frozen foods and foods packed under modified atmosphere or in dried conditions.[12]

Natural Purification Mechanisms

It is widely believed that streams purify themselves and that certain water sources are reliably safe for drinking. These concepts have some truth but do not preclude the need for disinfection to ensure water quality (Box 88-4).

Storms usually deteriorate surface water quality by washing solids, organic materials, and microorganisms into water sources; however, rainwater can also flush streams clean by dilution and by washing microbe-laden bottom sediments downstream.[118,135] Every stream, lake, or groundwater aquifer has limited capacity to assimilate waste effluents and storm water runoff entering the drainage basin. Self-purification is a complex process that involves settling of microorganisms after clumping or adherence

TABLE 88-3 Viability of Enteric Pathogens in Water

Organism	Conditions	Survival	Reference
Vibrio cholerae	Cold	4-5 wk	Felsenfeld, 1965[108]
	Tropical	>1 yr	Perez-Rosas, 1989[238]
Campylobacter	Cold	3-5 wk	Blaser, 1980[29]
	Temperate stream	3-10 days	Singh, 1990[290]
Escherichia coli	Temperate stream	13 hr	Singh, 1990[290]
	Tropical	>1 yr	Perez-Rosas, 1989[238]
Salmonella	Temperate stream	Half-life 16 hr	Perez-Rosas, 1989[238]
Yersinia	Temperate stream	540 days	Singh, 1990[290]
Shigella	Temperate stream	Half-life 22 hr	Singh, 1990[290]
	Freeze/thaw	Yes	Dickens, 1985[96]
Enteric pathogens	Freeze/thaw	Yes	Dickens, 1985[96]
Salmonella typhi	Ice/frozen debris	5 mo	White, 1992[336]
Viruses	Cold	17-130 days	Sattar, 1978[281]
			WHO, 1979[343]
Enteric viruses	15°-25° C (59°-77° F) water	6-10 days	Rose, 1996[276]
Enteric viruses	4° C (39.2° F) water	30 days	Rose, 1996[276]
Norwalk virus	Groundwater, 25° C (77° F) kept in dark	61 days	Seitz, 2011[285]
Enteric adenovirus	Cold	Months	Mena, 2009[208]
Hepatitis A virus	Cold	1 yr	Biziagos, 1988[25]
			Thraenhart, 1991[312]
	Fresh, sea, wastewater	12 wk	Biziagos, 1988[25]
	<0° C (32° F)	6 mo	Thraenhart, 1991[312]
Giardia	Cold	2-3 mo	Bingham, 1979[23]
			DeReigner, 1989[89]
	15° C (59° F) lake, river	10-28 days	DeReigner, 1989[89]
Entamoeba histolytica	Cold	3 mo	Chang, 1953[59]
Microsporidia	4° C (39.2° F)	>1 yr	Marshall, 1997[198]
Cryptosporidium	Cold	12 mo	Current, 1985[86]
Ascaris eggs	Wet or dry	6-9 yr	WHO, 1981[344]
Hookworm larvae	Wet sand	122 days	WHO, 1981[344]

WHO, World Health Organization.

to particles, sunlight providing ultraviolet (UV) destruction, natural die-off, predators eating bacteria, and dilution. Environmental factors include water volume and temperature, hydrologic effects, acid soil contact, and solar radiation. The process is time dependent and less active during wet periods and winter conditions. Hours needed in flow time downstream to achieve a 90% bacterial kill by natural self-purification vary with pollution inflow and rate of water flow. They have been measured at approximately 50 hours in the Tennessee River, 47 hours in the Ohio River, and 32 hours in the Sacramento River, all in summer.[118]

Storage in reservoirs or lakes also improves microbiologic quality, with sedimentation as the primary process. A 100- to 1000-fold increase in fecal coliform bacteria can be found in bottom sediments compared with overlying water. This removal must be considered temporary, influenced by recirculation of organisms trapped in bottom sediments.[89,117] In optimal conditions, 10 days of reservoir storage can result in 75% to 99% removal of coliform bacteria, and 30 days can produce safe drinking water. Generally, 80% to 90% of bacteria and viruses are removed by storage, depending on inflow and outflow, temperature, and no further contamination. Cysts, with a larger size and greater weight, should settle even faster than bacteria and viruses.[5]

Groundwater is generally cleaner than surface water because of the filtration action of overlying sediments, but wells and aquifers can be polluted from surface runoff. Spring water is generally of higher quality than surface water, provided that the true source is not surface water channeling underground from a short distance above the spring.

Drawing conclusions from the preceding factors is difficult. The major factor governing the amount of microbe pollution in surface water is animal and human activity in the watershed.[95] The settling effect of lakes may make them safer than streams, but care should be taken not to disturb bottom sediments when obtaining water.

BOX 88-4 Water Quality: Key Points

- In general, cloudiness indicates higher risk for contamination and lower effectiveness of chemical and UV disinfection techniques; however, in remote wilderness water, most sediment is inorganic, and clarity is not an indication of microbiologic purity.
- The major factor determining amount of microbe pollution in surface water is human and animal activity in the watershed.
- Streams do not purify themselves but may dilute a limited source of contamination.
- Settling effect of lakes may make them safer than streams, but care should be taken not to disturb bottom sediments when obtaining water.
- Groundwater sources (springs and protected wells) generally have lower microbiologic contamination because of the filtration action of overlying sediments but may have more chemical contamination.

STANDARDS FOR WATER DISINFECTION

Because coliform bacteria originate primarily in the intestinal tracts of warm-blooded animals, including humans, they are used as indicators of possible fecal contamination.[135] Although compelling reasons exist for testing other organisms before determining the safety of drinking water, cost and relative difficulty in testing for viruses and protozoa are major obstacles to expanding routine water testing, so coliform remains the worldwide standard indicator organism. In the United States, the EPA still considers coliform a useful indicator, but coliform bacteria occur in large numbers in many water distribution systems that have no problem with waterborne disease.[327] Therefore, the EPA is moving to *E. coli* as a more specific indicator of human and animal contamination. In addition, contamination with other organisms has become common, resulting in expansion of U.S. regulations to test for organisms such as *Cryptosporidium*. Molecular probes should make this process much easier but may not indicate infectivity.[214,309]

The basic federal law pertaining to drinking water is the 1974 Safe Drinking Water Act, which was expanded and strengthened by amendments in 1977, 1986, and 1996.[214,349] Additional rules were added in 1989, 1996, 1998, and 2006.[50,262] The EPA Revised Total Coliform Rule (2013) sets maximum contamination level goals of zero for waterborne pathogens but allows a more practical maximum contamination level (MCL) as an enforceable standard. It also establishes a systems approach to monitoring and testing.[321] WHO guidelines are regarded internationally as the most authoritative framework on drinking water quality.[347]

All standards acknowledge the impracticality of trying to eliminate all microorganisms from drinking water, allowing a small risk for enteric infection.[38,262,293,329] Risk models are used to predict levels of illness and desired levels of reduction, with the reality that large numbers of people in the United States have increased susceptibility to enteric infections because of decreased immunologic competency.[262] For example, EPA and Canadian guidelines suggest *Giardia* cyst removal with the goal of ensuring high probability that consumer risk is no more than one infection per 10,000 people per year.[38,256,262] The concept of risk is important for wilderness travelers as well, because it is impossible to know the risk of drinking the water in advance, and it may not be practical to eliminate all risk with treatment.

Generally, the goal of treatment is to achieve a 3- to 5-log reduction in the level of microorganisms; treatment must reduce *Giardia* or *Cryptosporidium* by 99.9% (3 log) and enteric viruses by at least 99.99% (4 log).[255]

STANDARDS FOR PORTABLE DISINFECTION PRODUCTS

The EPA and National Sanitation Foundation (NSF International) are the primary agencies that set standards for disinfection products and protocols for testing to meet these standards. NSF, the Public Health and Safety Company, is a not-for-profit, nongovernmental organization and world leader in standards development and product certification. EPA standards and NSF Protocol P231 (Microbiological Purifiers) were used to create NSF Protocol P248 (Emergency Military Operations Microbiological Water Purifiers) to test individual water purifiers for field military operations. Other pertinent NSF protocols include UV (P55), Reverse Osmosis (P58), and Point of Use (P53).

EPA Registration

Mechanical Filters. Until recently, no testing criteria were mandated for EPA registration. The EPA does not endorse, test, or approve mechanical filters; it merely assigns registration numbers. However, registration requirements distinguish between two types of filters: those that use mechanical means only and those that use a chemical, designated as a *pesticide*. Standards were developed to act as a framework for testing and evaluation of water purifiers for EPA registration, as a testing guide for manufacturers, to assist in research and development of new units, and as a guide for consumers.[327]

Filter Testing. Current registration of mechanical filters requires only that the product make reasonable claims and that the location of the manufacturer be listed; no disinfection studies are required. However, many companies now use the standards as their testing guidelines. For mechanical filters, the standards should be applied only for those microorganisms against which claims are made, such as protozoa and bacteria only for most filters. Despite criticisms of the methodology and inconsistencies and loopholes in the reporting process, EPA standards are currently the best means to compare filters.

The EPA standards include performance-based microbiologic reduction requirements, chemical health limits for substances that may be discharged, and stability requirements for chemical(s) sufficient for the shelf life of the device. The unit should signal the end of effective lifetime (e.g., by terminating discharge of treated water) or give simple instructions for servicing or replacing within measurable volume, throughput, or time frame. There are currently no national guidelines for removal of chemicals by portable filters.

The EPA standards require that "challenge water" seeded with specific amounts of microorganisms be pumped through the filters at given intervals during the claimed volume capacity of the filter. Between bacteriologic challenges, different test waters without organisms are passed through the unit. Water conditions are specified to include average and worst-case conditions; the latter are 5° C (41° F) with high levels of pollution, turbidity, and alkaline pH. Testing must be done with bacteria (*Klebsiella*), viruses (poliovirus and rotavirus), and protozoa (*Cryptosporidium* has replaced *Giardia*). A 3-log reduction (99.9%) is required for cysts, 4-log reduction (99.99%) for viruses, and 5- to 6-log reduction for bacteria. Testing is done or contracted by the manufacturer; the EPA neither tests nor specifies laboratories.

To be called a "microbiologic water purifier," the unit must remove, kill, or inactivate all types of disease-causing microorganisms from the water, including bacteria, viruses, and protozoan cysts, so as to render the processed water safe for drinking. An exception for limited claims may be allowed for units removing specific organisms to serve a definable environmental need, such as removal of protozoan cysts.

CHEMICAL METHODS

Products that are used for treating municipal or private water supplies for drinking are considered pesticides and must be registered by the EPA Office of Pesticide Programs. Registration signifies the following:

- The composition is such as to warrant the proposed claims.
- The labeling and other material required to be submitted comply with the requirements of the act.
- The method will perform its intended function without unreasonable adverse effects on the environment.
- When used in accordance with widespread and commonly recognized practice, the method will not generally cause unreasonable adverse effects on the environment.

Thus, EPA registration implies only that the "pesticide" agent is not released into the water at unsafe levels.[7,40] This is less stringent than for filters that contain halogens.

The NSF and American National Standards Institute (ANSI) perform testing of products. Their certification is based on the following: (1) reduction claims on the label are true; (2) the product does not add anything harmful; and (3) the product label, advertisements, and literature are not misleading (info.nsf.org/certified/DWTU).

DISINFECTION METHODS: DEFINITIONS

Disinfection, the desired result of field water treatment, means removal or destruction of harmful microorganisms[201] (Box 88-5). Technically, disinfection refers only to chemical means such as halogens, but the term is also applied to heat and filtration and ultraviolet irradiation. *Pasteurization* is similar to disinfection but specifically refers to the use of heat, usually at temperatures below 100° C (212° F), to kill most pathogenic organisms. Disinfection and pasteurization should not be confused with *sterilization,* which is destruction or removal of all life forms.[178] The goal of disinfection is to achieve potable water, indicating only that a water source, on average over a period of time, contains a "minimal microbial hazard," so that the statistical likelihood of illness is acceptable. Water sterilization is not necessary, because not all organisms are enteric human pathogens.[142] *Purification* is removal of organic or inorganic chemicals and particulate matter to eliminate offensive color, taste, and odor. The term

BOX 88-5 Definitions of Water Disinfection Terms

Clarification: Techniques that reduce turbidity of water.
Coagulation-flocculation: Removes smaller suspended particles and chemical complexes too small to settle by gravity (colloids).
Contact time: Length of time that the halogen is in contact with microorganisms in the water.
Disinfection: A process that kills or destroys almost all disease-producing microorganisms, with the exception of bacterial spores. As applied here, refers to pathogenic waterborne microbes and is the desired result of water treatment.
Enteric pathogen: Microorganism capable of causing intestinal infection after ingested; may be transmitted through food, water, or direct fecal-oral contamination.
Halogen: Oxidant chemical (primarily chlorine and iodine) that can be used for water disinfection.
Halogen demand: Amount of halogen reacting with impurities in the water.
Potable: Implies "drinkable" water, but technically means that a water source, on average, over a period of time, contains a "minimal microbial hazard," so that the statistical likelihood of illness is acceptable.
Purification: Removal of organic or inorganic chemicals and particulate matter to improve offensive color, taste, and odor. Sometimes used by other sources to indicate microbiologic removal.
Residual halogen concentration: Amount of active halogen remaining after halogen demand of the water is met.
Reverse osmosis: A process of filtration that uses high pressure to force water through a nanopore semipermeable membrane that filters out dissolved ions, molecules, and solids.
Sterilization: A process by which all forms of microbial life, including bacteria, viruses, protozoa, and spores, are destroyed.

is frequently used interchangeably with disinfection, but purification as used here may not remove or kill enough microorganisms to ensure microbiologic safety.[334]

HEAT

Heat is the oldest means of water disinfection. It is used worldwide by residents, travelers, and campers to provide safe drinking water. In countries with normally safe drinking water, it is often recommended as backup in emergencies or when water systems have become contaminated by floods or a lapse in water treatment plant efficacy. Fuel availability is the most important limitation to using heat. One kilogram of wood is required to boil 1 L of water.[60] For wilderness travelers without access to wood, liquid fuel is heavy (Box 88-6).

Heat inactivation of microorganisms is exponential and follows first-order kinetics. Time plotted against temperature yields a straight line when plotted on a logarithmic scale.[159] The "thermal death point" is reached in shorter time at higher temperatures, whereas lower temperatures are effective with a longer contact time. Pasteurization uses this principle to kill enteric food pathogens and spoiling organisms at temperatures between 60° and 74° C (140° and 165.2° F), well below boiling.[115] Pasteurization is not intended to kill all pathogenic microorganisms in the food or liquid. Typical pasteurization processes include heating to 63° to 65° C (145.4° to 149° F) for up to 30 minutes and flash pasteurization using high temperature–short time at 71° to 72° C (159.8° to 161.6° F) for 15 to 30 seconds.[201] This will kill 99.999% of viable microorganisms in milk or in fruit or vegetable juice. Therefore, the minimum critical temperature for waterborne pathogens is well below the boiling point, 100° C (212° F).[151]

BOX 88-6 Heat as Water Disinfection Method

Advantages	Disadvantages
Does not impart additional taste or color to water	Does not improve taste, smell, or appearance of poor-quality water
Single-step process that inactivates all enteric pathogens	Fuel sources may be scarce, expensive, or unavailable
Efficacy is *not* compromised by contaminants or particles in the water, as with chemical treatment and filtration	Does not prevent recontamination during storage
Can pasteurize water without sustained boiling	

Relative susceptibility of microorganisms to heat: protozoa > bacteria > viruses.

Microorganisms have varying sensitivity to heat; however, all common enteric pathogens are readily inactivated by heat (Table 88-4). Bacterial spores (e.g., *Clostridium* spp.) are the most resistant; some can survive 100° C (212° F) for long periods but are not likely to be waterborne enteric pathogens. Boiling does not depend on water quality as does filtration or chemical disinfection. Heat kills or inactivates all enteric waterborne pathogens, regardless of whether they are freely suspended or present in particles.[284]

Parasitic eggs, larvae, and cercariae are all susceptible to heat. For most helminth eggs and larvae, which are more resistant than cercariae and *Cyclops* (the copepod that carries *Dracunculus*), the critical lethal temperature is 50° to 55° C (122° to 131° F).[287] Protozoal cysts, including *Giardia* and *E. histolytica,* are very susceptible to heat. *Cryptosporidium* is also inactivated at these lower pasteurization levels.

Common bacterial enteric pathogens (*E. coli*, *Salmonella*, *Shigella*) are killed by standard pasteurization temperatures of 55° C (131° F) for 30 minutes or 65° C (149° F) for less than 1 minute.[115,224] Studies have confirmed the safety of water contaminated with *V. cholerae* and *E. coli* after 10 minutes at 60° to 62° C (140° to 143.6° F) or after boiling water for 30 seconds.[130,264]

Viruses are more closely related to vegetative bacteria than to spore-bearing organisms[159] and are generally inactivated at 56° to 60° C (132.8° to 140° F) in 20 to 40 minutes or less.[3,239,307,316] Inactivation at higher temperatures is similar to that of vegetative bacteria. Death occurs in less than 1 minute above 70° C (158° F), as confirmed in milk products.[305]

Given its environmental stability and clinical virulence, HAV is a special concern. Data from food industry studies confirms susceptibility of HAV and other enteric viruses to heat at pasteurization temperatures, even in milk and other products with solids that shield the virus.[12] Widely varying data probably result from different models for virus infectivity and destruction and from the use of various test media.

BOILING TIME

The boiling time required is important when fuel is limited. The previous recommendation for treating water was to boil for 10 minutes and add 1 minute for every 305 m (1000 feet) in elevation. However, data indicate this is not necessary for disinfection. Evidence indicates that enteric pathogens are killed within seconds by boiling water and rapidly at temperatures above 60° C (140° F). In the wilderness, the time required to heat water from 55° C (131° F) to boiling temperature works toward disinfection. Therefore, any water brought to a boil should be adequately disinfected.[294] An extra margin of safety can be added by boiling for 1 minute or by keeping the water covered for several more minutes, which will maintain high pasteurization temperature without using fuel, or allowing it to cool slowly. Although the boiling point decreases with increasing altitude, this is not significant compared with the time required for thermal death at these temperatures (Table 88-5).

In recognition of the difference between pasteurizing water for drinking purposes and sterilizing to kill all microbes for surgical or laboratory purposes, many other sources, including WHO, now agree with this recommendation to simply bring water to a boil. The U.S. Centers for Disease Control and Prevention (CDC) and EPA still recommend boiling for 1 minute to add a margin of safety.[44] Other sources still suggest 3 minutes of boiling time at high altitude to give a wide margin of safety.[53,117,273,323]

TABLE 88-4 Data on Heat Inactivation of Microorganisms

Organism	Lethal Temperature/Time	Reference
Giardia	55° C (131° F) for 5 min	Jarroll, 1984[156]
	100° C (212° F) immediately	Bingham, 1979[23]
	50° C (122° F) for 10 min (95% inactivation)	Ongerth,1989[232]
	60° C (140° F) for 10 min (98% inactivation)	
	70° C (158° F) for 10 min (100% inactivation)	
	55° C (131° F)	Aukerman, 1989[8]
Entamoeba histolytica	Similar to *Giardia*	
Nematode cysts, helminth *eggs*, larvae, cercariae	50°-55° C (122°-131° F)	Shephart, 1977[287]
	65° C (149° F) for 1 min, 50° C (122° F) for 30 min	
Cryptosporidium	45°-55° C (113°-131° F) for 20 min	Anderson, 1985[6]
	55° C (131° F) warmed over 20 min	
	64.2° C (147.6° F) within 2 min	Fayer, 1994[106]
	72° C (161.6° F) heated up over 1 min	
Escherichia coli	55° C (131° F) for 30 min	Frazier, 1978[115]
	60°-62° C (140°-143.6° F) for 10 min	Neumann, 1969[224]
Salmonella, Shigella	65° C (149° F) for <1 min	
Vibrio cholerae	60°-62° C (140°-143.6° F) for 10 min	Rice, 1991[264]
	100° C (212° F) for 30 sec	
E. coli, Salmonella, Shigella, Campylobacter	60° C (140° F) for 3 min (3-log reduction)	Bandres, 1988[13]
	65° C (149° F) for 3 min (all but a few *Campylobacter*)	
	75° C (167° F) for 3 min (100% kill)	
E. coli	50° C (122° F) for 10 min ineffective	Groh, 1996[130]
	60° C (140° F) for 5 min	
	70° C (158° F) for 1 min	
Viruses (multiple potential food-borne)	56° C (132.8° F) for 30 min	Tuladhar, 2012[316]
	73° C (163.4° F) for 3 min (>4-log reduction)	
Viruses	55°-60° C (131°-140° F) within 20-40 min	Alder, 1992[3]
	70° C (158° F) for <1 min	
Hepatitis A	98° C (208.4° F) for 1 min	Krugman, 1970[173]
	85° C (185° F) for 1 min	Thraenhart, 1991[312]
	61° C (141.8° F) for 10 min (50% disintegrated)	
	60° C (140° F) for 19 min (in shellfish)	Peterson, 1978[240]
	60° C (140° F) for 10 min	Baert, 2009[12]
	75° C (167° F) for <0.5 min	Bidawid, 2000[20]
	80° C (176° F) for 3 min; 85° C (185° F) for ≤1 min (in various food products)	
Hepatitis E	60° C (140° F) for 30 min	Thraenhart, 1991[312]
Bacterial spores	>100° C (212° F)	Alder, 1992[3]

IMPROVISATION

Hot Tap Water

Although attaining boiling temperature is not necessary, it is the only easily recognizable end point without using a thermometer. Other markers, such as early bubble formation on the bottom of the pot, do not occur at a consistent temperature. When no other means are available, the use of hot tap water may prevent traveler's diarrhea in developing countries. Neumann[224,225] cultured samples from the hot tap water of 17 hotels in west Africa with water temperature ranging from 57° to 69° C (134.6° to 156.2° F) and found no coliform bacteria in 15 samples; one sample yielded a single colony and another sample two colonies. As a rule of thumb, water too hot to touch fell within the pasteurization range. Bandres and associates[13] measured hot tap water temperature in 14 hotels in four different countries outside the United States. Most temperatures were 55° to 60° C (131° to 140° F), but one was 44° C (111.2° F), one was 65° C (149° F), and several were 52° C (125.6° F). The authors concluded that hot water from taps would not be safe to drink. Groh and colleagues[130] showed that tolerance to touch is too variable to be reliable, because some people found 55° C (131° F) too hot to touch.

From these studies, one can conclude that if water has been sitting in a tank near 55° to 60° C (131° to 140° F) for a prolonged period, enteric pathogens will be significantly reduced, likely to potable levels. Neumann's suggestion (using water too hot to touch) is reasonable if no other method of water treatment is available.

TABLE 88-5 Boiling Temperatures at Various Altitudes

Altitude (ft)	Altitude (m)	Boiling Point
5000	1524	95° C (203° F)
10,000	3048	90° C (194° F)
14,000	4267	86° C (186.8° F)
19,000	5791	81° C (177.8° F)

Solar Heat

Pasteurization has been successfully achieved using solar heating. Bottom temperatures of 65° C (149° F) have been obtained for at least 1 hour in up to three 3.7-L jugs. Exposure to full sunshine in Kenya destroyed *E. coli* in 2-L clear plastic bottles within 7 hours if the maximum temperature reached 55° C (131° F). No thermal inactivation occurs below 40° C (104° F). Inactivation using solar heat is a combination of thermal and UV irradiation.[21,160,203] A solar cooker constructed from a foil-lined cardboard box with a glass window in the lid can be used for disinfecting large amounts of water by pasteurization. Most often, clear plastic bottles are placed on a reflective metal surface. This is a low-cost method for improving water quality, especially in refugee camps and disaster areas,[204,207,268] and is effective even with high turbidity[4] (see Ultraviolet Light, later).

PHYSICAL REMOVAL

TURBIDITY AND CLARIFICATION

River, lake, or pond water is often cloudy and unappealing. *Turbidity* (cloudiness) is an optical measurement of light scattering as it passes through water. Visibility in water with turbidity of 10 nephelometric turbidity units (NTU) is about 75 cm (30 inches) and with 25 NTU is 25 cm (10 inches). Turbidity is caused by suspended organic and inorganic matter, such as clay, silt, plankton, and other microscopic organisms. High turbidity is often associated with unpleasant odors and tastes, most often caused by organic compounds and metallic hydroxides with a much smaller particle size.[71,181] Clay-organic complexes may also carry pesticides or heavy metals. Bacteria, as well as viruses, may be adsorbed to particulate matter or may be embedded in it, and in highly contaminated water, microorganisms tend to aggregate and clump. In one study, 17% of turbidity particles contained attached microbes, averaging 10 to 100 bacteria per particle.[181] Organisms in the centers of these conglomerates are afforded some protection from disinfectants. Even the flocculate produced by a chlorination-flocculation tablet may harbor viable organisms.[244] Therefore, removal of turbidity and particulates may be important in preventing chemical or infectious illness.

Of 106 samples from various sources in 13 developing countries, 33% exceeded 5 NTU and 64% exceeded 1 NTU, which is the maximum turbidity level set by the EPA before water chlorination.[176] As expected, turbidity was lower in improved sources, but only 5 in 22 of these urban water sources had any detectable free chlorine residual. Household studies in developing countries indicate that most consumers find water with less than 5 NTU esthetically acceptable for drinking. The EPA has set a turbidity standard for treated drinking water at less than 0.3 NTU 95% of the time.[321]

Clarification to remove turbidity can be accomplished by simple settling, chemical processes, or filtration (Box 88-7). It is the first step in municipal water treatment, and when needed, is an important initial step in field- or household-level disinfection, before using the final treatment method of filtration or chemical disinfection; clarification greatly improves the efficacy of these techniques.[185,283] Even if turbidity is caused by benign inorganic particles, such as clay, removal is desirable for improving esthetic quality of the water. Filtration can remove larger particles, but cloudy water can rapidly clog a filter. Sedimentation and coagulation-flocculation are other clarification techniques routinely used in municipal disinfection plants that can be easily applied in the wilderness for pretreatment of cloudy water, which is then disinfected by microfiltration or halogenation. Coagulation-flocculation and filtration are also used to remove *Giardia* and *Cryptosporidium* cysts that are more resistant to chlorine. Early experiments with water heavily contaminated with feces containing HAV demonstrated that filtration and sedimentation alone did not prevent infection, but reduced severity of the illness. Water pretreated with coagulation, settling, and filtration and subsequently disinfected with 0.4 ppm of residual chlorine was noninfectious, whereas water chlorinated to 1 mg/L without pretreatment remained infectious.[222,223] Thus, removing particulate matter decreases the number of microorganisms and halogen demand.[161,221,248]

BOX 88-7 Summary of Water Clarification Techniques

Technique	Process	Uses, Advantages
Sedimentation	Settling by gravity of large particulates	Requires only time Improves water esthetics
Coagulation-flocculation	Removes suspended particles, most microorganisms, some dissolved substances	Simple process, easily applied in field Greatly improves water quality Improves efficacy of filtration and chemical disinfection
Activated carbon (charcoal)	Removes organic and some inorganic chemicals	Removes toxins such as pesticides and many heavy metals, and removes chemical disinfectants Improves taste and esthetics of water
Filtration	Physical and chemical process	Removes microorganisms and particulates; nanofiltration may remove chemicals and monovalent ions (salt). Charcoal stage may improve taste and remove chemicals.

BOX 88-8 Coagulation-Flocculation

Advantages	Disadvantages
Highly effective to clarify water and remove many microorganisms and some other contaminants	Unfamiliar technique to many consumers
Improves efficacy of filtration and chemical disinfection	Adds extra step unless combined flocculent-disinfectant tablet
Inexpensive and widely available	
Simple process with no toxicity	

Relative susceptibility of microorganisms to coagulation-flocculation: protozoa > bacteria = viruses.

SEDIMENTATION

Sedimentation is the separation of suspended particles large enough to settle rapidly by gravity, such as sand and silt. Water is allowed to sit without agitation. After sediment has formed on the bottom of the container, the clear water is decanted or filtered from the top. The time required depends on the size of the particle. Generally, 1 to 3 hours are adequate for large particles such as inorganic sands and silts. Microorganisms, especially protozoan cysts, eventually settle, hastened by attachment to organic biologic particles; reductions up to 90% may be achieved within 1 to 2 days.[60,206] However, the organisms are easily disturbed during pouring or filtering. Reservoirs take advantage of sedimentation to improve microbiologic quality. In conclusion, sedimentation is often effective in reducing water turbidity and will improve microbiologic quality, but is not recommended as the sole means of disinfection.

COAGULATION-FLOCCULATION

Smaller suspended particles and chemical complexes too small to settle by gravity are called colloids. Most of these can be removed by chemical precipitation, known as coagulation-flocculation (C-F), a technique that has been used to remove unpleasant color, smell, and taste in water since 2000 BC. This technique is used routinely in large municipal disinfection plants, but is simple enough to be used at the household level and outdoors[82,259,294] (Box 88-8).

Coagulation is achieved with addition of an appropriate chemical that alters the physical state of dissolved and suspended solids, causing particles to stick together on contact because of electrostatic and ionic forces.[71,322] Aluminum salts (alum), iron, and lime (alkaline chemicals principally containing calcium or magnesium and oxygen) are frequently used, readily available coagulants. Rapid mixing is important to obtain dispersion of the coagulant. The second stage, *flocculation,* is a purely physical process obtained by prolonged gentle mixing to increase interparticle collisions and promote formation of larger particles. The flocculate particles are large enough that they can be removed by sedimentation or by filtration with relatively large pore size, including a tightly woven cloth.[180]

To clarify water by C-F in the field, add 10 to 30 mg of alum per liter of water. The exact amount is not important, so it can be done with a pinch of alum, lime (calcium oxide), or both for each gallon of water, using more if the water is very cloudy. Next, stir or shake briskly for 1 minute to mix the coagulant, then agitate gently and frequently for at least 5 minutes to assist flocculation. Settling requires at least 30 minutes, after which the water is carefully decanted or poured through a cloth or paper filter. The process can be repeated, if necessary.

During the process of C-F, protozoan cysts and bacteria act as particles and viruses react as colloidal organic particles, with removal of 1 to 2 log of these microorganisms.[180] C-F removes most coliform bacteria (60% to 98%),[81] viruses (65% to 99%),[85,253,293] *Giardia* (60% to 99%), helminth ova (95%),[287] heavy metals, dissolved phosphates, and minerals.[71,190,322,343] Organic and inorganic compounds may be removed by forming a precipitate or by adsorbing onto aluminum hydroxide or ferric hydroxide floc particles.[322] Coagulation generally removes large molecules that absorb poorly on granular activated carbon (GAC).[9]

Despite removal of most microorganisms, a subsequent disinfection step is advised. Products combining flocculants with chlorine provide a two-step process that removes turbidity and allows effective disinfection by chlorine.[259]

Toxicity

Questions have been raised concerning the association of aluminum with central nervous system (CNS) toxicity in mammals, but these effects have been observed only after exposures other than ingestion. Most of the aluminum in alum is removed with the floc. A report from the National Academy of Sciences concluded that aluminum in drinking water does not present a significant risk.[322] Alum is a common chemical used by the food industry in baking powder and for pickling. It can be found in some food stores or at chemical supply stores.

Alternative Agents

Many inorganic and organic compounds can be used as a coagulant, including lime (calcium oxide) or potash (from wood ash).[152] In an emergency, bleaching powder, baking powder, or even the fine white ash from a campfire can be used.[319] Other C-F agents used traditionally by native peoples include seed extracts from the nirmali plant in southern India, moringa plants in Sudan, crushed almonds, dried and crushed beans, and rauwaq (a form of bentonite clay).[60]

ADSORPTION

Adsorbents, such as charcoal, clay, and other types of organic matter, have been used for water treatment since ancient times.[179] These processes are often combined with filtration or coagulation, because these substances are used as the filter media and also can act as coagulants.[294] Clays can decrease turbidity and microbes in water by about 90% to 95%, but adsorption is not the main action of ceramic or clay filters. Vegetative matter, including burnt rice hulls and activated (burnt) coconut shell, also have adsorptive capacity.

Granular Activated Carbon

Granular carbon (i.e., charcoal) is widely used for water treatment and medical detoxification. Activated carbon is a natural material derived from bituminous coal, lignite, wood, coconut shell, and other materials that are activated by steam and other means. When activated, charcoal's regular array of carbon bonds is disrupted, yielding free valences that are highly reactive and that adsorb dissolved chemicals.[119,277] GAC is the best means to remove toxic organic and inorganic chemicals from water (including disinfection byproducts) and to improve odor and taste.[221,322] Thus, it is widely used in municipal disinfection plants and in home under-sink devices. GAC also removes radioactive contamination.

Many, but not all, viral particles, bacteria, and protozoan cysts are removed by GAC filters, primarily by adherence to GAC,[141,221] and some cysts are trapped in the matrix.[190] GAC does not kill microorganisms; in fact, bacteria attach to and colonize charcoal, where they are resistant to chlorination because the chlorine is adsorbed by the GAC.[179,221,322] This bacterial contamination has not been found to be harmful because the usual heterophilic bacteria are not enteric pathogens. Enteric pathogens have been shown to survive on GAC, but if an active biofilm exists, the pathogens are rapidly displaced by heterophilic bacteria and fail to become established. Therefore, nonpathogenic bacterial colonization is encouraged in municipal plants.[257] However, these properties of carbon indicate that it will not reduce pathogenic microbes in water over an extended period, and an alternative means of disinfection should always be used.

Eventually, the binding sites on the carbon particles become saturated and no longer adsorb; some molecules are released as others preferentially bind.[221] Unfortunately, no reliable means are available to determining precisely when saturation is reached. Filters using charcoal in compressed block form as the filter element may clog before the charcoal is fully adsorbed. Presence of unpleasant taste or color in the water can be the first sign that the charcoal is spent. To test the activity of the charcoal, one may filter iodinated water or water tinted with food coloring. With regular use, the lifetime of GAC is probably measured in months; it is substantially longer with infrequent use. GAC can be "recharged," but this is not practical for small-quantity use.

Granulated activated carbon is best used after chemical disinfection to make water more palatable by completely removing the halogen[221,336] and other chemical impurities that result in bad odor and taste. For point-of-use field filters, activated carbon is used in granular or powder form, or extruded into a block that acts both as a depth filter and an adsorbent. Block carbon is more effective than granular carbon because the passages are smaller, forcing closer contact with the carbon. Ingested particles of charcoal are harmless. With increasing industrial and agricultural contamination of distant groundwater, final treatment of drinking water with GAC may be important for some wilderness users.

FILTRATION

Filters are appealing because of their simplicity and suitability for commercial production. Portable water treatment products are the third highest intended purchase of outdoor equipment, after backpacks and tents.[157] Filtration is a standard step in municipal disinfection and widely used in the food and beverage industry, as well as many other industrial processes. Many different types of media, from sand to vegetable products to fabric, have been used for water treatment throughout history in various parts of the world. Filters have the advantages of being simple and requiring no holding time (Box 88-9). They do not add any unpleasant taste and may improve taste and appearance of water. However, they require space and add weight to packs or baggage. All filters

BOX 88-9 Filtration

Advantages	Disadvantages
Simple to operate	Adds bulk and weight to baggage
Mechanical filters require no holding time for treatment (water is treated as it comes out of filter)	Most filters not reliable for adequate removal of viruses
Large choice of commercial products	Expensive relative to chemical treatment
Adds no unpleasant taste and usually improves taste and appearance of water	Channeling of water or high pressure can force microorganisms through the filter.
Rationally combined with halogens for removal or destruction of all pathogenic waterborne microbes	Eventually, clog from suspended particulate matter; may require some maintenance or repair in field
Different pore sizes available determine removal of microorganisms and smaller substances, including sodium (salt)	Smallest pore sizes (nanofilters, as in reverse osmosis) require higher pressure.
Effectiveness not dependent on water temperature	Freezing water within filter element will compromise or destroy some filters.

Susceptibility of microorganisms to filtration: protozoa > bacteria > viruses.

eventually clog from suspended particulate matter, present even in clear streams, requiring cleaning or replacement of the filter. As a filter clogs, it requires increasing pressure to drive the water through, which can force microorganisms through the filter. A crack or eroded channel allows passage of unfiltered water. Bacteria can grow on filter media and potentially result in increased water contamination, but illness has not been demonstrated.[354] Silver is often incorporated into the filter media to prevent this growth, but it is not totally effective (see Silver, later.)

Filtration is usually a dual process: physical (separation of particles from liquid) and chemical (attachment of microorganisms to the medium). Many variables influence filter efficiency, including the characteristics of the filter media and the water, as well as flow rate. Filtration can reduce turbidity, bacteria, algae, viruses, color, oxidized iron, manganese, and radioactive particles.[85]

Many filters constructed with various designs and materials are marketed for field use. Surface, membrane, hollow-fiber, and mesh filters are very thin with a single layer of fairly precise pores, whose size should be equal to or less than the smallest dimension of the organism. These filters provide little volume for holding contaminants and thus clog rapidly, but can be cleaned easily by washing and brushing without destroying the filter. Maze or depth filters depend on a long, irregular labyrinth to trap the organism, so they may have a larger pore or passage size. Contaminants adhere to the walls of the passageway or are trapped in the numerous dead-end tunnels. Granular media, such as sand or charcoal, diatomaceous earth, or ceramic filters, function as maze filters. A depth filter has a large holding capacity for particles and lasts longer before clogging, but it may be difficult to clean effectively because many particles are trapped deep in the filter. Flow can be partially restored to a clogged filter by back flushing or surface cleaning, which removes the larger particles trapped near the surface. For ceramic filters, surface cleaning is highly effective but removes a tiny layer of the filter medium. Hollow-fiber and pleated filters rely on large surface area to avoid clogging by particles.

The size of a microorganism is the primary determinant of its susceptibility to filtration (Table 88-6 and Figure 88-1). Filters are rated by their ability to retain particles of a certain size, which is described by two terms. *Absolute rating* means that 100% of a certain size of particle is retained. *Nominal rating* indicates that more than 90% of a given particle size will be retained. Filter efficiency is generally determined with hard particles (beads of known diameter), but microorganisms are soft and compressible under pressure. Waterborne pathogens often adhere to larger particles or clump together, making them easier to remove by physical processes.[206] Therefore, observed reductions are often greater than expected based on their individual sizes.[294]

In general, portable filters for water treatment can be divided into *microfiltration* with pores down to 0.1 μm, *ultrafiltration* that can remove particles as small as 0.01 μm, *nanofiltration* with pore size as small as 0.001 μm or less, and *reverse osmosis* with pore size 0.0001 μm or less. Microfilters are effective for removing protozoa and bacteria, algae, most particles, and sediment, but allow dissolved material, small colloids, and some viruses to pass through. Ultrafiltration membranes are required for complete removal of viruses, colloids, and some dissolved solids. Nanofilters can remove other dissolved substances, including

TABLE 88-6 Microorganism Susceptibility to Filtration

Organism	Average Size (μm)	Maximum Recommended Filter Rating (μm)
Viruses	0.03	N/S
Escherichia coli	0.5 × 3-8	0.2-0.4
Campylobacter	0.2-0.4 × 1.5-3.5	Same as above
Microsporidia	1-2	N/S
Cryptosporidium oocyst	2-6 (mean 5)	1
Giardia cyst	6-10 × 8-15	3-5
Entamoeba histolytica cyst	5-30 (average 10)	Same as *Giardia*
Cyclospora	8-10	Same as *Giardia*
Nematode eggs	30-40 × 50-80	20
Schistosome cercariae	50 × 100	Coffee filter or fine cloth
Dracunculus larvae	20 × 500	Coffee filter or fine cloth

N/S, Not specified.

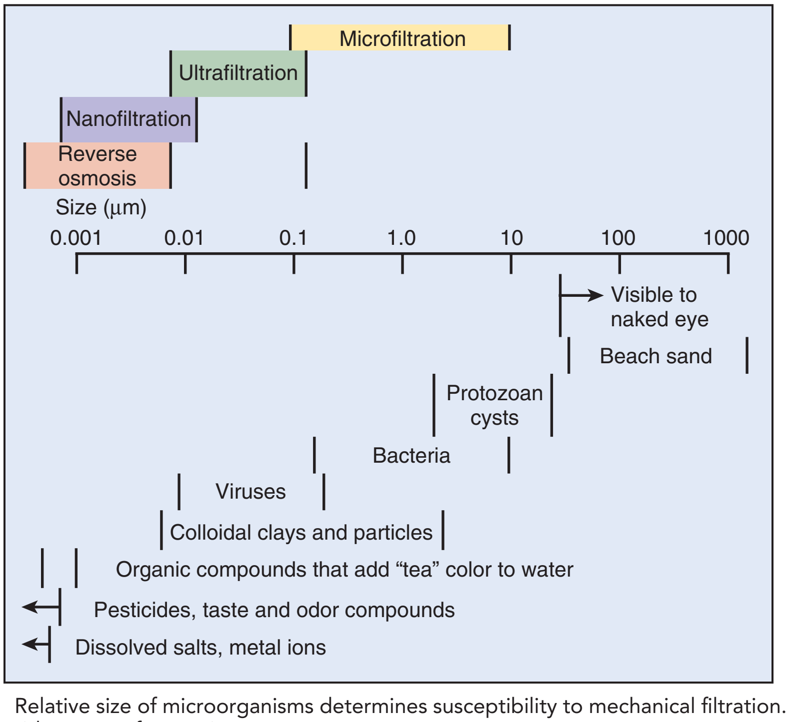

FIGURE 88-1 Relative size of microorganisms determines susceptibility to mechanical filtration. Mechanical filters span a wide range of pore sizes.

salts (sodium chloride) and endotoxins from water. Reverse osmosis removes monovalent ions (desalination) and almost all organic molecules.[180,201] All filters require pressure to drive the water through the filter element; the smaller the pore size, the more pressure required.

Simple portable filters are a reliable means to remove protozoan cysts and bacteria.[19] A microfilter membrane with a pore size of 0.2 µm can remove enteric bacteria. *Giardia* and *E. histolytica* cysts are easily filtered, requiring a maximum filter size of 5 µm. *Cryptosporidium* cysts are somewhat smaller than *Giardia* and more flexible; 57% are able to pass through a 3-µm membrane filter, so a filter with 1- to 2-µm pores is recommended.[273] Helminth eggs and larvae, which are much larger, can be removed by a 20-µm filter. *Cyclops* (the water-dwelling copepod that ingests the larva and transmits dracunculosis) can be removed by passage through a fine cloth.[287]

Adsorption and aggregation during passage through microfilters reduce viruses.[65,294] Virus particles may adhere to the walls of diatomite (ceramic) or charcoal filters by electrostatic chemical attraction, which can be enhanced by a coating on the filter or a positive charge.[104,120,123,126,257] Viruses in heavily polluted water often aggregate in large clumps and become adsorbed to particles or enmeshed in colloidal materials, making them amenable to filtration[253,322] Thus, turbidity (cloudiness from contaminants) may help remove pathogens with filtration, whereas it inhibits chemical disinfection. In one study, however, only 10% of total virus particles detected were recovered on 3- to 5-µm pore prefilters, suggesting that most were not associated with the suspended sediment.[228] Furthermore, adsorbed viral particles can be subsequently dislodged and eluted from a filter because of competitive binding and competing electrostatic forces.[120,247,315] Good ceramic filters now remove 99% to 99.9% of viruses, but the fourth log required by water treatment units remains a challenge. First Need filter has been able to meet the EPA standards for water purifiers, including 4-log removal of viruses, apparently through use of a charged media[123,126] (see Appendix A at the end of this chapter). Ultrafilters, such as Sawyer 0.02-µm hollow-fiber filter (or nanofiltration and reverse osmosis), can mechanically filter viruses. In general, however, microfilters should not be considered adequate for complete removal of viruses, except with special equipment.[334]

Reverse Osmosis

A reverse-osmosis filter uses high pressure (100 to 800 psi) to force water through a semipermeable membrane that filters out dissolved ions, molecules, and solids.[322] This process can desalinate water, as well as remove microbiologic contamination. If pressure or degradation causes breakdown of the membrane, treatment effectiveness is lost. Even *Giardia* cyst passage has been shown to occur in a compromised reverse-osmosis unit.[83]

Small, hand-pump reverse-osmosis units have been developed. Their high price and slow output currently prohibit use by land-based wilderness travelers, but they are important survival items for ocean travelers. Battery- or power-operated units are standard equipment on large boats. The U.S. Department of Defense uses large-scale mobile reverse-osmosis units for water treatment. These are considered the most fuel-efficient mobile units, producing the highest-quality water from the greatest variety of raw water qualities, capable of producing potable water from fresh, brackish, or salt water, as well as from water contaminated by nuclear, biologic, or chemical agents. The military units use pretreatment, filtration, and desalination, then disinfection for storage.[319]

Forward Osmosis

Osmotic pressure also can be used to draw water through a membrane to create highly purified drinking water from low-quality source water, including brackish water. These products use a double-chamber bag or container with the membrane in between. A high-osmotic substance is added to the clean side, which draws water from the dirty side. Because some form of sugar and/or salt is often used to create osmotic pressure, this may result in a sweetened solution similar to a sports-electrolyte drink (see Appendix A).

Choice of Filter (See Preferred Technique and Appendix A)

Because of their use at the household level in developing countries, ceramic filters have been tested most extensively.[104] They are effective at reducing turbidity and improving microbiologic quality, second only to chlorine for reducing microbial contamination.[21,65,67,298] Many designs function by gravity, an advantage for developing countries. As with all types of filters, results depend on the characteristics of the materials (e.g., ceramic, diatomaceous earth), water quality, product engineering, and prior extent of filter use.

There are extensive data on the effectiveness of filtration in other settings, but few data are available to compare different filters for field use. Most data for portable filters are from testing contracted by the filter manufacturer, and almost all filters perform well. Schlosser and colleagues[283] tested three hand-pump filters (Katadyn Mini Ceramic, First Need Deluxe, and SweetWater WalkAbout), all of which removed 3 log (99.9%) or more of viable bacteria, leaving none in the effluent.[180] Effectiveness often varies from laboratory to actual product use in the field.[354]

The military preventive medicine group has enumerated requirements for individual filters for field use.[318] Choice should be based on anticipated water quality, number of persons to be served, mode of travel and need for portability, and availability of power source. Hollow-microfiber filters, adapted from medicine and industry, are a recent addition to point-of-use field filtration.

For domestic use and in pristine protected watersheds where pollution is minimal and the main concerns are bacteria and protozoan cysts, microfiltration can be used as the only means of disinfection. For foreign travel and for surface water with high levels of human use or sewage contamination, higher levels of filtration or supplemental methods should be used.[104] Ultrafiltration or nanofiltration, now available with hollow-fiber technology, or reverse osmosis is an alternative. Otherwise, additional treatment with heat or halogens before or after filtration guarantees effective virus removal.[257] One rational use of filtration is to clear the water of sediment and organic debris, allowing lower doses of halogens with more predictable residual levels.[221] Microfilters are also useful as a first step to remove parasites and *Cryptosporidium* organisms that have high resistance to halogens. Bacteria can grow in filters, so filter media are sometimes coated with silver to prevent bacterial growth on the surface, but this does not maintain sterility (see Silver, later).

Improvised Filters

Filtration using simple, available products is of interest for use in developing countries and in emergency situations.[294] Rice hull, ash filters, crushed charcoal, sponges, and various fabrics have all been used. Typically, bacteria and viruses can be reduced by as much as 50% to 85% and larger parasites by 99%, depending on the media. Fine woven cotton fabric is effective at removing larger parasites, such as schistosome cercariae, *Fasciola* species, and guinea worm larvae.

The effectiveness at decreasing turbidity may be used as an indicator that any filter material will reduce microbiologic contamination (see Turbidity and Clarification, earlier). A comparison of three locally available clarification techniques (cloth filtration, settling/decanting, and sand filtration) on turbidity and chlorine demand demonstrated that all three mechanisms reduced turbidity: cloth filtration, 1% to 60%; settling/decanting, 78% to 88%; and sand filtration, 57% to 99%. Sand filtration and settling/decanting, but not cloth filtration, were effective at reducing chlorine demand compared with controls.[169] Lantagne and associates[177] noted that in a small number of surface water samples tested with moderate turbidity (>2 NTU), cloth filtration reduced turbidity by 18% to 52%.

Kozlicic and associates[170] tested five commonly available household materials (newspaper, filter paper, cotton, four-layer gauze, and white cotton cloth) for filtration efficiency. Newspaper performed poorly, being too slow. Cotton cloth performed best for both physical and microbiologic parameters of water (although the latter was poorly studied). The authors incidentally noted that melted snow with the top 4 to 5 cm (1.6 to 2 inches) removed was a better-quality water source than rainwater from roof runoff.[170]

Biosand Filters

Sand filters employ a technology that has been proved over centuries of time and is still used widely in municipal plants and at the household and community level. When constructed properly, they are very reliable, but with slow flow rates. Sand filters are highly effective at removing turbidity (in one study, reduced from 6.2 to 0.9 NTU) and improving microbiologic quality (99% efficacy).[98,255] Sand filters are constructed by forming layers of aggregate increasing in size from the top to the bottom. The top layer is very fine sand, and the bottom layer consists of large gravel. The container needs an exit port on the bottom. Water on the top layer forms a biolayer where microorganisms "eat" the pathogens that pass through them. Over time, the biolayer grows to the point where it will not allow any water to pass through. At this point, the layer needs to be removed by either drying out the layer and then removing it, or stirring it up and removing dirty water from the top[21] (Figure 88-2).

The optimum depth of a community or household sand filter is 2 m (6.6 feet), with diameter determined by the volume of water needed; however, a sand filter can be improvised with stacked buckets or barrels. For example, an emergency sand filter can be made in a 20-L (5.3-gal) bucket, composed of a 10-cm (4-inch) layer of gravel beneath a 23-cm (9.1-inch) layer of sand; a layer of cotton cloth, sandwiched between two layers of wire mesh, separates the sand and gravel layers.[169]

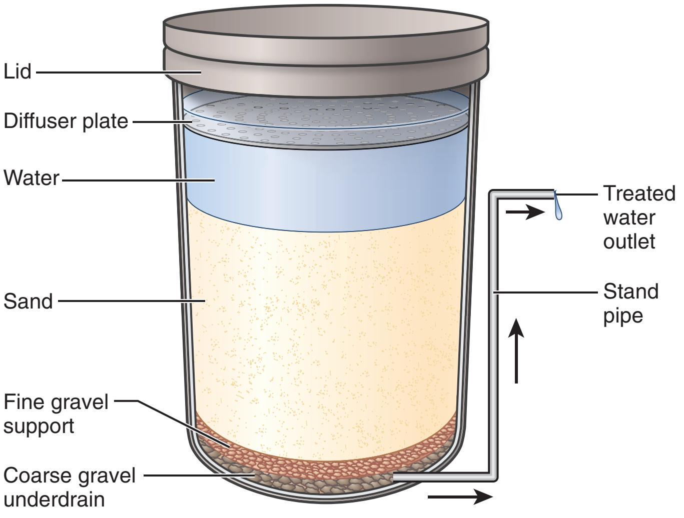

FIGURE 88-2 Biosand filter can be improvised from local materials. This may not function as well as an optimally constructed and operated biosand filter, but will significantly improve clarity and microbial content of the water.

CHEMICAL DISINFECTANTS

HALOGENS (CHLORINE AND IODINE)

Worldwide, chemical disinfection is the most widely used method for improving and maintaining microbiologic quality of drinking water. Chemical disinfectants used for water disinfection are strong oxidants. *Halogens*, chiefly chlorine and iodine, are the most common chemical disinfectants used in the field. Chlorine dioxide is now available for small-use field applications and gaining acceptance. Germicidal activity results from oxidation of essential cellular structures and enzymes.[57,178,201,221,226] Halogenated amines may be synthesized by white blood cells as part of the body's natural defenses to destroy microorganisms.[335] The disinfection process is determined by characteristics of the disinfectant, the microorganism, and environmental factors.[59,144,218] Dilute solutions do not sterilize water. The relative potency of common disinfectants to inactivate waterborne microbes is as follows:

ozone > chlorine dioxide > electrochemically generated mixed-species oxidant > free chlorine or iodine > chloramine

Ozone and chlorine dioxide are discussed later under Miscellaneous Disinfectants.

Variables With Chemical Agents

Understanding the principal factors of chemical disinfection allows intelligent and flexible use (Table 88-7).

Concentration and Contact Time. The major variables in the disinfection reaction are amount of disinfectant (concentration) and exposure time of the microorganism to the disinfectant (contact time). Concentration of disinfectant in water is measured in parts per million (ppm) or milligrams per liter (mg/L), which

TABLE 88-7 Factors Affecting Halogen Disinfection

	Effect	Compensation
Primary Factors		
Concentration	Measured in milligrams per liter (mg/L) or the equivalent, parts per million (ppm); higher concentration increases rate and proportion of microorganisms killed.	Higher concentration allows shorter contact time for equivalent results. Lower concentration requires increased contact time for equivalent levels of kill.
Contact time	Usually measured in minutes; longer contact time ensures higher proportion of organisms killed.	Contact time is inversely related to concentration; longer time allows lower concentration.
Secondary Factors		
Temperature	Cold slows reaction time.	Some treatment protocols recommend doubling the dose (concentration) of halogen in cold water, but if time allows, exposure time can be increased instead, or the temperature of the water can be increased.
Water contaminants, cloudy water (turbidity)	Halogens reacts with organic nitrogen compounds from decomposition of organisms and their wastes to form compounds with little or no disinfecting ability, effectively decreasing the concentration of available halogen. In general, turbidity increases halogen demand.	Doubling the dose of halogen for cloudy water is a crude means of compensation that often results in a strong disinfectant taste on top of the taste of the contaminants. A more rational approach is first to clarify water to reduce halogen demand.
pH	The optimal pH for disinfection is 6.5-7.5. As water becomes more alkaline, approaching pH 8.0, much higher doses of halogens are required.	Compensating for pH is not necessary for most surface water.

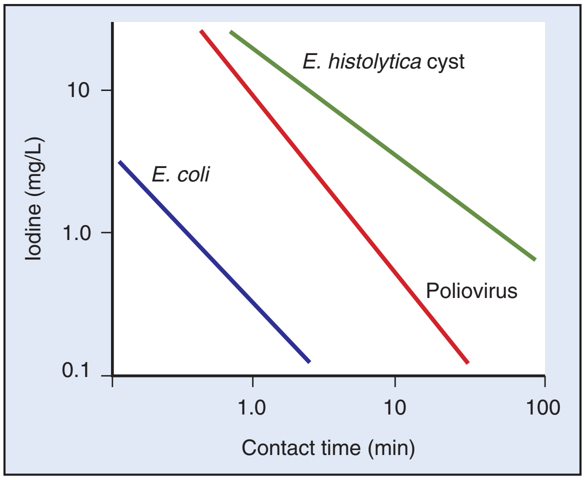

FIGURE 88-3 Relationship of halogen concentration and contact time for a given temperature and pH. The first-order chemical reaction results in a straight line over most values for each microorganism and halogen compound. *(Data from Chang SL: The use of active iodine as a water disinfectant,* J Am Pharm Assoc *47:417, 1958; and Water and Sanitation for Health [WASH] Project: Report on mobile emergency water treatment and disinfection units, WASH Field Report No 217, 1980, Arlington, Va.)*

are equivalent. Contact time is usually measured in minutes but ranges from seconds to hours. In field disinfection, halogen (iodine or chlorine) concentrations of 1 to 10 mg/L for 10 to 60 minutes are generally effective.

Theoretically, the disinfection reaction follows first-order kinetics. The rate of the reaction is determined by the initial concentration of reactants, and a given proportion of the reaction occurs in any specified interval.[144,336] This means that concentration and time are inversely related, and their product results in a constant for specified disinfectant, organism, percent reduction of viable microorganisms, and given conditions of water temperature and pH: concentration × time = constant (Ct = K)[180,336] (Figure 88-3). When concentration and contact time are graphed on logarithmic coordinates, a straight line results. This means that concentration and time can be varied oppositely and still achieve the same result.[14] In field disinfection, this can be used to minimize halogen dose and improve taste or, conversely, to minimize the required contact time.

In reality, the disinfection reaction deviates slightly from first-order kinetics, and Ct values do not follow the exponential rates described by the empirical equation because microorganisms do not act as chemical reagents ($C_n t = K$). An initial lag period may be seen before inactivation begins (e.g., because of penetration of the cyst wall), and inactivation declines for more resistant organisms or those shielded by aggregation or other particles[131,137,144] (Figure 88-4).

Contaminants. Organic and inorganic nitrogen compounds from decomposition of organisms and their wastes, fecal matter, and urea complicate chemical disinfection and must be considered in field water treatment. Vegetable matter, ferrous ions, nitrites, sulfides, and humic substances also affect oxidizing disinfectants.[100,221,336] These contaminants react, especially with chlorine, to form compounds with little or no disinfecting ability, effectively decreasing the concentration of available halogen.

Halogen Demand and Residual Concentration. Halogen demand is the amount of halogen reacting with impurities. The concept applies to all chemical disinfectant agents. Residual concentration is the amount of active disinfectant remaining after demand of the water is met. To achieve microbial inactivation in aqueous solution with a chemical agent, a residual concentration must be present for a specified contact time. Failure of chlorination in municipal systems to kill cysts or other microorganisms is usually caused by difficulty maintaining adequate residual halogen concentration and contact times, rather than by extreme resistance of the organism.[303]

Halogen demand and residual concentration in surface water are the greatest uncertainties in field disinfection and may account for laboratory efficacy being better than field effectiveness because of variability in source water.[185] Nitrogen appears in most natural waters in varying amounts, which relate directly to the sanitary quality of water. Cysticidal dose of halogens is strongly affected by the level of contamination in otherwise clean water.[59,129,303] Scant data are available on halogen demand of surface water (Table 88-8). Clear water is assumed to have minimal demand and cloudy water high demand. Surface water in the wilderness contains 10 times the organic carbon content of aquifer groundwater. The green or brown color in stagnant ponds and lakes, and in tropical and lowland rivers is usually caused by organic matter with considerable halogen demand. In some cases, such as runoff after storms and snowmelt, cloudy water may be caused by inorganic sand and clay that exert little halogen demand, but in general, chlorine demand rises with increased turbidity.[181] In addition, particulate turbidity can shield microorganisms and interfere with disinfection[85,161,181] (see Turbidity and Clarification, earlier).

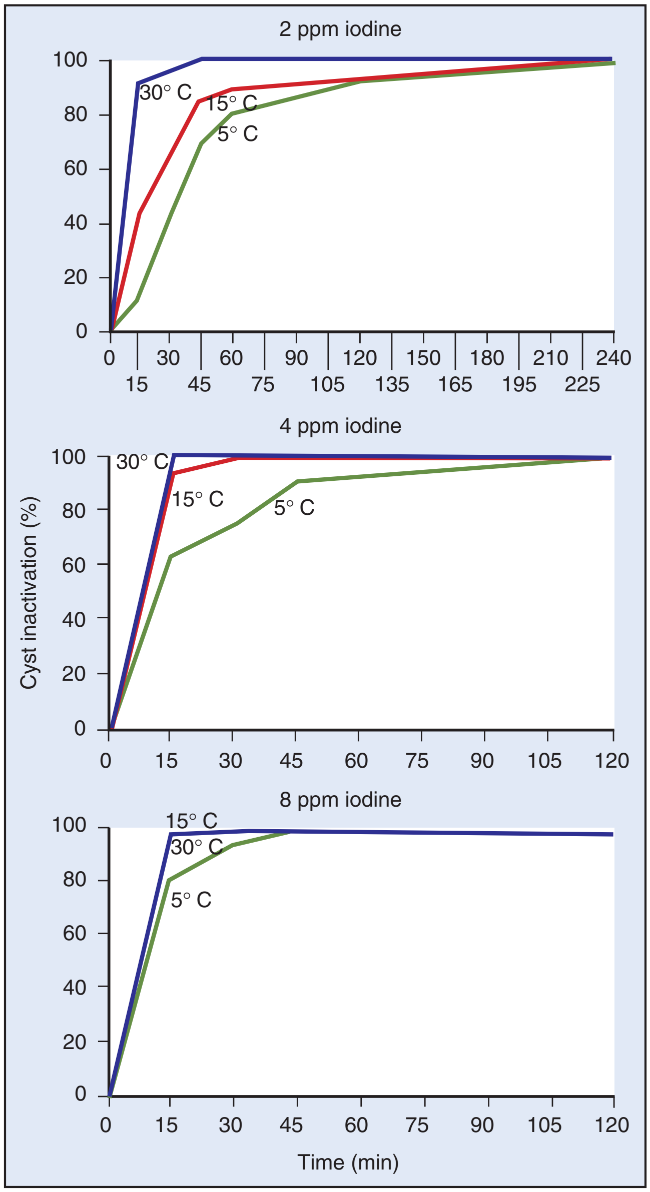

FIGURE 88-4 Effect of concentration and temperature on *Giardia* cyst inactivation by iodine. Low concentrations are effective at cold temperatures with prolonged contact time. *(From Fraker LD, Gentile D, Krivoy D, et al:* Giardia *cyst inactivation by iodine,* J Wilderness Med *3:351, 1992.)*

TABLE 88-8 Halogen Demand of Surface Water

Source	Halogen Demand (mg/L)	Reference
Cloudy river water, Portland, Oregon	3-4	Jarroll, 1980[154]
Cloudy water from clay particles	None	Chang, 1953[59]
Clear water with 10% sewage added	2	Chang, 1953[59]
Lily pond and turbid river water	5-6	Chang, 1953[59]
Colorado River; cloudy from inorganic sand, clay	0.3	Tunnicliff, 1984[317]
Unspecified surface waters	2-3	Culp, 1974[84]
Municipal wastewater	20-30	Culp, 1974[84]
High-elevation spring	0.3	Ongerth, 1989[231]
Western river	0.7	Ongerth, 1989[231]
Six watersheds in western Oregon	0.4-1.6	LeChevallier, 1981[181]
Small stream, Australia	1.3	Thomson, 1985[311]
Bolivian village (well and collected rain)	2	Quick, 1999[251]
Spring and well water, Haiti	≤1	Colindres, 2007[75]
Raw surface water from different sources in six different states	<1 to 17 (mean 6)	Lantagne, 2014[177]
Cloudy surface water (ponds, rivers)—household water sources in western Kenya	100-150	Crump, 2005[82]

The initial dose of halogen must consider halogen demand. For clear alpine waters, 1 mg/L demand can be assumed; for cloudy waters, the assumption is 3 to 5 mg/L. If a method is used that adds 4 mg/L to clear water, extra time can compensate for the lower expected residual concentration; in cloudy water, however, an increased dose of halogen, rather than prolonging the contact time, is needed to ensure free residual. The usual field recommendation to compensate for the unknown demand of cloudy water is a double dose of halogen (adding 8 to 16 mg/L). This crude means of compensation often results in a strong halogen taste on top of taste from contaminants. If the cause of turbidity is uncertain, the water should be allowed to sit; inorganic clay and sand will settle out, clarifying the water considerably. Other means of clarification, such as C-F or filtration, significantly reduce halogen demand.

Several simple color-strip tests are available for field use, such as those used for swimming pools and spas to measure the amount of free (residual) halogen in water. Testing in the wilderness for halogen residual may be reasonable for large groups but is not practical for most. Smell or taste of chlorine usually indicates some free residual. Color and taste of iodine also can be used as indicators. Above 0.6 ppm, a yellow to brown tint is noted.[336]

Temperature. Temperature influences rate of the disinfection reaction.[100,178,221] Cold water affects germicidal power and must be offset by longer contact time or higher concentration to achieve comparable disinfection.[128] The common rule is twofold to threefold increase in inactivation rate per 10° C (18° F) increase in temperature.

Temperature can be estimated in the field. Some treatment protocols recommend doubling the dose of halogen in cold water, but if there is no urgency, time can be increased instead of dose. Data for killing *Giardia* in very cold water (5° C [41° F]) with both chlorine and iodine indicate that contact time must be prolonged three to four times, not merely doubled, to achieve high levels of inactivation.[114,138] If feasible, raising the temperature by 10° to 20° C (18° to 36° F) allows a lower dose of halogen and more reliable disinfection at a given dose.

pH. Halogen oxidizes in water to form several compounds, each with different disinfection capabilities. The percentage of each halogen compound is determined by pH. The optimal pH for halogen disinfection is 6.5 to 7.5.[59,217] As water becomes more alkaline, approaching pH 8.0, much higher doses of halogens are required.

Although pH can be measured in the field, the relationship is too complex to allow meaningful use of the information. Most surface water pH is neutral to mildly acidic, which is within the effective range of any chemical agent used. On the alkaline side, some surface water with pH 7.0 to 8.0 begins to affect the chemical species of chlorine, favoring less active forms.[144] Certain desert water is so alkaline that halogens would have little activity; however, these waters are usually not palatable. At this time, compensating for pH is not necessary. Tablet formulations of halogen have the advantage of some buffering capacity.

Susceptibility of Microorganisms. The final variable is the target microorganism. Sensitivity to halogen is determined by the diffusion barrier of the cell wall or capsule and the relative susceptibility of proteins and cellular respiration to denaturation and oxidation.[57,221] Organisms, in order of increasing resistance to halogen disinfection, are enteric (vegetative) bacteria, viruses, *Giardia* cysts, bacterial spores, *Cryptosporidium* oocysts, and parasitic ova[54] (Tables 88-9 and 88-10). For example, *Entamoeba histolytica* cysts are 160 times as resistant as *E. coli* and nine times as resistant as hardier enteroviruses to chlorine (HOCl). Virucidal residuals of iodine (I_2) and HOCl are 5 to 70 times higher than bactericidal residuals.[57,180,221,320] Relative resistance between organisms is similar for iodine and chlorine. The physical state of the microbes also determines their susceptibility. Microbes that are aggregated in clumps or embedded in other matter or organisms may be shielded from disinfectants.

Bacteria. All vegetative bacteria are extremely sensitive to halogens. Inactivation involves oxidation of enzymes on the cell membrane and does not require penetration.[336] Little modern work has focused on bacterial agents because they are more sensitive than viruses and cysts, and little difference is evident between the bacterial pathogens.[144] Although halogens were first used to disinfect water during cholera epidemics in 1850, recent cholera epidemics prompted review of data that reaffirmed the susceptibility of *Vibrio cholerae* to low levels of chlorine and iodine.[80] *Campylobacter* has susceptibility similar to that of other enteric pathogens.[29]

Bacterial spores, such as *Bacillus anthracis*, are relatively resistant to halogens, but with chlorine, spores are not much more resistant than are *Giardia* cysts.[14,336] Quantitative data are not available for iodine solutions, but iodine kills spores. Fortunately, sporulating bacteria do not normally cause waterborne enteric disease.[142]

Viruses. Enteroviruses are more resistant than are enteric bacteria,[221] but they constitute such a large and diverse group of organisms that generalization is especially difficult.[58,178,322] Most studies have used poliovirus, a phage virus, or coxsackievirus. The mechanism of action for halogen inactivation of viruses has not been resolved. It is not clear whether the oxidant injures protein on the shell, a process similar to bacterial inactivation,[35] or penetrates the protein capsid by chemical transformation and then attacks the nucleic acid core, as in cyst inactivation.[336] Clumping and association of viruses with cells and particulate matter are thought to be significant factors affecting viral disinfection, causing departure from first-order kinetics.[102,295,325] Cell-associated HAV was 10 times more resistant than was dispersed HAV.

Most viruses tested against chlorine have shown resistance 10 times greater than that of enteric bacteria, but inactivation is still achieved rapidly (0.3 to 4.5 minutes) with low levels (0.5 mg/L) of chlorine.[102,325] Recent work with norovirus has refuted claims that it is highly resistant to chlorine.[164,288] Current data suggest that HAV is not significantly more resistant than other enteric viruses.[129,241,296,312] In one test using iodine tablets, HAV was inactivated under difficult conditions more readily than was poliovirus or echovirus.[295,296]

Cysts and Parasites. Protozoal cysts are considerably more resistant than are enteric bacteria and enteric viruses, probably because of cysts' physiologically inactive outer shell, which the disinfectant must penetrate to be effective.[57,336] Halogens can be used in the field to inactivate *Giardia* cysts (see Figure 88-4).[320] Testing on *G. lamblia* indicates similar sensitivity to both

TABLE 88-9 Disinfection Data for Chlorine*

Halogen†	Organism	Concentration (mg/L)	Time (min)	pH	Temp	Disinfection Constant (Ct)	Reference
HOCl	*Escherichia coli*	0.1	0.16	6.0	5° C (41° F)	.016	White, 1992[336]
FAC	*Campylobacter*	0.3	0.5	6.0-8.0	25° C (77° F)	0.15	Blaser,1986[28]
FRC	20 enteric virus	0.5	60	7.8	2° C (35.6° F)	30	Briton,1980[34]
Free Cl	6 enteric viruses	0.5	4.5	6.0-8.0	5° C (41° F)	2.5	Engelbrecht, 1980[102]
Free Cl	Norovirus	1	10	6.0	5° C (41° F)	10	Shin, 2008[288]
		5	20 sec			1.66	
FRC	Hepatitis A virus	0.5	1	6.0	25° C (77° F)	0.5	Grabow, 1983[129]
Free Cl	Hepatitis A virus	0.5	5	6.0	5° C (41° F)	2.5‡	Sobsey, 1975[293]
HOCl	Amebic cysts	3.5	10		25° C (77° F)	35	Chang, 1970[57]
FRC	Amebic cysts	3.0	10	7.0	30° C (86° F)	30	Stringer, 1970[303]
Free Cl	*Giardia* cysts	2.5	60	6.0-8.0	5° C (41° F)	150	Rice, 1982[263]
Free Cl	*Giardia lamblia* cysts	0.85	90	8.0	2°-3° C (35.6°-37.4° F)	77	Wallis, 1988[332]
Free Cl	*Giardia muris* cysts	3.05	50	7.0	5° C (41° F)	153	Rubin, 1989[279]
Free Cl	*G. muris* cysts	5.87	25	7.0	5° C (41° F)	139	Rubin, 1989[279]
Free Cl	*Giardia*			6.0	0.5° C (32.9° F)	170	Hibler, 1987[138]
Free Cl	*Giardia*			6.0	5° C (41° F)	120	Hibler, 1987[138]
Free Cl	*Cryptosporidium*	80	90			7200	Korich,1990[168]
FRC	Schistosome cercariae	1.0	30	7.0	28° C (82.4° F)	30	WHO, 1981[344]
Free Cl	Nematodes	2-3	120			(Not lethal)	NAS, 1980[221]
Free Cl	Nematodes	95-100	30			(95% lethal)	NAS, 1980[221]
FRC	*Ascaris* eggs	200	20	5.0	37° C (98.6° F)	2000	Krishnaswami, 1968[172]

FAC, Free active chlorine; *FRC*, free residual chlorine; *Free Cl*, free chlorine; *HOCl*, hypochlorous acid; *NAS*, National Academy of Sciences; *WHO*, World Health Organization.
*Also see reference 54. For Ct values of chlorine for *Giardia*, also see reference 320.
†These represent nearly equivalent measurements of the residual concentration of active chlorine disinfectant compounds.
‡Four-log reduction. Most experiments use 2- to 3-log (99% to 99.9%) reduction as the end point.

iodine and chlorine.[156] Lower temperature decreases effectiveness of halogens on *Giardia*: longer contact time is required in cold and dirty water.[121,137,153,295] Review literature frequently attributes exaggerated resistance of *Giardia* to halogens.[143] Jarroll and colleagues[154,155] tested two chlorine methods and four iodine methods for effectiveness against *Giardia* cysts. All methods were effective in warm water, but only two methods destroyed all cysts in cold water in recommended doses. Higher doses or longer contact times would make all these methods effective.

Cryptosporidium oocysts differ greatly from other protozoan cysts and are highly resistant to halogens. The Ct constant for *Cryptosporidium* in warm water with chlorine has been estimated to be 9600.[45] Other data demonstrated 90% inactivation with 80 ppm of chlorine after 90 minutes, 14 times more resistant than *Giardia* cysts.[168] Recent data using hypochlorous acid demonstrate a maximum inactivation rate for *Cryptosporidium* of 49% after 120 minutes.[237] The current recommendation for decontaminating chlorinated swimming pools is 20 mg for 9 hours (Ct 10,800).[39] From 65% to 80% of *Cryptosporidium* oocysts were inactivated after 4 hours by two iodine tablets in "general case" water.[121] This implies that 3-log inactivation could have been achieved after 3 to 4 more hours. Although halogens can achieve disinfection of *Cryptosporidium* in the field, this is not practical.[86,273,284,336] Resistance of *Cyclospora* and microsporidia is not well studied, but the oocysts are similar to *Cryptosporidium* and thus may resemble this protozoan more than they do *Giardia*. Both *Cryptosporidium* and *Giardia* are susceptible to chlorine dioxide.[64,168,237]

TABLE 88-10 Disinfection Data for Iodine

Halogen*	Organism	Concentration (mg/L)	Time (min)	pH	Temp	Disinfection Constant (Ct)	Reference
FRI	*Escherichia coli*	1.3	1	6.0-7.0	2°-5° C (35.6°-41° F)	1.3	National Academy of Sciences, 1980[221]
I_2	Amebic cysts	3.5	10		25° C (77° F)	35	Chang, 1970[57]
I_2	Amebic cysts	6.0	5		25° C (77° F)	30	Chang, 1970[57]
I_2	Amebic cysts	12.5	2		25° C (77° F)	25	Chang, 1970[57]
FRI	Poliovirus 1	1.25	39	6.0	25° C (77° F)	49	Berg, 1964[17]
FRI	Poliovirus 1	12.7	5	6.0	25° C (77° F)	63	Berg, 1964[17]
I_2	Poliovirus 1	1	6	7.0	18° C (64.4° F)	6	Berg, 1964[17]
I_2	Coxsackievirus	0.5	30	7.0	5° C (41° F)	15	Berg, 1964[17]
I_2	Amebic cysts	8	10	4.0-8.0	23° C (73.4° F)	80	Chang, 1953[59]
I_2	Bacteria, viruses	8	20		0°-5° C (32°-41° F)	160	Chang, 1953[59]
FRI	*Giardia* cysts	4	15	5.0	30° C (86° F)	60†	Fraker, 1992[114]
FRI	*Giardia* cysts	4	45	5.0	15° C (59° F)	170†	Fraker, 1992[114]
FRI	*Giardia* cysts	4	120	5.0	5° C (41° F)	480†	Fraker, 1992[114]

*FRI (free residual iodine) and I_2 (elemental iodine) are nearly equivalent measurements of the residual concentration of active iodine disinfectant compounds.
†100% kill; viability tested only at 15, 30, 45, 60, and 120 minutes.

Schistosome cercariae are susceptible to low concentrations of chlorine.[339] Limited data on parasitic helminth larvae and ova indicate the presence of such high levels of resistance that chemical disinfection is not useful.[172,221,287] However, these are not common waterborne pathogens and can be readily removed or destroyed by heat, filtration, or coagulation-flocculation.

Disinfection Constant. Given all the variables, the best comparison of disinfection power is the disinfection constant (Ct). Disparate results may be caused by lack of standardized experimental conditions of pH, temperature, chemical species of halogen, and species of microorganism or by different techniques for concentrating, counting, and determining viability of organisms.[144,221] The latter is especially a problem for cysts and viruses, which cannot be cultured easily.[281] The end point for disinfection effectiveness is now standardized by the EPA guidelines; most past studies used 99.9% for all organisms, with some using 99% or 99.99%. Differences between laboratory and field conditions also make extrapolation from data to practice inaccurate and suggest the need for a safety factor in the field. Despite variation, Ct remains a useful and widely used concept; values provide a basis for comparing effectiveness of different disinfectants for inactivation of specific microorganisms.[144,180,320] To use halogens for disinfection, a consensus organism (the most resistant target) determines the Ct.[144,178,336] For wilderness water, this has been protozoan cysts. Resistance of *Cryptosporidium* will not raise the threshold for halogen use; rather, it will force an alternative or a combination of methods to ensure removal and inactivation of all pathogens.

TABLE 88-11 Water Disinfection Techniques and Halogen Doses

	Add to 1 Liter or Quart of Water	
Iodination Techniques	**Amount for 4 ppm**	**Amount for 8 ppm**
Iodine tablets	0.5 tab	1 tab
Tetraglycine hydroperiodide		
EDWGT		
Potable Aqua		
Globaline		
2% iodine solution (tincture)	0.2 mL 5 gtt*	0.4 mL 10 gtt
10% povidone-iodine solution†	0.35 mL 8 gtt	0.70 mL 16 gtt
Saturated solution: iodine crystals in water	13 mL	26 mL
Saturated solution: iodine crystals in alcohol	0.1 mL‡	0.2 mL
Chlorination Techniques§‖	**Amount for 5 ppm§§**	**Amount for 10 ppm**
Sodium hypochlorite (household bleach 5%)	0.1 mL 2 gtt	0.2 mL 4 gtt
Sodium hypochlorite (household bleach 8.25%)	1 gtt	
1% bleach (CDC-WHO Safe Water System)¶	8-10 gtt	
Calcium hypochlorite** (Redi-Chlor [0.1-g tab])	0.25 tab	0.5 tab
Sodium dichloroisocyanurate (NaDCC)†† (Aquatab, Kintab)		1 tab (8.5 mg NaDCC)
Chlorine plus flocculating agent (Chlor-Floc)		1 tab‡‡

EDWGT, Emergency drinking water germicidal tablet.
*Measure of a drop varies from 16-24 gtt/mL; standard 20 gtt/mL is used here.
†Povidone-iodine solutions release free iodine in levels adequate for disinfection, but scant data are available.
‡Measure with dropper or tuberculin syringe.
§Recommended concentration of chlorine for emergency point-of-use water treatment varies across health agencies, but generally does not exceed 5 mg/L. For long-term household use in developing areas, CDC Safe Water System establishes a maximum of 2 mg/L, which is the limit of taste tolerance for many people (see reference 176.)
‖For treatment of large volumes, see reference 319 for TB MED 577, or see formula to calculate in reference 176.
¶Safe Water System for long-term routine household point-of-use water disinfection recommends a hypochlorite dose of about 2 mg/L in clear water and 4 mg/L in slightly turbid water. This results in a low yet effective target residual concentration with acceptable taste, but requires testing in a particular water source to ensure sufficient residual.
**Concentrated source of hypochlorite available as granules or tablets; useful for treating larger volumes of water; often used to treat swimming pool water.
††Available in different strengths to treat different volumes of water. Check packaging to determine proper dose.
‡‡Yields 8 ppm.
§§In usual situations, EPA recommends a target residual of 4 mg/L. For household use, CDC recommends less than 2 mg/L. Many of the recommended emergency doses exceed this threshold.[177]

TABLE 88-12 Recommendations for Contact Time With Halogens in the Field

	Contact Time in Minutes at Various Water Temperatures		
Concentration of Halogen	**5°C (41°F)**	**15°C (59°F)**	**30°C (86°F)**
2 ppm	240	180	60
4 ppm	180	60	45
8 ppm	60	30	15

Note: Data indicate that very cold water requires prolonged contact time with iodine or chlorine to kill *Giardia* cysts. These contact times have been extended from the usual recommendations in cold water to account for this and for the uncertainty of residual concentration.

CHLORINE

Chlorine has been used as a disinfectant for 200 years. Hypochlorite was first used for water disinfection in 1854 during cholera epidemics in London and was first used continuously for water treatment in Belgium in 1902. It is currently the preferred means of municipal water disinfection worldwide and the preference of CDC and WHO for individual household disinfection of drinking water where there is no community-level treatment. It is also recommended for emergency disinfection following disasters or other disruption in community treatment.[176] Extensive data support its use (see Table 88-9).[21,54,336]

Chemistry

Chlorine reacts in water to form the following compounds[100,201,336]:

$$Cl_2 + H_2O \rightarrow H^+ + Cl^-$$

$$HOCl \rightarrow OCl^- + H^+$$

At neutral pH, negligible amounts of diatomic chlorine are present. The major disinfectant is hypochlorous acid (HOCl), which penetrates cell and cyst walls easily. Dissociation of HOCl to the much weaker disinfectant hypochlorite (OCl^-) depends on temperature and pH. In pure water at pH 6.0, 97% of chlorine is HOCl; at pH 7.5, the HOCl/OCl^- ratio is 1:1; and above pH 7.5, OCl^- predominates.[336] The combination of these two compounds is defined as free available chlorine. Both calcium hypochlorite ($Ca[OCl]_2$) and sodium hypochlorite (NaOCl) readily dissociate in water, allowing the same equilibrium to form as when elemental chlorine is used.[178,336] Chloride ion (Cl^-, NaCl, or $CaCl_2$) is germicidally inactive. In addition, chlorine readily reacts with ammonia to form monochloramines (NH_2Cl), dichloramines, or trichloramines, referred to as *combined chlorine*. Chloramines have weak disinfecting power and are calculated as a disinfectant

TABLE 88-13 Chlorine Dose for Large-Volume Water Disinfection

$$\text{Dose}(\text{mg}_{Cl}/\text{L}_{water}) = \left(\text{Bleach concentration}(\%) \times \frac{10{,}000\ \text{mg}_{Cl}/\text{L}_{Cl}}{1\%} \times \text{Bleach added}(\text{mL}_{Cl}) \times \frac{1\ \text{L}_{Cl}}{1000\ \text{mL}_{Cl}}\right) / (\text{Volume of water}(\text{L}_{water}))$$

From Lantagne D, Person B, Smith N, et al: Emergency water treatment with bleach in the United States: the need to revise EPA recommendations, *Environ Sci Technol* 48(9):5093-5100, 2014.

in municipal sewage plants.[144,201,217,221,336] In field disinfection, however, these compounds are not considered, and only free residual chlorine should be measured. At doses of a few milligrams per liter and contact times of about 30 minutes, free chlorine generally inactivates greater than 99.99% of enteric bacteria and viruses.[297] The CDC-WHO Safe Water System for household disinfection in developing countries provides a dosage of 1.875 or 3.75 mg/L of sodium hypochlorite with a contact time of 30 minutes, sufficient to inactivate most bacteria, viruses, and some protozoa that cause waterborne diseases (http://www.cdc.gov/safewater/).[169] Chlorine bleaches organic matter, making water sparkling blue, as in swimming pools.[336]

Toxicity

Acute toxicity to chlorine is limited; the main danger is irritation and corrosion of mucous membranes if concentrated solutions (e.g., household bleach) are ingested. Numerous cases have been reported of short-term ingestion of very high residuals (50 to 90 ppm) in drinking water; one military study used 32 ppm for several months without adverse effects.[336] Animal studies using long-term chlorination of drinking water at 100 to 200 ppm have not shown toxic effects.[221]

Sodium hypochlorite is not carcinogenic; however, reactions of chlorine with certain organic contaminants yield chlorinated hydrocarbons, chloroform, and other trihalomethanes, which are considered carcinogenic.[221,322] Public health regulations limit residual chlorine in public systems to decrease ingestion of trihalomethane. The concern is now fueled more by public fears than by scientific conclusion.[336] The risk for death from infectious diseases if disinfection is not used is much greater than any risk from chlorine disinfection byproducts.[265,322,347] These compounds are not likely to form in clean wilderness surface water, because the organic precursors are not present.

Products and Techniques for Chlorination

Free chlorine is the most widely available and affordable of chemical water disinfectants.[297] For household or field water treatment, free chlorine can be obtained in liquid, granular, and tablet forms or generated from electrolysis of salt (Appendix B; for dosage information, see Tables 88-11 to 88-13). Tablets have the advantage of easy administration and can be salvaged if the container breaks. However, they lose effectiveness with exposure to heat, air, or moisture. No significant loss of potency results from opening a glass bottle intermittently over weeks, but activity is rapidly lost after a few days of continuous exposure to air with high heat and humidity. To extend shelf life, many tablets are individually wrapped in foil.

Superchlorination-Dechlorination. The process of superchlorination-dechlorination with different reagents is used in some large-scale disinfection plants to avoid long contact times and to remove tastes and smells. High doses of chlorine remove or oxidize hydrogen sulfide and some other chemical contaminants that contribute to poor taste and odor. This method of chlorination can readily be adapted to field use. High doses of chlorine are added to the water in the form of calcium hypochlorite crystals to achieve concentrations of 30 to 200 ppm of free chlorine. These extremely high levels are above the margin of safety for field conditions and rapidly kill all bacteria, viruses, and protozoa and could kill *Cryptosporidium* with a contact time of several hours or overnight. After at least 10 to 15 minutes, several drops of 30% hydrogen peroxide solution are added. This reduces hypochlorite to chloride, forming calcium chloride (a common food additive), which remains in solution, as follows:

$$Ca(OCl)_2 + H_2O_2 \rightarrow 2HOCl + Ca^{2+}(OH^-)_2$$

$$Ca(OCl)_2 + H_2O_2 \rightarrow CaCl_2 + 2H_2O + 2O_2$$

Excess hydrogen peroxide reacts with water to form oxygen and water. Chloride has no taste or smell. Hydrogen peroxide is also a disinfectant.[201]

The minor disadvantage of a two-step process is offset by excellent taste. Measurements to titrate peroxide to the estimated amount of chlorine do not need to be exact, but some experience is needed to balance the two and achieve optimal results. This is a good technique for highly polluted or cloudy water and for disinfecting large quantities. It is the best technique for storing water on boats or for emergency use. A high level of chlorine prevents growth of algae or bacteria during storage; water is then dechlorinated in smaller quantities when ready to use.

The two reagents must be kept tightly sealed to maintain potency of the reagents. Properly stored, calcium hypochlorite (70% available chlorine) loses only 3% to 5% of available chlorine per year. Hydrogen peroxide 30% is corrosive and burns skin, so should be used cautiously. There is currently no commercial formulation; however, the ingredients can be easily obtained and packaged in small Nalgene bottles.

IODINE

Iodine has been used as a topical and water disinfectant since the beginning of the 20th century.[178,201] Iodine is effective in low concentrations for killing bacteria, viruses, and cysts and in higher concentrations against fungi and even bacterial spores, but it is a poor algicide[59,128,221] (see Table 88-10 and Figures 88-3 and 88-4). Iodine has been used successfully in low concentrations for continuous water disinfection of small communities.[167] Despite several advantages over chlorine disinfection, iodine has not gained general acceptance because of concern for its physiologic activity. Recently, the European Union stopped the sale of iodine products used for water disinfection.

Chemistry

Iodine is the only halogen that is a solid at room temperature. Of the halogens, it has the highest atomic weight, lowest oxidation potential, and lowest water solubility. Its disinfectant activity in water is quite complex because of formation of various chemical intermediates with variable germicidal efficiency. Seven different ions or molecules are present in pure aqueous iodine solutions, but only elemental (diatomic) iodine (I_2) and hypoiodous acid (HOI) play major roles as germicides. Diatomic iodine reacts in water to form the following compounds[59,128]:

$$I_2 + H_2O \rightarrow HOI + I^- + H^+$$

I_2 is two to three times as cysticidal and six times as sporicidal as HOI, because it more easily diffuses through the cyst wall. Conversely, HOI is 40 times as virucidal and three to four times as bactericidal as I_2, because inactivation of organisms depends directly on oxidation potential, without involving cell wall diffusion.[57] Their relative concentrations are determined by pH and concentration of iodine in solution.[59] At pH 7.0 and 0.5 ppm of iodine, the concentrations of I_2 and HOI are approximately equal, resulting in a broad spectrum of germicidal action. At pH 5.0 to 6.0, most of the iodine is present as I_2, whereas at pH 8.0, 12% is present as I_2 and 88% as HOI. At higher concentrations of iodine, more HOI is present. Under field conditions, I_2 is the major disinfectant for which doses are calculated.[59]

Iodide is important because it readily forms when reducing substances are added to iodine solution. Iodide ion is without any effect for water disinfection and also has no taste or color, but is still physiologically active.

Toxicity

The main disadvantage of iodine is its physiologic activity, with effects on thyroid function, potential toxicity, and allergenicity.[236] Acute toxic responses generally result from intentional overdoses of iodine, with corrosive effects in the GI tract leading to hemorrhagic gastritis. Mean lethal dose is probably about 2 to 4 g (0.07 to 0.14 oz) of free iodine or 29.6 to 59.1 mL (1 to 2 oz) of strong tincture.[111] Iodide is absorbed into the bloodstream but has minimal toxicity (thus its use for radiographic imaging).

Sensitivity reactions, including rashes and acne, may occur with usual supplementation levels of iodine. Given the physiologic necessity of iodine, it is not clear why some people react to certain forms of the substance, such as iodized salt. As with other sensitivity reactions, these may occur with very low doses. Acute allergy to iodide is rare and manifests as individual hypersensitivity, such as angioneurotic and laryngeal edema.[236]

Chronic iodide poisoning, or iodism, occurs after prolonged ingestion of sufficiently high doses, but marked individual variation is seen. Symptoms simulate upper respiratory illness, with irritation of mucous membranes, mucus production, and cough.

Thyroid Effects of Iodine Ingestion. Iodine is an essential element for normal thyroid function and health in small amounts of 100 to 300 mcg/day. Excess amounts can result in thyroid dysfunction. Maximum safe level and duration of iodine ingestion are not clearly defined, making it difficult to provide recommendations for prolonged use in water treatment.

Most persons can tolerate high doses of iodine without development of thyroid abnormalities,[33] because the thyroid gland has an autoregulatory mechanism that effectively manages excessive iodine intake. Initially, excess iodine suppresses production of thyroid hormone, but production usually returns to normal in a few days.

Iodine-induced hyperthyroidism can result from iodine ingestion by persons with underlying thyroid disease or when iodine is given to persons with prior iodine deficiency.[33,278] During the worldwide campaign to eliminate endemic goiter and cretinism, 1% to 2% of residents developed hyperthyroidism from small amounts of dietary iodine supplementation. Groups at higher risk were older adults, Graves disease patients (especially after antithyroid therapy), and patients taking pharmacologic sources of iodine. Hyperthyroidism has been reported from iodine use as a water disinfectant in two travelers. Both were from iodine-sufficient areas and had antithyroid antibodies, suggesting underlying thyroiditis; one had a mother and sister with Hashimoto's thyroiditis.[187]

Iodine-induced hypothyroidism or goiter is much more common from excessive iodine intake. Hypothyroidism is attributed to prolonged suppression of thyroid hormone production induced by excess iodine levels, but the mechanism through which iodide goiter is produced is not well understood. The incidence of goiter varies and does not correlate well with quantity of iodine or with the level of hypothyroidism. Goiters were discovered among a group of Peace Corps volunteers in Africa and were linked epidemiologically to the use of iodine resin water filters.[114,165] Forty-four (46%) of the volunteers had enlarged thyroids, but 30 of these had normal thyroid function tests.

Iodine-induced hypothyroidism or goiter may occur with or without underlying thyroid disease but is more common in several groups[33,278,340]: (1) those with underlying thyroid problems, including prior treatment for Graves disease or subtotal thyroidectomy; (2) fetuses and infants, from placental transfer of iodide from mothers treated with iodides; (3) persons with subclinical hypothyroidism, especially older adults, in whom the incidence is 5% to 10%; and (4) patients with excessive iodide from medications (formerly potassium iodide; currently amiodarone).

Neonatal goiter is especially worrisome because it can lead to asphyxia during birth or hypothyroidism with mental impairment. Daily intakes as small as 12 mg have been reported to produce congenital iodide goiters, but generally, much higher doses are required.

Dose-Response or Threshold Level. The reported incidences of goiter, hypothyroid effects, and hyperthyroid response vary so widely that they provide no clear dose limits.[236] These data and other controlled trials of high doses have been reviewed.[11] The use of iodine for decades as a field water disinfectant by military and civilian populations without reports of associated clinical thyroid problems suggests that the risks are minimal and would be outweighed by the risk for enteric disease. Biochemical assays show that changes in thyroid function tests are common with excess iodine intake; however, changes in thyroid function usually remain subclinical. All changes reverted to normal within weeks to months without persistent thyroid disease.

Studying longer duration of ingestion, Freund[116] found minimal changes and no clinical problems when water with 1 mg/L of iodine was used to disinfect water at a prison for up to 3 years. Referring to the same project, Thomas and colleagues[310] reported that after 15 years of ongoing iodine use at 1 mg/L, iodinated water caused no decrease in serum concentrations of thyroxine (T_4) below normal values and no allergic reactions. Patients with prior thyroid disease had no recurrence with iodinated water; four patients with active hyperthyroidism were treated in standard fashion, and their condition remained well controlled despite the extra iodine intake. Also, 177 inmates gave birth to 181 full-term infants, and no neonatal goiters were detected.

The military studied long-term toxic effects of iodine, adding sodium iodide to drinking water at a naval base for 6 months.[216] The estimated daily dose of iodine per person was 12 mg for the first 16 weeks and 19.2 mg for the next 10 weeks. No evidence of functional changes or damage in the thyroid gland, cardiovascular system, bone marrow, eyes, or kidneys was noted. No increase in skin diseases, sensitization to iodine, or impaired wound healing or resolution of infections was evident.

Recommendations. The 2001 U.S. Department of Agriculture (USDA) Recommended Dietary Intake suggested an upper limit of 1.1 mg/day for adults, weight-adjusted for children. WHO did not set a guideline value for iodine in drinking water, because of a paucity of data and because it is not recommended for long-term disinfection.

The EPA and WHO, supported by the American Water Works Association (AWWA), have recommended iodine use for water disinfection only as an emergency measure for short periods of about 3 weeks. However, this period of short use appears arbitrary. The European Union revoked approval of iodine for water purification on October 25, 2009, and it can no longer be sold for this purpose.

Available data suggest the following:

- High levels of iodine, such as those produced by recommended doses of iodine tablets, should be limited to periods of 1 month or less.
- Iodine treatment that produces a low residual (1 mg/L or less) appears safe, even for long periods, in people with normal thyroid function. This would require very low doses of iodine added to the water or an activated charcoal stage to remove residual iodine.
- Persons planning to use iodine for a prolonged period should have their thyroid gland examined and thyroid function measured to ensure that a state of euthyroidism exists.
- The following groups should not use iodine for water treatment because of their increased susceptibility to thyroid problems:
  - Pregnant women
  - Persons with known hypersensitivity to iodine
  - Persons with a history of thyroid disease, even if controlled by medication
  - Persons with a strong family history of thyroid disease (thyroiditis)
  - Persons from areas with chronic dietary iodine deficiency

Products and Techniques for Iodination

Several formulations of iodine are available for field use. (See Tables 88-10 and 88-15 for efficacy, Table 88-11 for dosing, and Table 88-14 and Appendix B for details on commercial products, including tablets and crystalline iodine.)

Resins. Iodine can be bound to an inert resin to create a disinfectant with unique properties. These are considered "demand disinfectants" because iodine transfers from the resin

Preparation	Iodine (%)	Iodide (%)	Type of Solution
Iodine topical solution	2.0	2.4 (sodium)	Aqueous
Lugol solution	5.0	10.0 (potassium)	Aqueous
Iodine tincture	2.0	2.4 (sodium)	Aqueous-ethanol
Strong iodine solution	7.0	9.0 (potassium)	Ethanol (85%)

TABLE 88-14 Iodine Solutions

to the microorganism on contact, aided by electrostatic forces, but limited amounts of iodine dissolve in the water. Iodine binds to the wall or capsule, penetrates, and kills the organism. This effectively exposes the organisms to high iodine concentrations and allows reduced contact time compared with dilute iodine solutions. Residual iodine concentration in the water depends on the properties of the resin, temperature of the water, and presence of an activated charcoal stage.

Resins have proved effective against bacteria, viruses, and cysts but not against *C. parvum* oocysts or bacterial spores.[197] When *Cryptosporidium* oocysts were passed through a triiodide resin column, most were retained in the resin column, probably by electrostatic attraction to the resin. Of those that passed through, only a small percentage were inactivated within 30 minutes by the iodine.[324]

Data suggest that both contact time and iodine residual are important for optimal results.[110,196,197] Fifty percent of *Giardia* cysts were viable 10 minutes after passage through a triiodine resin. Viable *Giardia* cysts could be recovered in 4°C (39.2°F) water 40 minutes after passage through an iodine resin.[196] A simple resin filter failed to pass the EPA protocol for "worst-case" water unless water was passed through the filter twice. The data implied that a holding (contact) time could have achieved the desired results.[122] The Canadian health department, challenging an in-line triiodine resin with highly polluted water, also found that a 15-minute contact time was necessary for warm water and 30-minute contact time for cold water.[6,103] The EPA conducted tests of triiodide resin against *E. coli* but not against other organisms, for which it relied on independent testing. It concluded that the product depends on a 0.2 ppm residual and that additional testing would be necessary below this level.

Resins are chemically and physically stable during conditions of dry storage at room temperature. Aqueous suspensions or resins retain biocidal potential for 15 years. No alteration in activity was observed after dry storage for 1 month at 50°C (122°F).[197]

Iodine Resin Filters. Iodine resins have been used for water disinfection in household or small systems and incorporated into filter designs for field use. Iodine filters are generally designed with two stages in addition to the iodine resin. A microfilter, generally 1 μm, effectively removes *Cryptosporidium*, *Giardia*, and other halogen-resistant parasitic eggs or larva. Because iodine resins kill bacteria and viruses rapidly, limited contact time is required for most water.[122] Addition of a third stage of activated charcoal removes dissolved residual, which may decrease efficacy.[196,314] In the United States, inconsistent results of product testing under variable conditions led to withdrawal of most filter models from the market. It was not clear whether failure to achieve desired results was related to inadequate contact with the resin or insufficient contact time with iodine residual. Resins are now being used in point-of-use household devices in other countries with generally good but variable microbial removal or inactivation. Significant levels of residual iodine are noted without a charcoal stage.[66]

Given some of the variability in results and uncertainty of mechanism of action, the U.S. outdoor gear companies have abandoned iodine resin–containing portable hand-pump filters, and only drink-through bottles remain on the U.S. market. Other products may still be available outside the United States or through Internet retailers.

CHLORINE VERSUS IODINE

A large body of data proves that both iodine and chlorine are effective disinfectants with adequate concentrations and contact times, except for dealing with *Cryptosporidium*.[142] Under identical water test conditions and using recommended dose and contact time, chlorine and iodine tablets are similar in their biocidal activity[243] (see Tables 88-9, 88-10, and 88-15). A few investigators have reported data suggesting ineffectiveness of common halogen preparations. Jarroll and associates[155,156] tested six methods of field disinfection and found that none achieved high levels of *Giardia* inactivation at the recommended dose and times. However, this failure simply reflected the need for longer contact times in cold water.[188] Ongerth and colleagues[232] tested seven chemical treatments for *Giardia* inactivation in clear and turbid water at 10°C (50°F). None achieved 99.9% reduction in 30

TABLE 88-15 Data on Efficacy of Chlor-Floc and Iodine Tablets

Halogen	Dose	FRC (mg/L)	Time (min)	Temperature	Organism	Log Reduction	Reference
Chlor-Floc	1 tab or 2 tabs	4-7	5	10°-20°C (50°-68°F)	Bacteria	6	Powers, 1994[244]
		4-14	20	10°-20°C (50°-68°F)	*Giardia muris*	3	
			5	10°-20°C (50°-68°F)	Rotavirus	4	
			20	10°-20°C (50°-68°F)	Poliovirus	Inadequate	
	1 tab		12	25°C (77°F)	Poliovirus	Inadequate	
Globaline	2 tabs		20	Various	Bacteria	6	
			45	5°C (41°F)	*G. muris*	3	
			20	5°C (41°F)	Rotavirus	4	
			60	5°C (41°F)	Poliovirus	60	
AquaPure	2 tabs	7-11	40	5°C (41°F)			Powers, 1992[246]
	1 tab		30-40	15°-25°C (59°-77°F)	Bacteria	6	
				15°-25°C (59°-77°F)	Rotavirus	4	
				15°-25°C (59°-77°F)	Poliovirus	2	
			20	15°-25°C (59°-77°F)	*G. muris*	2	
Globaline	2 tabs	10	60	15°C (59°F)	*Giardia*	3	Powers, 1991[245]
	1		180	5°C (41°F)	*Giardia*	3	
	2		120	5°C (41°F)	*Giardia*	3	
Iodine tablets	1 or 2	8-16	60	5°-25°C	Hepatitis A	4	Sobsey, 1991[295]
		8	60	5°C (41°F)	Poliovirus, echovirus	Insufficient	
		16	60	5°C (41°F)	Poliovirus, echovirus	4	

minutes. All iodine-based chemical methods were effective at 8 hours, but none of the chlorine preparations was effective, even after this extended time. Although these results after 30 minutes in cold water are to be expected, the 8-hour results do not conform to other experimental data on chlorine. Unfortunately, the authors did not test for residual halogen, although initial levels achieved should have been effective, and they did not test at regular time intervals to determine when the iodine methods had achieved the target reduction of organisms. Schlosser and co-workers[283] found that sodium hypochlorite tablets, sodium dichloroisocyanurate tablets, and iodine in ethanol used according to package instructions removed 2 to 3 log of bacteria in clear water, but less in turbid river water. This suggests the need for clarifying dirty water before halogen use and, if possible, providing extra contact time in any situation.

Iodine has some advantages over chlorine. Of the halogens, iodine has the lowest oxidation potential, reacts least readily with organic compounds, is least soluble, is least hydrolyzed by water, and is less affected by pH, all of which indicate that low iodine residuals should be more stable and persistent than corresponding concentrations of chlorine.[85,128,167,221] The major disadvantage is its physiologic activity.

Taste

Objectionable taste and smell are the major problems with acceptance of halogens. Most objectionable taste in treated water is derived from dissolved minerals, such as sulfur, and from chlorine compounds, chloramines, and organic nitrogen compounds, even at extremely low levels.

People are familiar with the taste of chlorine compounds; tap water usually contains 0.2 to 0.5 ppm of chlorine, swimming pools 1.5 to 3.0 ppm, and hot tubs 3.0 to 5.0 ppm. Most persons familiar with the faint taste of chlorine in water note a distinct taste at 5 ppm and a strong, unpleasant taste at 10 to 15 ppm.[271] With the promotion of chlorination for household use, focus groups on taste testing have found that the majority of CDC-WHO Safe Water System users are comfortable drinking water with a free chlorine residual of up to 2 mg/L; however, there is significant regional variation in the acceptable maximum residual, and many found the taste objectionable and unsuitable at 3 to 4 mg/L.[176] The higher sodium hypochlorite dosages necessary to ensure maintenance of chlorine residual in turbid waters exacerbate the taste and odor concerns.[169]

Elemental iodine at 1 mg/L is undetectable. Most persons can detect iodine solutions at 1.5 to 2 mg/L but do not find it objectionable.[26,85,117] Distinct taste and odor are produced by 8 ppm of iodine; however, tablets yielding these concentrations were preferred by military personnel over tincture of iodine in equivalent doses.[59,218]

Taste tolerance or preference for iodine over chlorine depends on the individual. Opposite preferences have been documented when direct comparisons are done.[229,246] Informal taste tests suggest that most persons prefer the taste of iodine to chlorine at concentrations typically used in the field. In addition, iodine forms fewer organic compounds that produce highly objectionable taste and smell.

Taste can be improved by several means (Box 88-10).

Minimizing Dose. The relationship between halogen concentration and time allows use of the minimum necessary dose, with a longer contact time (see Tables 88-9 and 88-10).

Theoretically, doubling the contact time allows a 50% reduction of halogen dose at any level. Although this relationship holds true at the higher field doses of halogens, as the levels drop, the reaction departs from mathematical models, and the straight-line graph has a "tail" (see Figure 88-4). This departure from strict first-order kinetics and the uncertainty of halogen demand in field disinfection mean that a margin of safety must be incorporated into contact times at lower doses.

Of all standard iodine doses, iodine tablets yield the highest dose (8 mg/L with an intended contact time of 10 minutes in warm water). The tablets cannot be broken in half but can be added to 2 qt instead of 1 qt of water to yield concentrations consistent with the other preparations. The recommended doses of the liquid iodine preparations yield 4 mg/L. Because even clear surface water has some halogen demand, this dose of 4 mg/L should generally not be reduced for surface water, but for backing up tap water in developing countries or prefiltered water, the dose may routinely be cut in half for an added dose of 2 ppm with a few hours of contact time.[114,138,178] A similar approach can be used for chlorination methods. None of these concentrations will destroy *Cryptosporidium* oocysts.

BOX 88-10 Improving the Taste of Halogens

Decrease dose and increase contact time.
Clarify cloudy water, allowing decreased halogen.
Remove halogen.
Use granular activated charcoal to remove disinfectant.
Chemical reduction techniques
- Ascorbic acid
- Sodium thiosulfate
- Chlorination-dechlorination (uses hydrogen peroxide)

Alternative Techniques

Heat
Filtration
Chlorine dioxide
Ultraviolet irradiation
Photocatalytic (TiO_2)

Temperature and organic matter in the water may be manipulated. Increasing the temperature of the water, especially when initially near 5° C (41° F), decreases the Ct constant (see Tables 88-9, 88-10, and 88-15 and Figure 88-4). Filtering water before adding halogen improves the reliability of a given halogen dose by decreasing halogen demand, allowing a lower dose of halogen.[221] Sedimentation or coagulation-flocculation cleans cloudy water and lowers the required halogen dosage considerably, in addition to removing many of the contaminants that contribute to objectionable taste.

Dehalogenation. Halogen can be removed from water after the required contact time. Activated charcoal removes iodine or chlorine, allowing standard or even high doses to be used without residual taste. The relative instability of chlorine in dilute solutions can be used to decrease taste over time. Chlorine residual in an open container decreases 1 mg/L in the first hour, then 0.2 mg/L in the next 5 to 8 hours, for a total of 2.0 to 2.5 mg/L in 24 hours. UV light also depletes free chlorine.[336]

Alteration of Chemical Species (Reduction). Several chemical means are available to reduce free iodine or chlorine to iodide or chloride that have no color, smell, or taste. These forms have no disinfection action, so the techniques should be used only after the required contact time. In superchlorination-dechlorination, hydrogen peroxide "dechlorinates" water treated with calcium hypochlorite by forming calcium chloride.

Two other chemicals that may be safely used with any form of chlorine or iodine are ascorbic acid (vitamin C) and sodium thiosulfate. Ascorbic acid is widely available in crystalline or powder form. Grinding up tablets that have binders may cloud the water. Ascorbic acid is a common ingredient of flavored drink mixes, which accounts for their effectiveness in covering up the taste of halogens.[229,271] Sodium thiosulfate similarly "neutralizes" iodine and chlorine. A few granules in 1 qt of iodinated water decolorizes and removes the taste of iodine by converting it to iodide. In reaction with chlorine, it forms hydrochloric acid, which is not harmful or detectable in such dilute concentration. Thiosulfate salts are inert in vivo and poorly absorbed from the GI tract. Sodium thiosulfate is available at chemical supply stores.

Copper-zinc alloys act as catalysts to reduce free iodine and chlorine through an electrochemical reaction (see Copper and Zinc, later).

MISCELLANEOUS DISINFECTANTS

PEROXYGENS

Peroxygens are strong oxidizing agents with potent antimicrobial activity that incorporate various active forms of oxygen.[201]

Ozone

Ozone is an unstable form of oxygen, with the chemical formula O_3. In solution, it decays to O_2, producing free hydroxyl radicals. Both ozone and the hydroxyl radicals are two of the most powerful oxidants and thus are effective disinfectants, so they are widely used in municipal water treatment plants.[24,180,201,227,336] Ozone and chlorine dioxide are the only chemical disinfectants that have been demonstrated effective against *Cryptosporidium* in typical concentrations.[19,64,168,235,237]

Advantages of ozone disinfection are that it has high efficacy against all groups of microorganisms and that it produces very few disinfection byproducts.[19] Ozone is a colorless gas manufactured by passing air or oxygen through a high-voltage current discharge. The resulting ozone-rich gas is then dissolved in water, but it is not stable. Clearly this is not conducive to small, point-of-use generation, so consumers should be skeptical of techniques claiming to rely on ozone. Because it is not chemically stable after generation, no form of ozone can be used for point-of-use applications in the field.

Chlorine Dioxide

Chlorine dioxide (ClO_2), a potent biocide, has been used for many years to disinfect municipal water and in numerous other large-scale applications. Until recently, the benefits of chlorine dioxide have been limited to large-scale applications, because it is formulated as a volatile gas that must be produced on-site with sophisticated chemical-generation equipment. Newer methods enable cost-effective and portable ClO_2 generation and distribution for use in an ever-widening array of small-scale applications (Box 88-11).

For point-of-use treatment of water, chlorine dioxide is produced on site from the reaction of sodium chlorite with acid.[24,294] For example:

$$5NaClO_2 + 4HCl \rightarrow 4ClO_2 + 5NaCl + 2H_2O$$

Chlorine dioxide is not as unstable as ozone but does not produce a lasting residual. It does not form chlorinated compounds in the presence of organics and is efficacious over a wide pH range. Byproducts of chlorine dioxide are chlorite (ClO_2^-) and chlorate (ClO_3^-).

Chlorine dioxide has no taste or odor in water. It is capable of inactivating most waterborne pathogens, including *C. parvum* oocysts, at practical doses but at extended contact times of 2 to 4 hours.[64,168,219,237] It is as least as effective a bactericide as chlorine and far superior as a virucide.[201,336]
There are several commercial point-of-use applications using chlorine dioxide in liquid or tablet form (see appendices at the end of this chapter).

MIXED-SPECIES DISINFECTION (ELECTROLYSIS)

Passing a current through a simple brine salt solution generates free available chlorine, as well as other "mixed-species" disinfectants that have been demonstrated effective against bacteria, viruses, and bacterial spores.[280] The process is well described and can be used on both large and small scales. It is practical and economic enough to be useful in developing areas of the world. The exact composition of the resulting solution is not well delineated because many of the compounds are evanescent and unstable. The main effect is probably caused by a combination of ClO_2, ozone, superoxides, and hypochlorous acid, giving the resulting solution greater disinfectant ability than a simple solution of sodium hypochlorite.[201] It has even been demonstrated to inactivate *Cryptosporidium*.[330] (See product appendices for more information.)

BOX 88-11 Chlorine Dioxide (ClO_2)

Advantages	Disadvantages
Effective against all microorganisms, including *Cryptosporidium*	Solutions not stable, so do not expose tablets to air, and use generated solutions rapidly.
Low doses have no taste or color	No persistent residual, so ClO_2 does not prevent recontamination during storage.
Field products now available for individual and small-group field use and simple to use	Sensitive to sunlight, so keep bottle shaded or in pack during treatment.
More potent than equivalent doses of chlorine	
Less affected by nitrogenous wastes	

Relative susceptibility of microorganisms to chlorine dioxide: bacteria > viruses > protozoa.

HYDROGEN PEROXIDE

Hydrogen peroxide (H_2O_2) is a strong oxidizing agent but considered a weak disinfectant for use in water treatment.[30,221,351] It is used widely as a preservative in the food industry, attractive because the byproducts are oxygen and water. In high doses (35% to 50%), H_2O_2 is a sterilant used in industry for medical and food equipment; for odor control in sewage, sludges, and landfill leachates; and for many other applications. Hydrogen peroxide is popular as a wound cleanser. It is considered nature's disinfectant because it is naturally present in milk and honey, helping to prevent spoilage.

Small doses (1 mL of 3% H_2O_2 in 1 L water) are effective for inactivating bacteria within minutes to hours, depending on the level of contamination. Tested against seven bacterial strains, hydrogen peroxide killed 1×10^6 colony-forming units per milliliter overnight, with 80% kill in 1 hour. Viruses require higher doses and longer contact times. It is a promising sporicidal agent in high (10% to 25%) concentrations.

Solutions lose potency in time, but stabilizers can be added to prevent decomposition.[30]

Although hydrogen peroxide can sterilize water, it is not widely used as a field water disinfectant, perhaps because of a lack of data for protozoan cysts and quantitative data for dilute solutions, and because the high concentrations known to be effective are very caustic. H_2O_2 may be used synergistically in combination with many other disinfectants and processes.

POTASSIUM PERMANGANATE

Potassium permanganate is a strong oxidizing agent with some disinfectant properties. It is used in municipal disinfection to control taste and odor. It has been used in a 1% to 5% solution as a drinking water disinfectant[218] and is still used for this purpose in some countries, as well as for washing fruits and vegetables.

Bacterial inactivation can be achieved with moderate concentrations and contact times (45 minutes at 2 mg/L, 15 minutes at 8 mg/L). A 1:5000 (0.5%) solution controlled *V. cholerae* and *S. typhi* contamination of fruits and vegetables. The virucidal action has been tested, but without titrations of virus that remained after various periods of contact time, so the rate of action is not known. In most instances, however, a 1:10,000 solution destroyed the infectivity of virus suspensions in 30 minutes at room temperature; 30 mg/L was effective in inactivating HAV within 15 minutes.[312]

Although potassium permanganate clearly has disinfectant action and is frequently used in some parts of the world, it cannot be recommended for point-of-use water disinfection unless it is the only means available, because quantitative data are not available for viruses, and no data are available for protozoan cysts. Packets of 1 g to be added to 1 L of water are sold in some countries. A French military guide from 1940 instructed users: "To sterilize water, use a solution of 1 gram of $KMnO_4$ for 100 grams of water. Add this solution drop by drop to the water to sterilize until the water becomes pink. The operation is considered sufficient if the water remains pink for half an hour."[61] The solutions are deep pink to purple and stain surfaces. The chemical leaves a pink to brown color in water at concentrations above 0.05 mg/L. Small deposits of brown oxides settle to the bottom of the water container. A few drops of alcohol will cause this residual color to disappear.

CITRUS

Citrus juice contains limonene, which has biocidal properties. It is one of several essential oils and plant extracts that are used as disinfectants, cleaners, deodorizers, and antiseptics. Lemon or lime juice has been shown to destroy *Vibrio cholerae* at a concentration of 2% (equivalent of 2 tbsp/L of water) with a contact time of 30 minutes. A pH of less than 3.9 is essential, which depends on the concentration of lemon juice and the initial pH of the water.[88] Lime juice also killed 99.9% of *V. cholerae* on cabbage and lettuce and inhibited growth of *V. cholerae* in rice foods, suggesting that adding lime juice to water, beverages, and other foods can reduce disease risks.[294] More research is needed before this can be recommended as more than an ancillary or emergency measure. Commercial products using citrus cannot be recommended as primary means of water disinfection. It has been used to enhance solar UV disinfection.[112]

METALS

Metals form positive ions in water, which is the basis for their antimicrobial effects.[201] The metals most often used, silver and copper, are considered "heavy" metals and have the problems of bioaccumulation and toxicity, as with other well-known toxic metals, including mercury, arsenic, and lead.

Silver

Silver ion has bactericidal effects in low doses. Although widely used as a disinfectant, the literature on antimicrobial effects of silver is confusing and contradictory.[147,193,221,336,342] Concentrations in water less than 100 parts per billion (ppb) are effective against enteric bacteria. The reaction follows first-order kinetics and is temperature dependent.

At the recommended concentration of 50 ppb for water treatment, disinfection requires several hours. Experimental results indicate 18% survival of *E. coli* at 3 hours at 40 mcg/L. *S. typhi* was reduced more than 5 log at 50 mcg/L with a 1-hour exposure; poliovirus was not reduced at 50 mcg/L with a 1-hour exposure.[15] Data on silver for disinfection of viruses and cysts indicate limited effect, even at high doses.[57,221]

Silver is physiologically active. Acute toxicity does not occur from small doses used in disinfection, but argyria, which is permanent discoloration of the skin and mucous membranes, may result from prolonged use. For this reason, a maximum limit of 50 ppb of silver ion in potable water is recommended, with an upper limit of 10 g per lifetime (NOAEL—no observed adverse effect level). This would be reached only after drinking 3 L/day containing 0.1 mg/L over 70 years. WHO acknowledges that the daily intake of silver when used to maintain the bacteriologic quality of drinking water can constitute the major route of oral exposure but states, "It is unnecessary to recommend a health-based guideline value because [silver] is not hazardous to human health at concentrations normally found in drinking water."

Large-scale use of silver for water disinfection has been limited by cost, difficulty controlling and measuring silver content, and physiologic effects. Short-term field use is limited by its marked tendency to adsorb onto the surface of any container (resulting in unreliable concentrations) and interference by several common substances. Calcium, phosphates, and sulfides interfere significantly with silver disinfection. Organic chemicals, amines, and particulate or colloidal matter may also interfere, but no more than with chlorine.

Nevertheless, water disinfection systems using silver have been devised for spacecraft, swimming pools, and other settings.[336] The advantage is absence of taste, odor, and color. Persistence of residual silver concentration allows reliable storage of disinfected water. Silver can be supplied through a silver nitrate solution, desorption from silver-coated materials, or electrolysis. When coated on surfaces, silver acts as a constant-release disinfectant that produces aqueous silver ion concentrations of 0.006 to 0.5 ppm, which are sufficient to disinfect drinking water.[197] Because of this attractive feature, silver-based devices are being designed and tested in developing countries. In Pakistan, a nylon bag with silver-coated sand was designed to place in earthenware pitchers that store water. Silver incorporated into alum is also being tested in India.[60] Low levels of chlorine may be synergistic with silver.

Use of silver as a drinking water disinfectant has been much more popular in Europe, where silver tablets (Micropur) are sold widely for field water disinfection. They have not been approved by the EPA 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. Micropur Forte tablets release free chlorine for disinfection and silver for prolonged persistence of antimicrobial activity (see Appendix B at the end of this chapter).

Since bacteria grow on filter media or membranes, the filter is usually impregnated or coated with silver to inactivate pathogens that pass through the filter pores or to limit bacterial growth in the filter itself (bacteriostatic). Ceramic filters coated with silver have higher removal rates of bacteria, and filters that had been just recoated with silver initially yielded much higher disinfection efficiencies but were not able to sustain them.[15,22,119] However, filter cartridges impregnated with silver still become colonized with heterotrophic bacteria, and effluent bacterial populations are about as large as units without silver. These bacteria have not been linked to increased illness.[15,104,119,257] Colonization of filters with pathogenic coliform bacteria has not been demonstrated, but protective effect cannot be attributed to silver impregnation.[104,257]

Copper and Zinc

Copper is most frequently used as a molluscicide, algicide, and fungicide, although it is also bactericidal in very low concentrations and is virucidal.

Kinetic degradation fluxion (KDF) is a high-purity copper-zinc formulation that uses the basic chemical process of oxidation-reduction (redox) to remove chlorine, heavy metals (e.g., lead, mercury), iron, and hydrogen sulfide from water supplies. Its main actions are through its strong redox potential of 500 mV because of the propensity to exchange electrons with other substances. The redox reactions change contaminants into harmless components: chlorine into chloride (removing the taste of chlorine or iodine from treated water), soluble ferrous cations into insoluble ferric hydroxide, and hydrogen sulfide into insoluble copper sulfide. Up to 98% of lead, mercury, nickel, chromium, and other dissolved metals are removed by KDF simply by bonding to the media. KDF controls buildup of bacteria, algae, and fungi and is used for this purpose in GAC beds and carbon block filters, extending the life of carbon and improving its effectiveness.

KDF or copper alone has bacteriostatic with some bactericidal activity; microorganisms may be killed by the electrolytic field and by formation of hydroxyl radicals and peroxide water molecules.[193] Although KDF has been ruled a "pesticidal device" by the EPA, it should not be used as the sole means of water treatment and is best combined with filtration or chlorination.

KDF media can be manufactured as granules, fine steel wool–like media, or brushes with wire bristles. Currently, this technique is mostly applied in industrial settings and household in-line filters. No portable products are currently designed for the outdoor market.

NANOPARTICLES: SOLAR PHOTOCATALYTIC DISINFECTION

Nanoparticles are particles between 1 and 100 nanometers (nm) in size with unique properties as adsorbents, catalysts, and sensors that have led to their exploration in many fields of science. Several nanomaterials have been shown to have strong antimicrobial properties and are being evaluated for use in water disinfection and purification. They are not strong oxidants themselves, and are relatively stable in water and nontoxic. Nanomaterials are already being used widely in industrial purification, but they show great potential for point-of-use applications as well. There are three categories of antimicrobial nanoparticles: naturally occurring substances, including chitin obtained from arthropod shells; metals and metal oxides, including silver (nAg), titanium dioxide (TiO_2), and zinc oxide (ZnO); and synthetic engineered materials, such as fullerene (nC60) and carbon nanotubes (CNT).[174,186] The metals are of particular interest for water disinfection applications because they can be activated by UV light to produce potent oxidizers.

Titanium dioxide has the advantage of activation by UVA rays in sunlight. High-energy, short-wavelength photons from sunlight promote the photochemical reactions. In addition to being an excellent disinfectant for various microorganisms, this process is unique in its ability to break down complex organic contaminants and most heavy metals into carbon dioxide, water, and inorganic substances, which is driving considerable research for industrial processes and large-scale water treatment. TiO_2 antimicrobial properties have been studied for their effect for more than 20 years. Recent work demonstrated inactivation of *Cryptosporidium*.[306] For field water disinfection, nanoparticles coated with TiO_2 can be integrated into a plastic bag and remain active for hundreds of uses[27] (see Appendix A).

ULTRAVIOLET LIGHT

Ultraviolet lamp disinfection systems are widely used to disinfect drinking water at the community and household levels (Box 88-12).[180] In sufficient doses, all waterborne enteric pathogens are inactivated by UV radiation (UVR). UVC light in the range of 200 to 280 nm is the most effective. The germicidal effect of UV light is the result of action on the nucleic acids of bacteria and depends on light intensity and exposure time.[55] Bacteria and protozoan parasites require lower doses than do enteric viruses and bacterial spores. However, all viruses, including hepatitis A and norovirus, are susceptible, with relatively minor differences, and follow similar kinetics.[140] Bacteria (vegetative cells) are significantly more susceptible to UVR than are viruses. *Giardia* and *Cryptosporidium* are susceptible to practical doses of UVR and may be more sensitive because of their relatively large size.[19,140,189]

In sufficient doses, UV irradiation can also remove odors and dechlorinate. UV treatment does not require chemicals or affect the taste of the water. It works rapidly, and excessive dosing to the water presents no danger; in fact, it is a safety factor. UV irradiation with lamps requires a power source and is costly. UV light has no residual disinfection power; water may become recontaminated, or regrowth of bacteria may occur.[104] Particulate matter can shield microorganisms from UV rays. A portable field unit is now available and has been shown to be effective in reducing bacteria and viruses (see Appendix A in this chapter).

Solar Disinfection

There is now strong evidence that UV irradiation by sunlight in the UVA range can substantially improve microbiologic quality of water and reduce diarrheal illness in developing countries. Because of its negligible cost and simplicity, solar disinfection (SODIS) is being rapidly adopted in many developing countries. McGuigan and colleagues[204] have published an excellent review. Recent work has confirmed efficacy and optimal procedures of the SODIS technique[55,76,230,294] (Box 88-13). Transparent bottles (e.g., clear plastic beverage bottles) are exposed to sunlight for a minimum of 4 to 6 hours, but some investigations demonstrate improved benefit from several sequential days. Multiple studies demonstrate reduction of enteric bacteria, viruses, and protozoan cysts, and some data exist for reduction of bacterial spores.[166,203,205,298] With a water temperature of 30° C (86° F), 6 hours of middle-latitude midday summer sunshine are required to achieve a 3-log reduction of fecal coliforms.[207]

Ultraviolet irradiation and thermal inactivation were strongly synergistic for solar disinfection of drinking water in transparent plastic bottles that was heavily contaminated with *E. coli* for temperatures above 45° C (113° F). Above 55° C (131° F), thermal inactivation is of primary importance.[202,204] Whereas thermal inactivation is effective in turbid water, UV effects are inhibited.[4,151,160,268] If cloudiness is obvious, the plastic bottles need to be exposed for 2 consecutive days to produce water safe for consumption. However, if water temperatures exceed 50° C (122° F), 1 hour of exposure is sufficient to obtain safe drinking water. The treatment efficiency can be improved if the plastic bottles are exposed on sunlight-reflecting surfaces such as aluminum or corrugated iron sheets. Use of a simple reflector or solar cooker can achieve pasteurization temperatures of 65° C (149° F). Effects can also be enhanced by adding small amounts of hydrogen peroxide, lemon juice, or lime juice.[112] Oxygenation induces greater reduction of bacteria, so agitation is recommended before solar treatment in bottles.

Various types of transparent plastic materials are good transmitters of light in the UVA and visible range of the solar spectrum. Plastic bottles are made of either polyethylene terephthalate (PET) or polyvinylchloride (PVC). The use of bottles made from PET instead of PVC is recommended because PET contains fewer additives than PVC. Glass bottles are not used for SODIS because the transmission of UVR through glass is determined by its content of iron oxide; ordinary window glass of 2-mm thickness transmits almost no UVA light. Because UVR is reduced at increasing water depth, the containers used for SODIS should not exceed a water depth of 10 cm (4 inches). Aged or heavily scratched plastic bottles show reduced UV transmittance, which in turn can result in less efficient inactivation of microorganisms.[207]

In summary, where strong sunshine and clear water are available, solar disinfection of drinking water is an effective, low-cost method for improving water quality and may be of particular use in refugee camps and disaster areas.[207]

BOX 88-12 Ultraviolet (UV) Irradiation

Advantages	Disadvantages
Effective against all microorganisms	Requires clear water
Imparts no taste	Does not improve water esthetics
Portable device now available for individual and small-group field use and simple to use	No residual effect; does not prevent recontamination during storage
Can use UV rays from sunlight in austere conditions (see Box 88-13)	UV lamps are expensive and require power source.

Relative susceptibility of microorganisms to UV irradiation: protozoa > bacteria > viruses.

BOX 88-13 Solar Disinfection (SODIS)

Advantages	Disadvantages
Utilizes sunlight	Requires clear water
Requires no special equipment or power; relies on local resources and renewable energy	No residual effect; does not prevent recontamination during storage
Improves the microbiologic quality of drinking water; including protozoan cysts	Does not improve water esthetics
Simple in application; can be used at household level in developing countries or refugee camps	Requires multiple bottles to treat large volumes of water; use maximum 2-L bottle.
Does not change the taste of water	Requires strong, direct, abundant sunlight, with prolonged exposure; dose low and uncontrolled
Can be used in austere environments	

Relative susceptibility of microorganisms to SODIS: protozoa > bacteria > viruses.

COMPARATIVE STUDIES AND PREFERRED TECHNIQUES

Presumably, standard protocols for product testing in experienced laboratories would provide comparable and reproducible results. However, studies that directly compare techniques or products often yield results that vary widely from the individual product testing. Actual efficacy in the field or household setting of developing countries vary significantly from laboratory

TABLE 88-16 Efficacy and Effectiveness of Point-of-Use Technologies for Developing World Households

Treatment Process	Pathogen	Optimal Log Reduction*	Expected Log Reduction†	Diarrheal Disease Reduction‡
Ceramic filters	Bacteria	6	2	63% (51%-72%) for candle filters
	Viruses	4	0.5	46% (29%-59%) for bowl filters
	Protozoa	6	4	
Free chlorine	Bacteria	6	3	37% (25%-48%)
	Viruses	6	3	
	Protozoa	5	3	
Coagulation/chlorination	Bacteria	9	7	31% (18%-42%)
	Viruses	6	2-4.5	
	Protozoa	5	3	
Biosand filtration	Bacteria	3	1	47% (21%-64%)
	Viruses	3	0.5	
	Protozoa	4	2	
SODIS	Bacteria	5.5	3	31% (26%-37%)
	Viruses	4	2	
	Protozoa	3	1	

Data from multiple studies, analyzed and summarized by Sobsey, 2008.[298] Also, data from references 22, 66, 220, and 294 and Table 7.8 in WHO, 2011.[347]
SODIS, Solar disinfection.
*Skilled operators using optimal conditions and practices (efficacy); log reduction: pretreatment minus post-treatment concentration of organisms (e.g., 6 log = 99.999% removal).
†Actual field practice by unskilled persons (effectiveness); depends on water quality, quality and age of filter or materials, following proper procedure, and other factors.
‡Summary estimates from published data; vary with consistency and correct use of technique, integrity of techniques (e.g., cracked filter), and other household sanitation measures.

effectiveness because of variations in source water clarity and levels of contamination.[185] Data for the effectiveness of water disinfection techniques for wilderness travelers are essentially all done in the laboratory and not in field settings during actual use. On the other hand, many studies have recently been done on point-of-use devices in households and refugee settings in developing countries, where contamination and the risk for illness are many times higher; thus, techniques can be evaluated for both microbiologic reduction under real use and reduction of illness attributable to water treatment[22,66,220,294] (Table 88-16). These techniques for the developing world are necessarily low cost, simple to use, and include some improvised methods, which make them particularly valuable for survival, disaster, or other austere situations characterized by suboptimal conditions and supplies. Furthermore, the need for household point-of-use water treatment in developing countries is stimulating innovative approaches to disinfection that combine multiple treatment steps in series, as is done in municipal plants. For those tasked with engineering water solutions for communities or populations in austere environments, point-of-use methods were found to be more effective than were source solutions.[68,176]

Several studies comparing halogens are noted earlier in the Iodine versus Chlorine section.[142,154,156,243,283] Lee and Lee[183] compared iodine, chlorine dioxide, mixed oxidants, and UVR for disinfection of coccidian oocysts to represent *Cryptosporidium* and found that only UVR consistently inhibited sporulation. Iodine in recommended contact times was little better than controls, and chlorine dioxide left almost one-quarter of oocysts viable in moderately contaminated water and was similar to controls in highly contaminated water. One important factor may have been the large number of organisms added to the water, which greatly exceeded likely levels encountered in surface water. Betancourt and Rose[19] reviewed methods for removal of *Cryptosporidium* and found UVR and filtration effective. Sobsey and colleagues[298] reviewed data for point-of-use methods for household disinfection in developing countries. All methods had high levels of optimal effectiveness, but their actual efficacy was much less over time, likely impacted by inconsistent use. Verma and Arankalle[331] evaluated eight different higher-technology household disinfection units sold in India, each using some combination of filtration, iodine resin, chlorination, and UVR. Average removal of hepatitis E virus was 1 to 3 log, except for a hollow-fiber membrane unit that achieved 6.5-log removal. This study highlights incorporation of common disinfection techniques into household appliances for point-of-use water treatment and the discrepancy between optimal and actual efficacy for these devices, which would certainly apply to field units as well. Similarly, another study compared ceramic filters and iodine resin household devices and found high levels of bacterial removal, but that reduction of viruses and microspheres did not meet standards of EPA protocols.[67] One recently developed household device that does not require power and combines the complementary methods of filtration and disinfection did meet EPA criteria for microbiologic reduction.[67]

Although the gap between optimal and actual efficacy is disturbing, it is reassuring that in actual field conditions, all point-of-use techniques will greatly decrease the number of microorganisms and risk for illness[66,68,185,298] (see Table 88-16). As in any wilderness medical situation, some basic assessment must be done of the likely level and type of contamination, methods of disinfection available, and tolerance of risk.

PREFERRED TECHNIQUE

Field disinfection techniques and their effects on microorganisms are summarized in Table 88-17. The optimal technique for an individual or group in the wilderness or traveling in developing countries depends on the number of persons to be served, space and weight available, quality of source water (Table 88-18), personal taste preferences, and availability of fuel. The most effective technique may not always be available, but any method should greatly reduce the load of microorganisms and reduce the risk for illness. A multibarrier approach for drinking water treatment, in which a combination of various disinfectants and filtration technologies are applied for removal and inactivation of different microbial pathogens, will provide a lower risk for microbial contamination.[19] Other excellent summaries of disinfection methods are available.[180,201]

A combination of clarification using coagulation-flocculation (C-F) and filtration followed by chlorination remains the standard for municipal water treatment worldwide. The CDC and WHO also promote chlorine for household-level point-of-use disinfection in the developing world.[297,347]

In austere situations such as disasters or refugee camps, hypochlorite (household bleach) also is widely recommended.[101,176,177] However, in an attempt to simplify for a broad range of people and to provide a margin of safety, the recommendations may lead to either inadequate or excessive concentrations. For cloudy

TABLE 88-17 Summary of Field Water Disinfection Techniques

	Bacteria	Viruses	*Giardia/Amebae*	*Cryptosporidium*	Nematodes/Cercaria
Heat	+	+	+	+	+
Filtration	+	+/−*	+	+	+
Halogens	+	+	+	−	+/−†
Chlorine dioxide	+	+	+	+	+/−†
UV	+	+	+	+	No data available
TiO_2 photocatalytic	+	+	+	+	No data available

*Most filters make no claims for viruses, but may remove up to 99%. Reverse osmosis and hollow-fiber ultrafiltration technology would be effective. General Ecology also has some data for virus removal.
†Eggs are not very susceptible to halogens but are very low risk for waterborne transmission.

water, chlorination-flocculation packets are the best and simplest method. If chlorine is not available, the SODIS technique or sand filters can be used with improvised materials.

For environments with a high-quality, low-risk source water, any of the primary techniques is adequate, with the understanding that the limitation for halogens is *Cryptosporidium* oocysts and that microfilters may not remove all viruses. Surface water, even if clear, in undeveloped countries where there is human and animal activity should be considered highly contaminated with enteric pathogens. Optimal protection requires heat, ultrafiltration, UV irradiation, or a two-stage process of filtration and halogens. Chlorine dioxide and photocatalytic TiO_2 are currently the only one-step chemical processes available. Even in the United States, water with agricultural runoff or sewage plant discharge from upstream towns or cities must be treated to remove *Cryptosporidium* and viruses. Water receiving agricultural, industrial, or mining runoff may contain chemical contamination from pesticides, other chemicals, and heavy metals. A filter containing a charcoal element is the best method for removing most chemicals.

Water from cloudy, low-elevation rivers, ponds, and lakes in developed or developing countries that does not clear with sedimentation should be pretreated with C-F and then disinfected with heat or halogens. Tablets combining C-F and chlorination are readily available and have extensive testing to demonstrate effectiveness.[82,97,243,259] Filters can be used but will clog rapidly with silted or cloudy water. A sand filtration unit can be improvised.[169] C-F will also remove some chemical contamination.

The preferred method of treatment for the military, when large-scale equipment can be brought to the site, is a reverse-osmosis water purification unit (ROWPU), because it can produce high-quality water from a low-quality source. For smaller groups, the military relies mainly on monitored chlorine. Individual means include iodine tablets, Chlor-Floc tablets, and chlorine liquid bleach.[319]

Chemical agents need to be used when water will be stored, such as on a boat, in a large camp, or for disaster relief. When only heat or filtration is used before storage, recontamination and bacterial growth can occur. Hypochlorite still has many advantages for stored water, including cost, ease of handling, and minimal volatilization in tightly covered containers.[213] A minimum residual of 3 to 5 mg/L should be maintained in the water. Superchlorination-dechlorination is especially useful in this situation because high levels of chlorination can be maintained for long periods, and when ready for use, the water can be poured into a smaller container and dechlorinated. Iodine works for short-term but not prolonged storage, because it is a poor algicide. Silver has been approved by the EPA for preservation of stored water. Chlorine dioxide does not maintain a residual concentration.

On oceangoing vessels where water must be desalinated during the voyage, only reverse-osmosis membrane filters are adequate. Water in the storage tanks should then be chlorinated.

In survival or austere situations such as disasters or refugee camps, hypochlorite (household bleach) or chlorination-flocculation packets may be available.

PREVENTION AND SANITATION

Studies in developing countries have demonstrated a clear benefit in the reduction of diarrheal illness and other infections from safe drinking water, sanitation, and hygiene (WASH).[68,149,191,210,250,251,260,297] Although a benefit can be demonstrated for the WASH interventions independently, the benefit is greater when all are applied together, especially with appropriate education.[60] Wilderness travelers essentially live in conditions similar to the developing world, without running water or sanitation. Unfortunately, many wilderness travelers confuse the continuing need for hygiene with the need to relax their standard of cleanliness.

TABLE 88-18 Choice of Method for Various Source Water

	"Pristine" Wilderness Water with Little Human or Domestic Animal Activity	Tap Water in Developing Country	Developed or Developing Country: Clear Surface Water Near Human and Animal Activity*	Developed or Developing Country: Cloudy Water
Primary concern	*Giardia*, enteric bacteria	Bacteria, *Giardia*, small numbers of viruses	All enteric pathogens, including *Cryptosporidium*	All enteric pathogens plus microorganisms
Effective methods	Any single-step method† Low-risk water; many would choose to drink untreated	Any single-step method† Risk varies depending on country; judgment required for decision to treat	1. Heat 2. Filtration plus halogen (can be done in either order) 3. Hollow-fiber ultrafiltration 4. Chlorine dioxide 5. Ultraviolet (commercial product, not sunlight)	CF followed by second step (heat, filtration, or chemical)

*Includes agricultural runoff with cattle grazing or sewage treatment effluent from upstream villages or towns.
†Includes heat, filtration, halogens, chlorine dioxide, and ultraviolet irradiation.
CF, Coagulation-flocculation.

HANDWASHING

Personal hygiene, mainly handwashing, prevents spread of infection from food contamination during preparation of meals.[209] A widely publicized study in the United States demonstrated that only 67% of Americans wash hands after using a public toilet. No one with a diarrheal illness should prepare food. A study of Appalachian Trail hikers showed that water disinfection, routine handwashing, and proper cookware cleaning were all associated with decreased diarrhea.[31] A *Shigella* outbreak among river rafters on the Colorado River was investigated and assumed to be waterborne from adjacent Native American communities, but was finally traced to infected guides who were shedding organisms in the stool and contaminating food through poor hygiene.[209] Simple handwashing with soap and water purified with hypochlorite (bleach) significantly reduced fecal contamination of market-vended beverages in Guatemala.[292] Gil and colleagues[127] tested water and objects in the kitchen in rural Peru and demonstrated widespread contamination.

Extensive research in the developing world demonstrated that treated water is often recontaminated before use, and proper storage techniques that prevent contact with hands and objects can decrease this risk for contamination.[70,297,348] Narrow-mouth jars or containers with water spigots are the best means to prevent contamination from repeated contact with hands or utensils.[259,270,292] In a refugee camp, using only a simple, improved bucket that did not allow dirty hands or a ladle to touch the water, there was 69% reduction in mean fecal coliform levels in the household water and 31% less diarrheal disease in children under 5 years of age among the group.[270]

KITCHEN AND FOOD SANITATION

Sanitation should extend to the kitchen or food preparation area.[191] In addition to handwashing, dishes and utensils should be disinfected by rinsing in chlorinated water, prepared by adding enough household bleach to achieve a distinct chlorine odor. Hargreaves[133] tested various combinations of wash and rinse water in three-bowl systems to determine what worked best for cleanliness, bacterial disinfection, and residual smell or taste of disinfectant. The optimal combination was water plus detergent in bowl 1 to remove the majority of food residue and grease; water with 10 mL of added bleach in bowl 2 to remove the remaining food residue and provide disinfection; and plain water in bowl 3 to remove residue of disinfectant. This is a variation of the most common method that adds the disinfectant to bowl 3 instead of bowl 2. If there is insufficient water or containers to provide a three-bowl system, omit bowl 3.

Washing fruits and vegetables in purified water is a common practice at all levels, from individual to the food industry. Washing has a mechanical action of removing dirt and microorganisms while the disinfectant kills microorganisms on the surface. However, neither reaches the organisms embedded in surface crevices or protected by biofilm or other particulate matter, which is why it is safer to peel most fruits and vegetables with rough skins.[163] When lettuce was seeded with oocysts, then washed and the supernatant examined for cysts, only 25% to 36% of *C. parvum* and 13% to 15% of *C. cayetanensis* oocysts were recovered in the washes. Scanning electron microscopy detected oocysts on the surface of the vegetables after washing.[233] A review of washing lettuce with various disinfectant solutions shows that high concentrations usually reduce level of viruses by 1 to 3 log.[12] Chlorine, iodine, or potassium permanganate is often used for this purpose in higher concentrations than would normally be palatable for drinking water. In the United States, chlorine wash at 20 to 200 ppm is the most common sanitizing treatment used by the fresh-produce industry and could also be used in the field by wilderness and remote area travelers.[234] Many newer technologies such as irradiation are available for the food industry but are not applicable in the field.

HUMAN WASTE DISPOSAL

The ultimate responsibility for wilderness travelers is proper sanitation to prevent contamination of water supplies from human waste. Some suggest that campers smear feces on rocks. Desiccation occurs, and UV rays in sunlight eventually inactivate most microorganisms, but rain may first wash pathogens into a water source.[63] Moreover, it will be repulsive to other campers. In the Sierras, feces left on the ground generally disappeared within 1 month, but it was not known whether disinfection occurred before decomposition or whether the feces washed away, dried, or were blown in the wind.[254] Despite more rapid decomposition in sunlight rather than underground, burying feces is still preferable in areas that receive regular use.

In the soil, microorganisms can survive for months.[326] A Sierra Club study found more prolonged microorganism survival in alpine environments.[254] The investigator marked group latrines in alpine terrain and returned 1 to 2 years later to dig test trenches. He found a thin crust of decomposition covering unaltered raw waste with high coliform bacteria counts. Microorganisms may percolate through the soil. Most bacteria are retained within 51 cm (20 inches) of the surface, but in sandy soil, this increases to 23 to 30 m (75 to 100 feet);[319] viruses can move laterally 23 to 92 m (75 to 302 feet).[281] When organisms reach groundwater, their survival is prolonged, and they often reappear in surface water or wells.[326]

The U.S. military and U.S. Forest Service recommend burial of human waste 20 to 30 cm (8 to 12 inches) deep and a minimum of 30 m (100 feet) from any water.[319,328] Decomposition is hastened by mixing in some dirt before burial. Shallow burying is not recommended because animals are more likely to find and overturn the feces. Judgment should be used to determine a location that is not likely to allow water runoff to wash organisms into nearby water sources. Groups larger than three persons should dig a common latrine to avoid numerous individual potholes and inadequate disposal. To minimize latrine odor and improve its function, it should not be used for disposal of wastewater.

In some areas, the number of individual and group latrines is so great that the entire area becomes contaminated. Therefore, sanitary facilities (outhouses) are becoming common in high-use wilderness areas. Popular river canyons require camp toilets, and all waste must be carried out in sealed containers.

REFERENCES

Complete references used in this text are available online at expertconsult.inkling.com.

APPENDIX A Water Disinfection Devices and Products for Field Use

Product lines are continuously evolving, and prices change frequently and vary widely. Prices quoted represent a current range from Internet advertising.

For most of these products, claims are substantiated only by company-sponsored and company-designed testing. Some results have been extrapolated to similar products. Products are tested using a standardized Environmental Protection Agency (EPA) protocol: depending on claims, filters must demonstrate removal or inactivation of 10^3 cysts (99.9%), 10^4 viruses (99.99%), and 10^6 bacteria under varying water conditions of temperature and turbidity. Few objective, comparable test results for these products are available. (See Comparative Studies and Preferred Techniques, earlier.)

Filter capacity is highly variable, depending on clarity of water. Numbers cited for capacity are usually based on clear water; testing using slightly turbid river water and following manufacturer instructions for cleaning reveals markedly different values. For all filters, it is recommended to pump dilute bleach solution through the unit after each trip and dry thoroughly before storage to decrease bacterial growth in the filter.

APPENDIX A

Product	Price	Structure/Function
Katadyn Endurance Series		http://www.katadyn.com Endurance filters contain a 0.2-µm ceramic candle filter, silver impregnated to decrease bacterial growth. Large units also contain silver quartz in center of filter.
Pocket Filter (Figure 88-5)	$300-370	Hand pump; 40-inch intake hose and strainer, zipper case; in-line carbon cartridge available; size: 10 × 2.4 inches; weight: 20 oz; flow: 0.75-1 L/min; capacity: 50,000 L.
Combi (Figure 88-6) Accessories: prefilter bottle adaptor, carrying bag	$175-$220	Small hand pump with ceramic filter and activated charcoal granule stage; with the optional "PLUS" package, the Combi can be connected to a water faucet for use in campers, cottages, or boats. Size: 2.4 × 12 inches; weight: 21 oz; flow: 1.0 L/min; capacity: up to 50,000 L; charcoal capacity: 200 L.
Expedition (Figure 88-7)	$1250-$1500	Large hand pump with steel stand for medium to large groups; size (packed in case): 23 × 6 × 8 inches; weight: 12 lb; flow: 4 L/min; capacity (per filter element): up to 100,000 L.
Ceradyn (Figure 88-8) and Gravidyn	$295-320	Gravity drip from one plastic bucket to another with three ceramic candle filter elements. Ceradyn uses ceramic candle filters, whereas Gravidyn filter candles combine ceramic and activated carbon elements; size: 18 inches × 11 inches diameter (26 inches high when assembled), 10-L water container; weight: 7 lb; flow: 4 L/hr; capacity: up to 150,000 L.
Siphon filter (Figure 88-9)	$65-$80	Gravity 0.2-µm ceramic siphon filter element without reservoir bag that can be used to make a gravity system out of any water container. Place one or more Siphon filter elements into a container, and let the water run through the hose into a lower-positioned vessel. Size: 6.3 × 2.6 inches; weight: 16 oz; flow: 5 L/hr; capacity: about 20,000 L.
Katadyn Backcountry Series		
Vario (Figure 88-10)	$95	Hand pump; 0.2-µm pleated glass fiber filter with 143-square-inch surface area, ceramic prefilter, and activated charcoal stage; attaches directly to water bottle; size: 7.5 × 4.0 inches; weight: 15 oz; max flow: 2 L/min (36 stokes/L); capacity: 2000 L.
Hiker and Hiker Pro (Figure 88-11)	$60-85	Hand pump; 0.2-µm pleated glass fiber with 107-square-inch surface and activated carbon core; size: 6.5 × 2.4 × 3 inches; weight: 11 oz; flow: 1 L/min (48 strokes/L); capacity: 750 L.
Gravity Camp and Base Camp (Figure 88-12)	$80-$100	Gravity filter with a 0.2-µm glass fiber filter (Hiker filter cartridge) plus granular charcoal; includes dirty water reservoir bag and tubing; Gravity Camp bag 6L, Base Camp Pro 10L; size: 10 × 6 × 2 inches; weight: 11 oz; flow: 2 L/min; capacity: 1500 L.
Katadyn Ultralight Series		
Mini (Figure 88-13)	$90-$110	Smaller, lighter hand pump; 0.2-µm ceramic filter with activated carbon; 31-inch intake hose and strainer, hard plastic enclosure and pump; size: 3.2 × 7 × 2 inches; weight: 8 oz; flow: 0.5 L/min; capacity: approx 7000 L.
Water Bottles		
MyBottle (Figure 88-14)	$40-$60	Drink-through bottle with either two stage: 0.2-µm fiberglass filter and activated carbon cartridge, or three-stage purifier cartridge with filter for protozoa, pentaiodide iodine resin (ViruStat), and activated carbon; weight: 10 oz; size: 10 inches high, 24 oz; capacity: up to 26 gal.
Microfilter	$40	Hand pump with 0.2-µm ceramic depth filter; size: 3.2 × 7 × 2 inches; weight: 8 oz; flow: 0.5 L/min; capacity: approx 2000 gal.

Continued

FIGURE 88-5 Pocket Filter. *(Courtesy Katadyn.)*

FIGURE 88-6 Combi. *(Courtesy Katadyn.)*

FIGURE 88-7 Expedition Filter. *(Courtesy Katadyn.)*

FIGURE 88-8 Drip Ceradyn. *(Courtesy Katadyn.)*

FIGURE 88-9 Siphon. *(Courtesy Katadyn.)*

FIGURE 88-10 Vario Filter. *(Courtesy Katadyn.)*

FIGURE 88-11 Hiker Pro. *(Courtesy Katadyn.)*

FIGURE 88-12 Katadyn Base Camp (cutaway view). *(Courtesy Katadyn.)*

FIGURE 88-13 Mini. *(Courtesy Katadyn.)*

FIGURE 88-14 MyBottle Purifier. *(Courtesy Katadyn.)*

Katadyn Claims

Endurance series and Mini with ceramic and carbon filter elements remove bacterial pathogens, protozoan cysts, parasites, and nuclear debris. Clarifies cloudy water. If filter clogs, brushing the filter element (which can be done hundreds of times before needing to replace the filter element) can restore flow, or filter elements can be replaced. Claims for removal of viruses by ceramic filters not made in the United States. Pocket Filter has a lifetime warranty.

Vario and Hiker are microfilters designed for high-quality surface water. They will eliminate *Giardia, Cryptosporidium*, and most bacteria; activated carbon core "reduces chemicals and pesticides, plus improves taste of water." Filters with large surface area are "guaranteed not to clog for 1 year."

MyBottle with iodine resin filter passed EPA tests to remove 3-log cysts, 4-log viruses, and 6-log bacteria. Patented ion-release technology and carbon scrubber dramatically reduce residual iodine.

Comments

Well-designed, durable products that are effective for claims. However, high filter volume capacity is optimistic and not likely to be achieved filtering average surface water. *Backpacker* magazine field tests found the flow comparatively slow, requiring more energy to pump and frequent cleaning. Abrading the outer surface can effectively clean ceramic filters; after multiple cleanings, it is necessary to use the gauge to indicate when filter thickness becomes too thin.

Pocket Filter is the original individual or small-group filter design. Metal parts make it durable, but the heaviest for its size. Expedition filter is popular for larger groups, especially river trips, where weight is not a factor. Complete virus removal cannot be expected, although most viruses clump or adhere to larger particles or bacteria that can be filtered. Silver impregnation does not prevent bacterial growth in filters.

Ceramic candle filters have been independently tested in household use in developing countries and shown to reduce turbidity and bacteria to WHO target levels for safe drinking water.[65]

Vario and Hiker were designed for the domestic backpacking market with higher water quality, where cysts and bacteria are threats, but viruses are less of a problem. The Hiker received top ratings by *Backpacker* magazine for field tests evaluating user-friendliness. These filters may be used with a halogen disinfectant for international travel or conditions, where high levels of contamination are possible.

MyBottle filter with iodine resin is currently the only water bottle or filter product available with iodine resin (see text). Drink-through design limits to single-person day use. The filter design with charcoal removing residual iodine and ingestion directly from the filter allows no contact time and may not provide complete viral protection in all situations.

Katadyn Desalinators

Reverse Osmosis Filters

Desalinator Survivor 06 (Figure 88-15)	$1000	Hand-operated pump, reverse-osmosis membrane filter with prefilter on intake line; size: 2.5 × 5 × 8 inches; weight: 2.5 lb; flow: 40 strokes/min yields 0.9 L/hr.
Survivor 35 (Figure 88-16)	$2200	Hand-operated pump, reverse-osmosis membrane filter with prefilter on intake line; size: 3.5 × 5.5 × 22 inches; weight: 7 lb; flow: 30 strokes/min yields 4.5 L/hr.
PowerSurvivor 40E PowerSurvivor 80E	$4000 $5000	Small, power-operated models in this line of reverse-osmosis filters; uses only 4 amps, so can run for extended periods on 12-volt power source; converts to manual operation in emergencies; pump size: 6.8 × 16.5 × 15.5 inches; prefilter 12 × 6 inches; weight: 25 lb; flow: 5.7 L/hr (1.5 gal/hr); 80E size: 6 × 16 × 14 inches; weight 34 lb; flow 12.9 L/hr (4.0 gal/hr).

Claims

Reverse-osmosis units desalinate, removing 98% of salt from seawater by forcing water through a semipermeable membrane at 800 psi. In the process, microorganisms are filtered out. The manual operation of these units makes them unique and useful for survival at sea or for use in small craft without power source.

Comments

Reverse-osmosis units are nanofilters capable of removing sodium molecules, as well as all microorganisms, including viruses. They are included here for sea kayaking and small-boat journeys in open water. These units can obviate the need for relying solely on stored water or can be carried for emergency survival. Reverse-osmosis filters currently are not practical for land travel because of cost, weight, and flow rates; however, the U.S. military uses truck-mounted reverse-osmosis filters on land for their ability to handle brackish water and remove all types of microorganisms. Note that the company does not make claims for viral removal because they assume that the membrane is imperfect and some pores will be imprecise, perhaps allowing viral passage. Higher-flow power models are available from the company (Model 80E, 160E).

British Berkfeld — U.S. distributor: James Filter http://www.jamesfilter.com/

Berkey Filters

Product	Price	Structure/Function
Models include: Travel, Big Berkey, Royal, Imperial, Berkey Light (Lexan, not stainless steel)		A line of stainless steel stacked bucket filters that operate by gravity drip and can accommodate variable numbers of candle filter elements. There are two types of filter elements: (1) ceramic with carbon core and silver impregnation, and (2) compressed carbon impregnated with silver (Black Berkey). The size of the lower reservoir varies from 1.5-6 gal. Price varies by size and number of filter elements. Flow depends on number of filter elements.
SS-4	$220	Stacked stainless steel containers with four 7-inch ceramic filters with activated carbon core; gravity flow; size: 20 × 8.5 inches (15 inches when nested); weight: 6.0 lb; flow: 24 gal/day; 2-gal capacity of lower container, capacity: 6000 gal.

Continued

British Berkfeld Claims and Comments

Ceramic filter is 0.9 μm absolute, but filters >99.99% of particles larger than 0.5 μm. Removes 100% cysts and 4- to 5-log bacteria. Complete protection requires chlorine treatment as the first step. Black (compressed carbon) filters remove 4- to 5-log cysts and bacteria.

The bucket filters are excellent for stationary base camps or expatriate homes. Ceramic candle filters will perform better than the carbon ones.

AquaRain Filter Systems		http://www.aquarain.com
AquaRain 200 (Figure 88-17) AquaRain 400 (Figure 88-18)	$160-200 $240-320	Stainless steel containers (3 gal each) with one to four silver-impregnated ceramic filters with carbon core; gravity flow; size: 22 × 10.25 inches; weight: 10 lb; flow: 1 gal/hr with four elements, 16 gal/day with two; capacity: 30,000-60,000 gal. Price depends on size and number of filter elements.

AquaRain Claims and Comments

Filter has 0.2-μm absolute pore size, removes 100% cysts and 4-log reduction of bacteria. Ceramic elements can be cleaned 200 times before replacement. Similar design as Berkfeld and Katadyn bucket drip filters, although ceramic elements differ slightly. No claims for viruses.

Ceramic candle filters have demonstrated efficacy in household use in developing countries, even removing most viruses due to aggregation with other microorganisms.[65]

Product	Price	Structure/Function
General Ecology		http://www.generalecology.com All filters contain 0.1-μm (0.4-μm absolute) Structured Matrix filter in removable canister.
First Need XLE Portable Water Filter (Figure 88-19)	$100-$130	Hand pump with intake strainer; outflow end connects directly to common water bottle and adapters available for Platypus bottles; self-cleaning prefilter float; size: 6 × 6 inches; weight: 15 oz; flow: 2 L/min; capacity: 600 L.
Trav-L-Pure (Figure 88-20) (Carrying case included)	$230	Filter and hand pump in rectangular housing (1.5-pt capacity); pour water into housing, then pump through prefilter and microfilter; size: 4.5 × 3.5 × 6.75 inches; weight: 22 oz; flow: 1-2 pt/min; capacity: 100-400 L.
Trav-L-Pure Camper (Figure 88-21)	$85	Trav-L-Pur canister with attachment to hose bib for recreational vehicles and trailers requires water pressure of 20 psi; flow: 0.5 gal/min (1.9 L/min); capacity: 570 L.
Base Camp (see Figure 88-12)	$700	Stainless steel casing and hand pump connected by tubing; size: canister 4.1 × 8.8 inches, pump 1.5 × 10.5 inches; weight: 3 lb; flow: 2 L/min; capacity: 500 gal. Also available with electric pump and can be hooked up in series to provide higher capacity and flow.

General Ecology has an extensive product line of larger-capacity filters for use on cars, boats, aircraft, and other situations requiring high-volume output where power is available. These use the Seagull IV purifier cartridge with a pump that pushes water through the system and a prefilter that can be cleaned. They can be operated off regular current or vehicle battery.

Claims

First Need Filter is a proprietary blend of materials, including activated charcoal. "Microfiltration" with 0.1 μm retention (0.4 μm absolute) "removes bacteria and larger pathogens" (cysts, parasites). "Adsorption and molecular sieving:" carbon absorbers remove chemicals and organic pollutants that cause color and taste; cavities in surface of adsorption material draw particles in deeper. Does not remove all dissolved minerals or desalinate. Proprietary process also creates ionic surface charge that removes colloids and ultrasmall particles through "electrokinetic attraction." Has passed laboratory tests as a purifier under single-pass conditions without added chemicals or hold time, reducing rotavirus test virus by 10^4 as well as bacteria by 10^6 and *Cryptosporidium* by 10^3.[126]

Comments

Reasonable design, cost, and effectiveness. All units use the same basic filter media. Most testing with *Escherichia coli* and *Giardia* cysts show excellent removal. Although they have not tested with hepatitis virus, testing with rotavirus and poliovirus indicate effectiveness against viruses. Charcoal matrix will remove chemical pollutants. Despite viral claims, recommend caution in highly polluted water; prior disinfection with halogen or clarification with coagulation-flocculation would provide additional security, and coagulation-flocculation would extend filter life, whereas filter carbon would subsequently remove halogen. The filter cannot be removed to clean, although it can potentially be back-flushed; so it must be replaced when clogged. Soft intake tubing collapses under pressure of pumping.

Product	Price	Structure/Function
Cascade Designs and MSR		http://www.cascadedesigns.com/MSR
MiniWorks EX (Figure 88-22)	$90	Hand pump, cylindrical ceramic filter with block carbon core, porous foam intake filter, and 10-μm stainless steel wire mesh screen; pressure-relief valve releases at 90-95 psi; storage bag (2 or 4 L) attaches directly to outlet of pump; size: 2.75 × 7.5 inches; weight: 16 oz; flow rate: 1 L/min (85 strokes/L); capacity: 400-2000 L (400 L under average conditions).
SweetWater Microfilter (Figure 88-23) Purifier Kit with Microfilter, purifier solution and Platypus water bag	$90 $90	Lexan body and pump handle; 80-μm metal prefilter; in-line 4-μm secondary filter; labyrinth filter cylinder of borosilicate fibers removes pathogens to 0.2 μm; granular activated carbon; safety pressure-relief valve; end-of-life indicator; outflow tubing has universal adapter that fits all water bottles; optional input adapter that attaches to sink faucet while traveling; size: 7.75 × 2 inches; weight: 11 oz; flow: 1.25 L/min (75 strokes); capacity: 750 L.
SweetWater Purifier solution	$10	A chlorine-based purifier solution containing 3.5% sodium hypochlorite; add 5 drops to each liter of filtered water, mix for at least 10 seconds, and wait 5 minutes.
HyperFlow (Figure 88-24)	$100	Hand pump using 0.2-μm hollow-fiber filter; attaches directly to top of water bottle for pumping; maintenance kit and replacement cartridges available; size: 7 × 3.5 inches; weight: 7.4 oz; flow: 3 L/min (1 L/20 strokes); capacity: about 1000 L.

Continued

FIGURE 88-15 Survivor 06. *(Courtesy Katadyn.)*

FIGURE 88-16 Survivor 35. *(Courtesy Katadyn.)*

FIGURE 88-17 AquaRain 200. *(Courtesy AquaRain.)*

FIGURE 88-18 AquaRain 400, showing ceramic candle filters. *(Courtesy AquaRain.)*

FIGURE 88-19 First Need Base Camp Filter. *(Courtesy General Ecology.)*

FIGURE 88-20 First Need XLE. *(Courtesy General Ecology.)*

FIGURE 88-21 Trav-L-Pure Camper Canister. *(Courtesy General Ecology.)*

FIGURE 88-22 MSR Miniworks EX. *(Courtesy Cascade Designs.)*

FIGURE 88-23 SweetWater Microfilter. *(Courtesy Cascade Designs.)*

FIGURE 88-24 MSR HyperFlow. *(Courtesy Cascade Designs.)*

APPENDIX A—cont'd

AutoFlow (Figure 88-25)	$120	Gravity drip filter using hollow-fiber filter cartridge; size: 4 × 6 inches; reservoir capacity: 4 L; weight: 13.8 oz; flow: 1.75 L/min; capacity: about 1500 L/cartridge.
Platypus CleanStream Gravity Filter (Figure 88-26)		0.2-μm hollow-fiber filter cartridge gravity drip in-line system or can be used in personal hydration pack system; size: 1.8 × 5.7 inches; weight: 13.7 oz; flow: 4 L in under 2.5 min; capacity: about 1500 L.
SE200 (Figure 88-27)	$239	Recently available, Community Chlorine Maker, manufactured for developing countries. Electrochemical generation of chlorine and other disinfectant species using table salt and current from a 12-volt battery or main power source. Each 5-min run generates enough disinfectant to treat 55 gal with residual concentration of 2-ppm free hypochlorite.

Cascade Designs and MSR Claims

MiniWorks EX

Fully field-maintainable, meaning that all elements can be removed, cleaned, and replaced. Removes protozoa (including *Giardia* and *Cryptosporidium*), bacteria, pesticides, herbicides, chlorine, and discoloration. Meets EPA standards for removal of cysts and bacteria. Ceramic filters reduced turbidity from 68.8 NTU to 0.01 NTU. Carbon has been shown to reduce levels of iodine from 16 mg/L to <0.01 mg/L for at least 150 L.

SweetWater Filter

Eliminates *Giardia, Cryptosporidium,* and other critical bacterial and protozoan pathogens, pollutants, heavy metals, pesticides, and flavors. Cartridge accessory. Lighter, more compact and durable than comparable models, and easiest to clean or replace. The company recycles filter cartridges.

HyperFlow and AutoFlow

Effective against bacteria, particles, and protozoa, but not against viruses, chemicals, or toxins.

Comments

MiniWorks EX

Very good filter design and function. Prefilters protect more expensive microfilter. Effective for claims; high quality control, and extensive testing. No claims are made for viruses, although clumping and adherence remove the majority (currently 2- to 3-log removal, but not 4-log required for purifiers). Reservoir bag that attaches to outflow for filtered water storage is convenient. Filter can be easily maintained in the field; maintenance kit and all replacement parts available. Ceramic filters can be cleaned by abrading outer surface many times without compromising the filter. A simple caliper gauge indicates when filter has become too thin for reliable function.

SweetWater

Well-designed filter at a reasonable price. Pressure-release valve indicates when filter needs cleaning, but this can be a problem as the filter clogs. A brush is provided for cleaning, and cartridges are replaceable.

HyperFlow and AutoFlow

These use microtubule, hollow-fiber technology that can provide higher flow rates with less pressure, which makes them amenable to gravity systems. HyperFlow is the first hand pump with microtubules, but others are likely to follow.

SE 200

The SE200 replaces the smaller Miox unit that used the same technology, generating current from small disk batteries. The science has been known for some time and is used in large commercial processes (http://www.miox.com). Although difficult to measure various disinfectant species generated, testing has confirmed that disinfectant activity is greater than with comparable concentrations of sodium hypochlorite. Cascade Designs is being safe and conservative in their claims, basing them solely on hypochlorite generation. http://www.cascadedesigns.com/msr/global-health/se200/product

Product	Price	Structure/Function
Sawyer Products		http://www.sawyerproducts.com/
PointONE biologic filter and Point Zero Two Purifier filter cartridges		0.1-μm (absolute) hollow-fiber membrane filter, composed of a cluster of microtubules. Purifier filter has 0.02-μm fiber filter. Water is drawn through the walls of the tubules by suction, gravity, or pressure applied by squeezing a bottle; both filter cartridges can be adapted as in-line cartridge for backpack water systems, gravity drip, faucet in-line systems, or polycarbonate drinking bottle with filter. Activated charcoal prefilter cartridge included for optional use; flow: depends on method used, about 1.5 L/min, 5 gal/30 min via gravity feed system; 30 mL/sec from drink-through; capacity: 1 million gal, but depends on clarity of source water. The two types of filters are available in a variety of products and combination packages, including drink-through bottles and in-line hydration systems; gravity drip, faucet attachments, and bucket filter adapter. As yet, there are no hand pump units. Products below may not be complete representation.
All in One	$70	0.1-μm filter can be used with 32-oz squeeze bag, drinking sports bottle, bucket adapter kit, faucet adapter.
Complete Purifier system (Figure 88-28)	$95-$220	Gravity drip system using either 0.1- or 0.02-μm filter with 2 bags (dirty and clean), available in 2-L, 4-L capacity.
Filter Bucket Adapter 0.1 or 0.02 (Figure 88-29)	$60-$130	Kit to attach filter cartridge to a plastic bucket or barrel for gravity drip; comes with hole cutter, adapter, and tubing to construct system. Either 0.1- or 0.02-μm cartridge can be used; flow: estimated up to 170 gal/day.
Squeeze Water Filter (includes 12-, 16-, and 32-oz pouches, water filter, and pop-up drinking spout)	$40	0.1-μm hollow fiber filter cartridge attaches to bags that can be squeezed to maximize flow. Squeeze water into water bottle or drink directly from the filter; weight: 3 oz; capacity: 1 million gal.

Continued

FIGURE 88-25 MSR AutoFlow. *(Courtesy Cascade Designs.)*

FIGURE 88-26 MSR Platypus CleanStream Gravity Filter. *(Courtesy Cascade Designs.)*

FIGURE 88-27 Cascade Designs and PATH SE200. (Developed with multiple global health NGO partners for developing-world communities.) *(Courtesy Cascade Designs.)*

FIGURE 88-28 Sawyer water treatment system. *(Courtesy Sawyer Products.)*

PointONE 10″ Filter Unit	$700	Filter cartridge and regulator with 0.1-μm absolute hollow-fiber membrane that attaches in-line to water line or plumbing; for school, hospital, and other settings with high-volume needs; regulator allows safe cleaning of the filter by back washing at an exact pressure; size: 10 inches long; flow: 5000 gal/day.

Claims

Microtubule technology (Figure 88-30) allows unprecedented flow rates and 0.1- or 0.02-μm absolute filtration. Highest level of biological filtration available on the market today; exceeds EPA standards. GAV prefilter removes lead, chlorine, odors, and taste sediment, whereas the microfilter removes bacteria, protozoa, and cysts. Biologic filters; 0.1-μm filter removes 7-log (99.9999%) bacteria and 6-log protozoa, but makes no claims for viruses; add chlorine to kill viruses. The Point Zero Two absolute purifier removes 99.99999% of bacteria, 99.9999% of protozoa and cysts, and 99.9997% of viruses from the water. It is impossible for any bacteria, protozoa, cysts, and viruses to pass through the filter.

Filters can be back-washed and are able to handle 40 psi, so they can be attached to faucets.

Comments

This technology has been used in industrial and medical processes, but only recently adapted to field water treatment. The Microfilter and Ultrafilter were carefully designed and tested. They are highly versatile, because designed as a cartridge that can be used in various systems from drinking bottles, to gravity drip systems, to in-line household systems. They offer a potential advantage over other water bottle filters because the hollow-fiber technology provides faster filtration with less pressure. The charcoal cartridge compromises some of this low-pressure flow, so is supplied separately for use only when needed. This is the first low-pressure ultrafilter to claim viral removal through mechanical filtration alone. The million-gallon guarantee is based on the large surface area of the tubules.

Bucket filter is a particularly creative application to these filters, with many applications in rural or developing countries.

Product	Price	Structure/Function
Hydro-Photon Inc		http://www.steripen.com/
SteriPEN Classic Traveler (Figure 88-31) (Comes with a thermoformed nylon carrying case)	$50-70	Portable, battery-operated (4 AA-lithium) ultraviolet (UV) water disinfection system. Disinfects up to 16 oz of clear water in less than 1 minute and 32 oz in 90 sec by stirring UV element in water; weight: 5.5 oz, with batteries; size: 7.6 × 1.5 × 1.5 inches; capacity: lamp lasts 8000 treatments; lithium batteries, 200 treatments.
AdventurerOpti	$90	Uses 2 CR123 batteries and is significantly smaller and lighter than Classic; weight: 3.8 oz; size 6.1 × 1.5 × 1 inches.
Ultra (LCD display) (Figure 88-32)	$100	Uses internal rechargeable lithium ion battery; weight: 5 oz; size: 7.3 × 1.6 × 1.3 inches; lamp life is 8000 cycles and can expect up to 100 uses from batteries.
Freedom	$100	Smallest and lightest unit, rechargeable battery through computer USB, AC outlet, or solar charger; weight: 2.6 oz; size: 5.1 × 1.4 × 0.8 inches; capacity: 40 treatments/charge; battery and UV lamp life: 8000 16-oz (0.5-L) treatments (1-L volumes disinfected by treating twice).
Sidewinder	$100	1-L bottle fits into unit with hand crank that generates UV light without batteries; weight: 16.6 oz; size: 8.6 × 5.5 × 3.8 inches; capacity: 8000 1-L treatments.

SteriPEN Claims

Highly effective against bacteria, viruses, and protozoa, including *Cryptosporidium* oocysts. UV light delivered destroys viruses, bacteria, and protozoa in 0.5 L (16 oz) of water in 48 sec or 1 L (32 oz) in 90 sec. Unit automatically turns off lamp after UV dose is delivered. Dose counter indicates when lamp replacement is necessary. In units that run on AA batteries, the recommendation is to use lithium, not alkaline batteries.

Testing demonstrates that Steri-PEN meets the EPA standards as a microbiologic water purifier.

Steri-Pen Comments

In general, UV light for water disinfection is well established from extensive scientific research and widely used for water treatment in large and medium-size applications, most of which require a fixed power and light source. The use of this portable technology is currently limited to small volumes of clear water; however, the potential is great for further advances that will increase its uses in the field. The price of some units has already decreased. Currently, one could do slightly larger volumes with multiple cycles. The testing for this device can be found on the website. Since particulates block the UV rays and shield microorganisms, testing was only successful in clear water, not in EPA "worst-case scenario" water unless prefiltered with microfiltration.[1] Therefore, users must prefilter or clarify cloudy water. The simplicity and rapidity of this technique are appealing.

Product	Price	Structure/Function
Puralytics		http://www.puralytics.com
Photocatalytic Titanium Dioxide Nanoparticles		
SolarBag	$90	3-L food-grade clear plastic bag with clear top and black backing and a coating of TiO_2 nanoparticles inside. Bag is filled with water and placed in sunlight, which activates the TiO_2 to catalyze a reaction to form active disinfectants (see text). The bag has backpack and handle straps to carry to and from water source; inlet debris filter; can be hung for water storage and water dispensed by a valve into canteen or pot as required. For disinfection, bag is placed flat or hanging in direct sunlight; disinfection requires 1-2 hr on sunny day and 2-4 hr on cloudy day; for unknown water sources, a food-safe dye can be used as a tracer and timer—when the color has cleared, the water has been purified. Dry weight: 100 g; size: 3 L; capacity: 250 L; shelf life: >2 yr.

Continued

FIGURE 88-29 Sawyer bucket filter. *(Courtesy Sawyer Products.)*

FIGURE 88-30 Microtubules in Sawyer filter cartridge. *(Courtesy Sawyer Products.)*

FIGURE 88-31 SteriPEN Classic. *(Courtesy Hydro-Photon.)*

FIGURE 88-32 SteriPEN Journey. *(Courtesy Hydro-Photon.)*

Shield 500 and 1000	$9500	High-volume unit that uses UV LEDs to activate nanotechnology mesh; size: 28 × 8 × 19 inches; weight: 89 lb; flow: 200-500 gal/day; power: 640 watts; pressure 15-60 psi; life span: 10 yr. Model 1000: 500-1000 gal/day.

Claims

Works through multiple photochemical processes. Selected wavelengths of UV light generate hydroxyl radicals (OH^-) without chemical additives. Disassociates and eliminates organic compounds from the water. Reduces heavy metal to less toxic, more elemental state and irreversibly adsorbs heavy metals, including mercury, lead, chromium, and arsenic. Disinfects pathogens more effectively than standard UV irradiation. After 2 hours in the sun on an 80° F sunny day, process will reduce 7-log bacteria, 5-log viruses, 90% heavy metals, and 90% organic compounds.

Comments

This is a new and promising technology for field water disinfection and purification (see section on nanoparticles). Significant testing and literature is available because it has multiple applications in industrial and community-level water treatment. Independent testing demonstrated effectiveness against *Cryptosporidium*.[306] Blue food dye is supplied to ensure continued function of bag.

Product	Price	Structure/Function
Hydration Technology Innovations (HTI)		
http://www.htiwater.com/hti.html		
X-Pack Ten 2-oz sports drink syrup charges and dye tabs	$64 $16.50	A plastic pouch with two compartments separated by a semipermeable membrane that provides ultrafiltration to 0.0005 μm (5 Å); fill one side with dirty or contaminated suspect water; add to the other side a specially formulated syrup supplied with the kit that contains salts and sugars. Volume: 1.8 L; weight: 3 lb, includes syrup charges; flow: 1 L/4 hr, can produce a total of over 5 L of hydration drink per day; capacity: 32 L; good for a total of 10 days of use after first use.
LifePack	$35	Single filter, six 2-oz syrup charges; 5-day filter life; 1.8-L bag capacity; 3 L/day.
SeaPack Includes eight 4-oz syrup charges	$85	Dual-chamber pouch, 1.8-L capacity each, separated by semipermeable membrane with nominal pore size of 3-5 Å; flow: 0.5 L/5 hr at 20° C (68° F); capacity: 4 L from seawater, or up to 24 L from freshwater; filter life: 10 days.
Expedition Includes ten 4-oz syrup pouches, cleaning kit	$299	Dual-reservoir water bladder for use with clean or contaminated water; uses osmotic filter cartridge that works by forward osmosis from osmotic syrup; one 4-oz (0.12-L) syrup pouch will filter about 2.5 L of water; capable of filtering fresh to brackish water; clean reservoir volume: 3.0 L, dirty reservoir volume: 2.5 L; flow: about 0.8 L/hr; filter life: 30-90 days (clean weekly).
HydroWell Includes twenty 14-oz syrup pouches, cleaning kit	$389	Dual 20-L cans with osmotic filter built into a standard water can cap; forward osmosis driven by one sports syrup pouch that fits into the cap; one syrup pouch will filter one 20-L can of fresh to brackish water; flow: about 1.2 L/hr; filter life: 30-90 days (clean weekly).

Claims

Forward osmosis—water is driven across the membrane, not by hydraulic pressure, but by osmotic pressure created by a standard sport drink powder on the clean side of the membrane. This syrup is formulated much like the concentrate for a typical sports drink containing about 4% sugar (this compares with some other sports drinks at 6% and soda at 12%). Capable of filtering highly turbid water (tested to 800 NTU). Minimum 3-yr shelf life when stored below 32.2° C (90° F).

Comments

Forward osmosis is based on sound technology, and these products provide a good solution for disaster supplies or survival cache with long shelf life. Less optimal when on the move, although the bags could be primed and carried throughout the day while filtering. For those who prefer fresh water, the resulting sweetened solution is a major disadvantage. Simple filters or chemical solutions are lighter and faster for fresh water but cannot handle brackish water as can some of the HTI products.

Large-Scale Field Products

The following are included as examples of multistage products that are available for large-volume field water treatment. This is not a comprehensive list of products, and many others are available, including trailer-mounted reverse-osmosis systems. These products require a power source and may require truck or trailer for transportation. Most chemical systems can be scaled up through using large containers or water bladders and multistation distribution systems.

Global Hydration Water Treatment Systems

http://www.globalhydration.com/canpure-water-purification-system.htm

Can Pure Water Purification System Various models available		Dual-process purification system incorporating six-stage microfiltration system and UV disinfection; optional residual chlorination using NaDCC tablets. Model 4: size: 23 × 23 × 24 inches; weight: 82 lb; output: 8500 L/day (2245 gal/day); power requirements: small generator (130 watts), can also be run on 12-volt DC or 120-volt AC. Model 5: size 23 × 23 × 29 inches; weight 83 lb; output: 5000 gal/day. Water Miracle: size: 40 × 40 × 86.6 inches; weight: 660 lb; output: 12,720 gal/day.

Complete stand-alone water treatment system designed to produce potable water in remote field conditions and in emergency and disaster situations. Compact; portable; capable of running off gas or diesel generator without electricity or gravity.

Continued

First Water Systems	http://firstwaterinc.com
Responder, Outpost, Villager	All M-line (mobile) units use high-strength UV bulb for disinfection with in-line prefilter for large particulates, a 0.2-μm sediment filter to reduce turbidity, and carbon block for improving taste and smell; all units can be supplemented with residual chlorination system; run off a variety of power sources, including solar, battery, or generator. Water bladder and distribution system available; filling station enables either four or six lines of people to obtain water at any given time. Aqua Bags for transport of clean water are 3-gal heavy-gauge food-grade plastic bags that weigh about 20 lb when full.
Responder	Portable model with canister configuration that runs on solar, on-board 12-volt battery, AC or DC power; size: briefcase size, 20 × 17 × 9 inches; 45 lb, including wheeled case; flow: 4 gal (16 L)/min, or about 600 gal (2500 L)/day per battery.
Outpost-4	Semiportable model water purification system runs exclusively off integrated solar system and an on-board battery; size: fits in the back of a pickup truck, SUV, minivan, mounted on wheeled frame; weight: 160 lb; flow: 4 gal (16 L)/min, or about 600 gal (2500 L)/day per battery (enough water for 1000 persons per day with multiple batteries).

Comments

The UV system forces the water to circulate around the UV bulb twice, providing significantly greater "contact time" and greater ability to neutralize biologic contamination. Cigarette lighter plug adapters for additional battery power and AC power. Using multiple batteries extends the usable time and the amount of water produced. All filters easily detach for rapid cleaning or replacement.

APPENDIX B Chemical Disinfection Products

See text for further discussion of chemical disinfectants.

IODINATION

IODINE SOLUTIONS

Iodine solutions commercially sold as topical disinfectants contain iodine, potassium or sodium iodide in water, and ethyl alcohol or glycerol (see Table 88-14). Iodide improves stability and solubility but has no germicidal activity and adds to the total amount of iodine ingested and absorbed into the body. "Decolorized" iodine solution contains iodide and should not be used for water disinfection.

IODOPHORS (POVIDONE-IODINE)

These solutions bind diatomic iodine to a neutral polymer of high molecular weight, giving the iodine greater solubility and stability with less toxicity and corrosive effect.[56,128] Povidone-iodine is a 1-vinyl-2-pyrrolidinone polymer with 9% to 12% available iodine. The iodophors are routinely used for topical disinfection, because they have less tissue toxicity than iodine solutions. Povidone is nontoxic.

In aqueous solution, povidone-iodine provides a sustained-release reservoir of halogen; free iodine is released in water solution depending on the concentration (normally, 2 to 10 ppm is present in solution). Data indicate persistence of about 2 ppm of free iodine at a 1:10,000 dilution,[128] equivalent to 0.1 mL (2 drops) added to 1 L of water. One report found these compounds similar in germicidal efficiency to other iodine-iodide solutions.[56] Conflicting values for available iodine and free iodine in dilute solutions result from the complex chemistry of povidone-iodine.[18,146]

CRYSTALS (SATURATED SOLUTION)

Because of limited solubility in water, iodine crystals may be used to generate an iodine solution for disinfection. A small amount of elemental iodine goes into solution (no significant iodide is present); the saturated solution is used to disinfect drinking water. Water can be added to the crystals hundreds of times before they are completely dissolved. Because iodine crystals evaporate in air, always keep covered with water.

To formulate this solution at home, put 4 to 8 g (exact amount does not matter) of crystalline iodine in a 1- or 2-oz bottle, and fill with water. An alternative technique is to add 8 g of iodine crystals to 100 mL of 95% ethanol. Increased solubility of iodine in alcohol makes the solution less temperature dependent and allows much smaller volumes to be used (8 mg/0.1 mL), which can be measured with a 1-mL syringe or dropper (2 drops). Residual iodine can be removed with granular activated carbon.

Product

Polar Pure

http://www.polarequipment.com/

Price: $15.00

Widely available through suppliers of outdoor products

Formulation: Eight grams of iodine crystals in a 3-oz glass bottle filled with water; 30- to 50-μm fabric prefilter provided; "trap" in bottle to catch crystals when pouring off water; capacity: 2000 qt; weight: 5 oz.

Instructions: The bottle cap is used to measure iodine solution: one capful is approximately 6.5 mL. Directions and color-dot thermometer are printed on the bottle. Recommended dose: 2 capfuls if iodine solution is 20° C (68° F) yields 4 ppm of iodine when added to 1 qt of clean water. To shorten contact time, warm water to 20° C (68° F) before adding iodine.

Comments

Saturated aqueous solution of crystalline iodine is an excellent and stable source of iodine. Recommendations are adequate for clear, warm water; however, because it is not feasible to warm all water, extend contact time to 1 to 2 hours for very cold water. Temperature of the iodine bottle also affects the concentration of iodine in the saturated solution (200 ppm at 10°C [50°F), 300 ppm at 20°C [68°F], 400 ppm at 30°C [86°F]),[59,128] which is the reason for the color-dot thermometer on the bottle. In the field, it may be easier to warm the bottle in an inner pocket than to estimate temperature and adjust the dose. The supernatant should be carefully decanted or filtered to avoid ingestion of the crystals;[353] this is aided by the weight of the crystals, which causes them to sink. Many people prefer crystalline iodine because of its large disinfectant capacity, small size, and light weight. The absence of iodide decreases total amount of iodine ingested. The glass bottle can break, and there are anecdotal reports of freezing in very cold temperatures.

Iodine in alcohol is a viable option that allows for much smaller doses because of higher solubility of iodine in alcohol. Currently, there is no commercial product, but it can easily be formulated at home.

IODINE TABLETS

The tablets contain tetraglycine hydroperiodide, which is 40% I_2 and 20% iodide.[56,218] They were originally developed by the military for individual field use because of their broad-spectrum disinfection effect, ease of handling, rapid dissolution, stability, and acceptable taste.[229,245,271]

One tablet contains 20 mg of tetraglycine hydroperiodide that releases 8 mg/L of elemental iodine into water; both diatomic iodine (I_2) and hypoiodous acid (HIO) are released. An acidic buffer provides a pH of 5.5 to 6.5, which supports better cysticidal than virucidal capacity but should be adequate for both. Tablets have the advantages of easy handling and no danger of staining or corroding if spilled. They are stable for 4 to 5 years under sealed storage conditions and for 2 weeks with frequent opening under field conditions, but they lose 30% of the active iodine if bottles are left open for 4 days in high heat or humidity.

Products

Potable Aqua (Wisconsin Pharmacal Co, Jackson, Wisconsin)
- http://potableaqua.com/
- **Price:** 50 tablets, $6.00; with PA Plus Neutralizing tablets, $9.00
- Widely available through suppliers of outdoor products
- Also sold as Globaline and EDWGT (emergency drinking water germicidal tablets)
- **Instructions:** One tablet is added to 1 qt of water. In cloudy or cold water, add two tablets. Contact time is only 10 to 15 minutes in clear, warm water; much more in cold, cloudy water (see Tables 88-10 to 88-12).
- To remove taste and color of iodine, add one tablet of Potable Aqua PA Plus, mix, and wait 3 minutes. PA Plus should be used *after* the 30-minute waiting period for Potable Aqua.
- If the tablets are gray or dark brown in color, they are still likely to be effective. If they are light green or yellow, it means they are probably no longer effective. An opened bottle should not be kept for more than 1 year.

Comments

This method was developed by the military for troops in the field. Advantages are unit dose and short contact time, but these concentrations create strong taste that is not acceptable to many wilderness users. The military requirements dictated a short contact time (10 minutes in clear, warm water), thus the relatively high concentration of iodine (8 to 16 ppm). With adequate contact time and moderate temperatures, one tablet can be added to 2 qt of water to yield 4 ppm of free iodine (see Table 88-15). Rather than use two tablets in cloudy water, clarify the water first.

PA + Plus "neutralizing" tablet contains approximately 45 mg of ascorbic acid (vitamin C), which converts iodine to iodide and removes the taste and color of iodine but has no disinfecting action. However, iodide is physiologically active, so concerns about toxicity or physiologic activity remain. For short-term use, iodine is safe and removing the taste is a major benefit. Ascorbic acid powder can be purchased at many health food stores and used to neutralize any iodine disinfecting solution.

CHLORINATION

Free chlorine is available from several compounds and widely available in liquid and tablet formulations. (See text discussion and Tables 88-11 and 88-12.)

Chlorine test strips or meters are widely available for large groups or disaster/community situations when testing for adequate chlorine residual is desired. Simple, inexpensive field test kits or swimming pool test kits with color strips are widely available from many different manufacturers to ensure adequate residual chlorine.

SODIUM HYPOCHLORITE

Household Bleach

Liquid household bleach is a sodium hypochlorite solution, most often 5.25%, but more recently 8.25%. It has the convenience of wide availability, low cost, and good stability. Sodium hypochlorite solutions are vulnerable to significant loss of available chlorine over time. Stability is greatly affected by heat and light. The 5% solution loses about 10% available chlorine over 6 months at 21.1°C (70°F) and freezes at 4.4°C (40°F). The liquid is corrosive and stains clothing if the bleach container breaks or leaks in a pack. Sodium hypochlorite solution in a squeeze dropper bottle is paired with several portable microfilter products to ensure viral disinfection (e.g., SweetWater Viral Stop).

The U.S. Centers for Disease Control and Prevention (CDC)–World Health Organization (WHO) Safe Water System promotes products worldwide with 1% sodium hypochlorite for water disinfection.[176] Recent evaluation indicates that the CDC Safe Water dose may be inadequate in organic-laden water,[101] whereas the U.S. Environmental Protection Agency (EPA) recommendations for emergency use of household bleach are too high, especially with household bleach concentration increasing to 8.25%.[177]

CALCIUM HYPOCHLORITE (DRY CHLORINE)

Calcium hypochlorite is a stable, concentrated, dry source of hypochlorite frequently used for chlorination of swimming pools. The usual formulation contains 70% concentration of chlorine. Calcium hypochlorite is inexpensive and available in tablets or granules through chemical supply or swimming pool supply stores; one common brand is HTH, but there are many commercial products.

Redi-Chlor (Gripo Laboratories, New Delhi, India)
- http://www.gripolabs.com
- 50 tablets in blister packs
- Price: $9.95
- Multiple strengths, including: 0.5 g, 1.0 g, 2.0 g, 2.5 g, for treating 20, 80, 200, 240 L, respectively
- Available from multiple suppliers
- **Formulation:** Redi-Chlor tablets come in different sizes and can be broken in half or fourths to treat different quantities of water. Recommended dose results in 2 to 5 mg/L residual chlorine. Add more for very cold water or if faint chlorine smell is not detected after contact time. Available in blister packs of 50 0.1-g tablets that treat 1 gal per tablet or 0.25-g tablets that treat 5 gal per tablet.
- **Instructions:** For situations where many water containers are to be disinfected, it is easier to use a concentrated disinfecting solution. EPA instructions: Add and dissolve one heaping teaspoon of high-test granular calcium hypochlorite (approximately 0.25 oz) for each 2 gal of water. The mixture will produce a stock chlorine solution of

approximately 500 mg/L (100 to 200 times desired strength for drinking). To disinfect water, add the chlorine solution in the ratio of one part of chlorine solution to each 100 parts of water to be treated. This is roughly equal to adding 1 pt (16 oz or approximately 0.5 L) of the stock chlorine solution to each 12.5 gal (50 L) of water to be disinfected.

See U.S. military instructions[319] and Table 88-13 for more details for dosing calcium hypochlorite for various strengths of chlorine and volume of water.

Comments

This is a convenient source of concentrated hypochlorite, which can also be used for superchlorination (see text).

HALAZONE TABLETS

Aquazone (Gripo Laboratories, New Delhi, India)
www.gripolabs.com
100/250/500/1000 tablets in plastic container or 50/60 tablets in blister packs
Tablets contain a mixture of monochloraminobenzoic and dichloraminobenzoic acids.[100] Each tablet releases 2.3 to 2.5 ppm of titratable chlorine.[229]

Comments

These tablets have been criticized because the alkaline buffer necessary to improve Halazone dissolution decreases disinfectant efficiency, requiring unacceptably high concentrations and contact times (6 tablets yield 15 mg/L with recommended contact time of 60 minutes) for reliable disinfection under all conditions.[271] The shelf life is 6 months; potency decreases 50% when stored at 40° to 50°C (104° to 122°F). A new bottle should be taken on each major trip or changed every 3 to 6 months. Halazone has mainly been replaced by newer tablet formulations of chlorine.

SODIUM DICHLOROISOCYANURATE

Sodium dichloroisocyanurate (NaDCC) is a stable, nontoxic chlorine compound that releases free active chlorine and forms a mildly acidic solution, which is optimal for hypochlorous acid, the most active disinfectant of the free chlorine compounds. Free chlorine is in equilibrium with available chlorine that remains in compound, providing greater biocidal capacity. NaDCC is more stable and provides more free active chlorine than other available chlorine products for water disinfection.

Manufacturers and Product Formulations

Gripo Laboratories (New Delhi, India)
http://www.gripolabs.com/nadcc_tablets.html
Tablets available in sizes to treat 1 to 100,000 L
Kintab (Bioman Products) (Mottram, Hyde, Cheshire, UK)
http://www.bioman.co.uk
Aquatabs (Medentech, Wexford, Ireland)
Six tablet strengths: 3.5, 8.5, 17, 33, 67, and 167 mg, depending on the volume to be treated, in individual foil-wrapped packets or strips. Larger quantities are available in tubs.
Also available through Global Hydration Water Treatment Systems (Kakabeka Falls, Ontario, Canada)
http://www.globalhydration.com/aquatabs-water-purification-tablets.htm
Packs of 24 or 50 tablets to treat 1 L/tab or 30 tablets to treat 20 L (5 gal)/tab
Pristine (Advanced Chemicals Ltd, Port Coquitlam, BC, Canada)
http://www.pristine.ca/

Formulation and Instructions

When dissolved in 1 L of water, each effervescent tablet releases 10 mg of free chlorine; 50% of the available chlorine remains in compound and is released as free chlorine as solution is used up by halogen demand. Aquatab also makes slow-dissolving tablets for larger quantities of water that contain trichloroisocynuric acid (TCCA), which acts similar to NaDCC.

Disinfection of clear surface water is accomplished at 10 mg/L in 10 minutes, 1 mg/L for tap water and 2 to 5 mg/L for well water. NaDCC is also used to wash fruits and vegetables in concentrations of 20 mg/L or higher.

The tablets have a 3- to 5-year shelf life.

Comments

This is a good source of chlorine available in multiple doses and formulations, including individually wrapped tablet form; higher-concentration tablets allow for disinfection of large volumes of water or for shock chlorination of tanks and other storage systems. Tablets have been shown to be effective for household use in developing countries.[65]

CHLORINATION-FLOCCULATION

Tablets contain alum and 1.4% available chlorine in the form of sodium dichloro-*s*-triazinetrione with proprietary flocculating agents. Bicarbonate in the tablets promotes rapid dissolution and acts as a buffer. One 600-mg tablet yields 8 mg/L of free chlorine.

Testing by the U.S. military demonstrated biocidal effectiveness similar to iodine tablets under most conditions.[243,244,246] Extended contact time was necessary for complete viral removal in some of the tests. Because of the ability to flocculate turbid water, the action was superior to iodine in some poor-quality water. The method is optimal for humanitarian disasters, where available surface water is often highly turbid.[97] Testing in households in developing countries demonstrates reduction of diarrhea episodes with proper use.[62,82,259]

Chlor-Floc (Deatrick & Associates, Alexandria, Va)
30 tablets individually sealed in foil packets; weight: 1.6 oz.; capacity: 30 L (8 gal)
Price: $9.00
Widely available through camping, military surplus, and survival websites
Formulation/instructions: One tablet for the clarification and disinfection of 1 L of water from polluted sources at temperatures of 25°C (77°F). At 5°C (41°F), use two 600-mg tablets to provide 2.8% available chlorine. To strain the sediment, pour the water through the cloth provided. The tablets are stable for 3 years if stored out of the heat in their packaging.
At 25°C (77°F), add 1 tablet; wait 7 minutes. At 15°C (59°F), add 1 tablet; wait 15 minutes. At 10°C (50°F), add 1 tablet; wait 15 minutes. At 5°C (41°F), add 2 tablets; wait 15 minutes.

1. Add 1 or 2 tablets (600 mg) to 1 L (1.1 qt) of water.
2. Shake for 1 minute to make sure that the tablets dissolve completely.
3. Wait for 7 to 10 minutes (or the necessary time), then strain through a piece of broadly woven cloth (e.g., T-shirt material) into clean container.
4. The clarified water is now ready for drinking.
5. If water is still murky, add an additional 0.5 tablet, and repeat steps 2 and 3.

After decanting, the water looks much clearer and is left with a free chlorine residual that produces microbiologically safer water without pronounced chlorine taste or odor.[62]

PUR Purifier of Water (Proctor & Gamble)
www.pghsi.com
Instructions: Sachet of powder containing ferric sulfate as a coagulant and calcium hypochlorite as a disinfectant. Add one sachet to 10 L of water, and agitate vigorously. After the flocculants have settled to the bottom, filter through a clean cotton cloth, and wait 20 minutes to drink.
This product is available to large relief organizations for use outside the United States in disaster and conflict situations. They will also begin distribution for individual users in the developing countries.

Comments

This is one of the individual field methods for U.S. military troops and suggested for potential use in developing countries by WHO.

PUR has been used at the household level in many developing world communities and disasters.[62,75,81,82,259] It is an excellent one-step technique for cloudy and highly polluted water (see Table 88-15). Souter and colleagues[300] demonstrated that this technique reduced bacteria (14 types) by 8 log, *Giardia* and *Cryptosporidium* by 3 log, and arsenic by 99.8%.

Alum and ferric sulfate are widely used flocculants that cause suspended sediment, colloids, and many microorganisms to clump, settle to the bottom, and readily be filtered or strained. Most *Cryptosporidium* oocysts would be removed by the flocculation. Some chlorine reacts with contaminants and is inactivated. It is important to confirm some chlorine taste and smell at the end of the contact time. For added safety, prolong the contact time up to 1 hour in cold, polluted, and dirty water.

In clear water without enough impurities to flocculate, the alum causes some cloudiness and leaves a strong chlorine residual. After treatment, water should be poured through a special cloth to remove flocculants and decrease turbidity.

Both products have undergone extensive testing in field situations.

CHLORINE DIOXIDE

Chlorine dioxide (ClO_2) is routinely used in large-scale water treatment applications, as a volatile gas that is generated on site. Chemical methods for generating ClO_2 using either tablet or liquid formulations are also available for point of use in the field. Advantages of ClO_2 are greater effectiveness than chlorine at equivalent doses and the ability to inactivate *Cryptosporidium* oocysts with reasonable doses and contact times.[219]

TABLETS

Katadyn Micropur MP-1
http://www.katadyn.com/usen/katadyn-products/
Price: 20 tablets, $8.00; 30 tablets, $12.95
Available through many suppliers of outdoor products

Potable Aqua Chlorine Dioxide Water Purification Tablets
Wisconsin Pharmacal Co, Jackson, Wis
Price: 20 tablets, $10.00; 30 tablets, $14.00
Available from many outdoor suppliers

Aquamira (McNett Corp)
http://www.aquamira.com/

Pristine
Advanced Chemicals Ltd, Port Coquitlam, BC, Canada
http://www.pristine.ca/
Tablets in blister packs
Price: 12 tablets, $8.00; 24 tablets, $14.00; 50 tablets, $24.00

Formulation and Instructions

The primary chemical reaction that produces ClO_2 in Katadyn MP-1 tablets is the acid-chlorite reaction using sodium acid sulfate as the acid, a well-known reaction for ClO_2:

$$5NaClO_2 + 4NaHSO_4 \rightarrow 4ClO_2 + NaCl + 2H_2O + 4Na_2SO_4$$

A small amount of chlorine in the tablet also catalyzes the otherwise sluggish reaction.

These tablets generate ClO_2 only when coming into contact with water. Shortly after a tablet is immersed into water, a saturated solution of the soluble solid constituents forms within the matrix of the tablet. ClO_2 is rapidly formed within the pores and then carried into the bulk solution by CO_2 effervescence, which ensures that the resultant solution is well mixed without the user having to agitate the container. After the ClO_2 gas is released, the material reduces into common salts.

Katadyn company product testing shows killing of bacteria and viruses within 15 minutes in any water conditions and inactivation of *Giardia* and *Cryptosporidium* within 30 minutes in clear warm water and 4 hours in cold and dirty water. One tablet is used for treating 1 qt or 1 L of water. Instructions are to insert rapidly into water after removing from the package and avoid exposure to sunlight during disinfection contact time.

Comments

This is an important addition to chemical methods for field disinfection. Several products have met the criteria for EPA registration as an antimicrobial water purifier. The extended contact time in cold, dirty water ensures that sufficient ClO_2 is generated and adequate residual remains for sufficient time to treat water in all conditions. Where possible, clarify the water to improve taste and esthetics, and warm the water to reduce contact time. Available tests appear well designed with multiple controls. There is also documentation that residual ClO_2 concentrations were well maintained during the recommended contact times. ClO_2 does not have extended persistence in water, so it should not be used to maintain microbiologic purity of stored water. Sunlight breaks down ClO_2, so for optimal effect, keep the water bottle in a dark location, such as inside a pack or bag, during disinfection time. For some reason, having these companies release testing data for their ClO_2 products is difficult, so efficacy of particular products cannot be assured.

LIQUID CHLORINE DIOXIDE PRODUCTS

Aquamira (McNett Corp)
http://www.aquamira.com/

Pristine (Advanced Chemicals Ltd, Port Coquitlam, BC, Canada)
http://www.pristine.ca/
Personal size: two 1-oz plastic bottles; capacity: up to 120 L (30 gal) of water; $15.00
Pristine also makes 2-oz bottles ($17.00) and larger packages for relief agencies to disinfect large quantities.

Aquarius Bulk Water Treatment
http://www.advancechemicals.ca/Aquarius-Bulk-Water-Treatment-System
Includes 10 kits of Pristine solution to treat 50,000 L
Available as a system with Terra Tank water bladders (5000- to 10,000-L capacity), Honda pump to fill the bladders, mixing and injection units, and six- to eight-spigot water-dispensing system.
The system is packed in metal chests and weighs 200 lb.

Formulation and Instructions

A stabilized solution of ClO_2 is mixed with phosphoric acid, which activates the chemical and is then mixed with water for disinfection. Contact times for inactivation of *Cryptosporidium* by Pristine range from 15 minutes in warm water using a triple dose to 7 hours using a single dose in very cold water. The two solutions are mixed together in a mixing cap and added to the water for treatment.

Comments and Claims

The chemistry of generating ClO_2 through a similar method is well described. Aquamira solution was not able to meet EPA purifier standards in cold, dirty water. Currently, claims for the solution include "kills odor causing bacteria and enhances taste of stored water." The Canadian liquid product, which appears to be the same, makes full claims, including *Cryptosporidium*. Given the volatility of ClO_2 and slow reaction times, concentrations may be variable because of the mixing process and time delay. Cold and dirty "worst-case" test water may be an issue in disaster situations but is not often encountered by wilderness users.

Aquamira tablets are registered as an EPA purifier, suggesting that tablets are the more stable and reliable form of chlorine dioxide.

MIXED-SPECIES DISINFECTION

SE200 Community Chlorine Maker (Cascade Designs/MSR, Seattle, Wash)
http://www.solutionsforwater.org/wp-content/uploads/2012/03/SE200-Entrepreneur-Fact-Sheet.pdf

Comments

The SE200 was developed by PATH (international nongovernmental organization/NGO) and Cascade Designs as a low-cost, portable, battery-powered, easy-to-use electrochlorination device that creates a concentrated chlorine solution to treat water effectively. The device uses salt, water, and a 12-volt DC battery to create 60 mL of a 0.75% chlorine solution, enough to treat up to 200 L of water over a 7-minute operation cycle (see Appendix A for more information).

Electrolysis of salt to produce chlorine has been used for more than a century. Passing a current through a simple brine salt solution generates free available chlorine, as well as other "mixed-species" disinfectants that have been demonstrated effective against bacteria, viruses, and bacterial spores.[280] The process is well described and can be used on both large and small scale (http://www.miox.com/). Mixed oxidants behave similar to chlorine dioxide and ozone, although these disinfectants are difficult to detect in finished water using usual methods. Cascade Designs bases the effect of the SE200 solution solely on the hypochlorite generated, which is the main residual, measurable species; however, the resulting solution has greater disinfectant ability than a simple solution of sodium hypochlorite, including inactivation of *Cryptosporidium*.[330]

SILVER

Micropur Forte Tablets (Katadyn)

http://www.katadyn.com/chen/katadyn-products/

Available as tablets, liquid, or powder and in various quantities for individual or large-scale use.

One tablet treats 1 L of clear water.

Claims: Eliminates bacteria and viruses in 30 minutes and *Giardia* in 120 minutes; conserves drinking water for up to 6 months; can be used in plastic or glass but not all metal containers. Shelf life: 5 years in original packaging and if stored under 25°C (77°F). Cloudy water can weaken the effect of chlorine and silver ions. Use filter for cloudy water.

Comments

Widely available in Europe, but not marketed in the United States, these tablets contain silver chloride 0.1% and NaDCC 2.5%. The chlorine kills viruses, bacteria, and *Giardia*. The silver adds to the disinfection capacity, as well as preventing recontamination if water is stored for up to 6 months. Contact time is 20 to 120 minutes, depending on the temperature of the water. Shelf life is 5 years, stored in cool, dry conditions.

Micropur Classic (Katadyn)

This product releases only silver ions.

Available in two sizes of tablets (for 1 qt or 5 qt), liquid (10 drops/gal), or crystals for treating larger quantities of water.

Claims: Conserves clear water for up to 6 months; deactivates bacteria after 2 hours of contact. The silver ions cling to the cell walls of microorganisms, thus hindering their growth; affected by some metal containers. Shelf life: tablets/powder, 10 years from manufacture date; liquid, 5 years.

Comments

Although having proven antibacterial effects, silver tablets are not licensed as a water purifier in the United States; however, they are widely used in Europe for this purpose. In addition to poorly documented effects on many different types of microorganisms, there is some difficulty controlling the residual concentration and concern over chronic effects (see section on metals and silver). The product that contains only silver without chlorine makes no claims for viruses and protozoa, because concentrations may not be adequate to kill these organisms. It has EPA approval to be marketed in the United States as a "water preservative" to maintain bacteria-free water for up to 6 months. Silver has the advantage of having no taste, color, or odor. Because of these and additional attractive qualities, other applications with silver are being developed and tested, including nanoparticle materials.

MISCELLANEOUS PRODUCTS

The following products *cannot* be recommended because of insufficient effectiveness data.

Traveler's Friend (NutriBiotic)

Description: Extract from citrus (grapefruit) seeds in 10-mL or 30 mL plastic dropper bottle. Recommended dose (drops/qt): 5 to 10 for filtered water, 10 to 15 for ice water, 10 to 20 for tap water, and 15 to 25 for untreated water. Allow 30 minutes for contact time.

Claims: "All natural treatment for drinking water." Nontoxic, noncorrosive; proved effective as disinfectant for bacteria, viruses, and protozoa. Claims also made for a multitude of health uses, from skin and nails to scalp.

Comments

Citrus extract is known to have some bacteriostatic effect (see text). This product was introduced into the health market and is now looking for a broader uses. Company data from independent laboratories support bactericidal and virucidal effects. However, protozoal tests were done with trophozoites, not cysts. The data have gaps, and too much of the marketing is testimonial to allow a recommendation at this time.

Aerobic Oxygen and Aquagen

http://www.oxygenforlife.net/index.html

Comments and Claims

According to company claims, these products contain other forms of oxygen electrolytes that kill harmful bacteria in stored water and have multiple health benefits when ingested in water or used topically. The company asserts that the product does not contain chlorine dioxide or hydrogen peroxide, but rather uses some unspecified, proprietary, stabilized electrolytes of oxygen. The implication is that it uses free oxygen radicals, but these are not chemically stable. Company-sponsored testing claims effective against *Salmonella,* cholera, *E. coli, Streptococcus, Pseudomonas, Staphylococus* A, and *Giardia*. No dose-time response has been developed to compare the product with other disinfectants.

Aerobic Oxygen was initially introduced into the health food market but is now being offered to the general travel market. It is advertised not only as a water disinfectant, but also for qualities from strengthening the immune system and energizing to curing headaches and tropical fish diseases.

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CHAPTER 89

Dehydration and Rehydration

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Body fluid balance is controlled by physiologic and behavioral actions.[51,100] However, when there is lack of fluid availability, exposure to extreme environments, or illness, inability to maintain fluid balance can seriously jeopardize health and ability to perform.[100] This chapter presents an overview of topics surrounding hydration, dehydration, and rehydration. The terms euhydration, hypohydration, and hyperhydration are used. *Euhydration* defines a "normal," narrow fluctuation in body water content; *hypohydration* and *hyperhydration* define, respectively, a general deficit and a general surfeit in body water content beyond normal. The term *dehydration* specifically defines the condition of hypertonic hypovolemia brought about by net loss of hypotonic body fluids. Isotonic or hypotonic hypovolemia, manifest by large losses of solute and water, is defined simply as *hypovolemia*.[92,127] Table 89-1 lists the two principal forms of body water deficit and the physiology and particular circumstances associated with each.

BODY WATER, FLUID TURNOVER, AND FLUID REQUIREMENTS

Total body water (TBW) is the principal chemical component of the human body and represents 50% to 70% of body mass[8] for the average young adult male. It is regulated within ±0.2% to 0.5% of daily body mass.[3,40] Body water is required to sustain the cardiovascular and thermoregulatory systems and to support cellular homeostasis. Although "normal" hydration is achieved with a wide range of water intakes by sedentary and active people across the life span, homeostasis of body water can be difficult to maintain when challenged by strenuous physical work, heat stress, or illness. Despite population variability in age, body composition, and physical fitness, it is important to note that variability in TBW is accounted for almost entirely by body composition, since lean body mass contains about 73% water and fat body mass consists of about 10% water.[223] Trained athletes have relatively high TBW values by virtue of having high muscle mass and low body fat. In contrast, obese individuals with the same body mass as their lean counterparts have markedly smaller TBW volumes. Any absolute fluid deficit has more severe consequences for individuals with smaller TBW volume.

Daily water balance depends on the net difference between water gain and water loss.[100] Approximately 5% to 10% of TBW is turned over daily[171] through obligatory (nonexercise) fluid loss. Water gain occurs from consumption (liquids and food) and production (metabolic water), whereas water losses occur from respiratory, gastrointestinal (GI), renal, and sweat losses. Water lost by respiration is influenced by inspired air and pulmonary ventilation. Importantly, the volume of metabolic water produced during cellular metabolism (~0.13 g/kcal) is approximately equal to respiratory water losses (~0.12 g/kcal),[52,140] which results in water turnover with no net change in TBW. GI tract losses tend to be negligible (~100 to 200 mL/day); however, certain illnesses, such as diarrhea, can lead to loss of large amounts of fluid and electrolytes. The ability to vary urine output represents the primary means to regulate net body water balance across a broad range of fluid intake volumes and losses from other avenues. Water losses in urine approximate 1 to 2 L/day. However, urine output volumes may be larger or smaller depending on daily fluid consumption and activity.[100] Minimum outputs of approximately 20 mL/hr and maximal volumes of approximately 1000 mL/hr are possible.

Net body water balance (loss = gain) is regulated remarkably well day to day as a result of thirst and hunger, coupled with ad libitum access to food and beverages, which offset water losses.[100] Although acute mismatches between fluid gain and loss may result from illness, environmental exposure, exercise, or physical work, it is a reproducible phenomenon that intakes are generally adequate to offset net loss from day to day.[54] It is recognized, however, that after significant body water deficits, such as those associated with physical work or heat stress, many hours of rehydration and electrolyte consumption may be needed to reestablish body water balance.[208] For example, if hypohydrated by more than about 4% of total body mass, it may take more than 24 hours to fully rehydrate through water and electrolyte replacement.[5,147] Although daily strenuous activity in a hot environment can result in mild water balance deficits even with unlimited access to food and fluids,[12,208] adherence to recognized water intake guidance[12,35,189] minimizes water deficits, as determined by daily body mass stability.[40]

An adequate intake (AI) for daily total water is 3.7 L and 2.7 L for adult males and females, respectively.[100] Of these prescribed volumes, 20% of the AI for water is found in food eaten during meals and snacks and the remaining 80% (~3 L for males and 2.2 L for females) can come from beverages of all types. Daily water intake, however, varies greatly for individuals and between groups. For example, daily water needs of sedentary men are approximately 1.2 to 2.5 L[2,155] and increase to approximately 3.2 L if performing modest physical activity.[93,95] Compared to sedentary adults, active adults who live in a warm environment are reported to have daily water needs of approximately 6 L,[229] and highly active populations have been reported to have much higher values.[184] Data are limited regarding fluid needs for women, but typically they exhibit lower daily water turnover rates than their male counterparts. In general, fluid requirements vary based on an individual's body size, activity level, and the environment in which the person works, lives, or performs.

HYDRATION ASSESSMENT

Human hydration assessment is a key component for prevention and proper treatment of fluid and electrolyte imbalances.[47,127,164] When fluids are limited, illness strikes, or if there is exposure to extreme environments, cumulative fluid deficits can threaten homeostasis, health, and performance.[127,189] Health is also threatened by fluid deficits that can increase the risk of serious heat illness and by fluid surfeits that increase the risk of hyponatremia.[33,141] In many clinical and most sports and wilderness medicine situations, hypertonic hypovolemia occurs when there is net loss of hypotonic body fluids. However, substantial solute (electrolyte) can also be lost in situations involving heavy work where heat stress induces profuse sweating, during cold or high altitude exposure, and in numerous illnesses and disorders (e.g., gastroenteritis, hyperemesis, diuretic treatment, dialysis) producing isotonic or hypotonic hypovolemia.[47,127,189] Appreciation for the different types of body fluid losses that occur in response to illness, fluid restriction, or exposure to extreme environments is fundamental to proper hydration assessment[47,127] (see Table 89-1).

Most circumstances involving strenuous work in austere environments require formation and vaporization of sweat as a principal means of heat removal. Thus, when sweat losses result in body water deficit, there is a predictable rise in extracellular tonicity, which modulates renal function and urine composition in accordance with the body water deficit.[177] The basic principles

TABLE 89-1 Two Principal Forms of Body Water Deficit		
Form	**Physiology**	**Circumstances**
Hypertonic hypovolemia	Body water loss > solute loss Movement of water from ICF to ECF space Partial restoration of ECF space	Sweat loss (exercise, environmental heat stress, or fever) Inadequate fluid intake Osmotic diuresis caused by glucosuria
Isotonic hypovolemia	Isotonic loss of body water and solute No net movement of water among body fluid compartments Larger contraction of ECF space than equivalent hypertonic body water deficit	Cold or high-altitude exposure Gastrointestinal losses (diarrhea, vomiting) Diuretic therapy

ECF, Extracellular fluid; *ICF,* intracellular fluid.

of body fluid regulation provide the framework for using blood (osmolality, sodium, fluid regulatory hormones) and urine (osmolality, specific gravity, color) as principal body fluid hydration assessment measures. Similarly, because humans maintain a relatively stable TBW pool despite diverse factors (e.g., climate, activity, dietary solute load) that affect water requirements,[100] acute changes in body mass may be used to accurately measure dehydration across medical disciplines.[17,40,222] Physical signs and symptoms (dizziness, headache, tachycardia, capillary refill time, sunken eyes, skin turgor) only manifest when fluid losses are severe and become debilitating.[74,217] These findings are too nonspecific to be useful in athletic settings[134] because they share symptoms indicative of other ailments (e.g., acute mountain sickness), and their use in assessment could lead to an incorrect diagnosis.

All hydration assessment methods vary greatly in applicability because of limitations such as the necessary circumstances for reliable measurement, principles of operation, cost, and complexity.[100,164] Table 89-2 lists advantages and disadvantages of numerous approaches and should be consulted when deciding on the choice of hydration marker. Definitive hydration assessment requires monitoring changes in hydration state. Although change can provide good diagnostic accuracy, it requires a valid baseline, control over confounding variables, and serial measurements.[43,135] Large population heterogeneity in part explains why there are presently few hydration status markers that display potential for high nosologic sensitivity from a single, more practical measure.[43,120] Although Table 89-3 provides euhydration thresholds for the most useful hydration assessment measurements, these measures require considerable methodologic control, expense,

TABLE 89-2 Hydration Assessment Techniques Summary		
Technique	**Advantages**	**Disadvantages**
Complex Markers		
Total body water (dilution)	Accurate, reliable (gold standard)	Analytically complex, expensive, requires baseline
Plasma osmolality	Accurate, reliable (gold standard)	Analytically complex, expensive, invasive
Simple Markers		
Urine concentration	Easy, rapid, screening tool	Easily confounded, timing critical, frequency and color subjective
Body mass	Easy, rapid, screening tool	Confounded by changes in body composition
Other Markers		
Blood Plasma volume Plasma sodium Fluid balance hormones	No advantage over osmolality (except hyponatremia detection for plasma sodium)	Analytically complex, expensive, invasive, multiple confounders
Bioimpedance	Easy, rapid	Requires baseline, multiple confounders
Saliva	Easy, rapid	Highly variable, immature marker, multiple confounders
Physical signs	Easy, rapid	Too generalized, subjective
Tilt test (orthostatic challenge)	Rapid	Highly variable, insensitive, requires tilt table or ability to stand
Thirst	Positive symptomatology	Develops too late and is quenched too soon

From Cheuvront SN, Sawka MN: Hydration assessment of athltetes, *Sport Sci Exchange* 18:1, 2005.

TABLE 89-3 Biomarkers of Hydration Status			
Measure	**Practicality**	**Validity (Acute vs. Chronic Changes)**	**Euhydration Cutoff**
Total body weight	Low	Acute and chronic	<2%
Plasma osmolality	Medium	Acute and chronic	<290 mOsmol
Urine specific gravity	High	Chronic	<1.020 g/mL
Urine osmolality	High	Chronic	<700 mOsmol
Urine color	High	Acute and chronic	<4
*Body weight	High	Acute and chronic	<1% change

From Cheuvront SN, Sawka MN: Hydration assessment of athletes, *Sports Sci Exchange* 18:1, 2005.
*Potentially confounded by changes in body composition during very prolonged assessment periods. Fluid balance should be considered adequate when the combination of any two assessment outcomes is consistent with euhydration.

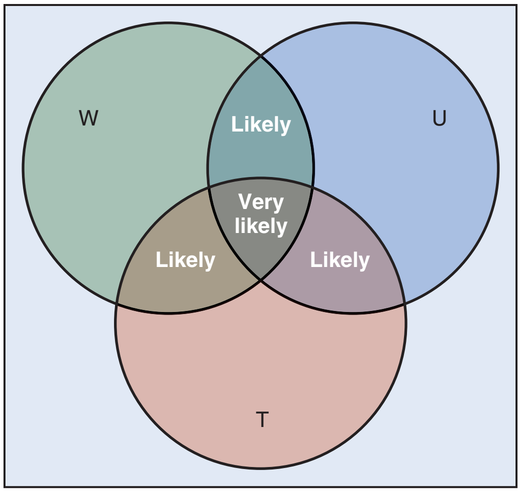


FIGURE 89-1 When two or more simple markers of dehydration are present, it is likely that a person is dehydrated. If all three markers are present, dehydration is very likely. *T*, Thirst; *U*, urine; *W*, weight. *(From Cheuvront SN, Sawka MN: Hydration assessment of athletes,* Sport Sci Exchange *18(1):1-5, 2005.)*

and analytical expertise and may not be practical, day-to-day hydration monitoring of athletic sojourners.

There is no scientific consensus on how best to assess hydration status in a field setting. In most field settings, however, additive use of first morning body mass measurements in combination with some measure of first morning urine concentration and gross thirst perception provides a simple and inexpensive way to dichotomize euhydration from gross dehydration resulting from sweat loss and poor fluid intake. This approach is represented using a Venn diagram decision tool[47] (Figure 89-1). It combines three of the simplest markers of hydration: body mass (weight), urine, and thirst (WUT). No marker by itself provides enough evidence of dehydration, but the combination of any two simple self-assessment markers can indicate when dehydration is likely. The presence of all three makes dehydration very likely. The balance between science and simplicity in the choice of these measures for field hydration assessment is outlined next.

Urine Concentration

Urinalysis is a frequently used clinical measure to distinguish between normal and pathologic conditions. Urinary markers for dehydration include urine volume, urine specific gravity (USG), urine osmolality (U_{Osm}), and urine color (U_{Col}). Urine is a solution of water and various other substances. Thus, its concentration varies inversely with volume, which is reduced with dehydration. Urine output generally approximates 1 to 2 L/day but can be increased by an order of magnitude when consuming large volumes of fluid.[100] This large capacity to vary urine output represents the primary avenue to regulate net body water balance across a broad range of fluid intake volumes and losses from other avenues. Whereas quantification of urine volume is impractical on a daily basis, quantitative (USG, U_{Osm}) or qualitative (U_{Col}) assessment of its concentration is much simpler. As a screening tool to dichotomize euhydration from dehydration, urine concentration (USG, U_{Osm}, U_{Col}) is a reliable assessment technique[12,20,207] with reasonably definable thresholds.

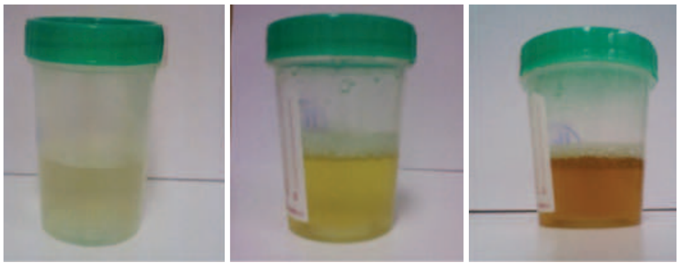
In contrast, urine measures often correlate poorly with "gold standards" such as plasma osmolality and fail to reliably track documented changes in body mass corresponding to acute dehydration and rehydration.[114,170] When acute fluxes in body water occur, changes in plasma osmolality that stimulate endocrine regulation of renal water and electrolyte reabsorption are delayed at the site of the kidney.[170] It is also likely that drink composition influences this response. Drinking large volumes of hypotonic fluids results in copious urine production long before euhydration is achieved.[211] Urine concentration measurements can be confounded by diet, which may explain large cross-cultural differences in urine osmolality.[128] Using the first morning void following an overnight fast minimizes confounding influences and maximizes measurement reliability.[12,207] Urinalysis of specific gravity, osmolality, and color can therefore be used to assess and distinguish euhydration from dehydration as long as the first morning void is used.

Inexpensive and easy-to-use commercial instruments are available for assessing USG and conductivity (osmolality equivalent);[20,207] a urine color chart is also available.[12] The simplest of these, color, is included in the Venn diagram. Under ideal circumstances, the urine (first morning) should be in a clean, clear vial or cup and the color assessed against a white background. Urine color can be compared against a urine color chart or assessed relative to the degree of darkness. Paler color urine (similar to lemonade) indicates adequate hydration; the darker yellow/brown the urine color (similar to apple juice), the greater the degree of dehydration. Assessing urine that has been diluted in toilet water or while in midflow may alter urine color. When in less-than-ideal conditions, urine in a urinal is less dilute. In the field, snow can provide a suitable background. Figure 89-2 presents example photos of urine color with corresponding numeric color,[12] USG, and urine osmolality values.

Body Mass

Body mass is a measurement often used in both laboratory and field environments for rapid assessment of an athlete's hydration changes. Changes in acute hydration are calculated as the difference between preexercise and postexercise body mass. The level of dehydration is best expressed as a percentage of starting body mass rather than as a percentage of TBW, since the latter ranges widely.[100] Using this technique implies that 1 g of lost mass is equivalent to 1 mL of lost water. As long as TBW loss is of interest, failure to account for carbon exchange represents the only small error (~10%) in this assumption.[44] Indeed, acute body mass changes (water) are frequently the standard against which resolution of other hydration assessment parameters are compared in the laboratory. In fact, if proper controls are made, body mass changes can provide a more sensitive estimate of acute TBW changes than do repeat measurements by dilution methods.[94]

There is also evidence that body mass is a sufficiently stable physiologic parameter for potential daily fluid balance monitoring, even over longer periods (1 to 2 weeks) that include strenuous exercise and acute fluid flux.[40,119] Young, healthy men undergoing daily exercise-heat stress maintain a stable first morning body mass as long as they make a conscious effort to replace exercise sweat losses.[40] Similarly, ad libitum intake of food and fluid will balance sweat losses incurred with regular exercise, resulting in a stable daily body mass.[119] Over longer time frames, changes in body composition (fat and lean mass) that occur with chronic energy imbalance are also reflected grossly as changes in body mass, thus limiting this technique. Clearly, if first morning body mass stability is used to monitor changes in hydration, it should be used in combination with another hydration assessment technique (e.g., urine concentration) to dissociate gross tissue losses from water losses if long-term hydration status is of interest.



USG = 1.004	USG = 1.016	USG = 1.035
Osmolality = 105	Osmolality = 522	Osmolality = 1252
Color = 2	Color = 4	Color = 7

FIGURE 89-2 Samples of first morning urine with urine specific gravity (USG), associated osmolality (mmol/kg), and color values.

Thirst

Although genuine thirst develops only after dehydration is present and is alleviated before euhydration is achieved,[92,100] thirst is one of the few reliable subjective feelings reported by humans in response to fluid restriction.[209] Plasma osmolality near 295 mmol/kg will produce an arginine vasopressin (AVP) level of approximately 5 pg/mL, which results in maximal urine concentrating capacity. The average plasma osmolality at which thirst is stimulated above baseline is also approximately 295 mmol/kg.[177] If we assume that a normal resting plasma osmolality of 285 mmol/kg becomes concentrated to 295 mmol/kg, the ratio 285/295 multiplied by a normal 42 L TBW gives an estimated 40.5 L, or 1.5 L TBW deficit, which is 2.1% dehydration for a 70-kg (154-lb) person. This is consistent with general observations of thirst insensitivity below a "threshold" fluid deficit (that thirst develops late). However, it is important to recognize that there is substantial individual variability in the plasma osmolality "set point" and the osmotic thresholds for AVP release and thirst perception. For example, Robertson and colleagues[178] report as much as a 10-fold difference between individuals in the slope of the line relating AVP to plasma osmolality. Clearly, thirst is a qualitative tool for hydration assessment, but positive thirst symptoms coupled with at least one additional Venn diagram marker suggests an increasing likelihood of dehydration.

Although plasma osmolality and TBW measurements are the hydration assessment measures for large-scale fluid needs,[100] no consensus exists for using one approach over another in a field or athletic setting. In most circumstances, using first morning body mass combined with some measure of first morning urine concentration (USG, urine osmolality and/or color) offers simple assessment and allows ample sensitivity (low false-negative) for detecting meaningful deviations in fluid balance (>2% body mass). This approach is represented using a Venn diagram decision tool[47] (see Figure 89-2). Again, it combines three of the simplest markers of hydration (WUT); no single marker provides enough evidence of dehydration, but two markers mean dehydration is likely, and all three make dehydration very likely. In a field setting, where a scale may not be available for body weight measures, the combination of first morning urine color and thirst may provide reasonable indication of the presence of dehydration.

SWEAT AND SWEAT PREDICTION

Muscular contractions involved with activity/exercise produce metabolic heat that is transferred from the active muscles to blood and then the body core. Subsequent body temperature elevations elicit heat loss responses of increased skin blood flow and increased sweat secretion so that heat can be dissipated to the environment.[198,200] Heat exchange between skin and environment is governed by biophysical properties dictated by surrounding temperature, humidity and air motion, sky and ground radiation, and clothing.[77] When ambient temperature is greater than or equal to skin temperature, evaporative heat loss accounts for all body cooling. Eccrine sweat glands secrete fluid onto the skin surface, permitting evaporative cooling when liquid is converted to water vapor. Sweat glands respond to thermal stress primarily through sympathetic cholinergic stimulation, with catecholamines having a smaller role in the sweat response.[200]

The rate of sweat evaporation depends on air movement and the water vapor pressure gradient between the skin and environment, so in still or moist air, sweat does not evaporate readily and collects on skin. Sweat that drips from the body or clothing provides no cooling benefit. If secreted sweat drips from the body and is not evaporated, higher sweating will be needed to achieve evaporative cooling requirements.[41,198] Conversely, increased air motion (wind, movement velocity) facilitates evaporation and minimizes wasted (dripping) sweat.[41]

Sweat losses can vary widely and depend on amount and intensity of physical activity and environmental conditions.[85,205] In addition, a number of factors can alter sweat rates and ultimately fluid needs. Heat acclimatization results in higher and more sustained sweating rates. Similarly, aerobic exercise training has a modest effect on enhancing sweating rate responses.[198,200] Wearing heavy or impermeable clothing or protective equipment can increase heat stress[133] and sweat rate but can limit evaporation of sweat and ultimately heat loss. Likewise, wearing heavy or impermeable clothing while exercising in cold weather can elicit unexpectedly high sweat rates,[73] which can increase fluid needs. Conversely, factors such as wet skin (e.g., from high humidity) and dehydration can act to suppress the sweating rate response.[198]

Sweat is hypotonic relative to plasma and typically half of plasma osmolality (~145 mmol/kg vs. 290 mmol/kg, respectively).[53] Losses of electrolytes in sweat depend on total sweat losses (over a given period) and sweat electrolyte concentrations. Typical sweat sodium concentration averages approximately 35 mEq/L (range, 10 to 70 mEq /L) and varies depending on genetic predisposition, diet, sweating rate, and heat acclimatization state.[6,26,54,75,210,224] Sweat concentration of potassium averages 5 mEq/L (range, 3 to 15 mEq /L); calcium, 1 mEq/L (range, 0.3 to 2 mEq/L); magnesium, 0.8 mEq /L (range, 0.2 to 1.5 mEq/L); and chloride, 30 mEq/L (range, 5 to 60 mEq/L).[26] Gender, maturation, and aging appear to have no discernible effect on sweat electrolyte concentrations,[138,148] although dehydration can increase sweat concentrations of sodium and chloride.[146] Sweat glands reabsorb sodium and chloride by active transport, but ability to reabsorb these electrolytes does not increase proportionally with the sweating rate. As a result, sodium and chloride concentrations of sweat increase as a function of sweating rate.[6,54] Heat acclimatization improves ability to reabsorb sodium and chloride; thus, heat-acclimatized individuals usually have lower sweat sodium concentrations (e.g., >50% reduction) for any given sweating rate.[6]

Sweat rates differ among various work activities and individuals.[198] Specifics on determining individual sweat rate and fluid requirements are covered later in the fluid replacement recommendations section. Figure 89-3 depicts generalized modeling approximations for daily sweating rates as a function of daily metabolic rate (activity level) and air temperature.[100] Metabolic rate and air temperature have marked effects on water needs. In addition to air temperature, environmental factors (e.g., relative humidity, air motion, solar load, protective clothing) influence heat strain and water needs.

Central to water consumption planning is the ability to predict water needs accurately in a variety of environmental conditions, with varying activity levels, loads, clothing ensembles, and personal protective equipment. Therefore, accurate water planning tools are helpful to minimize the logistical burden of water

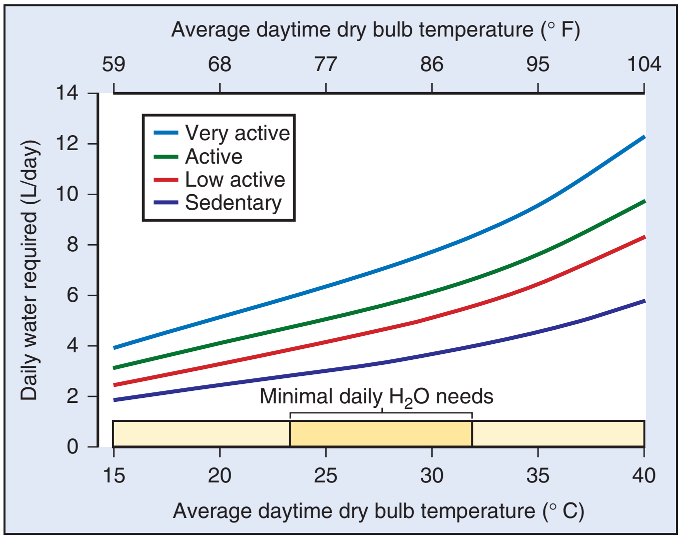


FIGURE 89-3 Generalized modeling approximations for daily sweating rates as a function of daily metabolic rate (activity level) and air temperature. *(From Institute of Medicine:* Dietary reference intakes for water, potassium, sodium, chloride, and sulfate, *Washington, DC, 2005, The National Academies Press.)*

transport while sustaining hydration. To calculate water needs, knowledge of sweat losses is critical, particularly for active populations and when exposed to heat stress.

The Shapiro equation has been used extensively to estimate sweating rates and calculate daily water needs.[205] This model calculates sweat rate (M_{sw}, expressed as $g \bullet m^{-2} \bullet h^{-1}$) and thus fluid needs as:

$$M_{sw} = 27.9 \times E_{req} \times (E_{max})^{-0.455}$$

where E_{req} is required evaporative cooling (in W/m^2), and E_{max} is maximal evaporative cooling capacity. E_{req} is calculated from metabolic heat production, clothing heat transfer characteristics, and the environment. E_{max} is derived from vapor transfer properties of the clothing worn and the environment. However, this equation has been shown to have limitations,[46] in that it often overpredicts fluids needs when exercise is longer than 2 hours, when improved uniforms and body armor are worn, and when high-intensity activity takes place in lower air temperatures. To address the need for improved prediction accuracy, Gonzalez and colleagues[84,87] developed and validated an updated algorithm (piece-wise [PW] model) that better predicts observed sweat losses (i.e., drinking water needs) in cool, temperate, warm-hot, high-altitude, and transient solar load environments. This new algorithm is based on metabolic demands, clothing, biophysical parameters, and environmental conditions, as with the legacy equation,[205] but expands the range of relevant environments, metabolic rates, and mission duration and includes modern clothing ensembles (e.g., body armor) potentially to provide estimates of water needs in both training and operational scenarios. Figure 89-4, from Jay and Webb,[101] depicts the adjustment to the sweat loss values yielded by the corrected Shapiro equation derived by Gonzalez and co-workers.[85] However, use of this updated algorithm is limited to individuals with extensive training in thermal biophysics and ultimately requires numerous measurement inputs.

The U.S. Army Research Institute of Environmental Medicine (ARIEM) recently developed and validated the equation just discussed that accurately predicts sweat losses (i.e., drinking water needs).[84,87] However, use of this newly developed equation was limited to experts trained in the art to produce tabled doctrine.[188] The military user community requested greater simplicity and flexibility for predicting water needs in real time. Thus, the goal of the project was to incorporate the newly developed water prediction equation into a "smart phone" application that has been termed the Soldier Water Estimation Tool (SWET) (Figure 89-5). This smart phone application has reduced the number of inputs by the user from about 25 to five, which pertain to activity level, clothing worn, temperature, relative humidity, and cloud cover. The application provides the user with the amount of water required for the specified conditions in liters per hour. Additionally, a "Mission Planner" tab adds the option to include the total number of people and total time of the mission. The Mission Planner then calculates and reports total water needs in liters, 1-qt canteens, 2-qt canteens, and gallons.

Future work in this area may be required to increase the applicability of sweat rate prediction equations, in particular under conditions with variable solar loads, in lower air temperatures of approximately 15°C (59°F), with clothing having low water vapor permeability, or with specialized equipment (e.g., American football), and with individuals possessing greater body mass and surface areas.[101]

PHYSIOLOGIC CONSEQUENCES OF DEHYDRATION

By virtue of tonicity and volume changes, dehydration has negative consequences on thermoregulation and performance. Dehydration is caused by voluntary fluid restriction, insufficient rehydration after daily activity, or physical activity/exercise in the form of thermoregulatory sweating. The most common form of dehydration during exercise in the heat is a water deficit without proportionate sodium chloride loss.[191] Individuals often start an exercise task with normal TBW and dehydrate over an extended duration. In some situations, however, an individual might initiate activity/exercise with a body water deficit because the interval between exercise sessions is inadequate or chronic fluid intake is insufficient to replace losses. During multiple-day treks or expeditions where individuals take part in prolonged daily sessions of activity/exercise, possibly in hot conditions, a fluid

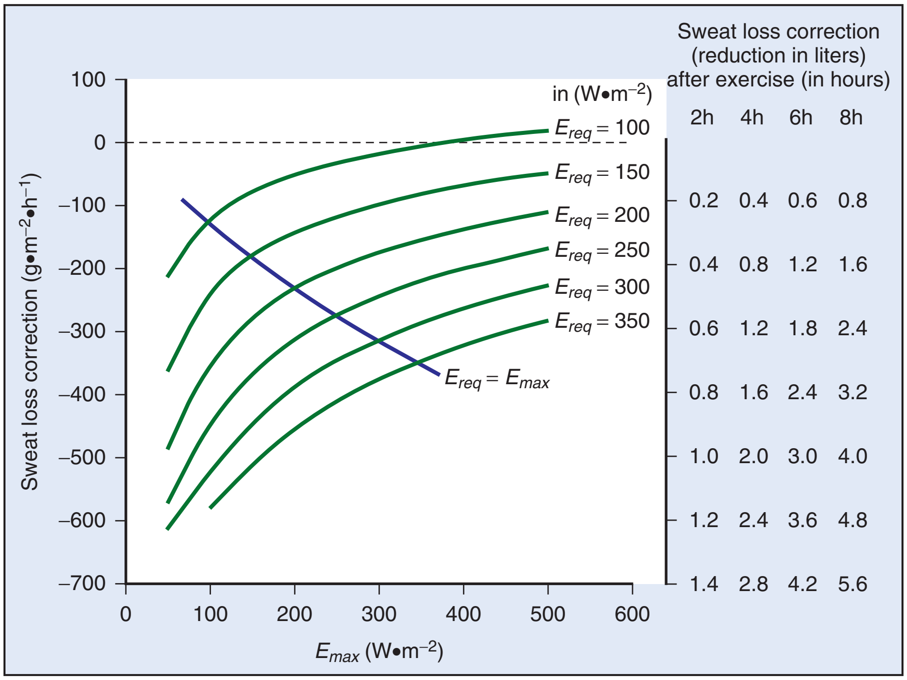


FIGURE 89-4 Sweat loss correction, where E_{req} is the amount of evaporation required to achieve heat balance, and E_{max} is the maximum rate of evaporation possible. The range of validity: E_{req} >50 W/m^2 and <360 W/m^2; E_{max} >20 W/m^2 and <525 W/m^2. Calculations for reference male with body surface area of 1.8 m^2. *(From Jay O, Webb P. Improving the prediction of sweat losses during exercise,* J Appl Physiol *107:375, 2009.)*

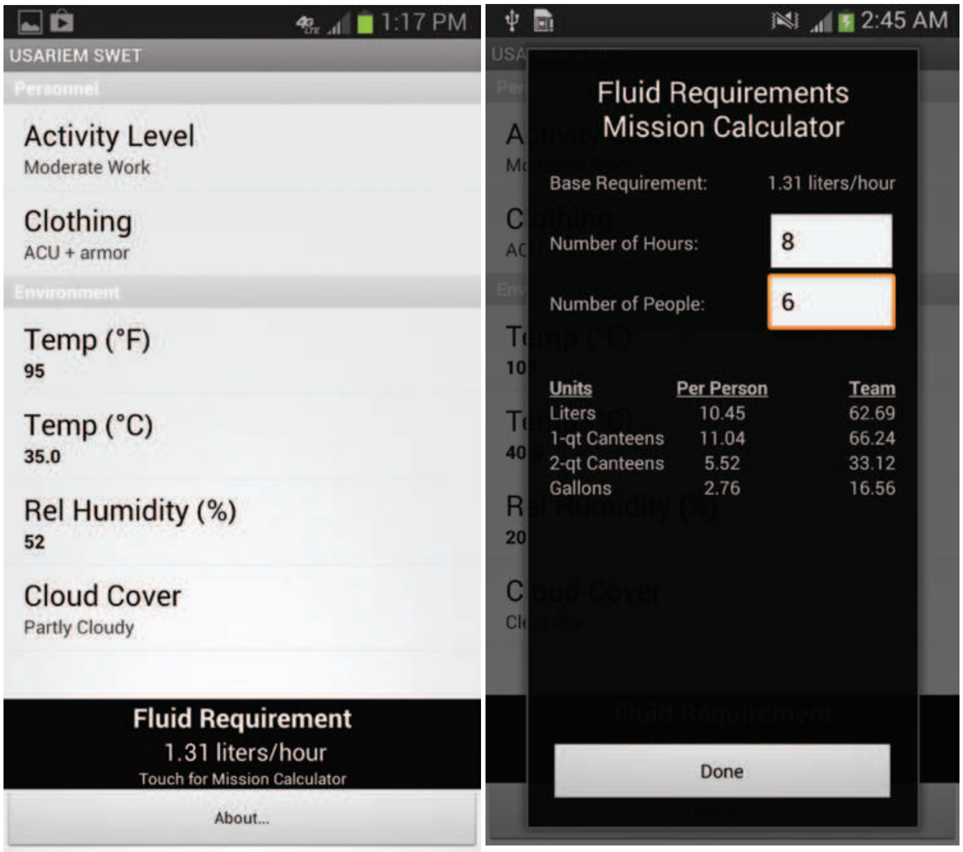


FIGURE 89-5 Soldier Water Estimation Tool (SWET). Main screen and Mission Planner screen.

deficit may be carried from one activity/exercise session to the next or from one day to the next.[83] In addition, individuals medicated with diuretics may be dehydrated before initiating exercise. Use of medications, such as acetazolamide taken prophylactically or while at altitude for acute mountain sickness, can have such an effect (and may increase risk for hyponatremia). This drug causes the kidneys to excrete bicarbonate, which acidifies the blood, increasing ventilation and blood oxygen content; however, it also increases fluid and electrolyte losses. If large sodium chloride deficits occur during exercise, extracellular fluid volume contracts and causes "salt depletion dehydration."

Dehydration increases physiologic strain, as measured by core temperature, heart rate, and perceived exertion responses during exercise-heat stress.[191] The greater the body water deficit, the greater is the increase in physiologic strain for a given exercise task.[4,142,143,201] Dehydration can augment core temperature elevations during exercise in temperate environments[30,154,195] as well as in hot environments.[50,193,203] The typical reported core temperature augmentation with dehydration is an increase of 0.1 to 0.2°C with each 1% of dehydration.[192] The greater heat storage associated with dehydration is associated with a proportionate decrease in heat loss. Thus, decreased sweating rate (evaporative heat loss) as well as decreased cutaneous blood flow (dry heat loss) are responsible for greater heat storage observed during exercise when hypohydrated.[69,70,151] The degree to which each of these mechanisms dissipates heat from the body depends on environmental conditions. However, both avenues of heat loss are unfavorably altered by dehydration.

When a person is dehydrated, the sweating rate is lower for any given core temperature, and heat loss through evaporation is reduced. In addition, as dehydration increases, there is reduction in total body sweating rate at a given core temperature during exercise-heat stress.[201] During submaximal exercise with little or no thermal strain, dehydration results in increased heart rate and decreased stroke volume, typically with no change in cardiac output relative to euhydration levels.[186,214] The addition of heat stress in combination with dehydration during exercise results in decreased blood volume, reducing central venous pressure (CVP) and cardiac output,[111,147] and creates competition between the central and peripheral circulation for limited blood volume.[150,183] As body temperature increases during exercise, cutaneous vasodilation occurs and superficial veins become more compliant, decreasing venous resistance and pressure.[183] Effects of reduced blood volume (from dehydration) and increased blood displacement to cutaneous vascular beds (from heat stress) are decreased CVP and venous return and, ultimately, cardiac output below euhydration values.[152,194]

ENVIRONMENTAL HEAT STRESS, DEHYDRATION, AND PERFORMANCE

Physiologic factors that contribute to dehydration-mediated aerobic exercise performance decrements include increased body core temperature, increased cardiovascular strain, increased glycogen utilization, and perhaps altered central nervous system (CNS) function.[159,191,200] Although each factor is unique, evidence suggests that they interact to contribute in concert, rather than in isolation, to degrade aerobic exercise performance.[40,191,200] The relative contribution of each factor may differ depending on the specific activity, environmental conditions, heat acclimatization status, and athletic prowess, but elevated hyperthermia probably acts to accentuate the performance decrement.

In a field or wilderness setting, individuals may perform activities that require anaerobic power or muscular strength. However, the impact of dehydration may not be consistent for each type of activity. The literature in this area can be difficult to interpret because laboratory performance studies are often conducted with small numbers of participants (≤10 per study) and may be statistically underpowered to detect small but important effects. A recent comprehensive review of the dehydration/performance literature used a novel approach to assess endurance and strength or power exercise dehydration studies.[45] This less conservative

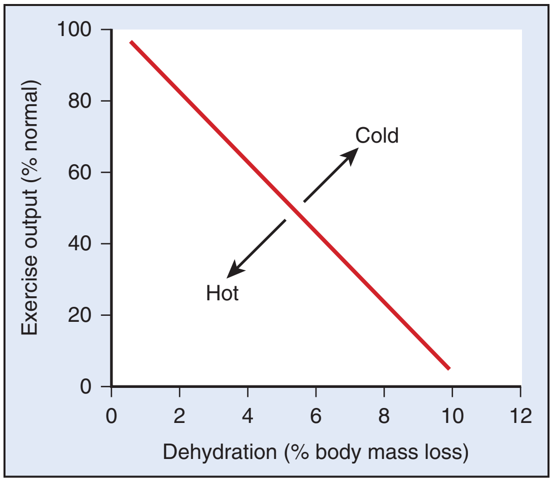


FIGURE 89-6 Percent decrement in exercise performance relative to percent dehydration (body mass loss). *(Redrawn from Adolph EF:* Physiology of man in the desert, *New York, 1947, Interscience.)*

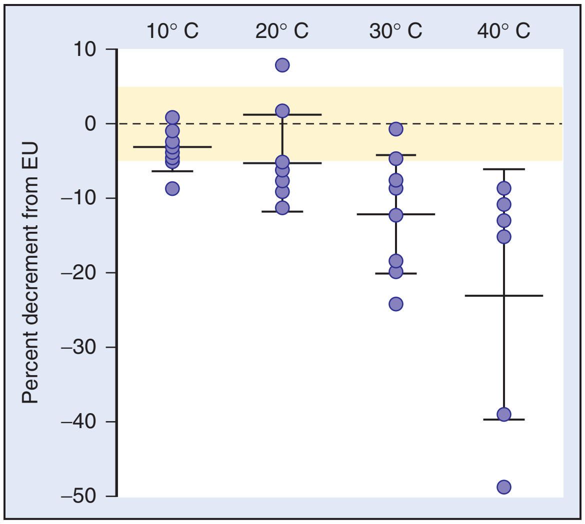


FIGURE 89-7 Percent decrement in total work performance relative to euhydration (*EU*) trial for all participants (n = 32) in 10°, 20°, 30°, and 40°C (50°, 68°, 86°, and 104°F) environments. Data are means; bars are 95% confidence interval. Shaded area represents coefficient of variation (±5%) based on performance variability measured during 2-week familiarization sessions.

approach counted the number of studies reporting a reduction in performance independent of p value with the assumption that the results should be 50% if caused solely by chance. The results were 53/60 negative performance observations (88%) for endurance exercise of 2% or greater body mass loss. For strength and power, 177/276 negative observations (67%) were observed, which coincides with findings that strength and power are negatively affected by dehydration, although to a small degree.[104]

Dehydration greater than 2% of body mass has been shown to degrade aerobic exercise performance in temperate-warm-hot environments.[36,42] As the level of dehydration increases, aerobic exercise performance is degraded proportionately.[100] The critical water deficit (>2% body mass for most individuals) and magnitude of performance decrement are likely related to environmental temperature, exercise task, and the individual's unique biologic characteristics (e.g., tolerance to dehydration). Therefore, some individuals are more or less tolerant to dehydration. Adolph and Dill[4] were among the first to document that during long-duration exercise in temperate or slightly warm environments, thermoregulatory sweating leads to progressive dehydration and results in lower exercise output (Figure 89-6). They derived this figure from limited exercise capability data and heart rate responses from a variety of exercise, heat stress, and dehydration conditions.

Exercise tasks that primarily require aerobic metabolism and that are prolonged are more adversely influenced by dehydration than are exercise tasks that require anaerobic metabolism or muscular strength and power.[196] The greater the level of dehydration, the greater is the magnitude of cardiovascular and thermoregulatory strain.[88] It has previously been demonstrated that high levels of aerobic fitness and acclimatization status provide thermoregulatory advantage. However, dehydration seems to cancel this protective effect during exercise-heat stress.[29,137,197] A comprehensive review of a number of studies that investigated the impact of dehydration on physical exercise capacity and maximal aerobic power found that in the majority of studies, exercise capacity decreased with levels of dehydration of as little as 1% to 2% body mass, although maximal aerobic power was not altered.[187] In addition, reduction in exercise capacity when dehydrated was further accentuated by heat stress.[58,158,169] In temperate environments, body water deficits of less than 2% body mass did not have a significant impact on maximal aerobic power. In a hot environment, however, a small to moderate water deficit (≥2% body mass) resulted in a large decline in maximal aerobic power.[58,158] A review of studies that observed the effects of progressive dehydration (>2% body mass) specifically on aerobic exercise performance found that in environments above 30°C (86°F), aerobic exercise performance was decreased by 7% to 60%.[42] It also appears that the magnitude of the effect increases as exercise extends beyond 90 minutes. Overall, this review found that the impact of dehydration on prolonged work efforts is magnified by hot environments and probably worsens as the level of dehydration increases.

Few investigations have studied the impact of dehydration on aerobic performance across a range of environmental temperatures. Cheuvront and co-workers[39] observed 8% reduction in total work during a cycling time trial when dehydrated by 2% or more of body mass in a 20° C (68°F) environment. However, in a 2°C (35.6°F) environment, no effect of dehydration was observed. Kenefick and associates[108] reported decrements in aerobic performance (15-minute cycling time trial) of −3%, −5%, −12%, and −23% in 10°C (50°F), 20°C (68°F), 30°C (86°F), and 40°C (104°F) environments, respectively, when volunteers were dehydrated by 2% or more of body mass. Figure 89-7 depicts the change in performance relative to euhydrated trials and relative to the coefficient of variation (test variability; shaded area) of the cycling test itself. Mean values that lie inside the shaded area are considered to be within the "noise" of the test and those that lie outside are considered to be meaningful. Based on the findings, it would appear that the temperature cusp where dehydration of 4% of body mass altered aerobic exercise performance occurred at 20°C (68°F). It is important to note that these reported results are the minimal decrements in performance that could be expected. Greater decrements could be expected during more prolonged work or with greater levels of dehydration (Figure 89-7).

Table 89-4 depicts the decrement in aerobic time trial (<60 minutes) performance across a continuum of environmental

TABLE 89-4 Percent Decrement in Aerobic Exercise Performance (Compared to Temperate) Across a Continuum of Environmental Temperatures and at ~3000 m With and Without Dehydration (≥2% Body Mass)

Environment	Euhydrated	Dehydrated
Cold (2°-10°C; 36-50°F)	—	~3%[39,108]
Temperate (~20°C; 68°F)	—	~5% to 7%[39,108]
Warm (~30°C; 86°F)	~8%[221]	~12%[108]
Hot (~40°C; 104°F)	~17%[65]	~23%[108]
Altitude (~3000 m; 9843 ft)	~11% to 15%[37,76]	~33%[37]

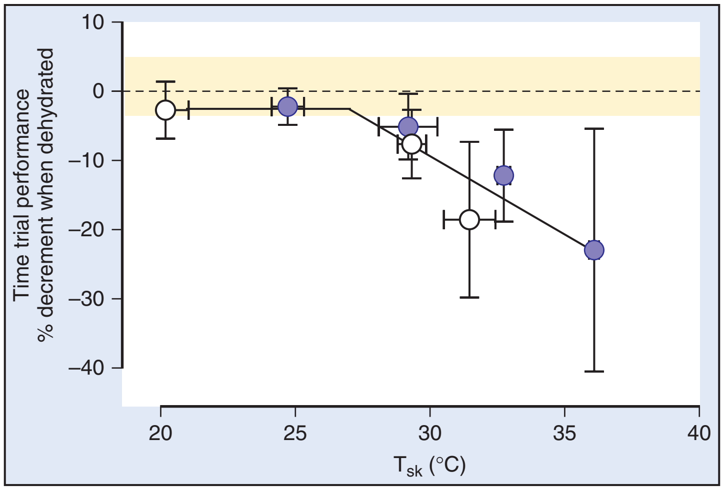


FIGURE 89-8 Percentage decrement in submaximal aerobic performance from euhydration as a function of skin temperature (T_{sk}) when dehydrated by 3% to 4% of body mass. Data are means (error bars are 95% confidence intervals) compiled from three studies,[39] employing similar experimental procedures and time trial (TI) performance tests. Filled circles represent 15-minute tests; open circles represent 30-minute tests. At a T_{sk} intercept of about 27°C (80.6°F), the percentage decrement in aerobic exercise performance declines linearly by about 1.3% for each 1°C rise in T_{sk}, similar to the single study of Kenefick et al. *(Data from Castellani JW et al: Effect of hypohydration and altitude exposure on aerobic exercise performance and acute mountain sickness,* J Appl Physiol *109(6):1792-1800, 2010; Cheuvront SN et al: Hypohydration impairs endurance exercise performance in temperate but not cold air,* J Appl Physiol *99:1972-1976, 2005; and Kenefick RW et al: Skin temperature modifies the impact of hypohydration on aerobic performance,* J Appl Physiol *109(1):79-86, 2010.)*

temperatures and at an altitude of about 3000 m (9843 feet) with and without hypohydration (>2% body mass loss). Without any degree of dehydration, certain environments (warm-hot, altitude) have a negative impact on aerobic exercise performance. It is important to note that in combination with these environments, dehydration further degrades aerobic exercise performance, and that with longer-duration exercise (>60 minutes), greater degradations in performance can be expected. However, by maintaining a well-hydrated state, the contribution of dehydration to degradation in exercise performance can be alleviated.

One explanation for the impact of dehydration on exercise performance is that during exercise in the heat, sweat output often can exceed water intake and lead to overall loss of body water and reductions in plasma and blood volume. The amount of body fluid lost through thermoregulatory sweating can vary widely but usually is in the range of 0.5 to 1.5 L/hr. The upper limits for fluid replacement during exercise-heat stress are set by the maximal gastric emptying rates, which have been reported to be 1.0 to 1.5 L/hr for the average adult,[139,149] but are reduced by exercise-heat stress and dehydration.[33] Although gastric emptying may or may not be sufficient to maintain hydration (depending on sweating rate), people tend to drink only after thirst develops. As presented earlier, the sensation of thirst appears at about 295 mmol/kg,[177] or about 2% of body mass loss. Thus, a significant amount of fluid loss occurs before the sensation of thirst drives fluid intake. During activity, if fluid intake occurs after signaled by thirst sensation and is less than fluid loss through thermoregulatory sweating, the outcome is progressive dehydration.

Thus, during exercise in the heat with high sweat rates, there is the simultaneous problem of reduced plasma volume from dehydration while skin blood flow requirements are elevated. This dual perturbation of reduced plasma volume and elevated skin blood flow secondary to sweating is likely an important physiologic mechanism (via the cardiovascular system) contributing to impaired aerobic performance. As a result of blood pooling in the skin and reduction in plasma volume, cardiac filling is reduced, and larger fractional utilization of oxygen is required at any given workload.[14] Ultimately, these responses have a negative impact on exercise/work performance, particularly in warm-hot environments.

Figure 89-8 plots the impact of dehydration on submaximal aerobic performance from several hypohydration studies,[39] complied by Sawka and associates.[190] These studies employed similar procedures over a broad range of skin temperatures (T_{sk}) from 20° to 36°C (68° to 96.8°F). Segmented regression was used to approximate the statistical T_{sk} threshold for performance impairment using individual study data points ($n = 53$ paired observations). The threshold that best minimized the residual sums of squares was shown as 27.3°C. Warmer skin accentuated performance impairment by about 1.5% for each additional 1°C rise in T_{sk}. Therefore, as ambient conditions become warmer and elevate cutaneous vasodilation, the adverse impact of dehydration is clearly demonstrated.[190]

The negative impact of dehydration on work performance can increase risk in a field or wilderness setting. Dehydration, in combination with heat stress, reduces maximal oxygen uptake, increases relative effort, and reduces work output. When dehydrated, an individual will not be able to trek as far or as fast compared to when the person is euhydrated. For example, when on a hike, dehydration can increase the duration of time required to complete the hike beyond what is to be expected for a given distance and terrain, especially in warm-hot environments. In the scenario of a day hike or a hike to a destination, this increases the time to complete the hike and could result in a hiker being caught outdoors in adverse weather or overnight unprepared.

DEHYDRATION AND WORK PRODUCTIVITY

As previously discussed, during physical work in the heat, sweat output often exceeds water intake, which leads to body water losses. Bishop and colleagues[23] observed that, in simulated industrial work conditions, encapsulated protective clothing produced sweating rates up to 2.25 L/hr. Likewise, wearing protective equipment such as full or half face masks can make fluid consumption more difficult and further contribute to dehydration in the workplace. Firefighters wear heavy protective clothing and are exposed to intense heat. Rossi[182] reported that firefighters wearing protective clothing and equipment while performing simulated work tasks in the heat can have sweat rates up to 2.1 L/hr. Also, workers often not only become dehydrated on the job, but may start the workday with a fluid deficit. Brake and co-workers[25] observed fluid losses and hydration status of miners under thermal stress while working extended shifts (12 hours). By measuring urine specific gravity at the start of a work shift, they observed that 60% of the miners reported to work dehydrated, and that their hydration status did not improve during the shift.

While many studies have observed the effect of dehydration on physical work capacity, few studies have observed dehydration's impact on manual labor productivity. Wasterlund and colleagues[227] studied forest workers in a 15°C (59°F) environment in two scenarios: (1) participants consumed fluid sufficient to maintain a normal hydration state and (2) participants consumed limited fluid, which resulted in 0.7-kg body mass loss (>1% dehydration). The measure of productivity was the amount of time to stack and debark 2.4 cubic meters of pulpwood. When workers were dehydrated, productivity of stacking and debarking pulpwood was reduced by 12%.

DEHYDRATION AND COGNITIVE PERFORMANCE

Cognitive (mental) performance, which is important when concentration, skilled tasks, and tactical issues are involved, has been shown to be degraded by dehydration and hyperthermia in some studies.[96,179] The evidence is stronger for a negative effect of hyperthermia than for mild dehydration on degrading cognitive/mental performance,[49] but the two are closely linked when performing exercise in warm-hot weather. The relative hyperthermia associated with dehydration could diminish psychological drive[28] or perhaps alter CNS function independent of temperature. Adolph and Dill[5] reported that dehydrated subjects fainted more quickly when faced with a change in body posture (orthostatic challenge test). Likewise, Carter and colleagues reported that individuals going from a seated to a standing posture who were dehydrated by more than 2% of body mass from heat exposure exhibited significant reduction in cerebral blood flow velocity and possibly cerebral oxygen availability. Intracranial volume is altered in response to dehydration,[63] although the exact functional consequence of this is unknown. However, despite these orthostatic and cerebrovascular changes, the plausibility of dehydration altering cognition on physiologic grounds (osmolality, volume) appears small.

Some studies reported that as little as 2% dehydration has been associated with impaired visual motor tracking, short-term memory, attention, and arithmetic efficiency,[90] as well as greater tiredness, reduced alertness, and higher levels of perceived effort and concentration. In contrast, other studies have reported no effect on cognitive function with 4% dehydration, even when combined with heat exposure.[66] Equivocal findings in this area could be caused by study differences, such as dehydration methods, or the residual effects of dehydration, which include fatigue or hyperthermia. In fact, reviews of the dehydration and cognition literature suggest that future research in this area should focus on the possible confounding effects of methods used to achieve dehydration (e.g., exercise heat exposure).[91,121] Differences in the choice of cognitive test(s) or lack of test familiarity may also be blamed.[22] It should be noted that studies reporting significant alterations in cognition with dehydration as low as 1% to 2% of body mass[10,48,79,90] did not establish a well-hydrated baseline.

Another important point not often considered is absence of a genuine physiologic mechanism by which dehydration might impair cognitive function. In general, dehydration by less than 2% body mass would shrink the intravascular space by less than 200 mL and raise plasma osmolality by less than 5 mmol/kg. Much larger changes in plasma osmolality are required to increase blood-brain barrier permeability,[172] which would not be possible with the levels of dehydration achieved in most of the dehydration and cognition literature. Neural activity is closely related to cerebral blood flow (CBF),[81] but CBF is maintained at rest after intracellular[31] and extracellular[181] dehydration of 2% to 3% of body mass. Dehydration can reduce CBF transiently when an orthostatic challenge is imposed,[31,181] but this effect relates only to the risk for syncopal episodes in low-tolerance individuals.[175] As previously discussed, the measured effects of mild dehydration on brain volume are also inconsistent.

It is generally acknowledged that dehydration has a negative effect on mood state and can produce unpleasant symptoms such as dry mouth, thirst, and headache. Many studies investigating the impact of dehydration on cognition consistently report alterations in mood state, such as perceived tiredness,[218] alertness,[153] fatigue, confusion, anger, and depression.[1,10,48,78,79,90,166] Kempton and colleagues[107] demonstrated that very mild dehydration (<2% body mass) did not impair cognitive performance or cerebral perfusion but did increase measures of mental sedation. Dehydration also produced a stronger increase in the frontoparietal blood oxygen level–dependent response during an executive function task, suggesting that higher levels of neuronal activity were required (and called on) to achieve the same performance. Physiologic effects of dehydration (change in plasma osmolality by >5 mmol/kg) are associated with strong sensations of thirst that have been associated with increases in activity in certain regions of the brain (on fMRI),[61,62,185] which supports the concept that these sensations can be distracters and necessitate greater brain activity to perform the same task.[107] This ability to overcome the negative effects of stressors and maintain an effective level of performance is termed *cognitive resiliency*. This resiliency in cognitive performance has been reported even with dehydration to 4% of body mass and when exposed to cool, warm, and hot environments. Negative mood states have been reported to enlist greater effort,[212] and thus individuals may elicit greater effort and detailed attention when in negative mood states such that decisions are unaffected by dehydration. Therefore, symptomatologic distracters associated with dehydration may be a more probable explanation for impairment in cognitive function reported with dehydration. Equivocal findings related to dehydration and cognition thus may be more likely caused by the variation in cognitive resiliency. This may help to explain why some people are able to maintain cognitive function,[66] whereas others are more easily disturbed.[11,228]

Whether caused by symptomatologic distraction, some as-yet unknown mechanism related to dehydration, or the combined effect of heat and dehydration, a greater number of accidents have been reported in the summer months.[225] When these accidents occur in wilderness situations, medical help may not be readily available, with dire consequences. Accidents such as trips or falls (possibly related to orthostatic intolerance as a result of dehydration) can result in broken bones, lacerations, or death (fall from a height). Accidents occurring during expeditions or when mountaineering can be traced to a poorly made initial decision (symptomatologic distraction resulting in mental fatigue, reduced alertness, and concentration) that led to subsequent poor decisions, further compounding the severity of the situation.

DEHYDRATION AND HEAT-RELATED ILLNESS

Dehydration increases the risk for heat exhaustion[4,136,202] and is a risk factor for heatstroke.[33,68,89,174] Other factors, such as lack of heat acclimatization, certain medications, genetic predisposition, and illness, often play a large role.[33,64] Historically, unexpected cases of heat-related illness were attributed solely to dehydration, because dehydration has been shown to impair thermoregulation and increase cardiovascular strain. However, it is now suspected that previous sickness or injury might increase susceptibility to serious heat illness.[105] Dehydration was present in about 17% of all heatstroke hospitalizations in the U.S. Army over a 22-year period.[33] In a series of 82 cases of heatstroke in Israeli soldiers, dehydration was present in 16% of cases.[68] Team physicians for American football clubs have observed during summer practice that dehydration, occasionally caused or exacerbated by emesis, contributes to heatstroke.[64,176] Dehydration has been associated with reduced autonomic cardiac stability,[34] altered intracranial volume,[63] and reduced CBF velocity responses to orthostatic challenge.

HYPONATREMIA

Hyponatremia describes a state of lower-than-normal blood sodium concentration, typically less than 135 mEq/L. It is also used to describe a clinical syndrome that can occur when there is rapid lowering of blood sodium, usually to a level below 130 mEq/L and accompanied by altered cognitive status. This is a serious medical condition that can result in death. Exercise-associated hyponatremia results from prolonged work (typically >5 hours), where sweating is the primary means of heat dissipation. Because sweat contains not only water but also small quantities of electrolytes, there is a progressive loss of water, sodium, chloride, and potassium. Hyponatremia most often occurs when individuals consume low-sodium drinks or sodium-free water in excess of sweat losses (typified by body mass gains), either during or shortly after completing exercise. However, drinking sodium-free water at rates near to or slightly less than the sweat rate can theoretically produce biochemical hyponatremia when coupled with progressive loss of electrolytes. Reductions in solute concentration of extracellular fluid promote water movement from the extracellular space into cells. If this fluid shift is of sufficient magnitude and occurs rapidly, it can congest the lungs, and result in brain swelling and altered CNS function. Signs and symptoms of hyponatremia often mimic those of heat injury and include confusion, disorientation, loss of faculties, headache, nausea, vomiting, aphasia, loss of coordination, and muscle weakness. In general, hyponatremia can be distinguished from heat injury by the presence of repetitive vomiting, abdominal distention, and production of copious clear urine. Complications of severe and rapidly evolving hyponatremia include seizures, coma, pulmonary edema, and cardiorespiratory arrest.

Hyponatremia tends to be more common with long-duration activities and is precipitated by consumption of hypotonic fluid (water). Figure 89-9 illustrates the interaction between drinking rate (water only) and plasma sodium concentration for a 70-kg (154-lb) individual in a 28° C (82° F) hiking environment at a moderate pace (6 km/hr), drinking at three different rates (200, 400, and 600 mL/hr); graph *A* predicts the percent change in body mass over time for the three drinking rates, and *B* predicts expected plasma sodium concentration. The slowest drinking rate (200 mL/hr) over the duration of the hike (12 hours) predicts an elevated plasma sodium level well above that of asymptomatic hyponatremia (135 mEq/L). However, this drinking rate also results in a greater than 4% level of dehydration, a level of fluid loss that would substantially degrade performance (yellow zone, Figure 89-9A). Because the drinking rate is well in excess of sweating rate, the fastest drinking rate (600 mL/hr) actually results in a body mass gain and is predicted to result in asymptomatic hyponatremia within 5 to 6 hours of activity and symptomatic hyponatremia (sodium <130 mEq/L; yellow zone, Figure 89-9B) by 10 hours. It is important to note that predicted changes in plasma sodium concentrations are different for individuals of greater or lesser body mass and with varying sweat rates and sweat sodium concentrations. For example, in individuals who lose large amounts of sodium in their sweat ("salty sweaters"), matching fluid intake to sweat loss may still result in hyponatremia from progressive sodium loss over long-duration activity.[141] Overdrinking hypotonic fluid is the mechanism that leads to exercise-associated hyponatremia. In general, consumption of water without electrolytes should never exceed 11 L (12 qt) during a single episode of rehydration. Consumption of electrolyte-supplemented beverages should substantially delay or prevent this outcome.

Exercise-associated hyponatremia has been observed during marathon and ultramarathon competition,[59,97,213] military training,[80,163] and recreational activities.[16] In athletic events, the condition is more likely to occur in females and slower competitors, both of whom gain weight (from drinking) during the event. Severity of symptoms is related to the magnitude by which serum sodium concentration falls and the rapidity with which it develops. If hyponatremia develops over many hours, it might cause less brain swelling and less adverse symptoms.[112] Unreplaced sodium losses contribute to the rate and magnitude of sodium dilution and in certain situations (e.g., salty sweaters) may be the primary reason for development of exercise-associated hyponatremia.[141,145] Nausea, which increases arginine vasopressin (AVP; antidiuretic hormone) secretion, along with exercise-heat stress, which reduces renal blood flow and urine output, can negatively

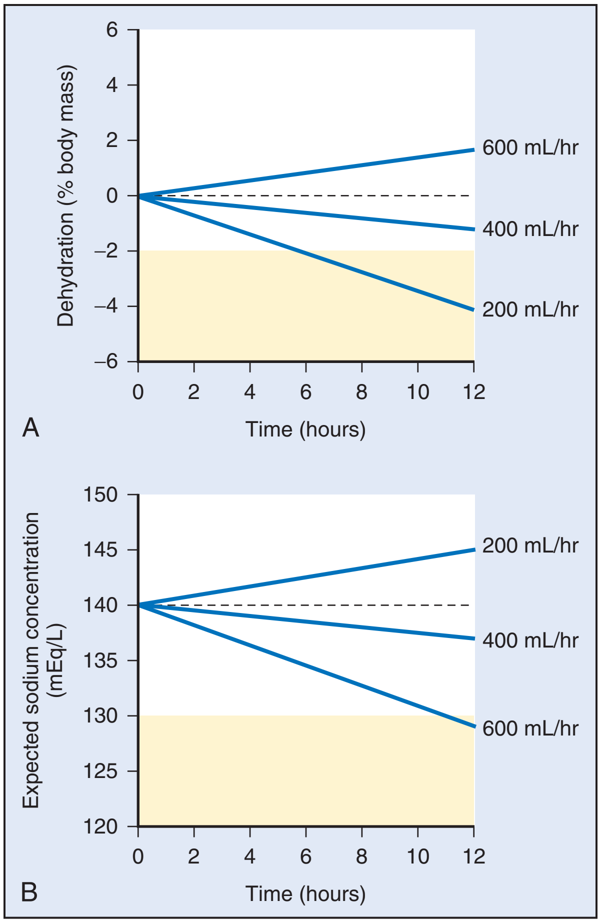


FIGURE 89-9 Prediction of the percentage change in body mass (**A**) and plasma sodium concentration (**B**) over 12 hours for three drinking rates, 200, 400, and 600 mL/hr for a 70-kg (154-lb) individual, in 28° C (82° F) hiking at 6 km/hr. The yellow zone in graph **A** represents the area where a substantial degradation in performance can be expected. The yellow zone in **B** represents the plasma sodium concentration where symptomatic hyponatremia will occur. *(Calculations from Montain SJ, Cheuvront SN, Sawka MN: Exercise associated hyponatraemia: Quantitative analysis to understand the aetiology,* Br J Sports Med *40(2):98-105, 2006.)*

affect the ability of kidneys to rapidly correct the fluid-electrolyte imbalance.[233] The syndrome can be prevented by not drinking in excess of sweat rate and by consuming salt-containing fluids or foods when participating in exercise events that result in many hours of continuous or nearly continuous sweating.

DEHYDRATION AND LIMITS OF SURVIVAL

Severe elevations in blood osmotic pressures are incompatible with life. Just as hyponatremia (blood hypoosmolality) can produce fatal brain swelling, severe hypernatremia (hyperosmolality) can produce fatal brain shrinkage. The physical forces of each can produce tearing of intracerebral veins, leading to cerebral hemorrhage.[9] Although other pathologic outcomes of severe dehydration may also have fatal consequences, the effects of hyperosmolality on CNS function have long been suspected as primary.[24]

Acute elevations in plasma osmolality to greater than 350 mmol/kg produce neurologic symptoms such as seizures and coma in animals; death in humans has been consistently observed in patients with plasma osmolality greater than 370 mmol/kg.[9] Postmortem analysis of human vitreous humor samples in cases of death from dehydration show marked sodium elevation (>170 mmol/L).[126] By using the formula 2.1 × Na^+ to estimate osmolality,[98] a value of 357 mmol/kg is obtained. It therefore appears that a plasma osmolality value of 350 mmol/kg can be considered as an approximate limit for human survival.

The level of lethal dehydration (plasma osmolality >350 mmol/kg) and the time required to reach it can be estimated. If we assume that a 70-kg (154-lb) person possesses 42 L of body water and has a resting plasma osmolality of 285 mmol/kg, the degree of pure water loss required to concentrate plasma osmolality to the lethal limit is (285/350) × 42 = 34.2 L, or 7.8 L. However, since electrolytes are also lost in urine and sweat, a reasonable correction can be applied (7.8/0.94), which yields 8.3 L. This gives a level of dehydration of almost 12% body mass and 20% of TBW. Although higher estimates have been made (~20% body mass), it is cautioned that as much as half of fasting weight losses derive from nonwater sources.[27] Under fasting conditions, Brown and colleagues[27] estimate that urine losses will stabilize at 0.5 L/day after the first day. The remaining losses from sweat depend on environmental temperature and body heat production.

Under hospitable indoor conditions, obligatory urine[27,100] and insensible sweat losses[100,115] add up to approximately 1.2 L/day, which makes survival without water possible for almost 7 days. This is longer than the 100-hour rule of thumb (~4 days)[168] but highly dependent on environmental and behavioral factors. For example, in a worst-case desert scenario where there are 10 hours of daytime high-temperature (>40° C [104° F]) environmental exposure and 14 hours of nighttime temperature(<20° C [68° F]) exposure, approximately 3.0 L/day of sweat loss can be added to the 0.5 L/day losses of urine when at rest.[27] This would limit survival to about 2.5 days. If the lost desert sojourner were to travel by night (14 hours) on foot through sand[82] at 4.8 km/hr (3 miles/hr) and rest unshaded during the day, 8.6 L/day of fluid losses[27,85] would limit survival to less than 1 day (23 hours). If traveling by day and night, sweat losses of approximately 0.60 L/hr (daytime) and 0.40 L/hr (nighttime)[85] would limit survival to about 16 hours. In each case, the distance covered would be about the same (42 to 48 miles).

DEHYDRATION AND SUSCEPTIBILITY TO COLD INJURY

A common response to cold exposure is cold-induced diuresis (CID), an increase in urine production associated with shift in fluid centrally induced by vasoconstriction.[199] In addition, when in a cold environment, attention to replacement of fluid losses is often neglected. If skin temperatures fall significantly, thirst is less noticeable in cold compared to hot weather.[110] In addition, individuals may voluntarily not drink fluid in an effort to decrease the need to urinate brought on by CID. Given the fluid loss brought on by CID, attenuation of thirst when exposed to cold, and voluntarily not ingesting fluid, dehydration can result. Dehydration in the cold may be more important during heavy exercise when core temperature is elevated and blood flow to skin increases to dissipate heat. If individuals in the cold are heavily clothed and traversing in snow (resulting in high metabolic rates),[165] they may overheat more readily and increase fluid losses because of thermoregulatory sweating. During cold-weather outdoor activities, individuals can still become dehydrated by 3% to 8% of their body mass.[72] For these reasons, maintaining hydration is important when performing work in cold environments.

Dehydration in a cold environment does not appear to have the same impact on exercise performance as in temperate or warm-hot environments. Recent data show that if skin temperatures are low, 4% dehydration has no effect on cycling performance in the cold.[39] However, if cold strain is minimized by clothing, thereby maintaining skin and core temperatures near those observed in temperate or even hot environments, dehydration will likely degrade performance.[72] Dehydration does not alter heat conservation, heat production, or CID responses[161,162] and thus does not appear to increase likelihood of peripheral cold-associated injuries. However, lack of significant impact on exercise performance and injury does not negate the importance of maintaining hydration while in a cold environment. Little is known regarding the impact of long-term, chronic dehydration similar to that experienced on long-duration expeditions/missions in cold environments, where water availability is limited and sense of thirst is diminished. Individuals should drink adequately during endurance activity to replace fluid losses and prevent dehydration, even when in a cold environment. When returning to a warm environment, individuals who have free access to food and fluid will rehydrate on their own. When in the field, ice and snow can be melted. However, the source of ice or snow should be known, because only clean snow or ice should be melted for drinking water. If unsure, water melted from snow or ice should be properly disinfected.

FLUID REPLACEMENT (BEFORE, DURING, AFTER)

The U.S. Army has developed fluid replacement and work-pacing guidelines that incorporate work intensity, environment, work-to-rest cycles, and fluid intake, as shown in Table 89-5.[144] These guidelines use wet bulb globe temperature (WBGT) index to mark levels of environmental heat stress and emphasize the need for sufficient fluid replacement during heat stress and concern for the dangers of overhydration. WBGT uses

TABLE 89-5 Fluid Replacement Guidelines for Warm-Weather Training (Applies to Average Heat-Acclimated Soldier Wearing BDU)

		Easy Work		Moderate Work		Hard Work	
Heat Category	WBGT Index (°F)	Work/Rest (min)	Water Intake (qt/hr)	Work/Rest (min)	Water Intake (qt/hr)	Work/Rest (min)	Water Intake (qt/hr)
1	78°-81.9°	NL	½	NL	¾	40/20 min	¾
2 (green)	82°-84.9°	NL	½	50/10 min	¾	30/30 min	1
3 (yellow)	85°-87.9°	NL	¾	40/20 min	¾	30/30 min	1
4 (red)	88°-89.9°	NL	¾	30/30 min	¾	20/40 min	1
5 (black)	**>90°**	**50/10 min**	**1**	**20/40 min**	**1**	**10/50**	**1**

Fluid intake should not exceed 1.5 qt/hr or 12 qt/day.
BDU, Battle dress uniform; *NL,* no limit to work time per hour; *WBGT,* wet bulb globe temperature.
The work/rest times and fluid replacement volumes will sustain performance and hydration for at least 4 hours of work in the specified heat category.
Individual water needs will vary ±0.25 qt/hr. Rest defined as minimal physical activity (sitting or standing), accomplished in shade if possible.
Wearing body armor: add 5° F to WBGT index.
Wearing mission-oriented protective posture (MOPP, chemical protection) overgarment, add 10° F to WBGT index.
Easy work: Weapon maintenance; walking hard surface at 2.5 miles/hr, ≤30-lb load; manual handling of arms; marksmanship training; drill and ceremony.
Moderate work: Walking loose sand at 2.5 miles/hr, no load; walking hard surface at 3.5 miles/hr, ≤40-lb load; calisthenics; patrolling; individual movement techniques (e.g., low crawl, high crawl); defensive position construction; field assaults.
Hard work: Walking hard surface at 3.5 miles/hr, ≥40-lb load; walking loose sand at 2.5 miles/hr with load.

environmental variables, such as solar radiation, humidity, and ambient temperature, in its calculation; automated systems for WBGT measurement are commercially available. The fluid replacement guidelines in Table 89-5 were designed to be simple and practical for use with large cohorts in situations where determining individual sweat rates would be impractical. These recommendations specify an upper limit for hourly and daily water intake, which safeguards against overdrinking and water intoxication. However, it is recommended that individuals performing endurance activities validate their sweat rates, because the guidelines do not account for individual variability.

AMERICAN COLLEGE OF SPORTS MEDICINE FLUID REPLACEMENT RECOMMENDATIONS

Current knowledge regarding exercise with respect to fluid replacement is presented in the 2007 American College of Sports Medicine (ACSM) Position Statement on Exercise and Fluid Replacement.[189] The position statement summarizes current knowledge regarding exercise with respect to fluid and electrolyte needs and the impact of imbalances on exercise performance and health. The statement stresses that individuals have varying sweat rates, and as such, fluid needs for individuals performing similar tasks under identical conditions can be very different. The ACSM Position Statement provides recommendations for hydration before, during, and after exercise/activity.

Before Exercise

The objective is to begin the physical activity euhydrated and with normal plasma electrolyte levels. If sufficient beverages are consumed with meals and a protracted recovery period (8 to 12 hours) has elapsed since the last exercise session, the person should already be close to being euhydrated.[100] However, if the person has sustained substantial fluid deficits and has not had adequate time or fluids/electrolytes in quantities sufficient to reestablish euhydration, an aggressive prehydration program may be merited. When hydrating before exercise, the individual should slowly drink beverage (e.g., ~5 to 7 mL/kg body mass, 350 to 490 mL for a 70-kg individual) at least 4 hours before the exercise task. If the individual does not produce urine, or the urine is dark (highly concentrated), the individual should slowly drink more beverage (e.g., another ~3 to 5 mL/kg body mass, 210 to 350 mL for a 70-kg individual) about 2 hours before activity. By hydrating several hours before exercise, there is sufficient time for urine output to return toward normal before activity. Consuming beverages with sodium (20 to 50 mEq/L) or small amounts of salted snacks or sodium-containing foods at meals will help to stimulate thirst and retain the consumed fluids.[131,173,208]

Hyperhydration can be achieved either by overdrinking or ingesting fluids (e.g., water) that expand the extracellular and intracellular spaces. Simple overdrinking usually stimulates urine production,[100] and body water rapidly returns to euhydration within several hours.[71,160,208] This means of hyperhydrating greatly increases the risk of having to void during activity/exercise[71,160] and provides no clear physiologic or performance advantage over euhydration.[106,116,117] In addition, hyperhydration can substantially dilute and lower plasma sodium[71,160] before starting exercise and therefore increase the risk of dilutional hyponatremia if fluids are aggressively replaced during exercise.[141] Enhancing palatability of ingested fluids is one way to help promote fluid consumption before, during, or after exercise. Fluid palatability is influenced by several factors, including temperature (preferred at 15° to 20° C [59° to 68° F]), sodium content, and flavoring.

During Exercise

The objective is to drink enough fluid to prevent excessive dehydration (>2% body mass loss from water deficit) during exercise by replacing sweat losses to help sustain performance. The amount and rate of fluid replacement depend on individual sweating rate, exercise duration, and opportunities to drink. Individuals should periodically drink (as opportunities allow) during activity if it is expected they will become excessively dehydrated from not drinking. Care should be taken in determining fluid replacement rates, particularly for prolonged exercise lasting longer than 3 hours. The longer the exercise duration, the greater are the cumulative effects of slight mismatches between fluid needs and replacement, which can exacerbate dehydration or dilutional hyponatremia.[141] Weight gain due to excessive fluid intake should be avoided. It is recommended that individuals monitor body mass changes during training/activity to estimate sweat loss during a particular exercise task. This allows customized fluid replacement programs to be developed for each person's particular needs.

The Institute of Medicine also provides general guidance for composition of "sports beverages" for persons performing prolonged physical activity in hot weather.[99] It recommends that fluid replacement beverages should contain about 20 to 30 mEq/L of sodium (chloride as the anion), 2 to 5 mEq/L of potassium, and 5% to 10% of carbohydrate.[99] The need for these different components (carbohydrate and electrolytes) depends on the specific exercise task (e.g., intensity and duration) and weather conditions. The sodium and potassium help replace sweat electrolyte losses, sodium also helps stimulate thirst, and carbohydrate provides energy. These components also can be consumed using nonfluid sources such as gels, energy bars, and other foods.

Carbohydrate consumption can be beneficial to sustain exercise intensity during high-intensity exercise events of 1 hour or longer, as well as less intense exercise/activity sustained for longer periods.[21,56,57,103,230] Carbohydrate-based sports beverages are sometimes used to meet carbohydrate needs while attempting to replace sweat water and electrolyte losses. Carbohydrate consumption at a rate of 1 g/min maintains blood glucose levels and exercise performance.[56,57] Most typical sport beverages contain carbohydrate sufficient to achieve this goal if drinking 1 L per hour or less. It should be noted that this rate of carbohydrate consumption was observed in highly fit, elite athletes. Most individuals would not work or perform exercise at a high enough intensity or for long enough duration to utilize 1 g/min. The greatest rates of carbohydrate delivery are achieved with a mixture of simple sugars (e.g., glucose, sucrose, fructose, maltodextrin). If fluid replacement and carbohydrate delivery are to be met with a single beverage, the carbohydrate concentration should not exceed 8%, or may even be slightly less, because highly concentrated carbohydrate beverages reduce gastric emptying.[102,226] Finally, caffeine consumption might help to sustain exercise performance[55] and likely will not alter hydration status during exercise.[57,231]

After Exercise

If recovery time and opportunities permit, consumption of normal meals and snacks with a sufficient volume of plain water will restore euhydration, provided the food contains sufficient sodium to replace sweat losses.[100] If dehydration is substantial (>2% body mass) with a relatively short recovery period (<12 hours), an aggressive rehydration program may be merited.[130,131,208]

Failure to sufficiently replace sodium losses prevents return to a euhydrated state and stimulates excessive urine production.[130,157,207] Consuming sodium helps retain ingested fluids and stimulates thirst. Sodium losses are more difficult to assess than water losses, and it is well known that individuals lose sweat electrolytes at vastly different rates. Drinks containing sodium, such as sports beverages, may be helpful, but many foods can supply the needed electrolytes. A little extra salt may be added to meals and recovery fluids when sweat sodium losses are high. Table 89-6 presents the electrolyte content of common sport drinks, tablets, and powdered additives.

Individuals looking to achieve rapid and complete recovery from dehydration should drink about 1.5 L of fluid for each kilogram of body mass lost. The additional volume is needed to compensate for increased urine production accompanying rapid consumption of large volumes of fluid.[207] Therefore, to maximize fluid retention, fluids should be consumed over time (and with sufficient electrolytes) rather than be ingested in large boluses.[113,232] Using intravenous fluid replacement after exercise may be warranted in individuals with severe dehydration, nausea, vomiting, or diarrhea, or who for some reason cannot ingest oral fluids.

TABLE 89-6 Electrolyte Content of Common Sport Drinks, Tablets, and Powdered Additives That can be Used to Help Replace Electrolytes Lost During Activity/Exercise

Product	Serv Size	CHO (g)	Na^+ (mg)	K^+ (mg)	Ca^{2+} (mg)	Mg^{2+} (mg)
CeraSport	8 fl oz	5	200	100	0	0
Ensure	8 fl oz	42	200	460	375	62.5
Elete Electrolyte Add-in	½ tsp	0	125	130	0	45
EleteTablytes	1 tablet	0	150	95	40	30
Gatorade (G2 Series)	8 fl oz	14	110	30	0	0
Gatorade (Pro Series)	8 fl oz	14	200	90	0	0
Lucozade Sport Lite	8 fl oz	5	0	0	92.5	0
Nutrilite	8 fl oz	14	110	30	0	0
Pedialyte	8 fl oz	6	253	192	25	2.5
Powerade	8 fl oz	14	100	25	0	0
Powerade Zero	8 fl oz	0	55	35	0	0
Vitaminwater Essential	8 fl oz	13	0	70	50	0
Vitalyte	8 fl oz	10	68	92	2.1	1.6

CHO, Carbohydrate.

Education

Alleviating dehydration should involve a combination of strategies that include assessment, education, and inclusion of practices that encourage fluid intake. Education is a vital component to help individuals maintain hydration before, during, and after activity. Informing individuals, especially those who perform work/activity in a hot environment, about hydration assessment, signs and dangers of dehydration, and strategies in maintaining hydration can help to reduce incidences of dehydration. Brake and associates[25] reported that individuals working in a thermally stressful environment were better able to maintain hydration when they were educated about dehydration, assessed their hydration state, and used a fluid replacement program while performing work.

MODIFYING FACTORS

Diet

One important aspect of an education and hydration program should stress the importance of consuming meals. Meal consumption is critical to ensure full hydration on a day-to-day basis.[3,4,211] Eating food promotes fluid intake and retention.[100] Sweat electrolyte losses can be replaced during meals in most individuals.[124,157,208] De Castro[60] observed food and fluid intake of 36 adults over 7 consecutive days and concluded that the amount of fluid ingested was primarily related to the amount of food ingested, and that fluid intake independent of eating was relatively rare. In addition, Maughan and colleagues, among others, reported that meals play an important role in helping to stimulate the thirst response, causing intake of additional fluids and restoration of fluid balance. Using established meal breaks may help replenish fluids and can be important in replacing sodium and other electrolytes.

Caffeine and Alcohol

Caffeine is contained in many beverages and foods. Recent evidence suggests that caffeine consumed in relatively small amounts (<180 mg/day) will likely not increase daily urine output or cause dehydration.[13] Maughan and Griffin[129] reviewed the literature on the effect of caffeine ingestion on fluid balance and concluded that doses of caffeine equivalent to the amount normally found in standard servings of tea, coffee, and carbonated soft drinks appear to have no diuretic action, and that their consumption will not result in fluid losses in excess of the volume ingested. Therefore, there would appear to be no clear basis for refraining from caffeine-containing drinks in situations where fluid balance might be compromised.

Alcohol can act as a diuretic, particularly at high doses, and can increase urine output. Therefore, alcohol should be consumed in moderation, particularly during the postexercise period, when rehydration is a goal.[206]

Facilities and Clothing

Anecdotal statements and interviews reveal that individuals will purposefully not drink fluid (voluntary dehydration) in certain situations, such as when bathroom facilities are not available, when in cold environments where exposure to the environment may be an issue, or when clothing systems are difficult to remove. Although logistical factors and conditions in the field may complicate access to facilities, a number of alternatives (e.g., toilet tents) can help to address this issue and reduce the practice of voluntary dehydration.

Gender

Women typically have lower sweating rates and electrolyte losses than men.[15,197,204] Women appear to be at greater risk than men to develop symptomatic hyponatremia when competing in longer-duration events such as marathon or ultramarathon races.[7,97] This risk can be alleviated by not overdrinking fluid.

Age

Older (>65 years) persons are generally adequately hydrated.[100] However, there is an age-related blunting of thirst response to water deprivation,[118,125,180] making older persons more susceptible to becoming dehydrated.[118] Older adults have age-related increases in resting plasma osmolality and are slower to restore body fluid homeostasis in response to water deprivation[167] and exercise[125] than are younger adults. If given sufficient time and access to water and sodium, older adults adequately restore body fluids.[123,125] Older persons are also slower to excrete water following fluid loads.[122,125,215,216,220] This slower water and sodium excretion increases sodium retention, which may lead to increased blood pressure.[123]

While thirst sensitivity to a given extracellular fluid loss is reduced in older adults, osmoreceptor signaling remains intact.[125,215,216] The osmotic and volume stimuli that result from dehydration impart important drives for thirst and drinking in older adults, just as in younger people.[18] Older adults should be encouraged to rehydrate during or after exercise.

Prepubescent children have lower sweating rates than adults, with values rarely exceeding 400 mL/hr.[19,138] However, sweat electrolyte content is similar (or slightly lower) in children compared with adults.[19] Lower sweating rates in children are probably the result of smaller body mass and metabolic rate, depending on age. Thermoregulatory sweating is not fully developed until adolescence.

Older adults and young children represent the extremes within the population, but regardless of age, if attention is paid to hydration guidelines, overdrinking will not occur, and hydration can be maintained.

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The views, opinions, and findings in this report are those of the authors and should not be construed as official U.S. Department of the Army position, policy, or decision unless so indicated by other official designation.

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Complete references used in this text are available online at expertconsult.inkling.com.

CHAPTER 90

Living Off the Land

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A survivor's ability to "live off the land" is in large part determined by the person's capacity to procure, prepare, and store food and water, as well as have a basic understanding of human nutritional needs. Meeting a person's nutritional needs is significant in the context of wilderness survival and living off the land. Human survival has always been held hostage to its own nutritional needs, and the success of the human species is directly related to a continued emphasis on achieving a balanced diet.[1,21]

ACHIEVING A BALANCED DIET

The Dietary Reference Intake for energy for moderately active men age 19 to 50 years is 2900 kilocalories per day, and for moderately active women of the same age group, 2200 kcal/day[8] (Table 90-1). Energy needs increase with greater physical activity and decrease in ambient temperature. Current dietary recommendations set forth by the U.S. Food and Drug Administration (FDA) call for daily intake of energy-yielding macronutrients to be composed of 60% carbohydrates, 30% fat, and 10% protein.[12] The U.S. Department of Agriculture (USDA) also suggests that food choices be based on variety and balance, with emphasis on plant foods, primarily grains.[23] However, these recommendations may not have realistic application to wilderness survival and living off the land. To better understand the probable composition of daily energy-yielding nutrients under these conditions, we can look at the macronutrient intakes of hunter-gatherers.

Anthropologic analyses of hunter-gatherer diets show that 45% to 65% of their macronutrients were derived from animal food, both hunted and fished. The remaining 35% to 55% was made up of wild plants. It is also estimated that the average macronutrient composition of hunter-gatherers was 38% to 49% fat, 20% to 31% protein, and 31% carbohydrate.[3] For hunter-gatherer societies living at more than 40 degrees latitude north or south, there was increasing latitudinal dependence on fished animal foods and decreased dependence on plant foods. Although hunter-gatherer diets were composed primarily of animal foods with a high intake of fat, field studies of 20th-century hunter-gatherers showed them to be generally free of the signs and symptoms of cardiovascular disease.[2]

Whatever the dietary intake comes to be in wilderness survival and living off the land, there are commonsense considerations to achieving a balanced diet. Of these, *variety* is probably the most important. Variety can help ensure that the requirements for energy-yielding macronutrients (fat, protein, and carbohydrates) and micronutrients (vitamins and minerals) are met. Variety essentially translates to a balance between the intake of animal and plant foods. This balance depends on factors of climate, competition, and food-type availability, and is worth every effort to attain.

ESSENCE OF SURVIVAL

Historically, people who foraged for food from the environment were victims of aircraft accidents isolated in far-off regions of the world. They needed to supplement meager rations—the food in their pockets and possibly the food contained in a survival kit (if they had one). Castaways who washed up onshore after their boats sank were forced to collect food from the coastal environment. Others who have scavenged for food included people who became lost, although most of these were seldom lost long enough for lack of food to become a real life-or-death issue. For those who were not found within the typical 72-hour window, the ability to recognize and gather locally available wild food may have enhanced their ability to fend off assaults of the environment and prolonged their lives. Anecdotal reports of these survivors describe how many of them scavenged for berries, roots, and various forms of animal life to satisfy their hunger. Gathering food from the environment becomes important when people find themselves unable to obtain food from conventional sources, and a long-term survival situation is anticipated.

There are other circumstances in which being able to gather wild foods could prove very valuable. For example, during periods of civil unrest, particularly when traveling overseas, it is possible to find oneself in a situation in which grocery stores, supermarkets, and other sources of food are not accessible. Being able to forage for food could provide a viable alternative to jeopardizing safety by coming into contact with unfriendly locals. Knowing how to procure food could be a valuable skill in areas where natural disasters have caused extensive damage to the affected community's infrastructure and food supply. Being able to live off the land and consume unusual foods could also become important if one is taken hostage by a terrorist or criminal group. Self-sufficiency in the gathering of food and water could be particularly important to an escaped hostage attempting to return to friendly hands, as opposed to depending on hostile locals or terrorist sympathizers. In each of these situations, one may need to live off the land to augment provisions, or, in a worst-case scenario, to replace food that is no longer available.

Although being able to gather food can be important, a person should not believe that he or she would be able to live off the land indefinitely. Believing that foraging for one's own food is possible in all situations is not realistic. The time of year, environment, inadequate knowledge, lack of skill, and injury may

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TABLE 90-1 Recommended Dietary Allowances for Energy

Gender	Age (yr)	Kilocalories per Day*
Male	11-14	2500
	15-18	3000
	19-24	2900
	25-50	2900
	50+	2300
Female	11-14	2200
	15-18	2200
	19-24	2200
	25-50	2200
	50+	1900

*Based on light to moderate activity levels.

severely limit a person's capability to forage for food. In fact, it may be more beneficial to limit activity by not aggressively searching for food than to expend the limited amount of energy stored in the body trying to procure food that may provide only meager energy.

Most survival manuals contain many pages devoted to identification of edible and toxic plants, techniques used to trap animals for food, and primitive fishing methods used to procure aquatic animal life. The techniques usually described are usually those used by indigenous people who still live off the land for their sustenance. The techniques depicted are presented as though they are methods that the average person could use when in an emergency and needing food. The fallacy lies in the belief that, based on a diagram or two accompanied by a paragraph of narrative, the techniques can be learned, remembered, and then used by the reader at some later date. More often than not, the techniques described *cannot* be learned by reading a book. A lifetime of training (or certainly months of practice) is needed for the techniques to become truly effective for the individual. Few people are willing to devote the time needed to develop expertise in the use of primitive food-gathering methods to a level of proficiency necessary in a survival situation.

During certain periods of the year in many parts of the world, very little, if any, natural food is available. The local people in these areas stockpile sufficient food to last through the lean times until natural sources of food are once again available. Even a well-trained and equipped survivor who arrives during these "lean times" is hard pressed to live off the land and can only hope that rescuers arrive promptly.

Living off the land is usually thought of as a task required to maintain life during a long-term survival experience in a remote corner of the world while awaiting rescue. Although this scenario occasionally happens, most of the survival experiences in North America are short term, during which the need to gather food from within the environment is not a survivor's primary focus. However, even in a short-term experience, knowing how to live off the land could prove beneficial to the survivor's physiologic need for food and psychological peace of mind. In some instances, being able to live off the land could mean the difference between surviving and dying.

The methods presented in this chapter are simple, practical, require a minimum of equipment, and most importantly, relatively easy to use in the field. Some practice will be required, but these procedures and techniques do not require a huge investment of time to develop basic skills.

WATER PROCUREMENT AND PREPARATION

Beside the need for energy-yielding macronutrients and micronutrients, the requirement for water must not be overlooked, because water is the most essential substance. Current recommendations on water intake recently released by the Institute of Medicine suggest daily intake of about 11 cups of total water for women and 16 cups for men.[7] These recommendations are based on the assumption that about 80% of a person's daily water intake comes from drinking beverages and the other 20% comes from water contained in food. Prolonged physical activity, heat exposure, extreme cold, and higher altitude increase water losses and therefore may raise daily fluid needs.

Many survivors begin their emergency already dehydrated (hypohydrated) and continue to dehydrate further when water supplies are limited and the quality of available water is suspect. There have been cases in which individuals needed water but, because of their fear that the water source was contaminated with *Giardia*, *Cryptosporidium*, or other harmful pathogens, delayed drinking or chose not to use the water at all. As a general rule, particularly in North America, because dehydration can very quickly reduce a survivor's ability to function efficiently and safely, it is usually better to drink the impure water. If the water was contaminated, the onset of symptoms will be days away. Hopefully, by then the individual will have access to medical care for treatment. Remember, doctors can cure giardiasis or cryptosporidiosis, but they can't cure "dead"! It should also be noted that gastrointestinal problems usually attributed to drinking contaminated water are in fact more often a result of poor personal hygiene habits.

The need to maintain body water levels and the physiologic impact of dehydration have been well documented in the medical literature (see Chapters 12, 13, and 89). In priority order after shelter and defending body temperature, the need to locate, procure, treat, and store water is the survivor's next most important need. Although water is important in every environment, lack of water becomes critical very quickly in hot, dry environments. Dehydration is also a critical problem at high altitude and at high latitudes where ice and snow must be melted to produce water. People who travel in these areas frequently have great difficulty obtaining water because of the hassles involved in collecting snow and ice, often under extreme weather conditions, and then having to produce the heat needed to melt it. In hot arid regions, where no surface water exists and only infrequent precipitation occurs, depending on tanks, springs, or other natural sources for water is a very questionable practice. Experienced desert travelers abide by the adage, "If you don't have it with you, you won't have it!" Lack of water in extreme conditions can lead to incapacitation within hours and death within days. Locating sources of water should be an important priority for the survivor.

FINDING AND COLLECTING WATER

Throughout much of North America, water is usually available from open sources of water, such as lakes, ponds, rivers, and streams, and can usually be obtained fairly easily. Despite this abundance of water, there have been cases in which survivors were unable to reach a water source because of their injuries.

Fundamental to finding water is recognition that it will always seek the lowest level possible and that, if present, some form of vegetation most likely indicates its presence. A good strategy to locate water is first to find a vantage point from which it is possible to scan the surrounding countryside. A person should slowly and methodically search for any indicators of water, such as green vegetation, birds flocking to specific areas, trails left by domestic or wild animals, and even large rock formations from which springs may originate or where water can become trapped. Human-made sources of water, such as windmills, tanks, dams, and irrigation canals, might also be observed. Look for water in low-lying areas, such as depressions, sinks, or tanks, where rainfall or melting snow is likely to collect. Water can often be found in these areas long after the last precipitation, especially if the areas are shaded. In arid areas where there is little vegetation to obstruct a person's view, a pair of binoculars can save a lot of walking.

Green Vegetation

Although the presence of any living vegetation is an indicator of subsurface water, the amounts of water are usually minuscule, and it is not available in sufficient quantity to justify any expenditure of energy in an attempt to dig for it. Most arid-area plants survive because their deep roots extend well below the earth's surface to gather small quantities of water available in the soil. Although it may not be appropriate to dig for this water, the process of plant transpiration can be capitalized on to collect a significant amount of water in a relatively short time. This process is described later.

Animal Trails

Most animals require water at regular intervals, usually once a day. By observing the movement of animals, it may be possible to determine the specific location of nearby water sources. Distinct trails are developed over time by both wild and domestic animals that travel to and from water sources on a regular schedule. Pay attention to forks in animal trails, because they often indicate the direction of a water source. If an animal trail forks into two trails, it is possibly leading a person away from a source of water. Conversely, if trails come together, an individual may be walking toward a source of water or food. Even though the direction to a water source can be determined, the distance to that source may be too far for the survivor to realistically reach on foot. Birds and animals have far greater capability to travel long distances without water than does a human. Consequently, it is usually better to stay in one place, as opposed to wandering around the desert looking for uncertain water sources.

Bird Movement

Most birds require water at least once per day. By watching their movement, especially in morning and evening hours of the day, a general direction of a water source may be determined. Once again, the urge to travel must be weighed against unknown distances and the questionable quality of water sources.

Open Water Sources

Collecting water from open sources is usually the easiest method available to the survivor. However, caution should be exercised. Lakeshores and the edges of rivers can be hazardous. Crashing waves, swift-moving water, undercut riverbanks, and unstable footing can all create problems. Swampy shorelines; heavy vegetation; lakes, streams, or ponds surrounded by cliffs; other difficult terrain; or unsafe ice conditions may preclude a person from getting close enough to a water source. Don't risk life and limb trying to climb or reach the water's edge when safer strategies can be used. Tie a line to a water bottle or container of some type and throw it or lower it into a water source from a safe location or vantage point. Because most water containers do not come with a reliable attachment point when the container is uncapped, make one by duct-taping a loop of parachute cord or nylon line to the side of the water container (Figure 90-1). Do not use the retaining strap that connects the cap to the water bottle for this purpose. In many cases, this strap will break or pull free from the full bottle as it is being retrieved from the water source, resulting in loss of the bottle.

In some instances, water sources may be very muddy or silty and need filtering or settling before they can be used (Figure 90-2). Rivers originating from glaciers carry large amounts of "glacial flour" that should be removed before consumption (Figure 90-3). This is best accomplished by allowing the water to settle overnight and then filtering it through fabric before drinking.

The water in some lakes, particularly those in the western United States, contains high concentrations of calcium carbonate and calcium bicarbonate in solution, which make the water nonpotable. Lakes of this nature are usually easy to identify because the calcium salts that are leached from the ground are deposited in the form of white powder around the perimeter of the lake as the water evaporates (Figure 90-4). Water containing high concentrations of calcium carbonate and bicarbonate tastes terrible and should not be consumed.

Water collected from rivers and streams should not be considered "pure" (Figure 90-5). *Giardia*, *Cryptosporidium*, and other harmful pathogens found in water sources are not deactivated by aeration or exposure to ultraviolet rays. All water should be disinfected and purified using methods described in Chapter 88.

FIGURE 90-1 Attach a lanyard loop to your water bottle. *(Courtesy Peter Kummerfeldt.)*

Seeps and Springs

The quantity of water produced by seeps and springs varies tremendously. In some cases, the amount will be only a few teaspoons per hour (Figure 90-6). In other cases, gallons of water can flow from the ground in minutes (Figure 90-7). Where the quantities are small, the flat edge of the opening of a plastic bag can be used to scoop the water from a shallow source, or if it is flowing, to collect the water as it runs into the bag. A short piece of vinyl aquarium hose also works well for sucking water from shallow collections or to recover water from narrow cracks in the rocks.

Tanks

After a rain, water collects in low-lying areas and may be found long after the last storms have passed through the area (Figure 90-8). Check out any depressions, sinks, or other low places

FIGURE 90-2 Muddy water should be allowed to settle and then be filtered. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-3 Rivers originating from glaciers are discolored by the glacial "flour" they are carrying. This water should be allowed to settle before filtering. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-4 Calcium salts leached from the soil are a common sight around many western U.S. lakes. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-5 All water should be disinfected if possible before it is consumed. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-6 Desert seep. *(Courtesy Peter Kummerfeldt.)*

where water could gather. Remember, the presence of vegetation and animals could provide a clue to the presence of a water source. Water sources like these should be checked carefully because they are frequently contaminated with debris that has been washed into the drainage. Finding the remains of animals that have died nearby or in the water, animal droppings, or other similar contaminants necessitates boiling, using halogens, or a filtration system designed to disinfect water (see Chapter 88).

Wells

It may be possible to locate abandoned open wells from which water may be obtained. Usually, the rope and bucket used to lift water from these wells will be missing, and a person will have

FIGURE 90-7 Desert spring. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-8 After rainfall, water can be found in desert tanks **(A)** and other depressions **(B)**. *(Courtesy Peter Kummerfeldt.)*

to improvise a means to lowering a container down into the well to retrieve the water. With a closed well, where the pump handle is present but secured, or where the water is piped to another location, it may be necessary to dismantle or damage the plumbing to access the water. This may not be possible without tools.

Windmills

Windmills that could provide a ready source of water are a common sight across North America, especially where little surface water exists (Figure 90-9). Typically, the water pumped to the surface is collected in a nearby tank or pumped directly into a trough from which livestock can drink (Figure 90-10). If this is not the case, it may be necessary to dismantle or damage the pipes associated with the windmill to gain access to the water. Without tools, this may not be possible.

FIGURE 90-9 Windmills are a common sight across the arid regions of the western United States and may provide a survivor with a source of water. *(Courtesy Peter Kummerfeldt.)*

Guzzlers

In arid areas, particularly in the western and southwestern United States, state wildlife agencies and conservation organizations have installed rainwater collectors called *guzzlers*. These water tanks can hold hundreds of gallons of water long after seasonal rains have passed (Figure 90-11). A guzzler consists of a concrete, metal, or fiberglass apron designed to gather precipitation and feed it into a holding tank, where it remains until it is consumed by thirsty animals or evaporates.

Dew

Dew forms on clear nights when the air temperature decreases and the water held in vapor or air suspension condenses on cool metal surfaces or on vegetation. Dew can be collected as it drains

FIGURE 90-10 Water pumped from the ground by windmills may be readily available to a survivor. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-11 **A** and **B,** Guzzlers collect and store rainwater for wildlife and others in need of water. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-13 A plastic bag, sheet of plastic, or other material erected as shown is a very efficient method to collect large amounts of rainwater quickly. *(Courtesy Peter Kummerfeldt.)*

from inclined surfaces on which it has formed, or it can be sponged up using an absorbent material. Campers' towels are one of the best materials for collecting dew (Figure 90-12). These highly absorbent towels quickly absorb moisture and can then be wrung out into a container or squeezed directly into a person's mouth. A sponge is also very useful for collecting dew. Dew must be collected early in the morning before it is evaporated by the sun's heat.

FIGURE 90-12 Campers' towels are very useful for soaking up dew or water from shallow sources. *(Courtesy Peter Kummerfeldt.)*

Rain

Rainwater can be easily collected by erecting a flat surface (Figure 90-13). Water collects on the upper surfaces of any material (it need not be waterproof) and drains to the lowest point, where it is collected.

Snow

For a normothermic person, there is no reason not to "eat" snow as an auxiliary source of water. However, for a person close to being hypothermic or who is already hypothermic, eating snow may increase loss of body heat and exacerbate the medical condition. Survival case studies reflect that individuals who chose to eat snow frequently experienced cuts and abrasions to the mouth mucosa as a result. If snow is the only source of water on hand, and no alternative methods are available to melt it, the snow should be collected, compacted by hand, and consumed in small enough quantities for heat within the mouth to melt the snow.

When snow falls and settles on the ground, it undergoes constant metamorphosis. During very cold periods, there may be very little moisture in the dry, fine, or wind-blown snow that accumulates on the ground. Over time, as snow accumulates, the weight of the upper layers of snow and the earth's latent heat cause the snow closer to the ground to change. It becomes more granular in nature and more like ice than snow. When comparing equal volumes of snow, snow collected from lower levels near the ground produces more water than does snow collected near the surface (Figure 90-14). Also, less heat will be needed to convert this snow to water.

Water Machine. The most efficient technique to convert snow into water is with what military survival schools call "a water machine" (Figure 90-15). A bag made from any available porous fabric (a T-shirt with the neck and armholes sewn shut has been used) is filled with snow and ice and hung near, but not directly over, a fire. The fire's radiant heat melts the snow in the bag and the water runs down to the lowest point of the bag, where it drains into a container. Continually refilling the bag with snow prevents it from burning. Gallons of water can be produced quickly and safely using this method. The following are the major advantages of using the water machine method:

FIGURE 90-14 Melting granular snow contained in a 1-gallon zipper-lock bag **(A)** produced the water shown on the right **(B)**. *(Courtesy Peter Kummerfeldt.)*

- Once the water machine is loaded with snow and positioned, no further action is needed until the bag needs to be filled with additional snow.
- A water machine works while a person is busy with other tasks. This saves energy.
- All the debris (e.g., leaves, grass, twigs, insects) commonly found in snow is filtered out by the cloth as the water drains into a container.

FIGURE 90-15 Water machines are the best method to use to quickly convert snow into water. *(Courtesy Peter Kummerfeldt.)*

- A metal container, normally needed to melt snow over a fire, is not required when using this method.

Traditionally, snow is melted by placing it in a metal container and then applying heat (Figure 90-16). Several problems soon become apparent when using this method:

- The size of container is usually quite small, which limits the amount of snow that can be melted at one time.
- When heat is applied to the container, the snow directly in contact with the heat at the bottom of the container melts and is converted to steam. This steam is absorbed by the remaining snow, leaving a space in the bottom of the container. If the snow is not constantly stirred and pressed into the container, it is possible to scorch the bottom of the container and even to melt the solder used to seal the seams.

FIGURE 90-16 Melting snow in a pot is a very inefficient, time-consuming method of obtaining water from snow. *(Courtesy Peter Kummerfeldt.)*

- Using this method requires constant attention.
- The water produced using this process tastes unpleasant (smoky) and often contains ash and other debris from the fire.
- The system is inefficient, increases the likelihood of being burned, and often results in damaged clothing.

Using Body Heat to Melt Snow. This is a very slow, inefficient method of procuring water. If this process is the only one available, a small quantity of snow (several cups) is placed in any available waterproof container. Preferably, this should be a soft plastic water bag, zipper-type bag, or other similar container that is then placed between layers of clothing. Because the amount of heat needed to convert snow to water is large and the amount of body heat available is finite, only small quantities can be melted at a time. Large quantities of snow will not melt fast enough to provide the survivor any benefit. Large quantities of snow may also cool the body too much.

Using the Sun to Melt Snow. Another method, frequently used in winter recreation, involves using a sheet of black plastic. A thin layer of snow placed on a piece of black plastic (or other dark-colored waterproof fabric) positioned in the sun will melt. The waterproof material should be positioned on an incline so that the melt water runs to the lower edge of the fabric and drains into a container (Figure 90-17).

Digging Holes to Collect Subsurface Water

Even though water is not visible on the surface of the ground, it may still be present in the soil in sufficient quantity to be collected. Locate low-lying areas where water is most likely to have accumulated, and dig down until damp layers of soil are located (Figure 90-18). Over time, water may seep into the hole, where it can be collected. If no indicators of the presence of subsurface water are present, dig a hole in the outside bend of a dry river bed. Look for a location where the centrifugal force of water flowing down river has eroded the outer bend of a curve and created a depression, where the last remnants of water flowing down the river will have accumulated.

Beach Wells

In a coastal, saltwater environment, it is possible to locate water sources near a beach that are fresh and potable. A hole dug behind the first line of sand dunes adjacent to the high-water mark will often fill with fresh water. Fresh water, which is less dense than sea water, will collect in the hole. Holes dug in sandy soils are very tenuous and tend to cave in constantly, which may make it necessary to shore up with driftwood the sides of any hole dug in sandy areas (Figure 90-19).

Solar Stills

Solar stills use a sheet of plastic and the sun's heat to capture evaporation from soil or plants or to distill nonpotable water. The water evaporates from its source (e.g., soil, plants, urine), condenses on the plastic sheet, and runs down the sheet into a collector, from where it is retrieved (Figure 90-20).

Solar stills are *not* a reliable method of obtaining water in arid areas. The quantity of water produced by a solar still depends on the amount of water contained in the ground. Because desert soils tend to hold little or no water, the amount that a survivor is likely to obtain must be balanced against the amount lost in the sweating process while constructing the device. In most cases, a person will likely lose more water than can be recovered from the still. Even if a solar still is constructed in ground that is saturated with water, its productivity in relation to the amount of effort expended is still questionable. If the ground is saturated, the other methods of water procurement described here will most likely work.

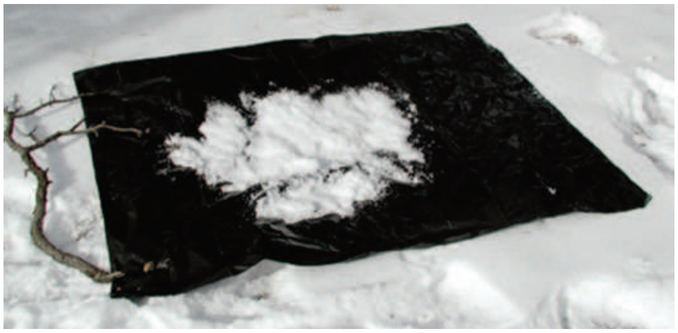


FIGURE 90-17 Solar heat and a sheet of black plastic can be used to melt snow. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-18 Damp, low-lying areas are ideal sites to dig for water. *(Courtesy Peter Kummerfeldt.)*

Water from Vegetation

A person's ability to collect water trapped by plants or contained within them can be a valuable aid to combating dehydration. Once again, a line must be drawn between methods that are practical and those based more on myth. Extracting water from a barrel cactus is a classic example of a survival "myth." Barrel cacti have been long featured in survival literature as a reliable source of water in arid regions (Figure 90-21). Several issues make this practice very questionable. First and most important, the quantity of fluid that can be extracted from a barrel cactus is very limited. Second, the fluid that is removed is not beneficial and may in fact be detrimental to an individual's health. Third, accessing the interior of a barrel cactus requires a substantial knife or other cutting tool. The outer skin of the cactus is very tough and covered with long spines. Barrel cactus should *not* be considered a source of water.

Water Vines

Throughout tropical and subtropical regions of the world, vines can be found that can provide a reliable supply of pure water when other sources are not available. Water-producing vines varying in size from pencil thickness up to the thickness of a male adult's forearm can even be found throughout much of the southeastern United States. Select vines with a large diameter. The greater the thickness of the vine, the more water it is capable of producing. Because water vines are woody and tough, they can be difficult to cut. A sharp knife or, better yet, a machete, will be needed to sever the vine.

To determine whether a vine is a suitable water source, the outer layers of the vine should be deeply scored with a knife. Vines that exude a white latex sap or a colored or foul-smelling sap should be avoided. If no sap is observed, or if the sap observed is clear and without aroma, a section of the vine can be cut as a water source. A 24-inch-long piece of vine should be cut by severing the higher end first and then cutting the lower end. If the lower end is cut first, the water contained within the

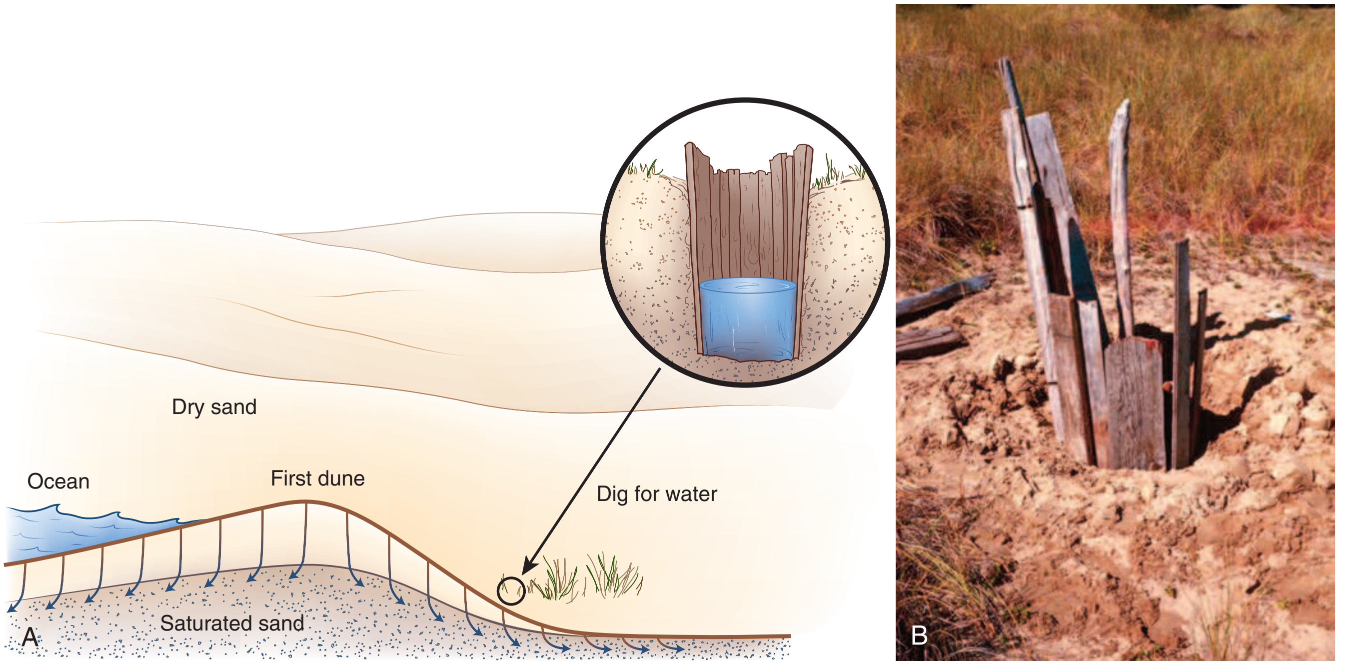


FIGURE 90-19 Beach wells dug behind the first sand dunes adjacent to the shore can produce potable water. *(Right courtesy Peter Kummerfeldt.)*

vine is drawn up by capillary action, and much less water will drain out by the time that the upper end is severed. This becomes apparent when the available knife is not large enough to cut through the tough vine quickly. In a test conducted in Florida by one of the authors (PK), a 24-inch by 4-inch section of water vine produced more than 1 cup of water.

Once detached, the section of vine is held vertically, and the water contained within the vine is allowed to drain into a container (perhaps a cupped hand), where it should be further evaluated. Liquid that is colored should not be consumed. Liquid that has an unpleasant aroma, other than a faint "woody" smell, also should be discarded. A small amount of the water should be tasted. Water that has a disagreeable flavor, other than a slightly "earthy" or "woody" taste, should not be used for drinking. This source could be used to satisfy external hygiene needs. If the water is still being considered for consumption, a small amount should then be held in the mouth for a few moments to determine if there is any burning or other disagreeable sensation. If any irritating sensation occurs, the water should be discarded. Ultimately, plant liquid that looks like water, smells like water, and tastes like water can be safely consumed in large quantities without further purification (Figure 90-22).

Transpiration Bags

The use of clear plastic bags to enclose living vegetation and capture the moisture transpired by the leaves can be an effective method of collecting water (Figure 90-23). A plant's survival depends on its ability to gather water from the soil. This water is passed up through the plant's roots, stems, and branches and is finally released as water vapor back to the atmosphere through pores in the leaves. This process is called *transpiration*. Water vapor is captured by enclosing as much living vegetation as possible within a clear plastic bag and sealing the opening shut with a cord or duct tape. The vegetation should be given a vigorous shake before placing it in the plastic bag to remove any insects, bird droppings, or other materials that might contaminate the

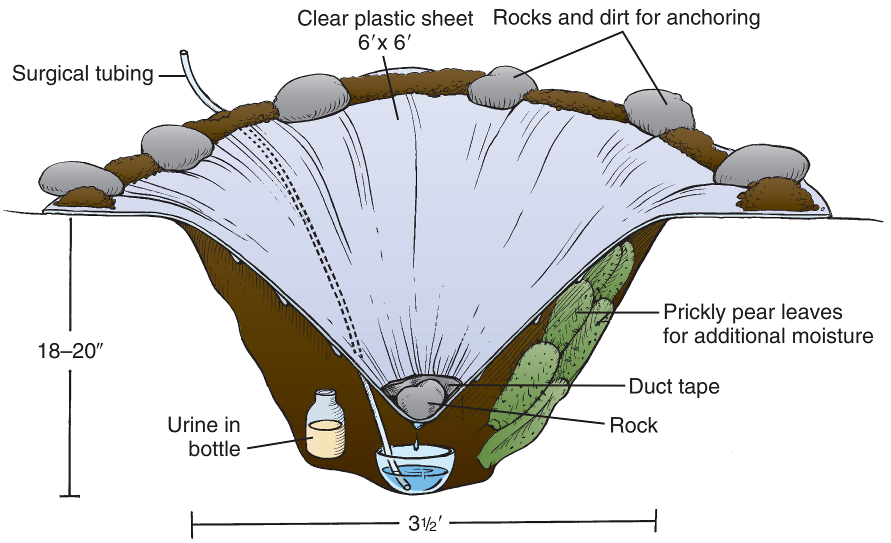


FIGURE 90-20 Solar stills are not a reliable procedure for obtaining water from the ground.

FIGURE 90-21 Barrel cacti do not contain water or water substitutes. *(Courtesy Peter Kummerfeldt.)*

water. Within a short period, water will begin to condense on the inner surface of the bag and collect into water droplets. Over hours, the droplets accumulate and drain to the lowest point.

The quantity of water obtained in this manner depends on the amount of water in the ground and the type of vegetation used. Other factors that determine water production include the amount of sunlight available, clarity of the plastic bag, and length of time the process is allowed to work. It is not uncommon to find that 2 or 3 cups of water, and sometimes much more, have accumulated over a 6- to 8-hour daylight period (Figure 90-24). This water is contamination free and does not require further purification.

Transpiration bags do not work at night, and they do not work well when opaque or colored bags are used. The process of transpiration slows down when it becomes dark. Depending on the temperature, the plastic bag can be left in place for 2 to 3 days, at which point the leaves become damaged by the heat that develops inside the bag, causing the process to stop. The water that collects can be removed from the bag by disassembling the apparatus and pouring out the water, or by punching a small hole at the lowest point in the bag and allowing the water to drain out. Neither of these procedures is optimal because one requires that the bag be reassembled and the other necessitates repairing the hole in the plastic bag. The best way to remove the water without disturbing the bag is to insert a length of vinyl aquarium hose through the neck of the bag down to the lowest point where water will collect. The water can then be sucked out or possibly siphoned into a container. When enclosing vegetation in the plastic bag, it is advisable to place a chicken egg–sized stone in the lower corner where the water will collect. The weight of the stone creates a separation between the enclosed plant life and the water and precludes the plant saps from leaching into the water.

Using the transpiration process is a practical method of collecting water in desert areas, but it is also useful in other areas where surface water is not available. Unlike deserts in other parts of the world, a considerable amount of vegetation is found in North American deserts. This is vegetation that may be used in the transpiration bag process. Most vegetation in desert areas is thorny, so considerable care should be taken to keep these thorns from tearing the plastic bag. Desert willow, a nonthorny shrub commonly found throughout the American southwest, is an excellent source of water. The poplar family of trees, including aspen and cottonwood, found in more temperate areas, is another good source when using this method of water procurement. Because the trees and shrubs that produce the most water are deciduous (lose their leaves in winter), the transpiration bag process is limited to the time of year when vegetation is in leaf.

HOW LONG A PERSON CAN LIVE WITHOUT FOOD

Other than external factors, such as wind, precipitation, and temperature extremes, individual physiology and tenacity to live remain the primary determinants for survival without food or with limited caloric intake. An obese person carrying a large amount of body fat who arrives in a survival situation will have more fuel to burn than will a thin person. Other factors notwithstanding, this individual should live longer. Skinny but determined survivors might live longer than expected because of their tenacity.

A distinction must be made between having no food available and having limited supplies. If consumption of food is lower than the rate at which energy is expended, the body uses its reserves of fat, carbohydrates, and proteins at a pace directly related to the rate at which the energy is depleted. Without any food, most people die within 40 to 60 days. Self-imposed food fasts, such as those endured in Irish prisons by IRA militants, ranged from 50 to 60 days with no caloric intake before death. When sleep deprivation and danger are combined with little or no food, a person's awareness, judgment, and ability to concentrate decrease rapidly. Individuals attempting to survive with little or no food become apathetic, lethargic, confused, and indifferent. Consequently, they are unlikely to stay alive for long in a physiologically challenging environment.

How long a person can live without any food varies tremendously. In adult volunteers who fasted for 30 to 40 days, weight loss was marked (25% of initial body weight). During more prolonged starvation, weight loss may reach 50% in adults and possibly more in children. Loss of organ weight is greatest in the liver and intestine, moderate in the heart and kidneys, and least in the nervous system. Emaciation is most obvious in areas where prominent fat deposits normally exist. Muscle mass shrinks, and bones protrude. The skin becomes thin, dry, inelastic, pale, and cold. The hair is dry and sparse and falls out easily.

Most body systems are affected. Achlorhydria and diarrhea are common. Heart size and cardiac output are reduced, the pulse slows, and blood pressure falls. Respiratory rate and vital capacity decrease. The main endocrine disturbances are gonadal atrophy, loss of libido in men and women, and amenorrhea in women. Intellect remains clear, but apathy and irritability are common. The victim feels weak. Work capacity is diminished because of muscle destruction and eventually is worsened by cardiorespiratory failure. Anemia is usually mild, normochromic, and normocytic. Reduction in body temperature frequently contributes to death. In famine edema, serum proteins are usually normal, but loss of fat and muscle results in increased extracellular water, low tissue tensile strength, and inelastic skin. Cell-mediated immunity is compromised, and wound healing is impaired. Total starvation is fatal in 8 to 12 weeks. For more information on starvation, see Chapter 87.

The season and weather establish additional constraints on a survivor's longevity. In a benign setting, with warm temperatures both day and night, no precipitation, plenty of water available, and wood for a fire, the physiologic need for food is not as great. On the other hand, a survivor in a cold, wet, and windy environment, with inadequate clothing and no shelter, fire, or food to generate heat, will quickly succumb to hypothermia. With food, survival outcome for an individual is still not guaranteed. However, provided that other priorities are met, life may continue long enough for a survivor to be found alive.

FIGURE 90-22 **A** to **E,** Water vines contain large quantities of water that can be recovered by cutting out a 60-cm (24-inch) section and draining the water into a container. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-23 Transpiration bag collecting the water transpired by desert willow. *(Courtesy Peter Kummerfeldt.)*

In a cold environment, generating heat to preserve body core temperature can be very difficult without adequate food intake. Shivering, which is a primary mechanism by which the body generates heat, rapidly depletes glycogen stored in the liver and muscles unless adequate food is available. Lacking sufficient clothing and food to protect against environmental insult, survivors must rely on their ability to build a shelter and start a fire to maintain core temperature.

Survival situations demonstrate the law of diminishing returns. During the initial hours of an emergency situation, survivors are in the best condition they will enjoy during their survival experience. The impact of the environment and the lack of food, water, and sleep result in continuous degradation of the body's ability to function normally and eventually take a toll on the survivor's ability to accomplish the tasks needed to survive. Any "heavy work" should be accomplished early. Strength, mobility, balance, and dexterity diminish as each day passes. The survivor's objective is to delay this degradation for as long as possible through intelligent use of practical food- and water-gathering techniques, and in so doing, increase the chances of being rescued alive.

Figure 90-24 Enclose a large amount of leafy vegetation in a clear plastic bag and seal the neck **(A).** Water transpired by the plant condenses on the inner surfaces of the bag and drains to the lowest point **(B)**, where it can be sucked out using a piece of vinyl hose **(C).** *(Courtesy Peter Kummerfeldt.)*

The ability to select, gather, and prepare natural foods, even in short-term experiences, is valuable physiologically, but perhaps even more so psychologically. When gathering food, survivors are actively involved in surviving, contributing to their own well-being. Although the amount of food gathered may be small, the satisfaction derived from catching a fish, snaring a squirrel, or gathering a hatful of edible berries can be a great morale builder.

People who are used to having all their food come from packages, cans, or other containers may need to overcome their reluctance to eat nontraditional foods that now come packaged in skin, hair, scales, or feathers. These aversions cause people to avoid consuming available wild foods that would enhance their chances of survival. Reluctance to eat insects, for example, is based in large part on the Western cultural belief that insects are "dirty" and that eating insects is done only by those who cannot afford better food. Additionally, the vast quantities of processed food available in developed countries have produced feeding habits in which people only consume the very best of the available foods and discard the rest. Survivors will not be so fortunate that they can pick and choose what they eat. They may have to capitalize on *any* potential food that comes their way.

Procuring wild foods involves procedures and techniques that some might view as cruel, unethical, or even illegal. For example, with the exception of trapping fur-bearing animals during legal seasons and the use of traps by licensed animal control personnel to remove "problem" animals, the use of snares to obtain food is against the law. Trapping and snaring techniques have been determined to be illegal because they are so effective and because they are virtually impossible for wildlife managers to monitor. Their effectiveness is the very reason they are highly recommended for survival. Under normal circumstances, federal, state, and local laws and regulations govern procuring food from the environment. Killing animals for food outside of prescribed hunting seasons is forbidden. Gathering plant foods and killing animals is specifically prohibited in national parks and other similar sanctuaries. Accepted hunting conventions also disfavor killing females with babies and younger animals. When faced with starvation and the choice between killing an animal and digging up enough plant bulbs to make a meal, it becomes a question of common sense. The survivor should gather necessary food and leave legal issues to be sorted out after the fact. It is extremely unlikely that a survivor who could clearly demonstrate a legitimate need would be charged with an infraction of the law. This does not mean that, in a short-term survival experience, it is appropriate to disobey the law, particularly if there are reasonable alternatives.

Feeding oneself in a long-term survival experience may necessitate harvesting and butchering wild game animals. These skills were once common in Western culture but now are uncommon. To some people, the act of taking any life is reprehensible, so even in a survival situation, when faced with killing an animal for food, they will have great difficulty or even may be unable to accomplish the task. Most often, however, hunger drives survivors to carry out what they need to do to stay alive.

When considering what should be eaten in a survival situation, some people focus all their efforts on plant foods. This misguided approach may be the result of advice given in out-of-date survival manuals and from well-intentioned, but ill-informed, writers of contemporary "how-to-survive" articles. Many of these articles devote numerous pages to identification and use of plants to sustain life. Except for the short term, it is almost impossible to survive indefinitely on gathered plant life alone, even if it is available. Fats and proteins provided by eating meat are far more sustaining than are the carbohydrates provided by eating vegetable matter. If plant and animal foods are both available, survivors should attempt to balance their diets by consuming fat, proteins, and carbohydrates in order to maintain health for as long as possible.

SUCCESS STORIES

Despite the difficulties of living off the land, survival for long periods is still possible when little or no food is available. Helen Klaben[11] and Ralph Flores survived 49 days in the Yukon in a wrecked aircraft on four 105-g (3.75-oz) cans of sardines, two 198-g (7-oz) cans of tuna fish, two 0.5-kg (1-lb) cans of mixed fruit salad, one 0.5-kg (1-lb) box of saltines, five small pieces of chocolate, and 30 g (2 tablespoons) of Tang. Bob Gotchen survived for 58 days during the winter following a forced landing in Northwest Territory, eating only a few mouthfuls of frozen fish and losing 74 lb (33 kg) in the process. James Scott survived under a rocky ledge in the Himalayas for 43 days during the winter without food before being rescued. In 1972, a Uruguayan soccer team stranded in the Andes by a crash landing survived for the next 72 days with little food. In 1979, Brent Dyer and Donna Johnson walked out of the Idaho wilderness 19 days after their plane crashed.

In the last two instances, the survivors, lacking other foods, consumed the flesh of humans who had died in the accidents. Despite their psychological disinclination to eat the flesh of another person's body, it was something that they did in order to survive. Based on the accounts of these incidents, published in *Alive: The Story of the Andes Survivors* by Piers Paul Read[18] and *The Sacrament: A True Story of Survival* by Peter Gzowski,[6] it could be argued that the small amounts of human flesh they ate were of minimal physiologic benefit but of significant psychological value. Although there is no physiologic reason why human flesh should not be consumed in an emergency, we are unwilling to do so as a result of our cultural beliefs and the long-standing prohibition against cannibalism. Eating the flesh of another human to survive after that person has died accidentally is not necessarily the wicked act of a demented person. Rather, it is a last choice, a means to an end, for a starving survivor.

WILD ANIMAL FOODS

Food available to a survivor may come from many sources, including snacks or other incidental food that survivors may have placed in their pockets, emergency food contained in survival kits, and last but not least, food that might be obtained from the surrounding environment. The ability to procure natural foods from the land depends on the following:

- Knowledge of natural foods available for each season in the relevant geographic region
- Some degree of proficiency in food-gathering methods and techniques
- Physical ability to gather food
- Availability of equipment needed to gather food or ability to improvise the equipment
- Skills needed to prepare food for consumption

Knowing the environment and the techniques to procure and prepare animal life for food could prove crucial to the successful conclusion of any survival situation. This section discusses the techniques a survivor might use to harvest and prepare commonly available animal life found throughout much of North America.

MAMMALS

All mammals are edible, but because of larger mammals' size, their ability to injure or kill the survivor, and the survivor's lack of a means to kill them, it is unrealistic to count on them all as a food source. Historically, survivors have targeted the rodent family (squirrels, muskrats, porcupines, marmots, nutria, rats, and mice) and other smaller mammals, such as rabbits and hares, for food. These animals may be captured or killed with the simple equipment and basic food-gathering skills possessed by any prepared survivor.

Rabbits and Hares

Members of this animal family are found in almost every environment, from the Arctic to the tropics, and have served as the main course for many survivors' dinners. Rabbit and hare populations are cyclic; at the peak of their reproductive cycle, they can be extremely numerous and easy to catch. This is especially true during the winter months, when they pack defined trails through the snow. This is a well-known characteristic of snowshoe hares, which are found throughout the northern portions of the United States, Canada, and Alaska.

Some people are reluctant to eat rabbit. This preference is sometimes based on cultural traditions. In the West especially, rabbits are thought of as "Easter Bunnies" or as "pets" and not as a food source. Additionally, because rabbit meat is not a common product for sale in the supermarket, people conclude that it is not a "good" food item. In other parts of the world, rabbits and hares are accepted meat sources. They certainly should be welcomed as a food item by a survivor. As with most wild animals, they contain very lean, high-protein, low-fat meat.

Simple loop snares described later in this chapter are an effective means to procure rabbits and hares. Properly set out in large numbers (at least 15 snares for every animal you expect to catch), loop snares work constantly for the survivor while other tasks are being accomplished. Rabbits and other small animals usually die quickly when caught in a snare. However, if the animal is found to still be alive when the snare is checked, it can be killed quickly by striking its cranium with a stout stick or by dislocating the neck vertebrae. Dislocating the vertebrae can be quickly accomplished by lifting the animal by its hind legs and then forcefully striking its neck directly behind the ears with the stick. Unconsciousness and death result instantaneously.

Once dead, the animal is suspended head-down by tying a line to one of its rear legs and then tying this line to an anchor (Figure 90-25). To remove the hide, begin tearing the skin away from legs and tail and then proceed to separate it from the body

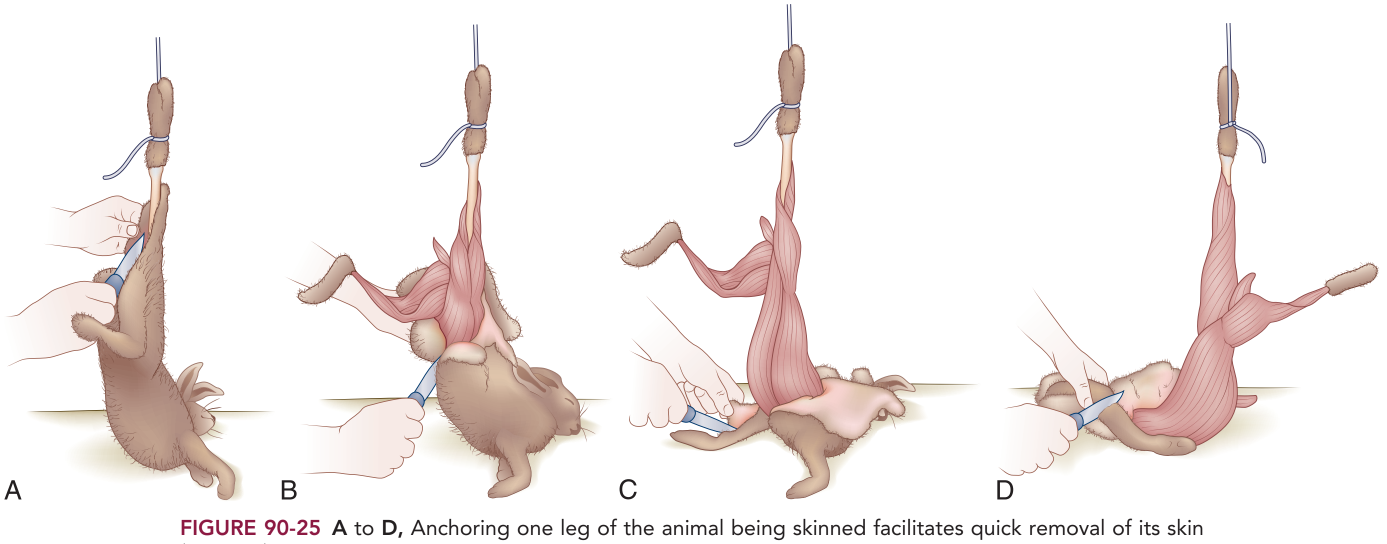


FIGURE 90-25 **A** to **D,** Anchoring one leg of the animal being skinned facilitates quick removal of its skin (see text).

by working the pelt over the forelegs and tearing it free from the front feet. Peel the hide free from the body until the only remaining attachment point is around the animal's neck. Use a knife to sever any remaining neck tissue and cut between the vertebrae if necessary. The hide can also be quickly removed from the body by cutting or tearing the skin at the midbody point and then grasping each side and pulling in opposite directions. Discard the head, hide, and feet. Lacking a knife, one can separate the head from the remainder of the carcass by grasping the head in one hand and the carcass in the other and pulling in opposite directions.

Once the skin is removed, the rabbit's entrails need to be removed. Open the abdomen by cutting through the belly muscles along a midline incision extending from pelvis to sternum. Without a knife, the skin and belly muscle tissue can be opened by tearing it with your fingers. Once this is done, locate and carefully remove the bladder intact, especially if it contains urine. The remainder of the internal organs, including the lungs and heart, can then be lifted out of the abdominal cavity and from within the chest walls. A minimum of cutting is necessary with a knife, but if one is not available, these organs can also be torn out. The carcass should then be washed with water (if available) and wiped free of any residual blood or other body fluids using a cloth or available vegetation.

Rabbits, hares, and other small animals are usually cut into pieces before cooking. However, in a survival situation, the animal can be left intact and cooked whole using the cooking methods described later in this chapter. Cooking the meat preserves it and provides the survivor with the option that portions not immediately consumed can be saved for later meals. Generally, the heart, liver, and kidneys are not eaten. However, there is no reason not to consume these organs, especially when food is limited. These organs and the head should be retained and added to any other available ingredients for a "survival stew."

Rabbits and hares are susceptible to tularemia and parasites, so if any snared animal appears to be in poor health, sluggish, or behaving unnaturally, the animal should not be handled or consumed. Rabbits and hares are also well known for serving as hosts to fleas and ticks, both of which will leave the host's body soon after it dies. It may be a good idea not to handle a freshly killed animal extensively for several hours. If you allow the animal to cool, pests will vacate the body.

Rodents

Despite the common aversion to eating rodents such as rats and mice, they can be an easily attainable and a valuable food source in a survival situation. They are widespread in distribution, usually found in large numbers, and can often be procured without the need for complex trapping procedures. Rodents commonly available to survivors in North America include squirrels (both ground and tree squirrels), porcupines, beavers, nutria, muskrats, groundhogs, prairie dogs, marmots, and a wide variety of rats and mice (Figure 90-26). Of this list, the only rodents that North Americans generally accept as food items are members of the tree squirrel family, which are frequently hunted and eaten, particularly in eastern parts of the United States. Groundhogs in the southeastern United States and prairie dogs and marmots in the West are still considered appropriate food. In other parts of the world, particularly developing nations, other types of rodents, including rats and mice, are used as a good source of protein. Other than our prejudices against eating rats and mice, there are no differences between types of rodents as to their edibility. They can all be used as a food source.

Rodents are prepared using the same procedures as those used to prepare rabbits and hares. With larger rodents, especially beavers and porcupines, the skin is tough and firmly attached, so removing it requires a sharp knife. When skinning a porcupine, considerable care should be taken to ensure that the sharp quills do not cause injuries. Puncture wounds caused by porcupine quills are painful and tend to become infected.

Larger Mammals

Large mammals may be available to a survivor, but lack of a rifle or shotgun usually limits sources to the smaller animals. It might be possible to salvage meat from the remains of larger animals that have been killed by predators or that died from natural causes. However, great care should be taken to ensure that predators are not in the vicinity when approaching a carcass. Most predators, particularly bears and mountain lions, will attempt to cover the remains of their kills or claimed animal carcasses with vegetation and soil. Covering the remains hides it from other predators and scavengers. A disturbed area surrounding a mound of earth and vegetation should serve as clear warning to the human survivor that a predator is nearby, and the area should be avoided.

FIGURE 90-26 Rodents. **A,** Red squirrel. **B,** Uinta ground squirrel. *(Courtesy Peter Kummerfeldt.)*

BIRDS

Birds are found in every environment and vary in weight from ounces to many pounds. Although all birds are edible, a number of species are not particularly appetizing. Birds that feed on fish and other aquatic animal life, as well as those that feed on carrion, are generally not considered desirable to eat. They can be eaten if no other food is available and if the survivor can tolerate the unpleasant odor and disagreeable taste of the meat. Skinning, rather than plucking the feathers, on these birds can reduce some of the unpleasant taste.

Because domesticated versions of wild birds make up a considerable portion of the meat eaten in a typical American diet, survivors are less likely to experience food aversion if they use birds as a food source. Wild game birds (turkeys, grouse, ducks, and geese) are similar to the domestic versions. Species of birds belonging to the gallinaceous (chicken-like) family (e.g., grouse, pheasant, chukar, turkey, and partridge [Figure 90-27]) are often included in the diets of survivors. In remote areas where there is little contact with humans, ruffed grouse, spruce grouse, and ptarmigan in particular are very trusting in their behavior and may allow a person to approach close enough to catch them by hand. In less remote regions where they are more wary, these

FIGURE 90-27 Grouse, ptarmigan, pheasant, and other gallinaceous birds often allow a person to approach closely. *(Courtesy Melissa Anderson.)*

birds can still be killed or captured relatively easily using techniques described later. Waterfowl, such as ducks, geese, and swans, are another group of birds that have helped to sustain survivors. Waterfowl are much more cautious and generally will not allow a person to approach. However, in the spring, when waterfowl molt and are unable to fly, they can be chased down and caught by hand or driven into nets erected close to the ground. They also can be killed or captured using the equipment and survival methods of gathering food described later. The families of birds collectively referred to as "game birds" provide much more meat by weight than do the nongame species. This is primarily because they have developed large breast muscles, or pectorals, which account for about 15% to 20% of the bird's weight. Smaller birds of the songbird varieties are edible, but when the feathers and internal organs are removed, not much meat remains.

All birds' eggs are edible (Figure 90-28), and if collected early in the incubation process, can be consumed in the same manner as a chicken egg. If incubation has progressed to the point where a "chick" has formed, the egg may still be eaten. However, to avoid aversion to this food source, the contents of the egg may have to be added to a "survival stew." Determining the state of maturation of the eggs in a nest is a difficult process. If a nest is located, leave the existing eggs in place, marking each egg if possible with a pencil mark or mud smear. On returning the following day, it is easy to determine which eggs are the newly laid ones. Any unmarked eggs should be "fresh" and can be cooked in the same manner as any domestic chicken egg. Always leave a few eggs in the nest to encourage the parent birds to return.

FIGURE 90-28 Wild turkey nest. All birds' eggs are edible and are best eaten before the embryos have developed. *(Courtesy Peter Kummerfeldt.)*

Preparation of birds for consumption is straightforward. Most methods used to catch a bird also result in its death. However, in the event that a bird is captured alive, the simplest method to kill it is to cut off the head after stunning it with a solid stick. Birds can be either skinned or plucked. Grouse, turkeys, pheasants, and other "chicken-like" birds are easy to skin, whereas ducks and geese should be plucked. Once waterfowl are plucked, the remaining pinfeathers can be singed off by holding the carcass over the flames of a fire.

Having skinned or plucked the bird, cut off the head, neck, feet, and wings. To remove the internal organs, create an opening from the vent to the middle of the breast cartilage. All the viscera can be extracted through this opening by inserting a hand or fingers, depending on the size of the bird, into the cavity. Tear loose the organs from their attachment points in the abdomen and thorax. Some birds use a crop to store food until it is transferred to the gizzard, where it is ground into pieces small enough to be digested. The crop is located in a V-shaped cleft in front of the breast and is easily removed by separating this food-filled pouch from the carcass by either pulling it or cutting it free with a knife. Once the feathers and the internal organs are removed, the outer body and interior should be thoroughly washed to remove any remaining blood or other body fluids that contribute to putrefaction.

An alternative method to quickly separate the "meatier" portions of the bird from the carcass without a knife is demonstrated in Figure 90-29. The bird's breast is first exposed by tearing through the skin. The bird is then placed on its back on the ground. Place a foot on each wing and pull the breast free from the rest of the carcass by grasping it with both hands and pulling firmly straight away from the back.

Birds can be cooked whole or in pieces using any one of the cooking methods described later.

INSECTS

The practice of entomophagy, the eating of insects, is well established in many parts of world, especially developing countries in Africa, Asia, and Central and South America. In these regions, insects have long been considered either a staple part of the diet or a delicacy. Although insects are not a component of a typical American diet, they can provide a valuable food source for the survivor. More than 1400 varieties of insects found around the world are edible.[17] Among those more commonly eaten by humans are grasshoppers, crickets, ants, beetles, butterflies, moths, dragonflies, and termites (Figure 90-30).

Not all insects are edible. Some contain powerful pharmacologic toxins that would cause significant illness if consumed; some insects (and other arthropods) can cause physical harm to the survivor. Spiders, scorpions, centipedes, millipedes, bees, hornets, and hairy caterpillars should be avoided. Because some insects harbor internal parasites, it is best to cook all of them before eating.

Advantages of eating insects include the following:

- Insects are usually easy to find.
- No sophisticated equipment or special skills are required to gather insects.
- Insects are often found in large quantities.
- Insects are nutritious and provide fats and proteins.
- Insects do not require extensive preparation before consumption.

Grasshoppers, crickets, and locusts are found throughout the world in a wide variety of environments (Figure 90-31). More than 1000 species of grasshoppers are found in North America. Grasshoppers contain 40% to 50% protein[19] and are best collected in the early morning when cold temperatures make them lethargic and easy to catch. Once captured, they should be left in a container overnight to purge. Then the head and any attached viscera, the smaller forelegs, the distal section of the hind legs, and the wings are removed before cooking. The insects can be

FIGURE 90-29 **A** to **E,** Removing the breast and leg meat from a grouse without using a knife. *(Courtesy Melissa Anderson.)*

FIGURE 90-30 Salmon fly. More than 1400 species of insects found around the world are edible. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-31 Grasshoppers are among the most commonly eaten insects. *(Courtesy Peter Kummerfeldt.)*

placed in the coals of a fire and roasted until crisp or baked in hot sand beside or below a fire. Grasshoppers can also be roasted by skewering several on a stick and holding them over the flames of a fire. A stew can be produced by adding grasshoppers and edible vegetation to a pot of boiling water and cooking them until the vegetation is tender. Crickets are prepared and cooked in the same way.

Termites can often be collected in large quantities, drowned in water, sun-dried, and then roasted over low heat. Prepared in this manner, they will keep for many months.

Butterfly and moth larvae are rich in protein (37%) and fat (13.7%) and are edible. The larvae can be roasted over a fire or boiled and then roasted.

Earthworms should be placed in water and allowed to purge before they are consumed. Once purged, they should be dried in the sun or over low heat and then added to other ingredients of a survival stew.

Beetles and beetle larvae are edible and are eaten around the world nearly as often as are grasshoppers and locusts. The insects should be roasted in the coals of a fire and then consumed. The indigestible head, legs, wings, and wing cases are best removed before the insect is cooked.

Snails are edible, easy to collect, and simple to prepare. Dropping snails into boiling water and allowing them to blanch for about 5 minutes facilitates removal of the meat from the shell. Snails can be eaten "as is" or added to a survival stew.

Ants require no preparation other than removing the mandibles before they are eaten.

REPTILES

Reptiles include turtles, terrapins, snakes, alligators, crocodiles, and lizards. Because they are cold blooded, some of these animals hibernate and consequently are not available year-round.

Turtles have long been used as a food source. With the exception of a few species, all forms of sea turtles, freshwater turtles, terrapins, and land tortoises are edible. Musk and yellow mud turtles both have glands that produce a strong-smelling scent and because of this are unsuitable for food. Turtles found in North America, including the alligator snapping turtle and common snapping turtle, are all considered good to eat. The alligator snapping turtle can weigh up to 200 lb (90.7 kg), and the common snapping turtle can weigh as much as 50 lb (22.7 kg).

The only practical way to kill a turtle is to cut off its head. The next step is to cut off the feet. This involves three steps: (1) with a sharp knife, cut the skin free from the shell around each leg, the neck, and the tail; (2) peel the skin free from each leg and the neck; and (3) sever each leg and the neck free from the body. The remainder of the edible portions of the turtle contained within the shell can then be withdrawn through one of the openings. With soft-shell turtles, the ventral shell can be separated from the dorsal shell by cutting through the tough cartilage that holds the two shells together. This exposes the internal organs, which can then be removed. Using a knife, separate the meat from the bones and trim off any fat as you do so.

Lizards, which vary in size from minute geckos to crocodiles more than 6 m (20 feet) long, are all edible. From a practical point of view, the smaller varieties provide little nourishment, so survivors are well advised to focus their attention on larger, more common species. Some lizards, such as the Gila monster found in a few southwestern U.S. states and the Mexican beaded lizard found in Mexico, have a venomous bite and should not be pursued as a food source (Figure 90-32). When catching other species of lizard, no special care is required. However, although they may not be venomous, they still can bite, and some have claws. Preparing lizards for a meal requires a sharp, strong knife. If it is not already dead, kill the lizard by cutting off its head. Open the abdomen and thorax to remove the internal organs. The feet should be removed and carcass rinsed with water. A lizard's skin is very firmly attached to its body and can be difficult to remove unless pieces of the body are boiled for at least an hour. Once cooked in this manner, the skin separates from the body without difficulty. The lizard can be consumed after this or, to improve the flavor, can be roasted over the coals of a fire.

FIGURE 90-32 Because Gila monsters are venomous, they should not be considered a food source. Other, nonvenomous species can be eaten. *(Courtesy Peter Kummerfeldt.)*

Alligators, crocodiles, and caimans, the largest members of the reptile family, are dangerous to humans and should not be considered as food unless they are small and can be handled safely. Small alligators and crocodiles can be caught by hand (Figure 90-33). They should be prepared in the same manner as other lizards. Most of the edible meat available from alligators and crocodiles is located in the tail and along either side of the spine. Because female crocodiles guard their nests and are very protective, caution should be exercised when attempting to catch small crocodiles or when attempting to gather crocodile eggs from the nest.

Snakes, both venomous and nonvenomous, are edible. One should proceed very cautiously when attempting to capture and kill a snake for food. A snake is best killed by pinning it to the ground with a long stick and then cutting off its head with a sharp knife. Take care not to be bitten and envenomed by a severed head. To remove the animal's skin, make an incision beginning at the vent and extending the full length of the body. By tying a piece of string to the snake's body at the head end and pulling against this anchor, the skin can be easily and quickly removed. A second slit is then made to access the snake's internal organs. These should be removed. Cook 2.5- to 5-cm (1- to 2-inch) sections of the snake using any of the techniques described later.

AMPHIBIANS

Frogs found around water throughout the United States are all edible. However, as a general rule, only the larger species provide sufficient meat to justify the effort expended in pursuing them. Brightly colored frogs found in Central and South America are highly toxic and should be avoided. The most efficient method of catching frogs is to "gig" or spear them using a two- or three-pronged spear point attached to the end of a 1.8-m (6-foot) or longer pole. Frogs can also be caught using fishing

FIGURE 90-33 Small crocodiles may be easy to catch and can be eaten. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-34 **A** to **D**, Scaling and cleaning a fish. *(Courtesy Peter Kummerfeldt.)*

line and a hook baited with an insect. Catching frogs by hand should be avoided because this method expends far more energy than is returned by the relatively small amount of flesh provided. To kill a frog, sever the spinal cord behind the head with a sharp knife and then remove the skin. Cut off the feet and discard them. The frog's meaty hind legs are the parts usually eaten, but the entire carcass, once skinned, has good food value. Frogs are best soaked in cold water for several hours and then cooked.

Toads secrete a toxin through their skin and are considered inedible. Unlike frogs that are most frequently found around riparian areas and waterways, toads are dry-land animals. Use this habitat preference as a differentiator when collecting frog-like animals for food.

FISH

Of all the animals available to a person trying to live off the land, fish are likely to be the most abundant and easiest to catch. They are also one of the few relatively available sources of fat—a food component not present in large quantities in any of the other smaller land animals that a survivor is likely to procure. Fish are often available year-round and can be caught using less sophisticated equipment than that needed to procure landforms of animal life. Fish of many species can be found in almost every water system throughout the world. Few bodies of water are completely barren.

All freshwater fish are edible, even varieties that are not usually used for food in North America, such as carp, suckers, and gar. Because fish tend to decompose quickly, they are best eaten soon after removing them from the water. All fish should be cooked before eating because some species are known to carry parasites, such as the *Anisakis* worm. This includes both freshwater and saltwater varieties. Depending on the species, scaling a fish is usually the first step in preparing it for a meal. Scaling is best done using a knife and scraping the skin from the tail toward the head of the fish. In some species, including trout, the scales are very small and do not need to be removed before cooking. Other species of fish, such as catfish, are better skinned. A cut is made through the skin behind the gills completely around the body of the fish. The skin is then pulled from the body until only the white flesh remains. A Leatherman multitool or a similar tool with pliers jaws is particularly helpful in accomplishing this task.

With all the scales or skin removed, the viscera are removed by opening the abdominal cavity and removing all the internal organs. Once they are removed, a dark band of material is visible lying along the spine just below the vertebrae. This material, the posterior kidney, must be removed, which is usually accomplished by slitting the membrane that covers the kidney and scraping it out using a thumbnail or a sharpened end of a stick (Figure 90-34). Rinse the cleaned fish with water to remove all remaining blood, slime, and other materials to enhance flavor and delay putrefaction. Be especially careful when cleaning all spiny-rayed fish (e.g., bass, perch, catfish) because the spines in their fins can cause puncture injuries that may be painful or easily become infected. Do not eat the head, spinal cord, or liver of tropical fishes, and become familiar with unusual forms of seafood poisoning, such as occurs from eating puffer fish (see Chapter 78).

CRUSTACEANS

Crayfish inhabit most water systems, both still and moving, throughout much of North America. They can be gathered by turning over rocks in a river or by dangling bait, such as a piece of meat, into the lower levels of a waterway. Crayfish are attracted to the scent given off by the meat and will grab it with a powerful claw and hang on until lifted from the water. Other than pulling off the head after it has cooked, no additional preparation is needed for this food source. They can be dropped into boiling water and left until they turn red. When no container is available, crayfish can be cooked in the coals of a fire. Most edible meat will be found in the tail, with small portions also found in the large claw.

MOLLUSKS

Freshwater mollusks, commonly called mussels or "freshwater clams," live in many freshwater systems and are easily collected by hand. All varieties are edible. Although mollusks are very "chewy," they are nutritious, filling, and easy to gather. They must be thoroughly boiled to destroy harmful organic life absorbed by the animal. Certain shellfish should be avoided during toxic seasons and conditions (see Chapter 78).

METHODS OF PROCURING ANIMALS FOR FOOD

Snaring is one of the most productive methods available for procuring animal food. Snaring techniques for animals, birds, and fish are fairly easy to learn, require a minimum of equipment, and most importantly, once set up, continue to work while the survivor is busy performing other tasks. Although there are traps that will kill or hold large animals, such devices usually require considerable energy and expertise to assemble. Survivors should concentrate their efforts on catching small mammals, birds, and fish, which usually are more abundant, less wary, and require less complicated techniques for capture.

Simple Noose Snares

The simplest form of snare is a noose made from wire, fishing line, cable, parachute line, or other similar material placed over the entrance to an animal's burrow, along its trail, or near a watering or feeding area. The snare must be securely anchored so that when the animal is snared around the neck, foot, or body, it either dies from strangulation or is held in place until the device is checked. In many parts of the world, a simple loop snare is a wildlife poacher's method of choice for illegally procuring animals. This effectiveness makes use of a simple loop snare the food procurement method of choice for survivors trying to live off the land. Successful snaring depends on a person's knowledge of the animals' habits, ability to read signs left by the animals, ability to construct snares from available resources, and knowledge about where one is most likely to catch an animal. Snaring efforts should be focused on larger members of the rodent family, such as tree squirrels, ground squirrels, marmots, muskrats, woodchucks, porcupines, and prairie dogs. A word of caution: this family of animals, deer mice in particular, is a known host for fleas that transmit a variety of infectious agents (see Chapter 45).

For the inexperienced survivor, setting out many simple noose snares provides the best opportunity to procure food. First, construct an "eye" in the end of a length of wire by twisting the wire back around itself several times. Twist the loop that is created into a figure-8 and then bend the upper loop into the lower loop as shown in Figure 90-35. The opposite end of the wire is then passed back through the eye, forming a loop that is adjusted according to the size of the animal being sought. Although simple loop snares can be made from many materials, soft brass wire, aircraft safety wire (0.51 mm [0.02 inch]), or braided picture-hanging wire are best (Figure 90-36). Picture-hanging wire, floral stem wire, and bead wire are available from many hobby shops and are sold either by the pound or by the spool in a variety of gauges; 13.5 m (15 yards) of 24-gauge wire should be included in a survival kit. This wire is strong, flexible, and difficult for an animal to gnaw through when trapped. The wire should be supple enough to shape into a loop, yet stiff enough to retain the loop shape when it is positioned. Simple loop snares made from string, parachute line, shoelaces, and other similar materials may work, but more often than not, the animal is able to free itself and escape before the snares are checked. When materials other than wire are used, noose snares must be checked at least three times a day (morning, noon, and evening) to kill any snared animals that are still alive before they are able to chew through the noose and escape. When wire is used, the trap should be checked in the morning and in the evening. Commercial snares, which could be included in a survival kit, are available. Because they use a locking mechanism that only slides one way (tighter), they are even more effective than those that might be improvised (Figure 90-37).

It is important to study animals in the area. Look for their signs, such as dung, footprints, food remnants, den sites, hair, or other indicators of their movement or presence. Try to determine

FIGURE 90-36 Suitable wire for snares can be found in hobby shops, automobile parts stores, and picture-frame galleries. *(Courtesy Peter Kummerfeldt.)*

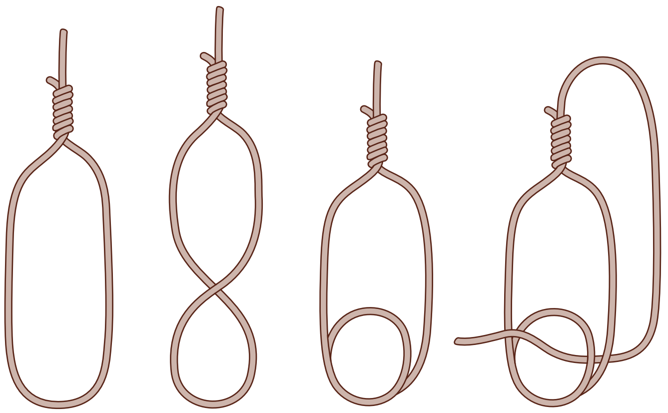


FIGURE 90-35 Snare wire "eye." Twist the loop into a figure-8, and then bend the upper loop into the lower loop as shown.

FIGURE 90-37 Unlike an improvised wire snare, Thompson Self-Locking Snares have a locking device that prevents an animal from escaping once it is held. *(Courtesy Peter Kummerfeldt.)*

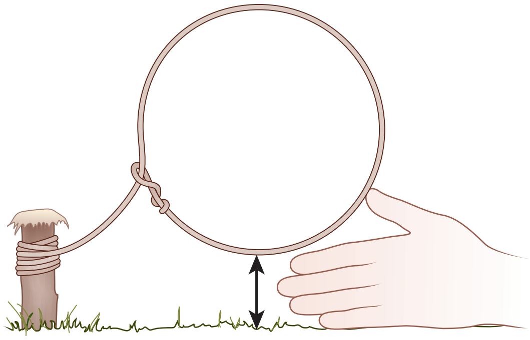


FIGURE 90-38 A rabbit snare loop should be about 10 cm (4 inches) in diameter and positioned 3 to 4 fingers-width above the ground.

their size, time of day they move, height above the ground they carry their head, size of their head, and other useful information that might assist in their capture. When constructing the snare, the size of the loop should be large enough to pass over the animal's head, but not so large that the animal can pass right through the loop. For a rabbit or hare, the noose should be fist-sized, and the lower edge of the loop should be placed 3 to 4 fingers-width above the ground (Figure 90-38). The wire should be secured to a nearby branch or stick, which prevents the animal from leaving the area once held by the snare. As the animal moves down the trail or emerges from or enters a den, its head passes through the noose, which tightens around its neck (Figure 90-39). The animal usually will lunge forward in an effort to free itself, and thus be strangled. During the summer months, it may be difficult to clearly identify where animals are moving. Because of this, it may be more appropriate to identify burrows or feeding areas in which to place snares (Figure 90-40). Using vegetation to hide the snare and funnel animals into it increases the catch rate. During the winter months, squirrels, rabbits, and hares often use the same trail through the snow as they move from one location to another. These are ideal sites to position loop snares (Figure 90-41). The packed trail guides a rabbit or squirrel directly into the loop. Once held, depending on the temperature, animals usually cool quickly and die. It may be necessary to thaw out a carcass before it can be skinned.

It is wise to situate snares in a pattern, known as a *trap line*, so that they can be easily found when checking for snared animals. Tying a flag to a nearby branch also expedites locating a snare, especially after snow has fallen. Knowing where each snare is located saves energy otherwise wasted in hunting for difficult-to-find snares, and also reduces the likelihood of contaminating the area with human scent, which may discourage animals from moving through the locale.

It is possible that a captured animal will be found still alive and only restrained by the noose. In this situation, it must be dispatched as quickly and humanely as possible. The expedient way to accomplish this is to use a stout club and strike the animal's head forward of the ears on the upper surface of the skull. Once is usually sufficient, but check for signs of life before

FIGURE 90-39 A snare should be situated on a game trail, preferably in a location that is naturally confined.

FIGURE 90-40 In the summer, it may be difficult to tell where animals are moving. Locate their burrows or dens and place snares in the entryway. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-41 During the winter, snowshoe hares pack very distinct trails in the snow. These are ideal places to locate one or more snares. *(Courtesy Peter Kummerfeldt.)*

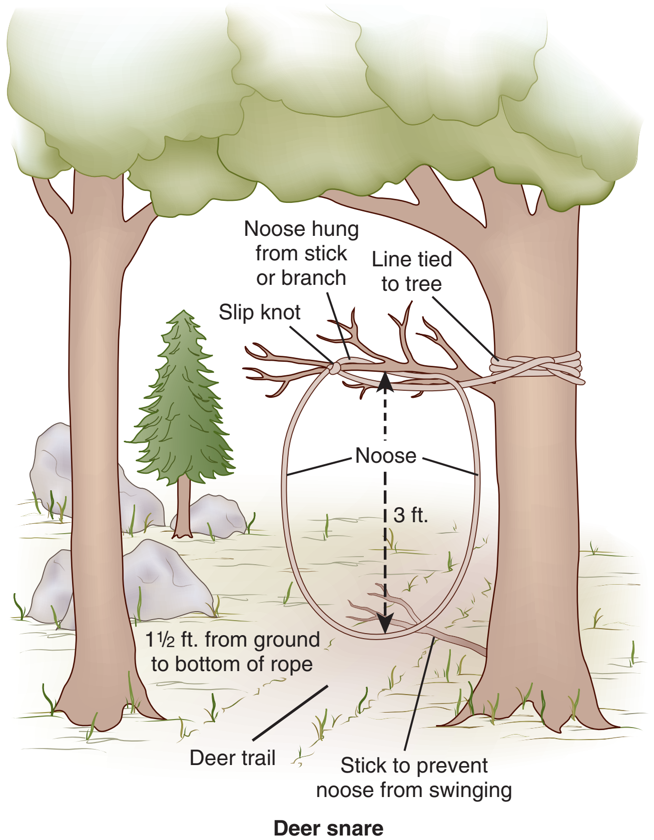


FIGURE 90-42 Parachute cord or similar material can be braided to make a snare that is strong enough to hold larger game.

handling the carcass. A second blow may be necessary. Be careful, because any animal, regardless of size, can inflict a serious bite if handled.

For larger animals, a stronger noose is necessary. This can be made by twisting two strands of wire together and then forming a loop from the doubled wire, or by using nooses made from braided parachute line or similar materials. Tie a secure fixed loop in the end of the line using either an overhand loop knot or a bowline and then position the loop over a game trail (Figure 90-42). Tie the opposite end to the trunk of a nearby tree or stout overhead branch. It may be necessary to use vegetation to hold the noose open when using very supple materials. A good rule of thumb is that it will take at least 15 snares to successfully catch one animal.

An animal may escape after being snared. It may be caught by one or both hind feet and may manage to escape by twisting the wire until it breaks. Predators, both four-legged and winged, will quickly find and eat a snared animal, leaving little for the human survivor. This is another reason why it pays to check traps frequently. Also, the loop may be disturbed or moved out of place without catching an animal. This usually happens because the snare has been set too close to the ground or the loop is too small. As with virtually all skill development, practice builds proficiency.

Baited Snare

A simple loop snare with a long line attached to the end can be positioned where animals or birds are feeding. Bait is placed within the circumference of the snare. When the animal (or bird) steps into the noose, the watching survivor pulls the loop closed. Many nooses attached to pegs can be placed throughout a feeding area where birds or animals congregate. As they feed, their legs become entangled in the snares. A snare could also be placed where an animal would have to reach through a noose to retrieve bait and become snared as it did so.

FIGURE 90-43 A wire noose attached to the end of a long stick is an effective device for catching birds, lizards, fish, and snakes.

Noose Stick

A noose made from wire or nylon monofilament can be attached to the end of a pole, then passed over a bird's head and pulled tight to capture it. This method of snaring birds is most useful when trying to catch any of the grouse family (ruffed grouse, sage grouse, dusky grouse, spruce grouse, and ptarmigan). These birds can often be approached very closely and will allow a noose to be passed over their head. The noose stick can also be used to catch lizards and other reptiles (Figure 90-43).

The noose stick can be made in two ways. Construct a noose about 15 cm (6 inches) in diameter, and attach the opposite end of the wire or monofilament directly to the end of a pole by wrapping the wire around one end of the pole several times and then around the main body of the snare to secure it (Figure 90-44). The distance between the pole and the noose should be about 25 cm (10 inches). To catch a bird, the noose is passed over its head, and when the pole is lifted, the bird strangles. The second method requires a longer piece of wire, or a combination of a wire noose and other line. The end of a piece of wire or line is wrapped around the end of the pole and secured (Figure 90-45). The opposite end of the wire is then passed back under the wraps, and a noose is created. To use this method, the noose is passed over a bird's or lizard's head, or even around a fish, and then closed by pulling on the end of the wire.

Squirrel Pole

Using a single strand of brass or steel wire, make a small loop about 6.35 cm (2.5 inches) in diameter in one end of the wire and attach the opposite end to the lower side of a 1.8-m (6-foot)–long pole (Figure 90-46). Snares are situated every 20 cm (8 inches) along the length of the pole, with the lower edge of the

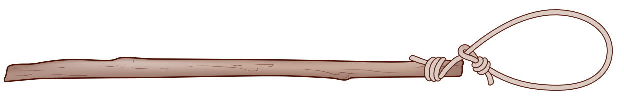


FIGURE 90-44 Noose stick with slip loop.

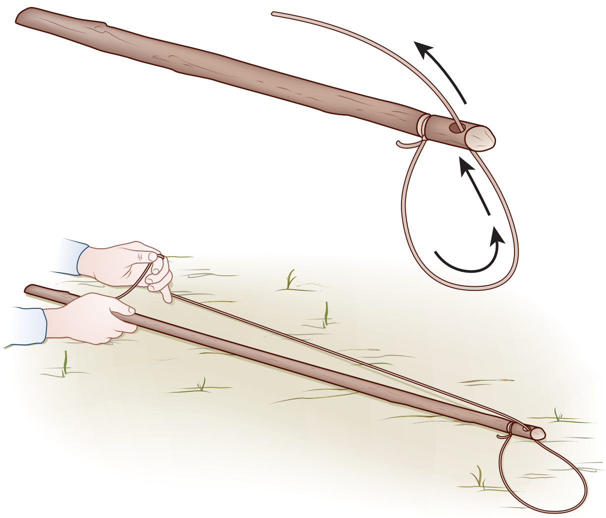


FIGURE 90-45 An alternative method of assembling a slip loop.

loop positioned about 5 cm (2 inches) above the limb. The pole with the attached loops is then leaned against a tree or used to bridge a space between two trees where squirrel activity has been observed. Squirrels are inclined to take the line of least resistance and will run up, down, or across the pole. Once they become snared in a loop, they usually fall off and are strangled. To condition the squirrels to use the pole, it can be prepositioned before attaching the snares for several days. Once the animals become accustomed to taking the shortcut, the snares can be attached. The wire snares should be long enough so that when snared, the squirrel hangs well below the pole and is unable to reach up and grasp the underside of the pole or to touch the ground with its hind legs when hanging. It is quite common to snare several squirrels at a time by using this method. They are inquisitive animals and will investigate another squirrel that has become snared and become trapped themselves in one of the remaining snares. A series of loop snares placed along a tree limb will work in the same fashion as the squirrel pole.

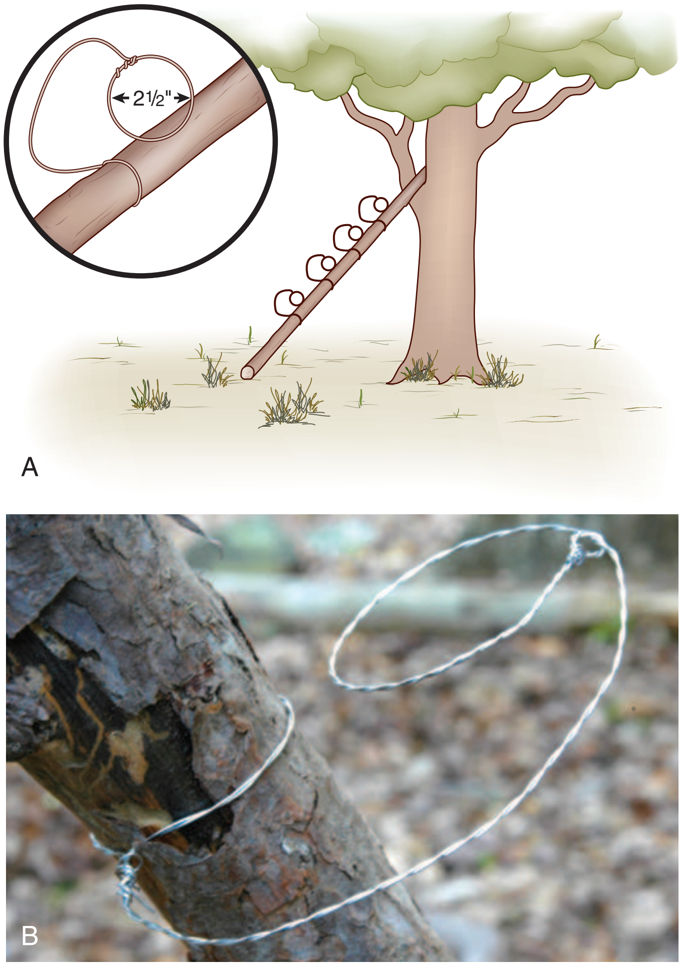


FIGURE 90-46 Squirrel pole. *(Bottom courtesy Peter Kummerfeldt.)*

FIGURE 90-47 Sim Lovejoy "flip" or catapult. *(Courtesy Mr. Sim Lovejoy.)*

Catapult (Slingshot or Flip) Hunting

In its simplest form, a catapult, or "flip" as it is known in the southeastern United States, consists of a Y frame made from wood or metal with two pieces of surgical tubing tied to each end of the fork and a soft leather pouch attached to the other end of the surgical tubing pieces (Figure 90-47). Although catapults are often called by the misnomer "slingshot" in some regions of the United States, a catapult should not be confused with a sling, which consists of two long thongs attached to a leather pouch. Placing a golf-ball-sized stone in the pouch, the pouch and thongs are twirled overhead, and when one of the thongs is released, the stone is launched toward a target. With a catapult, which is much easier to use and much more accurate than a sling, the projectile is launched by stretching surgical tubing and then releasing the pouch propelling the projectile toward the target.

A properly constructed catapult is one of the best weapons available with which to gather animal food. Catapults are relatively small devices; are powerful, accurate, and inexpensive to make or buy; and use projectiles that can be picked up from the ground. With practice, a person with a catapult is quite capable of killing any of the smaller animals and birds that the individual is likely to encounter.

Commercially available catapults come in many varieties, including the simple forked-stick type and "hi-tech" versions that are even equipped with laser sights (Figure 90-48). Catapults that come with a folding handle are especially suitable for inclusion in a survival kit. Perhaps the best option available is to preassemble the surgical tubing and leather pouch or to buy commercially available catapult replacement parts and include those

FIGURE 90-48 Commercial "wrist rocket" style of catapult. *(Courtesy Peter Kummerfeldt.)*

in an emergency kit. A forked stick is then cut on-site to assemble the catapult (Figure 90-49).

The catapult user will quickly realize that should the surgical tubing snap when under tension, facial or eye injuries may result. The use of protective eye equipment is highly recommended. Inspect the condition of the tubing frequently when using the catapult, and replace it immediately if any sign of deterioration is present.

FIGURE 90-49 Catapult parts can be placed in a survival kit and then assembled on-site. *(Courtesy Mr. Sim Lovejoy.)*

FIGURE 90-50 Firing a catapult. Eye protection is advised. *(Courtesy Peter Kummerfeldt.)*

Although it is possible to kill larger animals with a catapult, more suitable-sized targets include rabbits, hares, squirrels, and most birds. With animals of this size, clean, humane kills can be made out to ranges of about 25 m (~27 yards). For the inexperienced catapult hunter, closer is always better. Many animals, especially those not traditionally hunted, will allow a person to get close if the approach is quiet and slow. Rabbits, grouse, and pheasants in particular are inclined to stay put, giving the hunter an excellent opportunity to get within range before taking a shot. This is especially true in remote parts of the country where animals that are not commonly pursued allow much closer approaches than they might in an area where hunting is frequent.

For a right-handed person, the catapult is grasped in the left hand. A projectile is slipped into the pouch and held in place using the thumb and index finger of the right hand. When the target is within range, the pouch is held at the anchor point, which is usually the base of the ear, the bend of the jaw, or the corner of the mouth. The left arm is extended, stretching the rubber between the pouch and the frame (Figure 90-50). Stretching the rubber produces the energy needed to launch the projectile toward the target and kill the animal on impact. The target's head is centered in the V of the catapult's frame, and when it is properly aligned, the pouch is released. As the pouch is released, the left wrist is rotated forward, or "flipped," to avoid injury to the hand holding the catapult frame. If hit, the animal is usually killed outright, but if only stunned, it can then be dispatched by striking it on top of the head with a stout stick.

Suitable projectiles, or rocks about the size of an average marble, can be difficult to find in the field. However, they may be acquired along riverbanks or along the shoreline of lakes, where the erosive action of water produces smooth, round stones.

Freshwater Fishing

As a general rule, the survivor should focus efforts on catching smaller fish rather than the larger ones. Smaller fish are not as wary or conditioned and are more likely to be caught using improvised fishing equipment. They are also less likely to break improvised fishing equipment.

When the rules that limit how fish can be caught in a recreational setting are preempted by the priority of surviving, a person can take advantage of otherwise-illegal techniques such as gill netting, spearing, and snaring. These are methods that require uncomplicated, simple equipment. They are techniques that can be used with little practice and that offer the best chance of procuring food. In a survival situation, the simplest fishing techniques are usually best.

Although it is possible to improvise fishhooks from many materials, the results are often crude and too large for most freshwater fishing and are not strong enough to withstand the

FIGURE 90-51 Commercial survival fishing kit. *(Courtesy Peter Kummerfeldt.)*

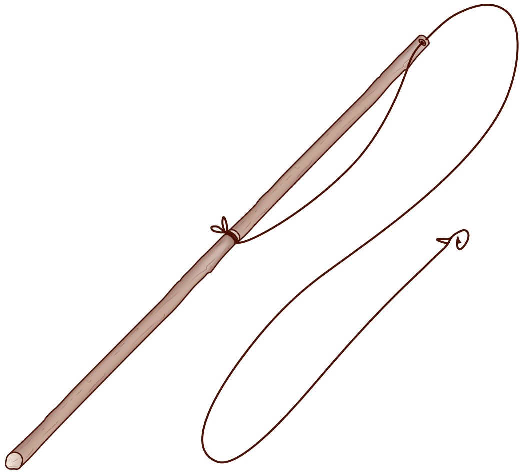


FIGURE 90-52 Improvised fishing pole.

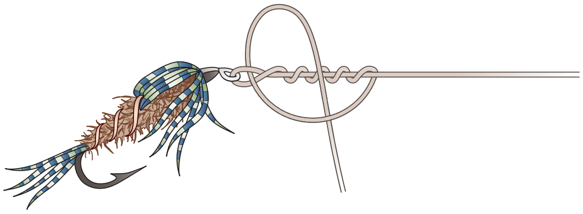


FIGURE 90-53 Improved clinch knot.

struggles of a fish trying to escape. Fishing line can be improvised by unraveling clothing, twisting fibers from various plants together, or using other available line. However, the effectiveness of improvised fishing line is far inferior to the quality and strength of monofilament line. For these reasons, commercial fishing equipment, including line, hooks, split shot, flies, lures, and a commercial fish spear point or a trident frog gig, should be parts of every survival kit. Prepackaged, commercially assembled emergency fishing kits are available (Figure 90-51). These come in varieties suited for saltwater fishing or use in lakes and rivers.

Pole fishing allows the user to reach out from the bank and place a baited hook exactly where it is most likely to attract a fish. For trout and similar-sized fish, cut a pole 1.8 m (6 feet) long with a 2.5-cm (1-inch)–thick butt from willow, alder, or other similar shrub. The size of the targeted fish determines the thickness of the pole needed, whereas the springiness of the material selected reduces the chance of the line breaking as the fish struggles to free itself. The line, which should be one and a half times the rod length or slightly longer, is attached at two points. The first attachment point should be the midpoint of the pole and the second at the tip. In this way, if the tip of the pole should break as a fish is being landed, the line is still attached at the lower point, and the fish, along with the hook and line, is not lost (Figure 90-52). When tying on a hook or lure, use a clinch knot (Figure 90-53).

Bait can usually be found either in the water or in the surrounding area. Try to determine the types of natural foods that the fish are eating by examining the stomach contents of the first fish caught, and if possible, use these same foods for bait. Examine the underside of rocks lifted from the river for any insect life. Most of the insects observed will be very small, but some are large enough to be gathered and then impaled on a small hook. Aquatic insect life can also be gathered by seining the water with an improvised net, such as one made from a shirt (Figure 90-54). Stand on the upstream side of the net, and disturb the streambed with your feet. Insects washed free from the gravel will be flushed into the waiting net. This method usually produces larger aquatic life that can be used for bait. Other insect life suitable for bait, such as grasshoppers, crickets, and worms, can usually be found along the lakeshore or riverbank.

FIGURE 90-54 Seine net improvised from a shirt.

In moving water, it is usually best if the bait is cast upstream and allowed to drift with the current along the streambed. This simulates a free-floating insect or one that has fallen into the water and drowned. At the end of the drift, the bait is removed from the water and recast to a new drift line. This cast-and-retrieve process is repeated until a fish is caught. In still or slow-moving water, a bobber made from a piece of wood or other buoyant material should be used with the bait suspended below it. The distance between the bobber and the bait is adjusted until a bite is detected. Because 98% of fish feeding is below the surface, position the bait close to or right on the bottom of the river. A fish taking the baited hook will disturb the bobber, which is the primary indicator that there is a bite or hooked fish. The line is lifted quickly and the hooked fish removed from the water. To ensure that the fish is not lost, place an improvised net below it or use an improvised gaff to assist in recovery of the fish. Sliding the fish up onto the bank rather than lifting it from the water will reduce the chances of the line breaking and the fish escaping with the fishhook. In most situations, flies or bait fished below the surface will catch more fish than those presented on or closer to the water surface.

An improvised **dip net** is a very useful food-gathering tool. The net can be used to scoop up speared fish, to land those caught on a hook and line, or even to catch fish at a constricting point in a waterway. Small fish can often be caught using a dip net improvised from a shirt. Two poles attached to the sides of a shirt can be used to scoop out minnows and other small fish (see Figure 90-54).

Hand fishing works well in smaller, shallower rivers where fish take shelter beneath undercut stream banks, under sunken logs, and around other river debris. When hand fishing, the person enters the water some distance above the spot where undercut banks are likely to shelter fish. Moving downriver, the person muddies the water and drives the fish downstream. Concentrating the fish in this way increases the odds of catching one. The individual then lies on the bank above a likely hideout and, moving slowly so as not to scare the fish, reaches into the water and carefully feels for any fish that may be present (Figure 90-55). Most fish, trout in particular, will tolerate being lightly handled. When the person touches the smooth skin of the fish, it is quickly pinned to the underside of the bank or to the bottom of the river, and then, when the body is firmly grasped, the fish is flipped out onto the bank. Trying to grip the fish by the gills or some other part of its anatomy underwater is usually not successful.

Other hand fishing methods include "noodling," whereby the person reaches into underwater holes in the riverbank or under sunken logs for catfish. Once a fish is detected, the person grasps its lower lip or gills and hauls it from the water. This process is not without risk because the resting areas favored by catfish are also those favored by turtles. This can result in a nasty bite. In the United States, catfish habitat is also water moccasin (cottonmouth snake) habitat.

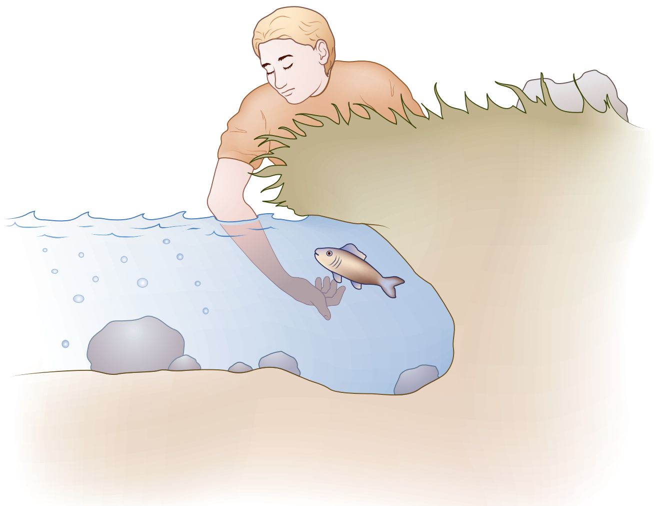


FIGURE 90-55 Hand fishing.

FIGURE 90-56 Fish or frog trident points, also called "gigs." *(Courtesy Peter Kummerfeldt.)*

Spear fishing is an effective technique available when fish are found in large schools or dense concentrations that make hitting a target much easier. Spear fishing is also a useful technique where fish can be seen, but the water is too deep for hand fishing, or where fish are too wary to be approached closely. In addition to fish, spears can also be used to procure a variety of other animals, such as frogs, lizards, and snakes. Although spear points can be improvised, the success of spear fishing largely depends on the availability of a commercial spear point. A trident point is one of the most versatile food-gathering devices available to the survivor and should be included in a survival kit (Figure 90-56). The spear point is easily attached to one end of a 2.4-m (8-foot)–long pole using a small nut and bolt (which usually come with the trident when purchased) inserted through the holes in the spear point and through the shaft of the spear.

Even though a commercial spear point may not be available, it may be possible to improvise one from available pieces of hardwood. Sharpen the end of the shaft with a knife and then harden it by turning the now-pointed end in the flames of a fire. An improvised spear should be used to impale a fish, pinning it to the river bottom, and then lifting it out by hand. Although many fish will escape this method, some will die from their injuries and may float to the surface, where they can be recovered.

To use a fish spear effectively, hold the spear point just below the surface of the water rather than standing poised with the spear held over the shoulder while waiting for a fish to come by. Placing the spear point just below the water surface reduces the aiming problems caused by water refraction and greatly increases the odds of striking the fish.

The fisherman moves slowly from a downstream position toward a resting fish or waits patiently for a fish to come within range. When within reach, the fish is impaled with a quick strike and pinned to the river bottom. Rather than lifting the fish directly from the water using the spear point, thereby risking not only the loss of the fish but also the spear point, reach down and grasp the fish with your free hand and lift it while it is attached to the spear point.

Hand line fishing greatly extends the reach of the fisherman. Many yards of line can be wrapped around a line holder, which is then unwrapped before the fisherman casts a baited hook into

FIGURE 90-57 Beverage can hand line. *(Courtesy Peter Kummerfeldt.)*

FIGURE 90-58 Improvised gaff made from a large fishhook. *(Courtesy Peter Kummerfeldt.)*

the water. Hand lining requires a substantial weight attached to the line to pull the baited hook out into deeper water, where it is allowed to remain until located and taken by a fish. When hand line fishing, the line is held in the fingertips awaiting the feel of a fish taking the bait, when the line is withdrawn quickly and the fish hooked. With a fish on, the line is quickly retrieved hand-over-hand until the fish is landed. When casting, as the bait is thrown, line control can become a problem, so tangles are common. This problem can be resolved by winding the line around the base of a beverage can or similarly shaped smooth object. The base of the can is then pointed toward the open water, and the line is cast. The weight pulls the line off of the can, and the baited hook flies out free of tangles (Figure 90-57). As the line is retrieved, it is once again wound onto the can until the next cast is made.

With **snaring,** as with snaring land animals, a wire loop attached to the end of a stout pole can be used to catch fish. Select wire that is strong enough to overcome the struggles of the snared fish (or, if limited in choice of wire, select smaller fish). The wire must also be supple enough to close quickly but stiff enough to retain the loop as it is passes through the water and over the fish's body. Attach one end of the wire to a 1.8-m (6-foot)–long pole, and create a loop in the other end large enough to pass over the head of the fish. The distance between the end of the pole and the loop should be about 30 cm (12 inches). The fisherman then approaches a resting fish from directly behind (downstream) and slowly passes the noose over its head, moving the noose toward the fish's midsection. With some fish, it may work better to pass the noose from behind and over the fish's tail. When positioned properly, the pole is then lifted, tightening the noose, and the fish is removed from the water.

Gaffing involves a large fishhook lashed securely to a long pole, which can be used to snag a resting fish and lift it from the water. To prevent the loss of the hook, should the pole break when landing larger fish, attach a length of line to the hook eye and tie it off to the stronger midpoint of the pole (Figure 90-58). Gaffing is particularly effective when fish are confined and can be approached carefully from the bank or by wading. Approach the fish slowly from downstream, and when within reach of the gaff, place the hook close to a "thick" part of the fish and strike upward quickly. Expect the fish to struggle vigorously and attempt to free itself from the hook. As quickly as possible, remove the fish from the water and strike its head above the eyes with a stout limb to kill it.

The methods discussed to this point require the active participation of a person. Sometimes, considerable amounts of energy can be expended using these techniques. These methods also expose a survivor to existing weather conditions, contact with cold water, and depending on the fishing methods used, risk for becoming hypothermic. From a survival perspective, better fishing techniques would reduce the amount of energy expended by the survivor, reduce exposure to inclement weather conditions, and limit contact with cold water while increasing the chances of catching a fish. The following are examples of passive fishing techniques that, once constructed, work for the survivor with little further expenditure of energy.

Given the time, materials, and ability, it is possible to improvise a **gill net.** However, it is much wiser to include a small (1.21 m × 3.66 m × 6.35 cm [4 feet × 12 feet × 2.5 inches]) commercially available gill net in a survival kit (Figure 90-59). The net can be used to trap fish and can also be erected on land to trap small animals and birds. Floats, made from pieces of wood or other buoyant material, need to be attached along the length of the upper edge of the net, and weights, made from stones, attached to the lower edge. Some experimentation will be necessary to find a balance where the floats remain on the surface while the stone weights fully extend the net into the depths of the water. It is better to use many smaller stones as weights than to use a few larger ones. The net is then placed in still or slow-moving water, anchored, and left to trap passing fish (Figure 90-60). The net can also be placed in a naturally constricted location or in a narrow point in the waterway created by the survivor from logs and rocks. To expedite catching fish, a person

FIGURE 90-59 Commercial survival gill net. *(Courtesy Peter Kummerfeldt.)*

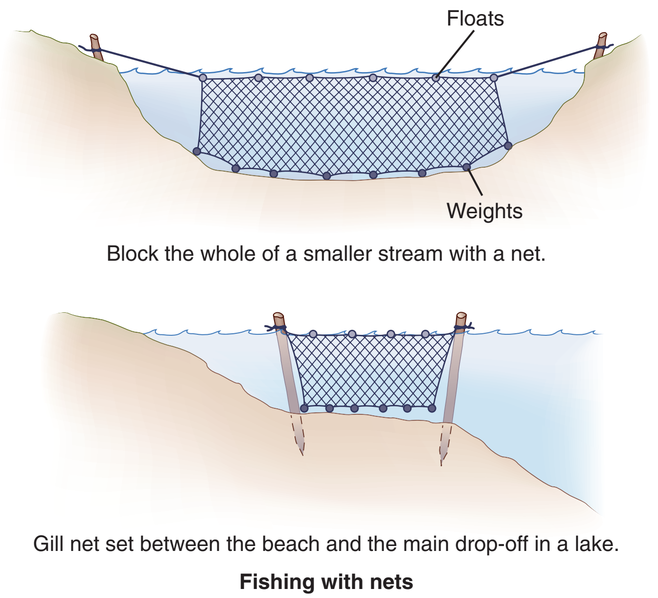


FIGURE 90-60 Setting a gill net to catch fish in slow-moving or still water.

would enter the water upstream of the net and move noisily downstream, scaring fish into the trap. Gill nets used in moving water must not be left in the river unattended. Debris floating downstream will collect in the net and soon destroy it. The net should be checked at least once a day and more often if the floats are seen bobbing or being drawn underwater, indicating trapped fish or river debris entangled in the net.

Set lines are usually a single hook attached to a length of line. One end is tied to an anchor onshore, and a baited hook is tied to the other end, which is cast into the water (Figure 90-61). The line can also be tied to a branch or other similar anchor point overhanging the water. The branch serves as a "fishing rod" and plays the fish until the fisherman retrieves it. Multiple set lines placed along a riverbank or along a shoreline provide the best opportunity to catch fish with the least amount of energy expended. Lines with multiple hooks attached along the length of the fishing line can also be assembled and used to catch fish. Commercial "trigger" devices, such as Speedhooks (Figure 90-62), greatly improve the fisherman's chances of hooking a fish. These devices are spring-loaded and automatically set the hook when a fish nibbles the bait. Set lines should be checked several times a day to rebait any empty hooks and to remove fish that have been hooked before other predators eat them.

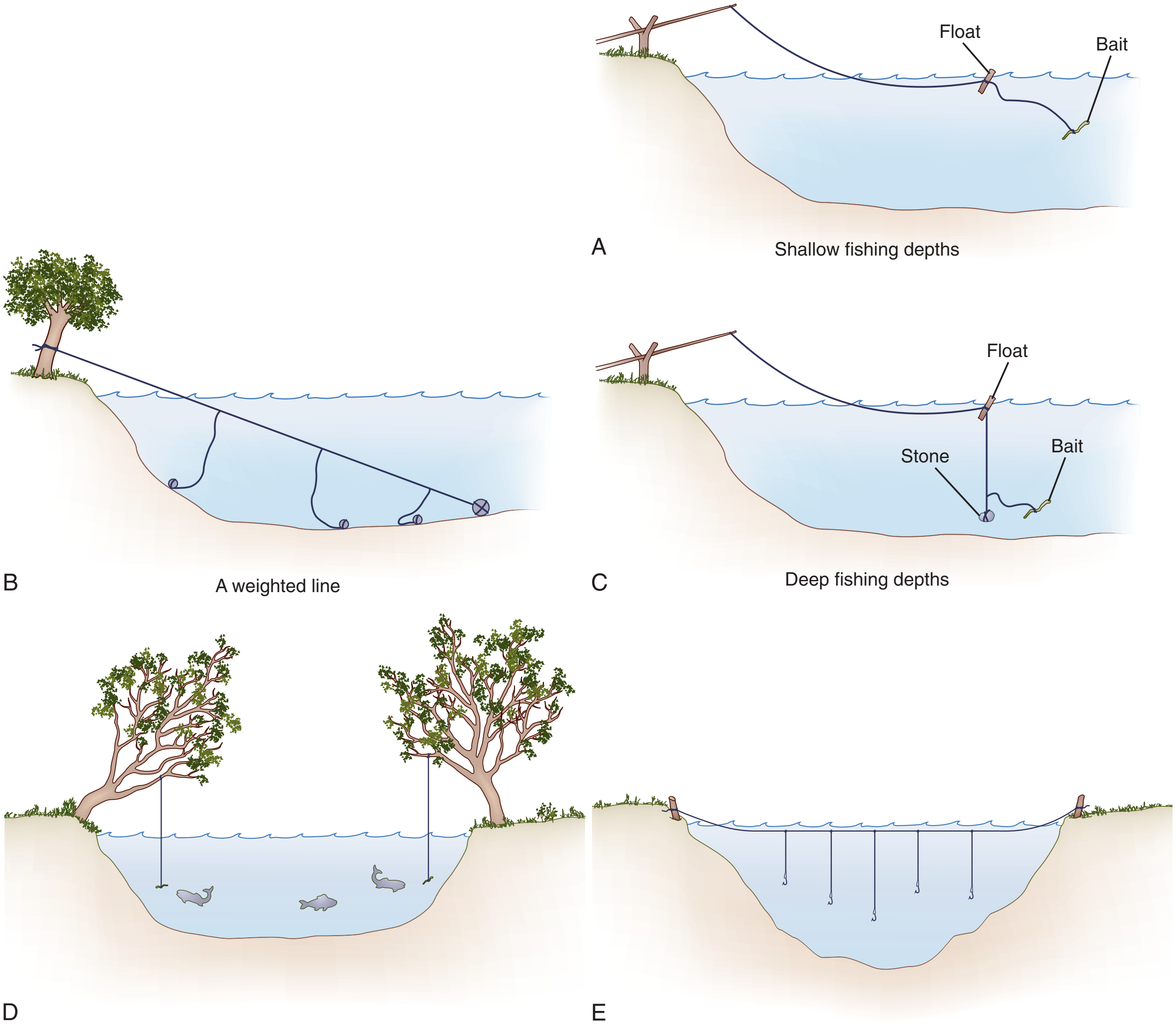


FIGURE 90-61 **A** to **E,** Set lines.

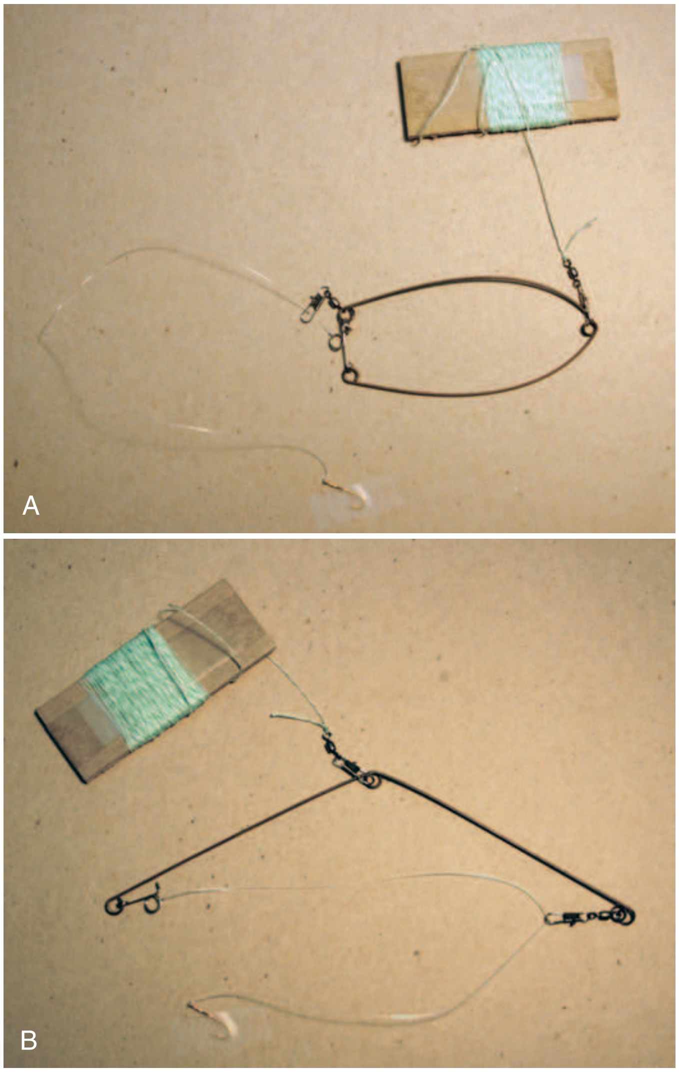


FIGURE 90-62 Commercial Speedhooks. Set position **(A)** and sprung position **(B)**. *(Courtesy Peter Kummerfeldt.)*

Survival Firearms

Having a firearm—rifle, shotgun, or handgun—with you in a survival event greatly increases your chances of becoming a more effective "hunter-gatherer." There is a big difference between trying to kill a rabbit 20 yards away with a slingshot and killing it with a .22-caliber rifle or a shotgun. Firearms eliminate the need to approach close to a potential food source. With a rifle, if one has decent stalking skills, it is possible to approach within the firearm's effective range without the targeted animal being becoming aware of human presence. A person will need to be more active when hunting with a firearm, so it is important to weigh energy expenditure against the caloric return from any animal procured.

With the decision to carry a firearm comes the responsibility to develop the proficiency necessary to be safe and to acquire adequate marksmanship and hunting skills. With good coaching, the degree of skill needed to become an accurate shot with a rifle can be achieved relatively quickly. The degree of accuracy required with a shotgun is not as critical, so proficiency may be achieved more quickly than with a rifle. The same cannot be said for handguns. To be used effectively as a food-gathering tool, or for personal defense, a handgun requires considerable time at the target range before any reasonable degree of skill can be achieved.

Knowing how to use a firearm safely and effectively is the proper first step. To further increase the possibility of putting food in the pot, it is necessary to study the activities of the animals in the area. Being able to anticipate the behavior of animals increases the chances of being in the right place at the right time. There is no shortcut to achieving this skill. Time spent in the field observing the activities of small game animals that one day might become a meal is time well spent.

A survival firearm intended for food gathering should be lightweight and compact, easy to use, easy to maintain, small caliber, and accurate to about 100 yards (91 m). Using these criteria, the best choices are shotguns and .22-caliber rifles. Because handguns are much more difficult to shoot accurately, they are not recommended as "food-gathering devices."

One of the most useful survival firearms is a combination .22-caliber rifle/20-gauge shotgun (Figure 90-63), such as those made by Savage Arms Company. A .22-caliber barrel is stacked on top of the 20-gauge shotgun barrel. The user can easily choose which barrel to use before pulling the trigger, either a single projectile or a mass of shot to dispatch the animal.

Hunting Guidelines

1. Be careful with any weapon. Despite its small caliber, a .22 bullet can travel over a mile and still cause injury.
2. Keep the weapon in good working order. Pay particular attention to ensuring that the barrel does not become clogged with dirt, snow, or other debris. A blocked barrel may explode, causing serious damage to the weapon and injuries to the user.
3. Limit targets to smaller animals and birds. The .22 rifle or shotgun is quite capable of killing larger animals when bullet placement is perfect, but it likely that the inexperienced hunter will be much more successful procuring rabbits, squirrels, grouse, etc.
4. Do not aim the weapon at any animal unless you are planning to kill it.
5. Get as close as possible to the animal you are trying to kill, increasing the likelihood of a fatal shot.
6. Squeeze the trigger only when the animal is motionless. Do not shoot at moving targets.
7. Fire from the steadiest position available. Always use an available resting object for a prop to steady your aim and maximize accuracy in order to make an effective and humane kill.
8. Hunt within established regulations and hunting seasons; however, if you are in a life-or-death survival situation and need food, it is unlikely that you would be cited for killing an animal out of season.
9. Always make sure to positively identify your target.

Because of the possibility of encountering predatory animals in Canada, Alaska, and some parts of the lower 48 states, the need for a having a survival weapon takes on the aspect of self-defense. In this instance, a handgun of .44 caliber or higher, rifle of .375 caliber or higher, or 12-gauge shotgun with slug ammunition makes more sense. Because calibers such as these tend to destroy too much meat, they are not as good for killing smaller game for food, but they better serve the need of self-defense.

When transporting firearms across state and international borders, comply with all international, federal, and state regulations. The book *Traveler's Guide to the Firearms Laws of the Fifty States* provides a wealth of information regarding travel with firearms within the United States.

WILD PLANT FOODS

Plants have always been valuable sources of food and nutrients. They are readily available throughout most of the world and are often easily procured. Foraging of wild plants, usually considered weeds, has seen people through many wars, famines, and droughts.[10,13] Studies demonstrate that wild plants are a good source of food in survival situations, allowing survivors to perform hard and prolonged physical work during periods of restricted food intake.[13] They can increase daily food mass by fivefold.[15] Wild plants are a critical component for wilderness survival and living off the land.

Wild plants are packed with a plethora of nutrients, particularly B vitamins, ascorbic acid (vitamin C), and antioxidants. Studies show that wild plants have significantly higher nutrient

FIGURE 90-63 **A,** Savage .22/20 gauge "over and under" survival firearm. **B,** Breech showing .22-caliber barrel stacked on top of 20-gauge shotgun barrel. **C,** .22-caliber and 20-gauge ammunition. **D,** Butt plate showing ammunition stored in the stock.

ratios than do cultivated varieties.[5,14,16] It is believed that the longevity factor in the Mediterranean diet may indeed be the consistent and continued dietary integration of wild plants.[22] Of the 80,000 known edible plant species, only about 200 are cultivated regularly, and only three (corn, wheat, and rice) function as staples in modern Western societies.[20]

PROCUREMENT OF WILD PLANT FOODS

When one is harvesting wild plants, careful consideration must be given to identification, procurement, preparation, toxicity, and plant abundance (Figure 90-64). When considering plant abundance, it may once again be best to look at the practices of hunter-gatherers. Scientific analysis has shown that hunter-gatherers likely prioritized the collection of wild plants to provide the greatest ratio of energy capture to energy expenditure, in what has been called "optimal foraging."[3] Optimal foraging would clearly be advantageous to any wilderness survival situation and living off the land.

Before heading into the wilderness, it is wise to familiarize yourself with the types and abundance of edible wild plants that grow in the particular region in which you will be traveling. Because it would be impossible to list the tens of thousands of known edible plants throughout the world, this chapter concentrates only on the most common. Tables 90-2 to 90-6 list some

Text continued on p. 2085

FIGURE 90-64 Gathering blue camas bulbs for a meal. *(Courtesy Peter Kummerfeldt.)*

TABLE 90-2 Temperate Region Wild Plants

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Acer saccharinum *Acer saccharum*	Maple	 Courtesy Denise Martinez.	Sap, young leaves, inner bark	Boil sap to concentrate sugars. Young leaves can be eaten raw or cooked. Inner bark should be boiled. Can also be dried, ground, and added to flour to make bread.
Allium spp.	Wild onion, wild garlic, wild chive	 Courtesy Denise Martinez.	Young leaves, bulbs	All can be eaten raw or cooked.
Amaranthus spp.	Amaranth, pigweed	 Copyright iStockphoto.com/y-studio.	Seeds, young shoots, leaves	Seeds can be eaten raw, cooked, or roasted. Can also be ground into flour. Shoots and leaves can be eaten raw or cooked. Will concentrate toxic levels of nitrates if grown in contaminated soils under drought conditions.

Continued

TABLE 90-2 Temperate Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Chenopodium spp.	Lamb's-quarter, goosefoot, quinoa	 Copyright iStockphoto.com/DaisyLiang.	Leaves, seeds	Leaves can be eaten raw or cooked. Seeds must be boiled to remove saponins.
Cichorium intybus	Chicory	 Copyright iStockphoto.com/BasieB.	Roots, young leaves, flowers, flower buds	Leaves, flowers, and flower buds can be eaten raw or cooked. Roots taste best when cooked in several changes of water.
Cirsium vulgare	Thistle	 From Peterson LA: *A field guide to edible wild plants of eastern and central North America,* Peterson Field Guide Series No 23, Boston, 1977, Houghton Mifflin, color plate 10. Copyright 1977 by Lee Peterson. Reprinted by permission of Houghton Mifflin Company. All rights reserved.	Young shoots, stems, leaves, receptacle	All can be eaten raw or cooked.

TABLE 90-2 Temperate Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Hemerocallis spp.	Day lily	 Courtesy Denise Martinez.	Roots, young shoots, flower buds, flowers	Young roots can be eaten raw. Older roots must be cooked. Young shoots, flower buds, and flowers can be eaten raw or cooked.
Malva neglecta	Mallow, cheeseweed	 Courtesy Denise Martinez.	Young shoots leaves, flower buds, flowers, unripe fruit	All can be eaten raw or cooked.
Medicago sativa	Alfalfa	 Courtesy Denise Martinez.	Leaves, flowering tops	All can be eaten raw or cooked.

Continued

TABLE 90-2 Temperate Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Pinus spp.	Pine	 Courtesy Denise Martinez.	Young shoots, inner bark, male inflorescences, pine nuts, sap	All can be eaten raw or cooked. Inner bark best when gathered early in the year. Pine nuts best when roasted. Sizes differ depending on species. Sap can be used as cough drops.
Polygonum bistorta	Bistort		Roots, young shoots, leaves	Roots are best when cooked. Young shoots and leaves can be eaten raw or cooked.
Portulaca oleracea	Purslane	 Courtesy Denise Martinez.	Roots, leaves, stems	All can be eaten raw or cooked. Best when cooked.
Pteridium aquilinum	Bracken fern		Very young fronds	Cook in several changes of water. Fronds contain ptaquiloside, the high consumption of which has been linked to esophageal cancer.[9] Fronds also contain thiaminase, which destroys thiamine (vitamin B_1) in the body.
Quercus spp.	Oak	 Courtesy Denise Martinez.	Acorns	Some species have sweet acorns, which can be roasted or eaten raw. Most other species have bitter acorns, which are best when chopped and boiled in several changes of water.

TABLE 90-2 Temperate Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Rosa spp.	Wild rose	 Courtesy Denise Martinez.	Petals, rosehips	All can be eaten raw or cooked.
Rubus spp.	Blackberry, raspberry, dewberry	 From Letcher Lyle K: *The wild berry book: Romance, recipes, and remedies*, Minocqua, Wis, 1994, NorthWord Press, p 43. Copyright Larry West.	Berries, leaves	Berries can be eaten raw or cooked. Leaves can be used for tea, although excessive consumption can induce labor.
Rumex crispus	Sorrel, curly dock	 Courtesy Denise Martinez.	Leaves, seeds	Boil leaves in several changes of water. Seeds must be removed from their astringent hulls.

Continued

TABLE 90-2 Temperate Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Sagittaria latifolia	Arrowhead, Wapato	 Courtesy Denise Martinez.	Tubers at end of rhizomes	All can be eaten raw or cooked.
Taraxacum officinale	Dandelion	 Courtesy Denise Martinez.	Roots, leaves, flower buds, flowers	All can be eaten raw or cooked.
Trifolium repens	Clover	 Courtesy Denise Martinez.	Leaves, roots, inflorescences, seeds	All can be eaten raw or cooked. Seeds can also be used for sprouting.
Typha latifolia	Cattail	 Courtesy Denise Martinez.	Roots, base of leaves, young shoots, unripe inflorescences, pollen, seeds	All can be eaten raw or cooked. Remove green outer leaves to find white, tender base. Unripe inflorescences can be roasted like corn on the cob. Seeds can be obtained by removing down.

TABLE 90-2 Temperate Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Urtica dioica	Nettle	 Courtesy Denise Martinez.	Young shoots and leaves	All can be eaten raw or cooked. Protect hands and arms while harvesting to avoid contact dermatitis. Stinging is reduced when nettle is wet. Avoid eating excessive amounts of old leaves because they can lead to kidney lesions.
Vaccinium spp.	Blueberry, huckleberry, bilberry, cranberry	 From Letcher Lyle K: *The wild berry book: Romance, recipes, and remedies*, Minocqua, Wis, 1994, NorthWord Press, p 58. Copyright Brett Baunton.	Fruit	Can be eaten raw or cooked.

TABLE 90-3 Desert Region Wild Plants

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Agave parryi	Agave	 Courtesy Denise Martinez.	Trunk	Dig up trunk before flower stalk appears. Chop off leaves at base and cook for several days. Flower stalk, flower buds, and flowers are also edible. They taste best when cooked.

Continued

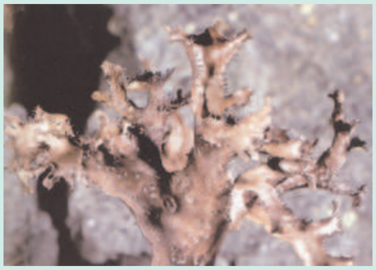
TABLE 90-3 Desert Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Cereus giganteus	Saguaro		Fruit	Can be eaten raw or cooked. Fruit falls to ground when ripe. Use stick to dislodge fruit if still attached.
Echinocactus horizonthalonius	Barrel cactus, visnaga	 From Huey GHH, Houk R: *Wild cactus,* New York, 1996, Artisan, p 23.	Pulp (hydration and food), fruit	All can be eaten raw or cooked. To obtain fluid: chop off top, mash pulp inside stem, and then strain fluid through cloth.
Opuntia ficus-indica	Prickly pear, cholla	 Courtesy Denise Martinez.	Fruit, young joints	All can be eaten raw or cooked. Plant is best gathered with a three-pronged stick. Glochids (bristles) are best removed by rubbing in sand or scrubbing in running water.

TABLE 90-3 Desert Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Yucca baccata	Yucca	 Courtesy Denise Martinez.	Flower stalk, flower buds, flowers, fruit	Flower stalk tastes best when cooked. The remainder can be eaten raw or cooked.

TABLE 90-4 Arctic Region Wild Plants

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Arctostaphylos uvaursi	Bearberry, kinnikinnick	 Courtesy Denise Martinez.	Fruit, leaves	Fruit can be eaten raw or cooked. Leaves can be used to make tea.
Cetraria islandica	Iceland moss	 From Department of the Army: *The illustrated guide to edible wild plants,* Guilford, Conn, 2003, Lyons Press, p 53.	All parts	Boil in several changes of water.
Empetrum nigrum	Crowberry	 From Letcher Lyle K: *The wild berry book: Romance, recipes, and remedies,* Minocqua, Wis, 1994, NorthWord Press, p 141. Copyright Joy Spurr.	Fruit	Can be eaten raw or cooked.
Papaver nudicaule	Arctic poppy		Leaves, petals, flower buds, seeds	Can be eaten raw or cooked.

Continued

TABLE 90-4 Arctic Region Wild Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Salix arctica	Arctic willow	 Copyright iStockphoto.com/RONSAN4D.	Young shoots	Can be eaten raw or cooked.

TABLE 90-5 Tropical Region Plants

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Bambusa spp.	Bamboo		Young shoots	Can be eaten raw or cooked.
Colocasia esculenta	Taro	 Courtesy Denise Martinez.	Root	Must be thoroughly cooked.
Maranta arundinacea	Arrowroot	 Copyright iStockphoto.com/SUSANSAM.	Root	Remove outer skin and cook thoroughly.

PART 13 FOOD AND WATER

TABLE 90-5 Tropical Region Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Psophocarpus tetragonolobus	Goa bean	 Copyright iStockphoto.com/karimitsu.	Young pods, mature seeds, root	Seeds should be parched and roasted. Other parts can be eaten raw or cooked.
Ziziphus jujuba	Jujube, Chinese date	 From Department of the Army: *The illustrated guide to edible wild plants*, Guilford, Conn, 2003, Lyons Press, p 37.	Fruit	Can be eaten raw or cooked. Tastes best when dried.

TABLE 90-6 Sea Plants

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Alaria esculenta	Dabberlocks	 From http://www.surialink.com.	Leaves	Dry in sun or over fire. Crush and make into soup.

Continued

TABLE 90-6 Sea Plants—cont'd

Scientific Name	Common Name	Photo	Edible Part(s)	Special Preparation
Chondrus crispus	Irish moss, carrageen moss	 From http://www.sb-roscoff.fr.	Leaves	Dry in sun or roast over fire. Crush and make into soup.
Palmaria palmata	Dulse	 From http://omp.gso.uri.edu.	Leaves	Dry in sun or roast over fire. Crush and make into soup.
Porphyra spp.	Nori, laver	 From http://www.solpugid.com.	Leaves	Dry in sun or roast over fire.

of the most common edible wild plants that can be found in specific regions of the world and how these plants are prepared. Many of these plants are easy to identify; others will take practice. Take every opportunity to practice identifying edible plants in the wilderness and in the city. Because of the challenges associated with properly identifying mushrooms and other fungi, they have been intentionally left off of the plant list. It is highly recommended that one avoid consuming fungi in a wilderness survival situation.

Understanding plant identification and toxicity is required for consumption of any wild plant. Many plants are poisonous (see Chapter 65). Tasting or swallowing even a small portion can result in severe cramping, diarrhea, rash, intestinal and metabolic disorders, and even death. When in doubt of the potential edibility of a wild plant, look for the common indicators of toxicity listed in Box 90-1.

If you have come across an unknown plant that does not exhibit any of the potentially poisonous characteristics, you can then apply the Universal Edibility Test (Box 90-2). Before testing a wild plant for edibility, make sure there is enough of the plant available to make the testing worthwhile. Test all parts of the plant separately for edibility, because some plants have both edible and inedible parts. Do not assume that a part of a plant that proved edible when cooked is edible when raw. Also, the

BOX 90-1 Seven Common Indicators of Plant Toxicity

1. Milky or discolored sap
2. Beans, bulbs, or seeds inside pods
3. Spines, fine hairs, or thorns
4. Dill-, carrot-, parsnip-, or parsley-like foliage
5. Almond scent in woody parts and leaves (likely contains cyanide)
6. Grain heads with pink, purple, or black spurs
7. Three-leaved growth pattern

BOX 90-2 Universal Edibility Test

1. Test only one part of a potential food plant at a time.
2. Separate the plant into its basic components—leaves, stems, roots, buds, and flowers.
3. Smell the food for strong or acrid odors. Remember that smell alone does not indicate whether or not a plant is edible or inedible.
4. Do not eat for 8 hours before starting the test.
5. During the 8 hours you abstain from eating, test for contact poisoning by placing a piece of the plant part you are testing on the inside of your elbow or wrist. Usually 15 minutes is enough time to allow for a reaction. If there is a reaction, eliminate the plant part as a food option.
6. During the test period, take nothing by mouth but the plant part you are testing and purified water.
7. Select a small portion of a single part and prepare it the way you plan to eat it.
8. Before placing the prepared plant part in your mouth, touch a small portion to the outer surface of your lip to test for burning or itching.
9. If after 3 minutes there is no reaction on your lip, place the plant part on your tongue, holding it there for 15 minutes.
10. If there is no reaction, thoroughly chew a pinch and hold it in your mouth for 15 minutes. *Do not swallow.*
11. If no burning, itching, numbing, stinging, or other irritation occurs during the 15 minutes, swallow the food.
12. Wait 8 hours. If any ill effects occur during this period, induce vomiting and drink copious amounts of water.
13. If no ill effects occur, eat 0.25 cup of the same plant part prepared the same way. Wait another 8 hours. If no ill effects occur, the plant part as prepared can be assumed to be safe to eat.

same plant may produce different reactions in different people. Bees that feed primarily on the nectar of plants (e.g., rhododendron) that are toxic to humans can produce poisonous honey (e.g., "mad honey"). Although this is extremely rare, it is worth noting if you come across a beehive in the wild.

PREPARATION OF WILD PLANT FOODS

Some wild plant foods can be eaten raw or with minimal preparation, but most need to be boiled in several changes of water to render them safe and palatable. Unfortunately, boiling often results in reduction of soluble vitamins and a plant's nutritive value. If you are unable to boil a wild plant, crush the edible plant part, put it in a sock, and securely place it in a running river for 1 or 2 days. This will help leach the astringent and bitter phytochemicals from the plant. You can do this in conjunction with boiling to help reduce preparation time.

COOKING METHODS

When possible, all wild animal foods should be thoroughly cooked before they are eaten to kill any parasites and to make the meat more palatable.

Roasting is probably the easiest way to cook a piece of meat, but is the least desirable of methods because much of the meat's nutritional value is destroyed or drips away when it is cooked in this manner. Despite this, it may be the only method that can be used when no container is available. Skewering the meat on a hardwood stick and then holding it over the flames is an expedient method to quickly cook animals, fish, or insects (Figure 90-65). Choose the stick carefully. Wood that is nonresinous is best because coniferous wood (pines, spruces and firs) may impart an unpleasant taste to the meat while it is being cooked. When using green wood, such as willow or alder, remove the bark before inserting it into the meat. By using wooden pegs, meat can also be pegged onto a slab of wood and placed near a fire, where the radiant heat will slowly cook the meat. In a rare circumstance, the wood may impart a toxin, so be familiar with toxic plants.

If a metal container is available, **boiling** is an excellent method to prepare food for consumption, especially if the broth that is created is also consumed. Alternatively, a bowl can be hollowed out of a piece of wood, which is then filled with water and the food to be cooked. Stones heated in a fire are then placed into the bowl with the food. The hot stones heat the water, and the food is cooked. As the stones cool, they are replaced with more hot ones taken from the fire. Do not use stones taken from a stream bank or other wet areas because they may explode when heated. Water contained in the rocks is converted to steam; the steam expands and explosively fractures the rock.

Baking is another effective way of cooking wild foods because the process is slow and much of the nutritive value is retained.

In *clay baking*, birds (with the feathers on) and fish (with the skin and scales) can be packed in mud or clay and then placed in the coals of a fire to bake. When using this method to cook a bird, the clay must be massaged into the feathers and the entire animal covered with a layer of clay several inches thick. Cooking time depends on the thickness of the clay and the size of the animal being cooked. Sixty minutes is usually sufficient. After this time, the hard clay shell can be broken away, exposing the cooked flesh. The skin, scales, or feathers will come away with the clay, leaving only the cooked flesh beneath.

For an *earth oven*, a hole about 2 feet deep and 2 feet square (or larger, depending on the quantity of food to be cooked) is dug, and a large hot fire is built in the hole. The fire is allowed to burn down until only coals remain and is then covered with a layer of soil. The food to be cooked is wrapped in a layer of cloth or packed in vegetation and placed in the hole. The hole is then filled in with the remaining soil and the oven left for 2 to 3 hours. After the prescribed period has elapsed, the soil is removed, and the package containing the food is carefully lifted out. Be careful when opening the oven because hot soil and steam can cause serious burns. The cooked bundles of meat and vegetation can be very fragile. Be watchful that the food is not contaminated with soil as it is taken out of the oven. Placing the wrapped food in the earth under a burning fire is a variation of this method.

Where the quantity of food is large, or an animal's carcass is to be cooked intact, a larger hole and more heat are required. For a *rock oven*, the hole is lined with rocks, and a fire is built within it. When the fire subsides, a layer of soil is placed over the hot rocks, the wrapped food is inserted, and the hole is covered with soil. Allow at least 2 hours to elapse before opening the oven to determine whether the food is cooked.

The process described above can also be used in a seashore environment. For a *sand oven*, a hole is dug in the sand, lined with rocks, and heated. The food, fish, crustaceans, shellfish, and so forth are wrapped in seaweed, placed in the hole, and left for 2 to 3 hours before removal.

Broiling foods can be achieved by placing a thin layer of flat stones over hot coals and then laying the food to be broiled on top of the stones. Meat can also be broiled by placing it on a flat rock and propping it close to a fire. Radiant heat will cook the meat. It may be necessary to turn the meat over at least once to ensure that both sides are cooked.

BASIC FOOD PRESERVATION

Most foods cannot be stored for any length of time in the wilderness without deterioration in freshness, palatability, and nutritive value. The main causes of this deterioration are microbial growth, enzyme action, and insect damage.[4] Techniques such as drying and freezing can help reduce the causes of deterioration and prolong the time that a food can be saved and eaten.

Of these techniques, drying is probably the most feasible method used in wilderness survival and living off the land. To dry meats, thinly slice them and place them across a stick or on a plank. Place them in a warm area with low humidity. You can also place them in direct sunlight. Turn meats regularly to ensure that the pieces dry throughout. Herbs (leafy plants) can be gathered and bound by their stems and hung upside down. Herbs

FIGURE 90-65 A to D, Roasting a fish on a stick. *(Courtesy Peter Kummerfeldt.)*

are best dried away from direct sunlight. Fruits and vegetables can be cut into small pieces and dried like meats. A screen can be made of any thin fabric, such as a light-colored T-shirt, to reduce the possibility of pest infestation. The screen should be placed so that it thoroughly protects, but does not touch, the drying food. All food should be dried in low-traffic areas free of dust.

If freezing food is a possibility, it is important to wrap the food well before freezing to avoid dehydration and cellular damage.[4] Ideally, the wrapping material should neither crack and become brittle at low temperatures nor absorb water, blood, or oil. Wrap the food with the inside of an animal hide. Foods to be frozen should be buried deeply to avoid the effects of light, changes in ambient temperature, and animal predation.

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