PART 15

Wilderness Equipment and Special Knowledge

CHAPTER 102

Wilderness Preparation, Equipment, and Medical Supplies

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Wilderness travel and recreation expose individuals to illness and injury far from medical care. Travelers must be prepared to diagnose and treat frequently encountered conditions and promptly recognize when illness or injury requires evacuation. Although easily recognized, certain common problems such as blisters and diarrhea may become serious obstacles to a journey. Less frequent, more serious conditions, such as occult infection or internal traumatic injury, may be unnoticed and may threaten life or limb. In the hands of experienced personnel, appropriate trip planning and the correct supplies can greatly reduce morbidity associated with medical problems in remote settings.

This chapter primarily focuses on terrestrial travel and begins with epidemiologic considerations in trip planning. An overview of pretrip preparation includes trip personnel training, strategies for injury and illness prevention, a framework for participant medical screening, and considerations for environmental and activity-specific risks. Potential components of medical kits, strategies for kit assembly, and additional specialized equipment are then discussed. Various medications useful in wilderness settings are reviewed, followed by discussion of common medical problems encountered in the wilderness. The final section provides a sample journey to illustrate key concepts in pretrip planning, illness management, and decision making.

EPIDEMIOLOGY REVIEW

Reviewing available data on injury and illness prevalence during wilderness excursions is an important component of thorough pretrip planning. Given the relatively limited amount of existing data and large regional and temporal variations in these statistics, consultation with prior expedition leaders, local guides, and other first-hand sources specific to the planned trip location and activity are particularly important. The most extensive research to help quantify the statistical risk of injury or illness during different types of wilderness activities has occurred in the fields of high-altitude and dive medicine, with limited studies in other fields,[46] including desert,[48] tropical, and aquatic environments.

Existing data suggest that in remote environments, incidence of traumatic injury (generally of a minor nature) exceeds that of medical illness, and among backcountry fatalities, traumatic etiologies are by far the most common.[13,18,22,25,26,34,47] Data from the U.S. National Park Service (NPS), which include both frontcountry and backcountry data, are consistent with this observation but also suggest that among higher-acuity wilderness medical events, such as those requiring advanced interventions (e.g., IV placement, medication administration, advanced airway management), medical illnesses are responsible for a significant proportion. Between 2007 and 2011, NPS data indicate emergency medical services (EMS) events occurred 64,045 times (45.9 times per 1 million visitors) and were categorized as medical (29%), traumatic (28%), and first aid (43%). The majority (61.4%) of the 1480 fatalities during this period were traumatic; among medical events, 1.8% were cardiac arrests.[11]

Falls, drowning, and blunt trauma constitute the most common causes of wilderness fatalities.[16,22,34] For life-threatening injuries, causes of preventable prehospital deaths include unrecognized trauma, exsanguination, asphyxia (often caused by inadequate airway management) and pneumothoraces. For nontraumatic deaths, cardiovascular disease is responsible for a significant proportion. Recreational activities, such as cycling or use of all-terrain vehicles, has been associated with significantly increased risk of injury.[8] Ice and rock climbing generate a unique array of injuries, including death from severe head trauma.

Common types of nonfatal injury include soft tissue damage (e.g., abrasions, lacerations, sprains), whereas more serious soft tissue injuries (e.g., dislocations, fractures) account for less than 5% of all trauma. The lower extremities are by far the most likely parts to be involved in minor orthopedic injuries,[30] emphasizing the importance of appropriate foot care and footwear selection.

In addition to trauma, wilderness travelers often report medical illnesses attributable to nonspecific syndromes, such as gastroenteritis or upper respiratory infections. These illnesses likely result in part from exposure to new pathogens and from travel conditions that preclude adequate preemptive hygiene measures. Other frequently reported medical problems include headache (exacerbated by high altitude), dyspepsia (from local food intolerance), dehydration, heat-related illness, dermatitis, sunburn, allergic reactions, blisters, and other integument-related problems.[6,16,30]

Environmental causes of illness predominantly relate to high altitudes and extremes of temperature and can generally be avoided with adequate planning and early recognition.[6,16,30,32]

It cannot be overemphasized that prior expedition leaders, local guides, and other first-hand sources can provide the best guidance when preparing for potential backcountry medical challenges, including availability of medications and emergency resources. This is especially true for foreign travel.

GENERAL PREPARATION

Careful evaluations of weather patterns, participant health, planned activities, rescue options, and journey duration are critical to pretrip preparation and can help guide prevention and treatment plans for anticipated injuries and illnesses (Box 102-1).

Prevention is of paramount importance when discussing management of injury and illness during wilderness recreation. Medical care may be greatly delayed, and in certain circumstances, timely, formal medical attention may not be an option.

Mode of travel, destination, duration, environment, planned activities, and the number of persons on any trip can vary to such a degree that, in reality, there is no universal planning strategy. Physicians in the office face the challenge of advising travelers about medicines and medical equipment, knowing that their patients could face decisions they are not qualified or prepared to make. Travelers and their physicians must recognize these limitations and seek appropriate consultation from experienced colleagues as well as from books, wilderness medicine courses, and myriad high-quality Internet resources (see Appendix A in this chapter).

It must be emphasized that regardless of a physician's prior wilderness medicine experience, it is essential to have detailed discussions with expedition leaders and past members regarding occurrence of medical problems, trauma, and utility and local availability of various medical supplies on previous, similar expeditions. Local rangers and EMS personnel can provide valuable information about weather patterns and risks specific to local terrain (e.g., propensity for mudslides, flashfloods, and electrical storms). Climbers and mountaineers will benefit from reading *Accidents in North American Mountaineering,* an annual publication that describes and analyzes climbing injuries and fatalities

BOX 102-1 Pretrip Checklist for General Preparedness

- ☐ Identify and outline trip itinerary.
- ☐ Conduct pretrip medical briefing to advise participants of risks.
- ☐ Ensure physical conditioning of participants is adequate.
- ☐ Ensure medical and dental checkups up-to-date (pretrip health questionnaires).
- ☐ Review immunizations status (specific to region of travel).
- ☐ Review potential injuries and medical conditions relevant to planned itinerary, activities, and participant medical conditions.
- ☐ Review potential rescue and evacuation routes throughout itinerary.
- ☐ Review of historic and current weather conditions (National Climatic Data Center, http://www.ncdc.noaa.gov; the National Weather Service, http://www.nws.noaa.gov; The Weather Channel, http://www.weather.com).
- ☐ Obtain medical insurance with evacuation coverage (where possible).
- ☐ Share itinerary with emergency contacts and necessary authorities.
- ☐ Establish knowledge of available communication and navigation tools.
- ☐ Establish plan for clean water supply (chemical or device disinfection vs. storage).
- ☐ Obtain medical alert medallions or cards as well as emergency contact information as needed.
- ☐ Compile and review equipment and medical supplies (quantity and expiration).

occurring each year in North America (http://publications.americanaplineclub.org).

Familiarity with evacuation resources (e.g., availability of search and rescue teams), communications devices (e.g., satellite phones, cell phone coverage), and navigation devices (e.g., maps, GPS) is an important component of trip preparation. A brief discussion of various communication and navigation devices is provided later in the section on specialized equipment, with a more in-depth discussion in Chapter 106. Using satellite or cell phones to activate a rescue can expedite patient care, but neither device should be regarded as a substitute for proper preparation and sound judgment during wilderness travel.

Rescue services in most mountainous regions outside the United States require accident insurance or a substantial cash payment before helicopter transport. If traveling in these areas, expedition members should work with group leaders to ensure that appropriate rescue and accident insurance coverage is obtained for all travelers. Many insurance companies (e.g., International SOS)[24] exist for this purpose and provide medical evacuation coverage to a hospital for stabilization and then evacuation to the home country. There are also environment-specific medical evacuation options. For example, members of the American Alpine Club receive $5000 of global rescue coverage without altitude limitations.[2] Travelers should also review life insurance, credit card benefits, and personal health insurance policies for both benefits and limitations related to travel and high-risk activities.

Travelers and their physicians should take a proactive and informed approach to the places they will visit. Attention should be given to regional hazards and locally available health resources. For example, drinking water quality and treatment options, endemic infectious diseases, environmental exposures, and venomous animals should all be considered and studied. Foreigners often underappreciate the diversity and burden of endemic infectious diseases. Although infections such as malaria, yellow fever, dengue fever, and schistosomiasis are commonly known, many region-specific endemic viral diseases (e.g., Japanese encephalitis, chikungunya), parasitic infections (e.g., leishmaniasis, balamuthiasis), and devastating bacterial infections (e.g., cancrum oris [necrotizing stomatitis]) are less familiar to many clinicians. For each geographic region of travel, the trip medical officer should take appropriate steps to understand indigenous venomous animals, endemic diseases, including their prevention and treatment, and local environmental hazards, including man-made dangers, such as unexploded ordnance.

Malaria prophylaxis, when required, should be used based on the U.S. Centers for Disease Control and Prevention (CDC) or World Health Organization (WHO) recommendations (Box 102-2). In areas with mosquitoes, persons should carry mosquito nets and insect repellent containing a sufficiently high concentration of *N,N*-diethyl-*m*-toluamide (DEET; this substance can be purchased at up to 100% concentrations at most wilderness stores). Details on malaria prevention, diagnosis, and management should be reviewed before departure to endemic regions (see Chapter 40).

Travelers should receive destination-appropriate immunizations as far in advance of travel as possible. One vaccine requiring significant discussion before administration is rabies vaccine. Within the United States, rabies vaccination is only considered for those routinely exposed in close quarters to specific wild animals (e.g., veterinarians, field scientists handling bats), because (1) the disease burden of rabies is relatively low, (2) the primary animal reservoir is not in urban or domesticated animals, and (3) there is widespread availability of safe, postexposure prophylaxis. When traveling outside the United States to certain resource-constrained regions, especially India and Central and South America, a large reservoir of disease is found in urban dogs, and postexposure prophylaxis may be less readily available. Given rabies' devastating prognosis, an informed decision regarding immunization must be made based on risk of exposure and access to prompt, postexposure treatment. The CDC provides specific information about exposure criteria, postexposure prophylaxis, and recommendations for vaccination[39] (see Chapter 31).

Before the trip, consideration should be given to caffeine, alcohol, and drug dependencies. Management of such dependencies is a sensitive and complex issue unlikely to be satisfactorily resolved in a wilderness setting. Eliminating access to substances to which individuals have chronic dependencies will often cause

BOX 102-2 Guidelines for Travel in Developing Countries

Before Travel

Consult local sources of medical help; the International Society of Travel Medicine Clinic Directory is available by phone request (770-736-7060) or online (http://www.istm.org).

Obtain up-to-date travel warnings from the Travelers' Health section of the Centers for Disease Control and Prevention (CDC) website at http://wwwnc.cdc.gov/travel/.

Consider purchasing the CDC's *Yellow Book,* a reference published every 2 years primarily for health care providers who advise on international travel. This resource can also be obtained in electronic format for Android or iOS devices.

Obtain necessary vaccinations and prophylactic medications (i.e., antimalarials). Recommendations are available from the CDC (http://www.cdc.gov) and the World Health Organization (http://www.who.int). Update vaccinations for tetanus, measles, mumps, pertussis, diphtheria, and rubella as needed.

During Travel

Contact the U.S. embassy on arrival if not registered prior to trip departure. Have extra copies of essential documents, such as passports, passport photo, yellow fever vaccination documentation (where applicable), and itineraries. Carry phrase books and dictionaries with phonetic and native script translations.

Use an insect repellent containing high concentrations of *N,N*-diethyl-*m*-toluamide (i.e., DEET). Formulations approaching 100% (if such are recommended) can be readily purchased. Citronella and other homeopathic remedies for this purpose are not as effective and therefore falsely reassuring.

Avoid ice, unboiled or nonbottled water, and uncooked food.

Take caution when wading or swimming in lakes and canals.

Avoid nocturnal travel and travel during inclement weather.

Do not use unsafe means of transportation (overloaded motor vehicles, vehicles without safety restraints, unregistered or unlicensed vehicles, motorcycles [with or] without helmets).

From http://www.cdc.gov/features/travelershealth.html.

hardship. For example, caffeine withdrawal is a significant cause of headaches among recreational trekkers at high altitude and is often mistaken for a symptom of acute mountain sickness.[17] Strategies for addressing dependencies should be discussed with both the individual member and the group leader. Caffeine and alcohol intake can each result in diuresis and dehydration. Excess alcohol should be avoided because it also causes peripheral vasodilation, which can result in excessive heat gain in hot environments and heat loss in cold or wet environments. Alcohol can also interfere with acclimatization and exacerbate symptoms of acute mountain sickness and should be avoided entirely at altitudes of more than 2438 m (8000 feet). In addition, alcohol's effects on judgment and sensory perception may result in failure to acknowledge early symptoms of environmental illness and may increase risk of injury.

PRETRIP EVALUATION FOR HEALTHY PARTICIPANTS

Regardless of a traveler's overall state of health, all participants in wilderness activities have the responsibility to investigate potential health risks associated with an upcoming excursion and to seek appropriate pretrip medical counseling, preferably from their personal physician.

This discussion provides a potential framework to assist medical personnel and trip leaders in evaluating healthy participants for wilderness travel. It is important for both the travelers being screened and personnel performing the screening to recognize the purpose and limitations of the process. Pretrip evaluation of travelers should not be used to "clear" participants; even the most thorough evaluation cannot absolutely ensure health and safety in the wilderness (e.g., occult coronary artery disease, traumatic injuries). Rather, the pretrip medical evaluation should aim to identify potential harms or risks, ensure all steps have been taken to minimize these risks, and determine if the potential risks are acceptable to the traveler and trip leader.

Medical optimization or harm reduction may occur through fitness training, medication changes, further diagnostic tests, or even by recommending the traveler not participate in the planned activity. These principles apply to evaluation of both healthy participants and those with existing medical conditions.

For our purposes here, "healthy participants" are members of a trip without any known, significant past medical history and who can demonstrate tolerance of activity levels at least comparable to those planned during the proposed trip. It is often a significant challenge to identify correctly participants who are "healthy," and the excellent health of individual participants should not dissuade the expedition medical leader, trip leader, or the participants themselves from completing comprehensive trip preparation.

Each participant must provide a complete medical history, including vaccinations relevant to the area of travel, chronic diseases, history of hospitalizations, surgical history, allergies, medications, and any specific medical concerns (see Appendix B). The designated trip medical personnel or trip leader should gather and review this information and inform prospective participants of potential risks involved with the planned excursion (see Chapter 100). Trip leaders should confidentially, but frankly, discuss medical problems with each participant. This might require a formal pretrip medical evaluation by another physician if any uncertainty exists about the candidate's suitability for the trip. Safety of the individual and group are the coordinator's first priorities.

There are limited data to help guide pretrip screening recommendations for otherwise healthy individuals. Appendix B of this chapter is an example of a pretrip medical screening form that can be used to assist with such evaluation. Although pretrip medical evaluations should involve the participant, participant's primary physician, expedition leader, and designated trip medical staff, ultimately it is the participants' responsibility to pursue adequate pretrip medical preparation and evaluation.

Even the most active and healthy individuals should begin a graduated exercise program at least 2 months before departure to minimize deleterious effects of muscular, metabolic, and mental fatigue inherent to long-distance and remote travel (see Chapter 95). This is especially important for people traveling to high altitudes; aerobic capacity in a sedentary person drops approximately 4% for each 300 m (1000 feet) above the 1200-m (4000-foot) level, but the loss is only one-half as great in an aerobically fit individual.[10,21] Similarly, instruction on careful stretching of muscle groups may increase efficiency and lessen the likelihood of soft tissue injury during exertion and minor accidents, and balance and agility training can be lifesaving in slippery, mountainous environments, such as found in rain forests and mountaineering.

If excessive environmental heat is anticipated, preparatory exercise in a hot and humid environment (this can be simulated with sweat clothing) for 1 hour daily for at least 7 days before departure helps preserve plasma volume (aldosterone effect) and sweat rate while lowering myocardial oxygen demand and sweat sodium content.[14] This acclimatization will be lost within 1 week if not maintained. Such conditioning should be practiced with caution because of the risk for dehydration.

For groups without trained medical leadership, participants should address these issues with their personal physicians before departure, either in person or by questionnaires (see Appendix B).

EVALUATION OF PARTICIPANTS WITH PREEXISTING MEDICAL CONDITIONS

Travelers with complex medical conditions participate in wilderness expeditions, although few data exist to help guide pretrip screening and preparation for these participants.[19] As a general rule, all existing medical conditions should be stable (well controlled), self-managed, and discussed with the participant's personal physician in the context of the planned trip.

Wilderness expedition participants must be encouraged to disclose medical conditions to expedition medical personnel, because existing medical problems can jeopardize not only the health of the affected participant but also that of other party members. Adequate pretrip planning can help mitigate this risk.

Much of the approach to evaluating participants with preexisting medical conditions is similar to that discussed for healthy participants. Once again, these participants should provide a thorough medical history (Appendix B), and the designated trip medical personnel should review this information, perform a thorough evaluation (likely including a physical examination), and inform prospective participants of potential risks involved with the planned excursion (see Chapter 100). Additionally, careful evaluation of the participant's functional status should include a review of daily activity level and ensure the participant is able to demonstrate an activity level consistent with, or in excess of, that required by the proposed trip without worrisome symptoms such as angina, lightheadedness, or severe dyspnea. Any concerning findings during this crucial component of the evaluation may prompt further workup.

Travelers with preexisting medical conditions carry the responsibility to discuss travel plans and request recommendations from their personal physicians (see Chapter 53). The physician should speak directly to the trip coordinator, and vice versa, if there are any doubts about medical suitability for the proposed itinerary. At-risk travelers should wear medical identification bracelets and be required to obtain and manage their own medications. The trip medical provider should know about these illnesses and carry replacement medications provided by these individuals for safekeeping.

Several common medical conditions, such as chronic obstructive pulmonary disease (COPD), asthma, cardiac disease, diabetes, allergies, and seizures, warrant special consideration during pretrip planning. Pulmonary hypertension, recent pulmonary embolism, history of recurrent spontaneous pneumothorax, sickle cell disease, and sleep apnea are considered contraindications to high-altitude travel.

Generally speaking, participants with chronic medical conditions should be encouraged to bring adequate supplies for at least two to three times the planned itinerary length, erring on the side of additional reserve supplies for more severe illnesses.

These participants should also bring necessary supplies for potential exacerbations when applicable (e.g., epilepsy, COPD).

Patients with a history of seizures should continue routine medications and also carry an injectable form of benzodiazepine, such as lorazepam (Ativan). Suppositories (rectal diazepam) are appropriate if the party is traveling in a cool or cold environment or with children (see Chapter 51).

Caution should be taken when travelers with a history of COPD or asthma are attempting high-altitude travel. A plan for rapid descent is essential, because people with asthma and COPD will predictably experience greater-than-normal difficulty as a result of hypoxia and air trapping from high altitudes. Similarly, dry air, exercise, or noxious stimuli (e.g., smoke, red tide) may exacerbate COPD processes.[28] Thus, a plan for rapid treatment should be in place before departure. Exercise in cold, dry air may trigger wheezing. Poor air quality, a byproduct of fossil fuel burning or even remote volcanic activity, along with winds that can "stir up" larger particulate matter such as dust or sand, can also cause irritation. In addition to carrying a β-adrenergic agonist metered-dose inhaler, travelers with COPD or asthma should carry a 2-week course of an oral corticosteroid (e.g., prednisone) plus an appropriate oral antibiotic (e.g., fluoroquinolone, advanced macrolide, or doxycycline). Studies of aircraft pressurized to 2438-m (8000-foot) altitude reveal that people with moderately severe COPD may have significant dyspnea at this attitude. This may serve as a surrogate marker for the altitude to which such individuals can safely travel.[1,7] People with mild to moderate COPD should not sleep above 3048 m (10,000 feet) because of the potential for nocturnal desaturation. The decision to travel to altitude with existing pulmonary disease is multifactorial.[31] Great caution must be advised for patients who chronically retain carbon dioxide, because small changes in the partial pressure of inspired oxygen can cause significant changes in their ability to oxygenate adequately.

Patients with a known history of significant cardiac disease warrant special consideration before participation in wilderness activities (see Chapter 50). All such travelers should undergo evaluations by their primary care and specialist physicians before travel. During travel, these patients should continue routine medications and provide copies of their most recent electrocardiograms to trip personnel (for comparison if evacuated to a facility with ECG capability). These participants also must be instructed when to withhold medications (e.g., not to take diuretics and other blood pressure–lowering medications when lightheaded or feeling weak).

Outdoor adventure travel can provoke angina among people with underlying heart disease. There is continued debate about the evaluation and advice a physician should provide patients with cardiovascular disease. Participants must be aware that no amount of pretrip evaluation, including stress testing or even coronary artery revascularization, can guarantee prevention of cardiac events in the backcountry. For prospective travelers with unstable angina, pulmonary hypertension, congestive heart failure, or obstructive or severe valvular disease (e.g., aortic stenosis), vigorous adventure travel is contraindicated. A traveler with a history of cerebral transient ischemic attacks may be able to participate in outdoor travel if attention is given to proper hydration and use of antiplatelet agents, such as aspirin or clopidogrel (Plavix), or other anticoagulants as indicated and prescribed by the treating physician. As the number of new antiplatelet and anticoagulant medications continues to increase, trip medical personnel must carefully review each participant's medication lists to identify travelers who may be at high risk of occult hemorrhage after trauma.

Diabetic travelers should be instructed to bring an ample supply of their routine medications, a functioning and spare glucose meter, and emergency glucose supply for patients on a regimen other than biguanide-only therapy (see Chapter 53, Table 53-4). Specific recommendations vary depending on the traveler's diabetes type (1 or 2) and medication regimen (e.g., if type 2 with insulin dependence). All diabetic travelers must consult with their personal physician before wilderness travel.

Outdoor travel often disrupts the normal meal schedules of diabetic travelers. Although some individuals need less insulin when participating in high levels of exercise, such as backpacking, this phenomenon is not true for all. Diabetic persons should monitor their blood glucose at least twice a day, regardless of how good they feel, modifying their insulin and eating regimens accordingly. Other group members in close contact with insulin-dependent diabetic travelers should know that the first two interventions for an ill-appearing diabetic person are a small amount of sugar in any form (e.g., juice, granulated table sugar, candy, syrup or honey), orally or under the tongue, and measurement of blood glucose level. For persons taking oral hypoglycemic agents with hypoglycemia refractory to sublingual sugar, injectable glucagon can be a useful adjunct, provided there is the medical expertise to administer it and manage its common adverse effects. During air travel, insulin-dependent diabetic persons should take their daily dose of insulin and eat according to the local time at departure. For a diabetic person traveling eastbound across multiple time zones, the day is effectively shortened. At arrival, the person should eat and administer insulin in accordance with local time but reduce the dose by one-third. For travel westbound, the day will lengthen, and a second dose of insulin after 18 hours of travel may be administered after glucose monitoring, if indicated (see Chapter 53).

Human immunodeficiency virus (HIV) infection does not preclude safe wilderness travel if the HIV-positive person is aware of his or her degree of immunosuppression and pays meticulous attention to water disinfection and pretrip immunizations. The decision for travel must be made with involvement of the patient's personal physician.

During pretrip evaluation, participants should be informed that many prescription drugs can predispose travelers to heat-, cold-, and altitude-related illnesses and to increased risk of dehydration-related emergencies, such as kidney stones or pancreatitis related to some HIV medications. Diuretic use may lead to intravascular volume contraction, impaired heat transfer to the skin, dehydration, and potentially life-threatening electrolyte abnormalities such as hypokalemia. Travelers taking diuretics should carry a packaged electrolyte replacement (i.e., oral rehydration solution) and a source of potassium (e.g., dried bananas, potato chips). The anticholinergic action of antihistamines, phenothiazines, and tricyclic antidepressants may result in hypothalamic dysfunction and diminished sweating with subsequent hyperthermia.

Patients with serious medical allergies or active illnesses should have an appropriate medical identification bracelet, anklet, medallion, or wallet card and should store personal medications in a protected but accessible location in their pack. Patients with a history of significant allergic reactions should carry at least two epinephrine autoinjectors or injectable epinephrine with a needle and syringe (see Bites and Stings, later). At a minimum, for each patient with a severe allergy, a second member of the expedition should be aware of the allergy and its appropriate treatment in case the patient becomes incapacitated during a severe acute allergic episode. Every traveler should carry a complete personal medication list during travel, with both generic and brand names listed.

Travelers who report dental problems during pretrip evaluation should be promptly evaluated by a dentist because untreated dental pathology can become a major obstacle to a successful trip. Travelers should also be advised to see their physicians about known sleep disorders, concerns for jet lag, and existing chronic pain issues before departure.

For a complete discussion of considerations for chronic diseases and wilderness travel, see Chapter 53.

TRAINING IN FIRST AID AND WILDERNESS SAFETY

No medical specialty or training pathway provides all the skills necessary to care for the many potential and real challenges faced during wilderness travel. Many courses and certifications in wilderness first aid and safety exist, with little evidence to suggest superiority of any one training strategy for wilderness first responders.[51] Appropriate pretrip training must be tailored according to personnel background (e.g., physician vs. lay provider), trip duration, and planned activities (e.g., training in mountain rescue).

Large expeditions frequently enlist experienced medical personnel for logistics planning or even to accompany the trip, whereas most small groups trekking into the wilderness do not have access to this expertise. Even when a physician is a party member, he or she may not be specifically trained in wilderness medicine or certified in a field of medicine with skills relevant to manage commonly encountered wilderness medicine scenarios.

For physicians joining expeditions, training and current proficiency in emergency medicine likely provide the greatest breadth of applicable knowledge and skills. Physicians trained in internal medicine or family medicine might provide suitable expedition physicians with adjunctive training or experience. Anesthesiologists (skilled in resuscitation and airway management) might also be able to function in this role and often provide expertise in altitude and diving physiology. In general, current certification (or equivalency) in basic life support (BLS), advanced cardiac life support (ACLS), advanced trauma life support (ATLS), and pediatric advanced life support (PALS) is desirable. Several organizations that support wilderness recreational activities recommend personnel obtain a minimum of Red Cross standard first aid or equivalent as well as certification in cardiopulmonary resuscitation (CPR) appropriate for the age of trip participants (see Chapter 80 for additional discussion of expedition medical officer qualifications).

Before departure, the trip coordinator should review emergency supplies with the group. The person should demonstrate proper use of mechanical devices and discuss medication indications. Groups planning an extended or high-risk outing may want to conduct a mock injury evaluation and management exercise.

Participants should be encouraged to take general courses in first aid and wilderness safety, with attention to the most fundamental skills. Some agencies that offer general and specialized training in skiing, mountaineering, river rafting, and other types of wilderness medicine are listed in Appendix A.

Additional information on training programs for physicians, residents, and medical students as well as nonphysician providers can be found in Box 113-9 in Chapter 113. Locally organized programs may be found through the American Red Cross, sporting goods stores, and continuing education departments of local colleges. Larger organizations, such as the Wilderness Medical Society (WMS), offer regular conferences and workshops nationally as well as referral to a large member community of experienced clinicians, researchers, lecturers, and experts worldwide.

TRIP DURATION AND ACCESS TO MEDICAL SUPPORT

When serious illness or injury occurs, the longer the delay in obtaining advanced medical assistance, the more likely may be the irreversible loss of physiologic function, life, or limb. One must anticipate delays in care when in rural or remote areas, because the nearest physician or hospital might not be equipped to handle a major injury or illness. Furthermore, expeditions with prolonged or limited evacuation options warrant additional consideration for equipment discussed later in this chapter.

Trip leaders and medical staff should be aware of potential evacuation options, including times to the nearest health facilities, throughout the itinerary. Party members should agree in advance about simple emergency distress signals, such as whistle or flashlight signals, to facilitate rescue during the expedition if needed.

Access to timely medical care can significantly impact the immediate treatment plan. For example, when a traveler sustains a deep extremity laceration, the likelihood of infection increases with each passing hour. Clear-cut guidelines used in hospitals to determine if suturing or stapling are appropriate become unclear, including the use of prophylactic antibiotics. If the patient can reach trained and equipped medical help within a few hours, it will suffice to control bleeding, irrigate with any source of potable water, and apply a sterile dressing held in place by improvised cravats or tape. Although not sterile, water reservoirs found in many packs, such as those made by Camelbak, can be used for irrigation when no other options exist (tubing from water reservoirs has also been used to attempt endotracheal intubation). If definitive care is more than several hours away, irrigation with water containing a topical disinfectant may be desirable. If care will be delayed 6 hours or more, a decision must be made whether to close the wound before evacuating the patient (see Chapter 21). Estimated time delay depends on the type of rescue services, method of contact, terrain, weather, and number of able-bodied (i.e., carrying) people.

Manually evacuating a patient is an option but requires a relatively mobile person or generally a minimum of 6 carriers if the person is immobilized. In this regard, it is important to know if other groups might be trekking in the same vicinity. If access is controlled by permit, the administering agency should be asked about neighboring parties' itinerary, which might influence the types of equipment carried if communication is established with other groups before departure. The likelihood of mishap increases as trip duration lengthens; this is partly attributable to unpredictable weather and cumulative effects of fatigue and repetitive strain injuries. In the case of a recognized need for evacuation, medical interventions, such as improvised splints, braces, and crutches, enabling self-rescue (i.e., walking under one's own power, with or without assistance) can make the difference between minor delays and costly, multiday evacuations involving search and rescue teams.

Long trips usually involve extensive planning, significant financial investment, and time away from work and family. Nevertheless, party members may be reluctant to shorten the trip and generally favor continuing in the face of mild medical disability and equipment failure. Groups planning to be away from civilization for more than 1 week should have a maximally diversified list of medical and contingency items.

ENVIRONMENTAL RISKS: WEATHER AND TERRAIN

Weather, terrain, and activity interact to increase the risk for illness or injury. It is essential for expedition medical staff to be familiar with historic and current weather and terrain conditions for planned itineraries before departure.

Particularly hazardous situations include winter climbing, mountaineering, skiing, and travel from low- to high-humidity environments, as in the equatorial tropics. Potential obstacles must be figured into estimates of maximum delay to medical assistance. National and global historic summary data indicating temperature ranges, winds, and duration, type, and amount of precipitation can be obtained from the National Climatic Data Center (see Box 102-2). State and national park services and state climatology offices can also provide detailed information about regional conditions. Local rangers and EMS personnel may provide valuable information about weather patterns and risks specific to local terrain and should always be considered during trip planning. The National Weather Service office nearest the travel site can provide short-term forecasts and in many regions broadcasts weather information between 162.40 and 162.55 MHz VHF (see Appendix A).

Knowledge of terrain and environmental conditions is also essential when selecting everything from socks to sleeping bags. A single manufacturer can easily have dozens of similar-appearing sleeping bags with ratings from extreme cold to warm weather with varying degrees of water resistance. The proper sleeping bag can be very expensive, but choosing the wrong gear for the trip can be even more costly. Chapter 110 provides a dedicated discussion of fabric and clothing selection strategies for wilderness travel.

SUPPLIES, KIT ASSEMBLY STRATEGIES, AND SPECIALIZED EQUIPMENT

There is no universal wilderness medical kit. The only perfect kit is the one that has what you need at the moment you need it. Most commercially available kits charge a premium for packaging and branding. Although packaging and kit organization are critically important, the components of retail kits can usually be purchased piecemeal and assembled for a fraction of the cost. Kits and equipment must be modified for each trip based on factors such as duration, number of participants, planned activities, endemic diseases, environmental conditions, and distance to definitive care. When building a medical kit, it is important to include supplies that do not require expertise beyond the scope of training for available personnel.

This section provides guidance on kit assembly strategies, including what and how much to bring, how to pack and organize, and what specialized equipment is available to address specific environmental hazards. Medications for trip medical kits are discussed later.

STRATEGIES FOR PACKAGING MEDICAL KITS

Medical supplies for an expedition may be divided into five components: (1) personal medical supplies; (2) comprehensive community medical supplies; (3) devices for the medically trained traveler; (4) specialized equipment for particular environmental and recreational hazards; and (5) supplies stored in a vehicle. Strategies for compiling each of these components are discussed later.

A medical kit can be assembled by customizing kits that are already available or by starting from scratch. Budget and time constraints, as well as skill and differing levels of training, influence this process. As skill and experience level lead to increased improvisational ability, travelers will find that the amount of equipment needed and size of first-aid kits may decrease. When assembling a medical kit, it is generally advisable that travelers not bring equipment (including medications) that requires skill, knowledge, or licensure beyond that which is immediately available. Inappropriate management of injury and illness can be more harmful than sticking to basic interventions or doing nothing at all.

As with any area of wilderness medicine, resourcefulness and opportunism may be helpful for packing medical kits. Each year, catalog and Internet-based outfitters have clearance sales that include many of the items discussed here and in other chapters. In addition, high-quality and normally expensive items (e.g., laryngoscopes, watertight boxes, sunglasses) are available in new and used condition on popular public auction websites. The reader is cautioned to purchase only from reputable sellers and to inspect all purchases for integrity and functionality.

How a kit is organized is almost as important as the contents of the kit. If items cannot be quickly and easily found, especially for emergency supplies, they are of little use. Size and organization of medical kits depend on the same trip-specific factors mentioned previously, including trip duration, number of participants, planned activities, and distance to definitive care.

For expeditions with the capacity to travel with larger kits, a brightly painted, clearly marked, watertight aluminum or plastic box can serve as a container for the comprehensive community medical kit. The underside of the lid can be an ideal place to secure equipment for treating immediately life-threatening emergencies, such as respiratory distress, anaphylaxis, hemorrhage, cardiovascular disease, and tension pneumothorax (see Figure 102-2 on p. 2289). For other kit designs, it may be preferable to create an emergency response module that includes supplies for responding to immediately life-threatening emergencies (e.g., airway equipment, epinephrine, tactical tourniquet, aspirin, 14-gauge vascular access catheter, gloves, trauma shears). Small to medium-sized duffel bags can be used to group equipment by category (e.g., medications, diagnostics, wound care, emergency response) within the kit. Medications can be further compartmentalized within the duffle by creating separate, zipper-locked, heavy-duty plastic bags labeled by category (e.g., antibiotics, analgesics) and system (e.g., respiratory/allergy, cardiovascular, gastrointestinal, ear/nose/throat, genitourinary/gynecologic, dermatologic).

Miscellaneous items that are not likely to be needed urgently or frequently can be stored under the duffel bags. Other useful items, such as repair supplies (Table 102-1), should also be considered but are usually better if packed separately.

For smaller kits, a variety of vessels can be used, including small backpacks, toiletry organizers, dry bags, and military surplus bags (Figure 102-1). Regardless of the size or style chosen for a medical kit, it is highly recommended to compartmentalize supplies as much as possible. This can be done using built-in compartments or packaging related items by category or system into heavy-duty, labeled plastic bags.

Liquids, ointments, and creams can leak easily, so take special care when packing these items, or consider repackaging in well-labeled, durable plastic bottles (e.g., small Nalgene bottles).

HOW MUCH TO BRING

Duration of the outing or expedition, party size, probability of specific illnesses, and maximum interval to medical care are primary factors when considering what and how much to bring into the wilderness. No single formula can be used to calculate quantities of trip supplies. A simple but often effective approach to determining how much to bring is to calculate the dosing schedule of each medication under consideration and then multiply it by the maximum interval to medical care and the number of people who are likely to require the specified therapy at any one time.

TABLE 102-1 Repair Supplies to Consider for Wilderness Travel

Item	Description	Uses and Comments
Multitool	Pocket tool that includes collapsible screwdrivers, pliers, awl, and saw	
Needle or sewing awl	With heavy thread: 30 g (1 oz)	Clothing and pack repair
Screwdrivers	Flat and Phillips No. 2: 88-177 g (3-6 oz)	For skis, No. 3 posidrive or filed-down No. 2 Phillips
Duct tape or reinforced strapping	2.5-10 cm (1-4 inches) wide and 1.5 m (5 yards) long; 59 g (2 oz) per person per trip	
Wire and nylon cord	Braided steel and braided nylon: 0.9-1.8 m (3-6 feet), 59 g (2 oz)	Repair of binding, boot, snowshoe, and pack
Needle-nose pliers	With wire cutters	
Vise-grip pliers	13 cm (5 inches); 148-237 g (5-8 oz)	
Awl	One multifunction knife per person per trip: 59 g (2 oz)	Repair of clothing, pack, and shelter
Glue	Two-component epoxy or meltable nylon glue stick: 30 g (1 oz)	
Spare bale and screws	Two per person per trip	Repair of ski binding
P-tex ski base stick	Meltable No. 1: 30 g (1 oz)	Repair of plastic ski base
Spare ski tip	Plastic or aluminum: 88-148 g (3-5 oz)	
Spare crampon wrench	No. 1; one per person per trip	
Knife sharpener	Diamond bar, ceramic, or stone: 59-89 g (2-3 oz)	

FIGURE 102-1 Example of a compact emergency response and diagnostics module made from a toiletry bag. This small kit contains emergency supplies (oral/nasopharyngeal airways, laryngoscopes, endotracheal tube, 14-gauge vascular access catheter, tactical tourniquet, epinephrine, gloves, eye protection, trauma shears, safety pins) and diagnostic equipment (pulse oximeter, sphygmomanometer, thermometer, precordial stethoscope, otoscope/ophthalmoscope, fluorescein).

For example, on a 2-week rafting trip that is 3 days away from the nearest pharmacy with 10 people, one can estimate how much metronidazole should be available for treatment of giardiasis. Assume all members become infected and require a treatment course of 5 days × 500 mg orally (PO) every 8 hours (q8h) = 15 tablets per person; 10 members × 15 tabs = 150 tabs. It is highly unlikely that all members would become infected, however, or that all would become infected at the beginning of the trip, so some participants should be able to complete medication courses with drugs obtained on returning home. Furthermore, evacuation time is only 3 days and could be done if supplies were dwindling. Thus, taking fewer than 150 tabs would be reasonable. To recalculate, if you assume only two-thirds of the trip members become infected and you bring enough only for the 3-day evacuation (7 persons × 500 mg PO q8h × 3 days = 56 tabs), you arrive at a more reasonable quantity to pack for such a trip.

The rationale for choosing which medications to bring on an excursion is based on the likelihood of injury or illness (increases with longer trip duration) and expected time frame for support and rescue. In a low-risk outing (e.g., 1-day hike), the interval to medical care is short (<4 hours), and trip duration (e.g., 1 day) places one at low risk of acquiring a medical illness that can only be managed in the field. Because traumatic injury or a life-threatening allergic reaction is always of prime concern, even during a low-risk outing, analgesics and medications for anaphylaxis can be extremely important. A moderate-risk trek (e.g., 1-day "ski-in" with 2 nights of winter camping) will have a longer interval to medical care (e.g., 4 to 12 hours) and a trip duration that increase the chance of injury and illness. With a "ski-out" time of 4 to 12 hours plus added time to return with organized help, expectations are that an ill group member will not receive sophisticated rescue efforts until the following day. In such situations, opioids to control pain, antibiotics to prevent infection from soft tissue injuries, and antiemetic or antidiarrheal medications to control gastrointestinal (GI) upset and preserve fluid and electrolyte balances become paramount. A high-risk outing (e.g., weeklong expedition with mountain climbing) precludes seeking formal help within a 12-hour period. With such an expedition, nonemergent problems (e.g., athlete's foot, infected blisters, dermatitis, asthma, bronchitis, sinusitis) are likely to occur, limiting the performance and enjoyment of some participants. In addition to carrying the medicines and supplies noted previously for low- and moderate-risk treks, one should have treatments to manage more persistent medical illness, including a full course of oral antibiotics for respiratory, abdominal, and soft tissue infections; oral and potent topical corticosteroids for dermatologic problems; and assorted ophthalmic and otic medications to deal with bothersome infections or allergic reactions affecting vital sensory organs.

PERSONAL MEDICAL KIT

For the purposes of this discussion, "personal medical kits" are small, on-person kits of essential supplies for each trip participant. Although containing only basic supplies, these are key components of an expedition's medical armamentarium. Carrying a minimum amount of items on one's person serves two purposes: (1) redundancy of essential supplies in the event of theft, damage, or loss during travel and (2) personal supply in the event of separation from travel partners. A sudden fall, avalanche, or swamping can quickly separate a person from the group and his or her gear.

The supplies for a personal medical kit should provide protection from the elements, permit self-treatment of minor traumatic injuries, allow signaling for purposes of search and rescue, and include an adequate supply of home medications. These items typically include assorted adhesive compress strips, a knife or razor blade, butane lighter or matches (preferably the waterproof, strike-anywhere type), plastic whistle, small reflective mirror, length of thin nylon cord, bandanna (which can double as a cravat or sling), and safety pins (Box 102-3). A nonperishable source of quick, high-energy food (e.g., candy, nutrition bar) is valuable during isolation to maintain strength and morale. These items can be compactly stored inside a plastic bag or small stuff sack and may be carried in either a pocket or a small pack. Zippered, passport-size waist belts are comfortable and inexpensive options.

As noted previously, all travelers should carry some form of identification, and those with serious medical allergies or active illnesses should have an appropriate medical alert bracelet, anklet, medallion, or wallet card. A copy of one's passport can be invaluable.

Participants with any medical condition prone to acute exacerbations (e.g. asthma, diabetes, severe allergies) must carry adequate supply of necessary medications in their personal medical kit. For example, travelers with a history of bee, wasp, or other anaphylactic or anaphylactoid reactions should carry at least two preloaded syringes of 1:1000 aqueous epinephrine solution (e.g., epinephrine autoinjector). Keep such devices in a cool, dark compartment, and inform others in the party about the medicine's location and proper use. Advanced practitioners might carry a vial of epinephrine and syringes with needles to increase versatility and lower cost. Asthmatic persons should carry extra inhalers for maintenance and treatment of exacerbations.

Certain contingency "essentials" should be carried on every venture. In addition to one's personal first-aid, hygiene, and

BOX 102-3 Contents of a Personal Medical Kit

On-Person Items

- Personal prescription medications, labeled, in plastic or waterproof lightweight box
- High-priority over-the-counter medications (see Table 102-2)
- Copy of identification
- Pencil and notepad (waterproof, depending on environment)
- Hat and sunglasses
- High–sun protection factor (SPF) sunscreen and lip balm
- Topographic map and compass and basic knowledge of their use
- Multitool knife (e.g., Swiss Army, Leatherman) or razor blade
- Nylon cord
- Whistle and small reflective mirror
- Plastic cable ties
- Lighter or waterproof matches
- Poncho or large, black or orange, plastic yard waste bag
- Adhesive compress
- Alcohol-based gel (e.g., Purell) for hands
- Alcohol swabs
- Adherent bandages
- Duct tape (exterior grade, weatherproof)
- Fluorescent surveyor's tape
- Bandanna, safety pins (see Chapter 46)
- Nonperishable high-energy bar or gummy bears
- Personal hygiene material
- Survival guide or first-aid booklet
- Personal mosquito netting for sleep (when appropriate)
- Ear plugs (sleep hygiene)

clothing items, a flashlight, extra pair of sunglasses, coins, and credit card for telephone calls (although the former is becoming obsolete) should be considered. Extra clothing, food, and water should be carried in proportion to the risk associated with the trip. These nonmedical items are discussed in greater detail in Chapter 111.

A host of over-the-counter (OTC) medications may be useful for wilderness travel and considered for a personal medical kit. Some commonly required, nonprescription items of value are listed in Table 102-2 (highlighted in green and marked with †). Analgesics for trauma are high-priority medications. For mild to moderate pain, acetaminophen or a non-steroidal anti-inflammatory drug can be effective alone or in combination. Decongestants are helpful for treating symptoms associated with upper respiratory tract infections. GI complaints may necessitate antacids, antidiarrheal agents, or promotility agents.

Antiseptic cream or ointment is useful when treating superficial skin infections, and a corticosteroid ointment is valuable for treating certain rashes or contact dermatitis. Aloe vera gel is useful for treating frostbite and burns.

In general, sunburn is best avoided by complete coverage with clothing, hats, and scarves along with fastidious application of a high–sun protection factor (SPF) (i.e., SPF > 30) sunscreen and lip balm. Ultrahigh-SPF sunscreens (i.e., 70 to 100 or more) are available in the United States but not in many low- and middle-income countries and should be purchased before departure. Anticipate sharing a significant percentage of your sunscreen supply.

Text continued on p. 2287

TABLE 102-2 Select Medications for Wilderness Travel*

Drug	Formulation	Select Indications	Comments
Analgesics**			
Acetaminophen† (Tylenol, paracetamol, APAP [acetyl-para-aminophenol])	500-1000 mg PO tabs	Analgesia, fever reduction	Although OTC, this drug can have significant analgesic effects, especially when used in combination with NSAIDs, or with opiates for moderate to severe pain. Caution in patients with history of liver disease or alcoholism. Overdose can be life threatening. Many flu remedies contain acetaminophen and should be accounted for in total daily dose calculations. Paracetamol is metabolized to acetaminophen.
Ibuprofen† (Advil, Motrin)	200 mg PO tabs	Analgesia, antiinflammatory	When no contraindications, NSAIDS should be considered in combination with acetaminophen for mild to moderate pain and with opiates if necessary for moderate to severe pain. This is not to be used if GI bleeding, pregnancy, chronic kidney disease, or severe dehydration is present. NSAIDs may help prevent acute mountain sickness. Caution with total daily dose and prolonged use.
Acetylsalicylic acid† (Aspirin, Bayer, Ecotrin)	325-500 mg PO tabs	Analgesia	This is not to be used if significant bleeding is present. Can be used for antiplatelet effect in suspected ACS (preferably chewed, non-enteric-coated tabs). May be administered PR.
Hydrocodone and acetaminophen** (Vicodin, Lortab, Norco)	5 to 10 mg/325 mg PO tabs, dose limited by total daily acetaminophen dose	Analgesia	As with all opiates, may cause severe constipation. Given concern for inadvertent acetaminophen toxicity, would recommend hydrocodone or oxycodone preparations without acetaminophen. Given hydrocodone's reclassification as Schedule II and variable metabolism, oxycodone may be considered as a more reliable analgesic.
Oxycodone**	5 mg PO tabs	Analgesia	As with many opioids, significant nausea, especially when taken without food. Monitor for constipation. May cause impaired reaction time, balance, and wakefulness.

Continued

TABLE 102-2 Select Medications for Wilderness Travel*—cont'd

Drug	Formulation	Select Indications	Comments
Tramadol** (Ultram)	50 mg PO tabs	Analgesia	Use caution, because may cause CNS depression and impair reaction time, balance, and wakefulness. May increase risk of seizures, especially in patients taking several drugs, including SSRIs, TCAs, and MAOIs. Multiple interactions.
Bupivacaine (Marcaine, Sensorcaine)	0.25% solution, maximum SC dose of 2.5 mg/kg	Advanced-tier local or regional anesthesia	Use with caution on the feet, because such use may allow further skin damage to go unnoticed. Hypotension and dysrhythmias can occur at toxic doses. IV injection can be fatal. Perineural injections may be effective for tooth pain and extremity fractures, and effects may last up to 10 hours. Soak gauze with this drug for topical and dental applications.
Lidocaine (Xylocaine)	1%-2% solution for injection with or without epinephrine; maximum SC dose of 4.5 mg/kg without epinephrine, up to 7 mg/kg with epinephrine	Local anesthesia	Conventional teaching is that lidocaine with epinephrine should not be used when injecting distal extremities (i.e., fingers, nose, penis, toes, ears) because of potential for vascular compromise. Consider bringing multiple small vials; repeat use of single vials is not recommended. Local anesthetic of choice for minor procedures because of fast onset and relatively wide therapeutic window. This short-acting agent (relative to bupivacaine) may be used as an antiarrhythmic in ACLS. Toxic doses may result in seizure or cardiac arrest.
Lidocaine jelly 2%	Apply to skin as needed or 30 min before procedure; 5 mL packages	Analgesia, prophylaxis for catheter insertion	Use with caution; it may allow further skin damage to go unnoticed.
Tetracaine	0.5% solution for eye drops	Analgesia for procedures	Should not be used if etiology of injury and expert consultation unavailable, because it can worsen injury.
Morphine sulfate**	20 mg IV/IM vial	Advanced-tier analgesia	Morphine may cause nausea, vomiting, rash (histamine release), hypotension, sedation, and apnea. Administer it with an antiemetic as a precaution.
Ketamine**	50 mg/mL, 5-10 mL vial IV (alternate dosing for IM and PO available)	Advanced-tier analgesia	Anticipate increased oral secretions and potential for hallucinations. May consider premedication with antisialagogue (glycopyrrolate, scopolamine) and sedative (midazolam). Can be used only by qualified and experienced providers to achieve sedation for surgical procedures or control of severe pain with relatively less respiratory depression than opiates.
Naloxone (Narcan)	0.4-2 mg SC, IM, IV, or by endotracheal tube	Opioid overdose	Naloxone may precipitate opioid withdrawal among chronic opioid users. Rare adverse effects include pulmonary edema and seizure.
Pentazocine** (Talwin)	50 mg PO tabs	Opioid agonist-antagonist	Pentazocine still has abuse potential. IV/IM formulations also available.
Capsaicin ointment†	2 g tube	Topical analgesic for osteoarthritis	Prolonged use may result in burns. Adjunct or alternative when NSAIDs or PO medications contraindicated.
Antimicrobials			
Albendazole (Albenza)	200 mg PO tabs	Anthelmintic with broad range of activity against neurocysticercosis, echinococcosis, ascariasis, hookworm, and trichuriasis	Not to be used by pregnant patients or by children <2 years old. Consider expert consultation before administration because significant contraindications exist.
Amoxicillin/clavulanic acid (Augmentin)	875 mg/125 mg PO tabs	Animal bites, oral infections, skin and soft tissue infections, severe acute otitis media, and tonsillopharyngitis	Contraindicated in patients with penicillin allergy. Can be used in conjunction with clindamycin for suspected polymicrobial anaerobic pulmonary infections (aspiration pneumonia).

TABLE 102-2 Select Medications for Wilderness Travel*—cont'd

Drug	Formulation	Select Indications	Comments
Artemether/lumefantrine (Coartem, Riamet)	20 mg artemether, 120 mg lumefantrine PO tabs	Malaria (*Plasmodium falciparum*) treatment in chloroquine-resistant areas (check CDC.gov for guidelines)	Can be used for malaria treatment, although significant side effects and contraindications exist. Use caution when purchasing in certain regions because significant quality differences may exist between manufacturers.
Artesunate	60 mg ampule for IV or IM	Severe malaria (*P. falciparum*) treatment in chloroquine-resistant areas (check CDC.gov for guidelines)	Can be used for malaria treatment, although significant side effects and contraindications exist. May not be able to purchase in certain regions.
Atovaquone/proguanil (Malarone)	250 mg/100 mg PO tabs	Severe malaria prophylaxis and treatment in chloroquine-resistant areas (check CDC.gov for guidelines)	Use with caution in a patient with severe GI upset. This is not to be used for complicated or cerebral malaria.
Azithromycin (Zithromax)	250 mg PO tabs	Pneumonia, otitis media, tonsillopharyngitis, gonococcal infection, bacterial sinusitis, traveler's diarrhea	May cause nausea, vomiting, and QT prolongation. Single 1000 mg dose may be more effective for traveler's diarrhea than divided dosing.
Bacitracin† (ointment)	28 g, 120 g, or 454 g tube	Topical infection prevention	Can cause allergic reactions. Clear affected area before application. Many potential alternatives.
Cefazolin (Ancef, Kefzol)	1 g vials IM/IV‡	Soft tissue infection, uncomplicated cystitis, crush injuries, open fractures	Penicillin allergy is a risk factor for cephalosporin allergy.
Ceftriaxone (Rocephin)	1 g vials, powder for reconstitution IM/IV‡	Pneumonia, meningitis, gonorrhea, intraabdominal infection, pyelonephritis, sepsis	Third-generation cephalosporin. Penicillin allergy is a risk factor for cephalosporin allergy.
Cephalexin (Keflex)	500 mg PO tabs	Superficial, soft tissue infection, streptococcal pharyngitis, uncomplicated cystitis	First-generation cephalosporin. Penicillin allergy is a risk factor for cephalosporin allergy.
Chloroquine (Aralen)	500 mg PO tabs	For severe malaria prophylaxis or treatment in chloroquine-sensitive areas (check CDC.gov for guidelines)	May cause nausea and diarrhea. Significant contraindications, including caution in patients with preexisting auditory problems, G6PD deficiency, psoriasis, or seizure disorder.
Ciprofloxacin (Cipro)	250-750 mg PO tabs	Traveler's diarrhea, cystitis, pneumonia, intraabdominal infection, prostatitis, sinusitis, typhoid fever, meningitis prophylaxis (off-label use)	Fluoroquinolones are not recommended for patients <16 years old because of the risk for cartilage injury and tendinopathies. Do not give with calcium containing foods or antacids (chelates quinolones). Avoid in patients receiving concurrent corticosteroids.
Ciprofloxacin otic solution (Cetraxal)	0.2% solution, formulations with dexamethasone available	Acute otitis externa; formulation for ophthalmic applications is 0.3%	May need ear wick for administration. Warm bottle in hand before administration to avoid adverse response. Pseudomonal resistance can occur.
Clindamycin (Cleocin)	150-450 mg PO tabs	Anaerobic infections; severe soft tissue infection (off-label use), toxic shock syndrome, pelvic inflammatory disease	May be useful for suspected MRSA soft tissue infections.
Doxycycline (Vibramycin)	100 mg PO tabs	Severe malaria prophylaxis, Lyme disease, *Vibrio cholerae, Chlamydia,* pneumonia, bronchitis, tick-borne rickettsial disease; may be useful for unidentified infections from marine environment	Not recommended for patients <8 years old because of teeth staining. Inactivated by calcium-containing products (food and antacids). Causes significant photosensitivity and pill esophagitis (remain upright at least 30 min after ingesting with full glass of water). Expired doxycycline is considered dangerously nephrotoxic.
Erythromycin	3.5 g tube, 0.5% ointment	Bacterial conjunctivitis, uncomplicated corneal abrasion	Consider antipseudomonal coverage (quinolone drops) if contact lens wearer.

Continued

TABLE 102-2 Select Medications for Wilderness Travel*—cont'd

Drug	Formulation	Select Indications	Comments
Fluconazole (Diflucan)	150 mg PO tabs	Vaginal and oropharyngeal candidiasis; coccidioidomycosis, dermatophyte (tinea) infections	Liver toxicity may occur. May be required for female patients taking concurrent antibiotics. Topical antifungals may be sufficient for tinea infections when available.
Ivermectin (Stromectol)	3 mg tabs PO (dosing in mcg/kg, usual dose 150-200 mcg/kg)	Scabies and lice (off-label use); onchocerciasis and strongyloidiasis; cutaneous larval migrans (*Ancylostoma braziliense* or *Ancylostoma caninum*); activity against *Wuchereria bancrofti, Brugia malayi, Mansonella ozzardi,* and *Loa loa,* although not first-line therapy.	Multiple doses are not well evaluated in patients with severe liver disease. Ivermectin is often more practical and effective than topical treatment for scabies (95% effective if given in two doses).[49] May not be necessary to bring, depending on travel conditions and geography.
Levofloxacin (Levaquin)	500 mg or 750 mg PO tabs	Intraabdominal infections, pneumonia, cystitis, traveler's diarrhea (off-label use)	In the absence of ileus, same bioavailability when given PO as IV. Tendon inflammation and rupture (e.g., Achilles tendon, rotator cuff, biceps) are significant concerns. Avoid concurrent calcium-containing foods and medications. Ciprofloxacin can often be considered an alternative. Avoid in patients taking corticosteroids.
Mefloquine (Lariam)	250 mg PO tabs	Chloroquine-resistant malaria prophylaxis and treatment (check CDC.gov for guidelines)	Dosed weekly for prophylaxis. Do not prescribe to patients with prior adverse reactions to mefloquine, which may include hallucinations and night terrors. Caution in patients with significant psychiatric history.
Metronidazole (Flagyl)	500 mg PO tabs	Suspected giardiasis; severe diarrhea or diarrhea with fever, blood, or leukocytes	Alcohol consumption may cause a disulfiram-like reaction. The use of metronidazole may increase the toxicity of lithium, phenytoin, and anticoagulants.
Moxifloxacin (Moxeza)	0.5% optic solution, 3 mL bottle	Bacterial conjunctivitis, corneal ulceration	Not first-line therapy for bacterial conjunctivitis (due to emerging resistance) unless contact lens wearer, because of high incidence of *Pseudomonas* infection
Penicillin V (Pen-Vee)	500 mg PO tabs	Dental infections, streptococcal pharyngitis	Multiple broad-spectrum alternatives may be more appropriate for wilderness travel.
Permethrin (Elimite)	60 g tube, 5% cream	Scabies and head lice	See Ivermectin above and discussion of permethrin-impregnated apparel in text.
Praziquantel (Biltricide)	600 mg (scored) PO tabs	Schistosomiasis, intestinal tapeworms, cysticercosis	Limited or no activity in acute exposure (larval stage). Consider inclusion in medical kit only if prolonged (>21 day) travel to endemic regions.
Quinine (Qualaquin)	650 mg PO tabs	Malaria treatment (P. *falciparum*) in chloroquine-resistant areas (check CDC.gov for guidelines)	Quinine may prolong the QT interval. An IV form is available if patient unable to tolerate PO route. Additional concurrent therapy may be required (e.g., doxycycline).
Rabies vaccine (RVA, RabAvert)	1 mL IM (vials)‡	Postexposure and pre-exposure rabies treatment	Dosing varies based on prior vaccination history. Wound cleansing and possibly immunoglobulin (at separate IM site) also required for postexposure prophylaxis.
Rabies immune globulin (Imogam, BayRab)	20 units/kg	Postexposure rabies treatment	Local wound infiltration with immune globulin, and remainder of dose given IM at a site remote to vaccine site. Consider inclusion in medical kit based on risk.
Trimethoprim-sulfamethoxazole (Bactrim, Septra)	160 mg/800 mg tab PO tabs	Cystitis, traveler's diarrhea, soft tissue infections	Caution in patients with chronic kidney disease or sulfa allergy.
Vancomycin	1 g vial IV‡	Meningitis, sepsis, suspected MRSA infection	Can cause profound hemodynamic instability with rapid administration. Only to be used by experienced personnel. For consideration by well-equipped trips staffed by qualified personnel.

TABLE 102-2 Select Medications for Wilderness Travel*—cont'd

Drug	Formulation	Select Indications	Comments
Cardiovascular			
Amiodarone	450 mg/9 mL vial	Antiarrhythmic in ACLS	Multiple contraindications and adverse reactions, including hemodynamic collapse and fatal arrhythmia with administration. Only to be considered by expeditions with advanced medical support.
Acetylsalicylic acid† (Aspirin, Bayer, Ecotrin)	325 mg PO tabs	ACS, analgesia, antiinflammatory	Increased risk for GI bleeding and other bleeding diatheses. Preferably chewed when used for ACS. Can be given PR.
Atropine	1 mg/mL vial	Symptomatic bradycardia, ACLS	This drug causes tachycardia and stool and urinary retention.
Clonidine (Catapres)	0.1 mg PO tabs	Hypertension	Clonidine may cause drowsiness and dizziness. Can lead to rebound hypertension.
Enoxaparin (Lovenox)	80 mg/0.8 mL prefilled syringes; subcutaneous administration only; weight-based dosing differs by indication	ACS, pulmonary embolism, deep vein thrombosis	Significant risk of bleeding.
Lidocaine	10 mL 2% vial, IV	Antiarrhythmic in ACLS	Potential for significant cardiac and neurotoxicity.
Metoprolol tartrate (Lopressor)	25 mg PO tabs	SVT and ACS	May impair exercise tolerance; may cause bronchospasm and unstable bradycardia.
Epinephrine	1 mL, 0.3 mg IM q 10-15 min for anaphylaxis; 10-300 mcg IV for anaphylaxis; 1 mg q 3-5 min for cardiac arrest	Anaphylactic reaction, hypotension, cardiac arrest, severe asthma, ACLS	Special consideration must be given to appropriate dosing, dilution, and route of administration, which vary considerably between indications. Advanced training and licensure required.
Epinephrine autoinjector (EpiPen)	0.3 mg single-dose autoinjector	Anaphylactic reaction	Inject into an extremity large muscle group (usually anterolateral thigh). Requires pretrip training. Requirement for all travelers with history of anaphylaxis. EpiPen Jr. (lower dose) may be required based on weight of travelers.
Nitroglycerin (Nitrostat, Nitrolingual)	0.4 mg sublingual tabs, or inhaler, 400 mcg/spray	Angina, select exacerbations of congestive heart failure	Relief of chest pain with nitroglycerin does not identify the pain as being cardiac in origin. Nitroglycerin is heat and light sensitive with a short shelf life. May cause hypotension and potentially life-threatening interactions with phosphodiesterase inhibitors, such as those used for erectile dysfunction (e.g., Viagra, Cialis, Levitra, Silagra).
Oxygen	Titrate to effect	Respiratory distress, ACS, decompression sickness, traumatic head injury, inhalational injury	Oxygen tanks are explosive, heavy, and bulky. Oxygen storage requires special attention and regular maintenance. Can be problematic if traveling by air.
Neurologic			
Alprazolam** (Xanax)	0.25-0.5 mg PO tabs	Insomnia, anxiety	Causes sedation and can lead to respiratory compromise. Potential for abuse and withdrawal.
Clonazepam** (Klonopin)	0.25-0.5 mg PO tabs	Insomnia, anxiety	Causes sedation and can lead to respiratory compromise. Potential for abuse and withdrawal.
Dextroamphetamine (Dexedrine, Dextrostat)	5 mg PO tabs	Fatigue, difficulty concentrating	May cause nervousness, diarrhea, or loss of appetite.
Diazepam** (Valium)	5 mg PO scored tabs	Anxiety, agitation, seizures	Causes sedation and can lead to respiratory compromise. Potential for abuse and withdrawal.
Dimenhydrinate† (Dramamine)	50 mg PO tabs	Antihistamine, motion sickness	Causes CNS depression.
Etomidate (Amidate)	20 or 40 mg vial, IV injection	Rapid-sequence intubation	To be used only by trained providers planning to intubate during emergencies. Can cause hemodynamic compromise by depressing sympathetic tone.
Haloperidol (Haldol)	5 mg/mL vial; IM, IV, PO formulations available	Agitation, mania, psychosis	Dystonic reactions may occur; treat these with diphenhydramine or benztropine (Cogentin). Can cause QT prolongation.

Continued

TABLE 102-2 Select Medications for Wilderness Travel*—cont'd

Drug	Formulation	Select Indications	Comments
Lorazepam** (Ativan)	2 mg/mL IM/IV	Anxiety, agitation, seizures, alcohol withdrawal	Causes sedation and can lead to respiratory compromise. Potential for abuse and withdrawal.
Meclizine† (Antivert, Bonine)	25 mg PO tabs	Vertigo, motion sickness prophylaxis	Adverse reactions include CNS depression and blurred vision (which can impair reading and ability to perform procedures requiring fine dexterity).
Midazolam** (Versed)	10 mg/mL vial; oral syrup also available	Anxiety, procedural sedation	Must be secured as significant abuse potential and side effects.
Modafinil (Provigil)	100 mg PO tabs	Circadian rhythm disturbances, shift work (e.g., night watch), fatigue	Use with caution in patients with cardiovascular disease or a history of psychiatric disorders.
Olanzapine (Zyprexa)	10 mg PO tabs; SL/IM administration available	Agitation, mania, psychotic disorders	Can cause tardive dyskinesia, neuroleptic malignant syndrome, orthostatic hypotension, and hyperglycemia.
Scopolamine (Transderm Scop)	1.5 mg TD patch	Motion sickness prevention, antiemetic	Significant anticholinergic symptoms, including blurred vision, CNS depression, and dyshydrosis (which can impair sweating and thermoregulation).
Succinylcholine	200 mg vial	Rapid-sequence intubation	Consider inclusion in medical kit only if personnel present with advanced airway equipment, training, and licensure. Review potentially life-threatening contraindications before use.
Dermatologic			
Clotrimazole† (Lotrimin, Mycelex)	1% cream	Topical fungal infections	Multiple alternatives exist.
Hydrocortisone† (Cortaid, Hytone)	1% cream	Contact dermatitis	Hydrocortisone is not to be used to treat infections. Repeated use can cause skin atrophy, especially on face, genital area, and dorsum of hand.
Triamcinolone (Aristocort, Kenalog)	0.1% ointment	Contact dermatitis, severe itching	Triamcinolone is significantly more potent than hydrocortisone OTC, although requires prescription. It should not to be used to treat infectious rashes. Repeated use can cause skin atrophy, especially on face, genital area, and dorsum of hand. Numerous alternatives exist.
Mupirocin (Bactroban)	2% cream, 15 g or 30 g tube	Impetigo	MRSA coverage for superficial infections. Components of OTC triple-antibiotic ointments (bacitracin-neomycin-polymyxin B) may be inferior to mupirocin for impetigo.
Diphenhydramine† (Benadryl)	25-50 mg PO tabs	Seasonal allergies, allergic reactions, dystonic reactions	Causes significant impairment of psychomotor performance and cognitive function.
Metronidazole (Metrogel)	Vaginal 0.75% cream	Bacterial vaginosis	The formulation tends to separate at high temperatures; consider an oral formulation for more compact and stable transport.
Nystatin (Nyamyc)	Vaginal suppositories and creams	Vulvovaginal candidiasis, balanitis, localized skin infections	Creams and suppositories tend to melt in warm or hot environments. Fluconazole is more stable and can be taken as a single oral dose, but it belongs to Pregnancy Category C and requires prescription. Nystatin is very inexpensive.
Permethrin (Elimite, Nix)	5% cream	Scabies; head lice may be treated with a 1% permethrin rinse	This cream causes temporary stinging. Treatment may be repeated after 7 days for increased efficacy. Read notes on ivermectin adjunctive therapy.
Polymyxin B, bacitracin, and neomycin ointments† (Neosporin)	15 g packs	Lacerations, superficial skin infections	This is not a substitute for systemic antibiotics for soft tissue infections.
Silver sulfadiazine (Silvadene)	1% cream, 50 g tube	Burns, large soft tissue injuries, open fractures	Remove cream from a previous application before reapplying. This drug contains sulfa.
Tolnaftate† (Tinactin)	1% cream, gel, spray, or powder	Localized skin infections that are suspected of being fungal in origin	The safety profile is unknown for pregnancy.

TABLE 102-2 Select Medications for Wilderness Travel*—cont'd

Drug	Formulation	Select Indications	Comments
Eye, Ear, Nose, and Throat Topical Medications§			
Artificial Tears†	10 mL container	Xerophthalmia (dry eyes)	Rule out foreign body, corneal abrasion, or other pathologies before use.
Cyclopentolate (AK-Pentolate, Cyclogyl)	1% drops, 5 mL container	Snowblindness (off-label use)	Decreases pain (photophobia) by decreasing ciliary muscle spasm. Not to be used for patients who need to walk or drive. It may cause acute angle-closure glaucoma. Scopolamine 0.25% and homatropine 2%-5% may be alternatives.
Diclofenac	0.1% drops	Snowblindness	Consider using adjunct PO analgesic.
Dexamethasone, neomycin, and polymyxin ointment (Maxitrol)	Drops or ointment	Snowblindness, disabling allergic conjunctivitis	Cortisporin (neomycin, polymyxin, and hydrocortisone) may be interchangeable with Maxitrol for otic and ophthalmic irritation.
Erythromycin ophthalmic ointment (Ilotycin)	0.5% ointment, 3.5 g tube	Corneal abrasions or ulcerations	The ointment stays on the eye but blurs vision; it should be used at night or while resting. Multiple alternatives exist.
Gentamicin (Garamycin) or Tobramycin (Tobrex) drops	0.3% drops	Corneal abrasions or ulcerations in contact lens wearers	May cause chemical keratitis. Interchangeable with ofloxacin or ciprofloxacin drops in select indications.
Moxifloxacin (Vigamox)	0.5% drops	Bacterial keratitis	Fourth-generation fluoroquinolone with possibly less resistance than earlier generation meds. Increased cost.
Neomycin and polymyxin B sulfate and hydrocortisone otic suspension (Cortisporin Otic Suspension)	Neomycin 0.35%, polymyxin B 10,000 units/mL, hydrocortisone 0.5%	Otitis externa	Must avoid the use of topical aminoglycosides if tympanic membrane ruptured.
Ofloxacin (Floxin Otic)	0.3% otic solution	Otitis externa	Second-generation fluoroquinolone. Multiple alternatives exist. A wisp of cotton wool placed in the ear as a wick will draw medication into the ear canal.
Oxymetazoline (Afrin)	0.05% nasal spray	Congestion, epistaxis	This drug may be sprayed on a laceration to temporarily decrease bleeding. It causes rebound congestion with prolonged use.
Pilocarpine (Isopto Carpine)	2% drops	Acute angle-closure glaucoma	Only to be used by experienced and appropriately trained personnel.
Phenylephrine (Neo-Synephrine)	0.5%-2.5% drops	To induce mydriasis	Only to be used by experienced and appropriately trained personnel.
Polymyxin B and trimethoprim eye drops (Polytrim)	10000 units/mL solution	Corneal abrasions or ulcerations, snowblindness	Ointments can be used instead of drops, but these impair vision and should only be used when patients are resting or sleeping. Worsening eye irritation suggests chemical keratitis caused by medication.
Prednisolone	1% drops	Allergic keratitis, acute angle-closure glaucoma	Because steroids may worsen eye infections, they are typically prescribed only on advice from ophthalmologist.
Tetracaine	0.5% drops	See Analgesia section	
Timolol (Istalol)	0.5% drops	Acute angle-closure glaucoma	Significant side effects can occur; should be used only under expert consultation.
Gastrointestinal			
Bismuth subsalicylate† (Pepto-Bismol, Kaopectate)	262 mg PO tabs	Abdominal pain, vomiting, diarrhea	With this drug, the stool and tongue may turn black; excessive intake can cause salicylate poisoning. May provide good GI prophylaxis from coliform infection if taken before meals.
Docusate sodium† (Colace)	100 mg PO tabs	Constipation	Docusate may cause diarrhea and abdominal cramping. Liquid form may also be useful for cerumen disimpaction.[43]

Continued

TABLE 102-2 Select Medications for Wilderness Travel*—cont'd

Drug	Formulation	Select Indications	Comments
Famotidine† (Pepcid)	20 mg PO tabs	Peptic ulcer disease, dyspepsia	Decreased stomach pH may predispose patient to GI infections. Consider including one H_2 blocker, because this will have faster onset than PPI (even faster if combined with calcium carbonate and/or magnesium hydroxide).
Lactase† (Lactaid)	250 mg PO tabs	Lactose intolerance	Travelers with known lactose intolerance are advised to bring lactase. Transient lactose intolerance often develops after traveler's diarrhea.
Loperamide† (Imodium)	2mg PO tabs	Diarrhea	Decreases symptoms in most cases of traveler's diarrhea, but has not been adequately studied for safety in patients with bloody diarrhea. Use contraindicated with certain diarrheal illnesses.
Meclizine† (Antivert)	25 mg PO tabs	Motion sickness, nausea	See Neurologic section.
Omeprazole† (Prilosec)	20 PO tabs	Peptic ulcer disease, dyspepsia	Decreased stomach pH may predispose patient to GI infections.
Ondansetron (Zofran)	8 mg PO tabs; 4 mg/2 mL vials	Nausea, vomiting	May cause QT prolongation; limited efficacy for motion sickness–induced nausea.
Promethazine (Phenergan)	25 mg PO tabs	Nausea, vomiting, motion-sickness	Especially effective for motion sickness. Acute dystonic reactions related to promethazine can be treated with diphenhydramine or benztropine. Do not use in pediatric patients. Black Box warnings exist.
Prochlorperazine (Compazine)	5 mg PO tabs; also available PR and as solution for injection, 5 mg/mL	Nausea, vomiting	Causes sedation and dystonia; is not for use in patients <2 years old. Acute dystonic reactions related to prochlorperazine can be treated with diphenhydramine or benztropine.
Senna† (Senokot)	8.6 mg PO tabs	Constipation	Constipation can be a significant challenge for many travelers, and care must be taken before severe constipation is mistaken for more serious illness.
Witch hazel pads† (Preparation H)	Package, 10 each	Hemorrhoids	Multiple alternative antihemorrhoidal medications exist.
High Altitude			
Acetazolamide (Diamox)	250 mg PO tabs	Acute mountain sickness treatment and prevention, acute angle closure glaucoma	Acetazolamide is contraindicated for patients with sulfa allergy; it may cause vertigo, diuresis-induced hypovolemia, paresthesias, and taste changes.
Dexamethasone (Decadron)	10 mg/mL vial for IV administration	High-altitude cerebral edema, antiinflammatory for allergic reactions	Dexamethasone may cause agitation, mood disturbances, hypertension, and hyperglycemia. Takes hours to achieve maximal effect. One IV corticosteroid may be sufficient for the purposes of a medical kit; many alternatives exist.
Nifedipine (Procardia, Adalat)	30 mg PO tabs	High-altitude pulmonary edema	Do not give to patients who are hypotensive. Nifedipine can also be used to treat hypertension.
Sildenafil (Viagra)	50 mg PO tabs	May enhance cardiovascular performance at high altitude, but still experimental	May cause hypotension, headache, lightheadedness, and blue scotomata. Sildenafil is not for patients who are taking nitrates or who have a history of retinal disease.
Respiratory			
Albuterol inhaler (Ventolin, Proventil, Salbutamol)	90 mcg/puff metered-dose inhaler	Asthma exacerbation, COPD	Albuterol may cause tachycardia or provoke anxiety.
Beclomethasone (QVAR, Vanceril)	40 mcg/dose aerosol inhaler	Chronic asthma	This is one of the inhaled corticosteroids given for chronic asthma; it may have fewer systemic side effects than oral corticosteroids.
Diphenhydramine† (Benadryl)	25-50 mg PO tabs	Seasonal allergies, allergic reactions, dystonic reactions	Causes significant impairment of psychomotor performance and cognitive function.
Epinephrine (Primatene Mist)	0.22 mg/puff aerosolized	Asthma exacerbation, allergic reactions (airway edema), anecdotal use for symptomatic bradycardia	Use with caution in older adults and those with known coronary disease.
Fexofenadine† (Allegra)	60 mg PO tabs	Seasonal allergies, urticaria	Nonsedating antihistamine is useful for the treatment of nasal congestion and allergy-induced itching; it costs more than diphenhydramine, but CNS effects are less pronounced.

TABLE 102-2 Select Medications for Wilderness Travel*—cont'd

Drug	Formulation	Select Indications	Comments
Promethazine/codeine**	6.25/10/5 mL syrup PO	Persistent cough	This may be a good medication for acute gastroenteritis in adults, due to the combined antiemetic (promethazine) and antimotility actions (codeine). Black Box warnings exist.
Ipratropium (Atrovent)	18 mcg/puff inhaler	Asthma exacerbation, intranasal administration for treatment of URI symptoms	Ipratropium is not for patients with life-threatening soy or peanut allergies. Also available in combination with albuterol (e.g., Combivent).
Loratidine† (Claritin)	10 mg PO tabs	Seasonal allergies, urticaria	Potentially less impairment in psychomotor performance and cognitive function than diphenhydramine, but may be less effective[5,40]
Phenylephrine†	10 mg PO tabs	Nasal congestion	Contraindicated in patients taking MAOI. Caution in patients with hypertension. Pseudoephedrine may be used as an alternative.
Prednisone (Deltasone, Pred-Pak)	5 mg PO tabs	Asthma exacerbation, allergic reactions, severe allergic contact dermatitis (poison ivy/oak)	Short-term side effects include insomnia and anxiety. Taper may be therapeutically beneficial, although rarely required when used in doses <50 mg daily for <5 days. Monitor for vaginal and oropharyngeal candidiasis.
Pseudoephedrine† (Sudafed)	30 mg PO tabs	Nasal congestion	May have significant cardiovascular and CNS effects.
Cetylpyridinium and benzocaine† (Cepacol)	20 PO lozenges	Sore throat	Acetaminophen and ibuprofen can be helpful adjunct to treating pharyngitis. Many alternative lozenges exist.
Miscellaneous Medications			
Oral glucose† (Glutose)	20 g PO tabs	Hypoglycemia	Hard candy or naturally sweetened fruit juice may be as effective.
Dextrose solution	50%, 25g/50 mL vial	Hypoglycemia	For advanced providers where IV access is possible.
Methylprednisone (Solu-Medrol)	1000 mg/vial‡	Anaphylaxis or severe asthma/COPD exacerbation	Can be used as alternative to dexamethasone, hydrocortisone, or prednisone in select indications.
Hydrocortisone powder	100 mg/2 mL	Anaphylaxis or severe asthma/COPD exacerbation	Can be used as alternative to dexamethasone, methylprednisone, or prednisone in select indications.

ACS, Acute coronary syndrome; *ACLS,* advanced cardiac life support; *CNS,* central nervous system; *COPD,* chronic obstructive pulmonary disease; *GI,* gastrointestinal; *IM,* intramuscular; *IV,* intravenous; *MAOIs,* monoamine oxidase inhibitors; *MRSA,* methicillin-resistant *Staphylococcus aureus*; *NSAIDs,* nonsteroidal antiinflammatory drugs; *OTC,* over the counter; *PO,* by mouth; *PPI,* proton pump inhibitor; *PR,* by rectum; *q,* every; *SC,* subcutaneous; *SL,* sublingual; *SSRIs,* selective serotonin reuptake inhibitors; *SVT,* supraventricular tachycardia; *TCAs,* tricyclic antidepressants; *TD,* transdermal; *URI,* upper respiratory tract infection.

*This table is intended to serve as a list of potentially useful medications for management of commonly encountered medical scenarios in the wilderness. The table should not be used as a treatment guide or as a substitute for manufacturer labels or information contained in the *Physicians' Desk Reference.* All medications listed here must be administered by personnel with appropriate training and licensure. Selection of medications to include in a first-aid kit must be tailored to the specifics of a trip including but not limited to the itinerary, number of travelers, preexisting medical conditions, potentially encountered conditions, and region of travel.

**Providers who bring opioids and other controlled/scheduled medications should do so only if appropriate licensure and training has been obtained. Nonphysician travelers must have a prescription from their personal physician and bring appropriate documentation while traveling. Laws for controlled substances are not universal, and traveling with certain medications may even be illegal in certain destination countries.

†Does not require a prescription in the United States.

‡Requires resuspension. Read package inserts to ensure adequate supply of solution. Usually a supply of any sterile IV fluid solution can work, although some medications may require sterile water to avoid precipitation.

§Caution with multiuse ophthalmic drop applicators because contamination can be source of bacterial keratitis.

Medications highlighted in green are considered high priority with high likelihood of use during wilderness travel.

Medications highlighted in red are considered a potential priority medication with less frequent use, but with potential for preventing significant morbidity or mortality.

Medications highlighted in blue may be considered high priority depending on region of travel or preexisting medical conditions.

If a travel party will not include a community medical kit, individual travelers should consider inclusion of additional high-priority medications (e.g., broad spectrum antibiotic) for their personal medical kit.

COMPREHENSIVE COMMUNITY MEDICAL KIT

A comprehensive, community medical kit is compiled and maintained by the trip's designated medical leader. This kit includes supplies needed to manage a broad range of anticipated injuries and illnesses, with emphasis on injury management and high-priority medications (Box 102-4 and Figure 102-2; see also Table 102-2). Bulky and heavy items, including most stock first-aid and contingency supplies, should be labeled and can be distributed among group members for storage and transport if there is no designated box or bag. A medical cross symbol should be placed on compartments containing the first-aid items. Repair materials are best kept in clearly labeled stuff sacks or watertight boxes independent of the first-aid and medical supplies. In hot environments, aluminum boxes (e.g., Zarges) tend to oxidize over time and leave unpleasant residues on their contents. Thus, materials should not be stored long term in these sturdy, lightweight boxes. Durable plastic boxes, such as those manufactured by Otter and Pelican, should be considered. Although they are durable, large cases are not practical for certain expeditions because of size and weight. A variety of more portable vessels (e.g., backpacks,

BOX 102-4 Contents of a Comprehensive Community Medical Kit*

Wound and Trauma Management
Liquid soap
Alcohol-based gel (e.g., Purell) for hands
Sterile, nitrile gloves
Nonsterile gloves
Splash shield and face protection
Syringes (2, 5, 10, 20 or 30, and 60 cc [mL])
Large- and small-gauge hypodermic needles (e.g., 18 and 25 gauge)
Sterile irrigation saline
Morgan eye lenses
Alcohol pads
Antiseptic towelettes
Povidone-iodine 10% solution (Betadine) or chlorhexidine (Hibiclens)
Wound closure strips (Steri-Strips)
Tincture of benzoin (or Mastisol)
Tissue glue for wound closure (2-octyl cyanoacrylate [Dermabond])
Suture materials (2-0, 4-0 nylon or silk with cutting needle; 3-0 Vicryl with tapered needle)
Disposable skin stapler and remover
Silver nitrate sticks
Esmarch bandage, 3 × 36 inches
Disposable scalpels with No. 11 or 15 blade
Hot and cold packs
Tactical tourniquet
10 × 10-cm (4 × 4-inch) sterile dressing pads
15 × 27-cm (5 × 9-inch) sterile dressing pads
9-cm (3-inch) sterile gauze bandage
Cotton-tipped applicators
Nonadherent sterile dressing
Xeroform and petroleum jelly (Vaseline) gauze burn dressings
Elastic bandage wraps with Velcro closures
Adhesive cloth tape
Adhesive, porous paper tape (1.3 cm [0.5 inch])
Gauze roll (11.4 cm × 3.7 m [4.5 inches × 4 yards])
Adhesive bandages (Band-Aids)
Tegaderm
Eye pad and eye shield
Moleskin, Blist-O-Ban, and silver duct tape
SAM Splints (15 × 110 cm [4.4 × 36 inch])
Aluminum finger splints
Kendrick (or improvised) femur traction device
Slishman Traction Splint
Slishman Rescue Harness
Triangular (cravat) bandage and safety pins
Headlamp
Hemostats and or needle drivers (Spencer Wells)
Trauma shears
Surgical scissors
Toothed and nontoothed forceps
Chlorhexidine surgical scrub brushes
Surgicel Nu-Knit, QuickClot
Plastic finger
Cotton pledgets
Nasal balloon device
Absorbable nasal packing
Urinary catheter, 14 French (catheter bag and tubing)
Absorbable nasal packing

Medications
Select medication listed in Table 102-2 (tailored to anticipated conditions and trip duration, party size, and available space)

Miscellaneous Items
Waterproof flashlight and matches
Signal mirror/dental mirror and whistle
Plastic resealable bags (e.g., whirlpacks)
Permanent markers (e.g., Sharpie)
Notebook and record-keeping supplies (waterproof, depending on environment)
Adhesive labels
Pill bottles and cotton balls
Nail clippers
Steel sewing needles, paper clips, and safety pins
Forceps for removal of splinters and ticks
Pocketknife or multitool knife
Trauma shears
Eyelet scissors
Silver duct tape
Tongue depressors
Chemical ice packs and heating packs
Sun hats and high-SPF sunscreen and lip balm
Emergency blanket (e.g., Space blanket, Pro Tech)
N,N-diethyl-*m*-toluamide–containing insect repellent (e.g., REI Jungle Juice 100)
Contact lens solution and case
Digital thermometers
Commercially made oral rehydration powder packs†

Equipment
Diagnostic instruments: see Table 102-3
Specialized equipment: see Box 102-7

Dental and Ear-Nose-Throat Supplies
Oil of cloves (eugenol), 3.5 mL; combine with calcium hydroxide powder to make temporary fillings
Calcium hydroxide powder or putty
Cavit (7 g)
Intermediate restorative material
Express Putty
Wooden spatulas for mixing and applying
Paraffin (dental wax) stick
Dental floss
Dental mirror
Cotton rolls and pellets
Ear curettes (consider for trips with aquatic activity)
Ear wicks (consider for trips with aquatic activity)

*This is intended to serve as a list of potential equipment that ultimately must be tailored to the specific details of the proposed trip itinerary.
†Recommend purchase of commercially-made ORS in line with current World Health Organization (WHO) guidelines (equimolar glucose:sodium and 200-310 mOsm/L). *Oral Rehydration Salts: Production of the new ORS*, Geneva, 2006, WHO Press. http://apps.who.int/iris/bitstream/10665/69227/1/WHO_FCH_CAH_06.1.pdf?ua=1&ua=1.

military surplus bags) can be substituted and should be organized using a strategy similar to that previously discussed.

MEDICAL SUPPLIES FOR THE MEDICALLY TRAINED TRAVELER

Expeditions traveling with physicians, remote medical support (via two-way communications), or other providers with advanced training may be able to incorporate a wide variety of additional supplies that are not recommended for untrained wilderness medicine providers (Boxes 102-5 and 102-6 and Tables 102-2 and 102-3). These supplies may vary widely based on trip factors and the training background of expedition medical personnel.

Delivery of medical care by nonphysician providers, including use of certain supplies, techniques, prescription and even OTC medications, represents a controversial wilderness medicine topic from medicolegal and ethical aspects (see Chapter 100).

Designated trip medical leaders, whether physicians or nonphysicians, should generally avoid bringing supplies (including medications) they are not familiar with and not licensed to use. If access to remote, formal medical support is available (e.g., via satellite phone to dedicated medical support staff), inclusion of advanced supplies may be appropriate. Alternatively, should the risks of a trip or a participant's preexisting condition warrant inclusion of advanced equipment, the trip medical leader should seek appropriate training and certification before disembarkation.

Certain necessary skills may be acquired in advanced first-aid, paramedic, or nursing classes. Intramuscular (IM) and intravenous (IV) medications should only be administered by personnel with formal licensure and training. Inclusion of IV access supplies

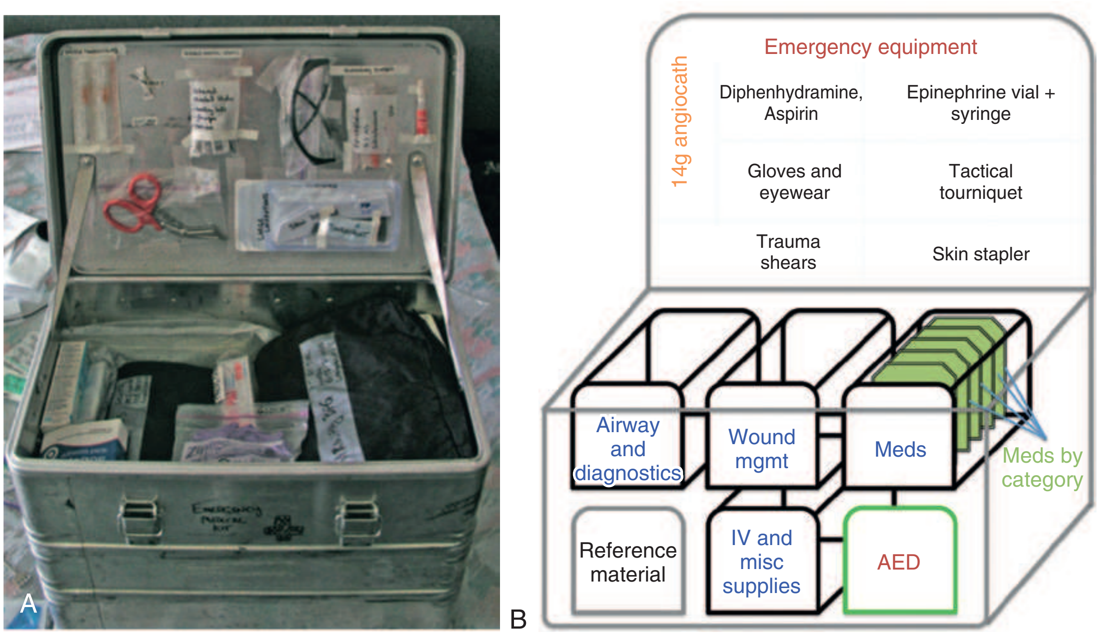

FIGURE 102-2 **A,** Medical kit from the Mongolian American Expedition to the Gobi Desert set up in watertight Zarges aluminum freight box. **B,** Schematic diagram suggesting arrangement for a comprehensive expedition medical kit.

and isotonic crystalloid solution may be reasonable to carry for certain expeditions. For conscious travelers with mild to moderate dehydration and no ileus, adequate rehydration can generally be accomplished using commercially available oral rehydration supplements (ORS).

Items such as surgical tools, advanced airway equipment, chest tubes, and mechanical suction devices may be appropriate for certain high-risk expeditions with adequately trained personnel. Material for splinting may be available in the surrounding environment. However, if the nature of the expedition is such that extremity injuries are possible, equipment for splinting and stabilization (e.g., Exos brace, SAM Splint, Fast Set-3 Moldable Splint Kit, Redi Universal Splint) should be considered.

The decision to bring oxygen on any trip requires special consideration. Oxygen supplies occupy significant space and weight and may have limited utility for certain expeditions (high-altitude and dive excursions being two notable exceptions). Careful review of protocols for safe transport, storage, and maintenance of oxygen must be undertaken regularly. Trip staff must be familiar with the quantity of oxygen available in the first-aid kit, use of regulators, and indications for appropriate use (e.g., routine use of oxygen in patients with suspected acute coronary syndrome and normal oxygen saturation is controversial[51]). For example, applying oxygen by face mask at 6 L/min for a

BOX 102-5 Contents of a Medical Kit for Expeditions and the Medically Trained Traveler

Medical reference materials (books, tablet, or smartphone*)
Comprehensive community first-aid kit (see Box 102-4)
Appropriate medications for select priority illnesses (see Tables 102-2)
Portable diagnostic instruments for wilderness travel (Table 102-3)
Advanced devices for the medically trained traveler (see Box 102-6)
Specialized equipment based on recreational and environmental hazards (see Box 102-7)

*When planning to use electronic medical reference material, significant limitations in battery life and Internet must be taken into consideration.

BOX 102-6 Advanced Devices for the Medically Trained Traveler*

Oral and nasopharyngeal airways
Bulb suction device
Self-inflating bag-mask ventilation device with pediatric/adult mask sizes
Oxygen supply (see text)
Laryngoscope (MacIntosh blade sizes 2, 3, 4, Miller 3)
Oral and nasogastric tubes, 14 French
Nasal cannula and nonrebreather facemask (if oxygen supply available)
Cricothyrotomy cannula or catheter (e.g., Abelson cannula) or prepackaged cricothyrotomy kit (e.g., Portex Cricothyroidotomy Kit, Nu-Trake cricothyrotomy device, Tactical CricKit)
Endotracheal tube (size 7.0 internal diameter and pediatric sizes when appropriate) and stylets
Laryngeal mask airway (LMA; sizes 3, 4, and 5)
King airway or Combitube
Gum elastic bougie
Chest tube set, 32 French (practical only on major expeditions) with capability for formal or improvised water seal
Heimlich valve
Intravenous tubing with high-flow drip chamber and spike (see Figure 19-25 for use as emergency cricothyrotomy device)†
Needles and syringes (for intravenous hydration and emergency injectables)
Intravenous catheters (assorted sizes 14, 16, 18, 20, and 22 gauge)
Sharps disposal device (biohazard disposal container)
Intravenous tourniquet
Intravenous fluid (normal saline, lactated Ringer's, or Plasma-Lyte)
Adjustable cervical collar
Automated external defibrillator (AED)
Surgical tools
Surgical or fine-dust masks, N95 mask when concern for tuberculosis (TB)

*Selection of the equipment listed here must be made at the discretion of the trip medical officer based on several factors, including level of training and space allotted for medical supplies.
†From Platts-Mills TF, Lewin MR, Wells J, et al: Improvised cricothyrotomy provides reliable airway access in an un-embalmed human cadaver model, *Wilderness Environ Med* 17:81, 2006.

TABLE 102-3 Portable Diagnostic Instruments for Wilderness Travel*

Device	Indication
Thermometer (e.g., ADTEMP 419 digital or other low-reading device)	Essential for evaluation of hypothermic and hyperthermic patients (e.g., infection, exposure).
Sphygmomanometer (blood pressure cuff)	Useful for accurate measurement of blood pressure, particularly in trauma patients and patients with tachycardia or altered mental status; may be used as an adjustable tourniquet. Ensure appropriate cuff sizes and stethoscope are also packed.
Stethoscope	Useful for auscultation of Korotkoff sounds for manual blood pressure measurement and for chest auscultation, particularly to evaluate for the presence of wheezing, pulmonary edema, or pneumothorax.
Precordial stethoscope	A precordial stethoscope with earpiece can be a useful and inexpensive tool for continuously monitoring heart rate and respiratory rate.
Urinalysis test strips (e.g., Clinitek)	Useful for evaluation of abdominal pain, urinary symptoms, ketosis, and hyperglycemia.
Chronometer (waterproof with second hand)	Useful for accurate measurement of heart rate and respiratory rate; also important when planning evacuations.
Urine pregnancy test (e.g., Baby Check, Midstream, SureStep, or one of many other generic and name brands)	Essential for evaluation of abdominal pain in women of childbearing age; a positive pregnancy test may raise the possibility of ectopic pregnancy, and immediate evacuation might be considered. These tests vary in sensitivity and may also produce false-positive results.
Pulse oximeter (e.g., Nonin)	Considerable variation exists in the quality of over-the-counter probes (https://www.ncbi.nlm.nih.gov/pubmed/27089002). Choosing a manufacturer who also makes FDA-approved (medical-grade) probes, ideally with plethysmography, is recommended (extra batteries likely needed). Keep in mind that most of these units do not feature alarms or capability to provide continuous monitoring.
Glucometer (e.g., Therasense)	Useful for routine diabetes management and for evaluation of ill-appearing diabetic individuals who may have too-low or too-high serum glucose levels.
Fluorescein dye strips	Necessary for diagnosis of corneal abrasions. The cobalt light source on an ophthalmoscope or a fluorescent light stick can be used to illuminate the fluorescein.
Magnifying glass	For foreign body identification and removal.
Otoscope	For foreign body or otalgia evaluation (infectious, inflammatory, and traumatic etiologies); consider a device with capability for pneumatic otoscopy. Do not forget specula (preferably reusable soft tips of varying sizes).
Ophthalmoscope	Devices with cobalt light filters when used in conjunction with fluorescein are especially useful for the diagnosis of corneal abrasions.
End-tidal carbon dioxide detector (e.g., Nellcor)	Colorimetric devices are available to help with confirmation of endotracheal tube placement, while quantitative digital devices remain expensive and not practical for many expeditions.
Rapid diagnostic tests	When traveling to endemic regions, purchase of rapid diagnostic kits can be useful when evaluating febrile illnesses. Several kits are available for malaria, dengue, and typhoid as well as other illnesses. These kits require a drop of blood on a test strip. Travelers must investigate sensitivity and specificity for specific manufacturers and types of organisms (e.g., *Plasmodium vivax* vs. *P. falciparum*) because this is an evolving technology, may not be FDA approved, and usually is available for purchase at pharmacies in country of travel.

FDA, U.S. Food and Drug Administration.
*Appropriate training is required for use of these devices.

nonhypoxemic patient with lower abdominal pain is not only unnecessary but also will quickly exhaust supplies. In this case, if a D-size oxygen cylinder were packed and appropriately filled before departure, at 6 L/min this tank would last only about 1 hour (425 L ÷ 6 L/min = 71 minutes). Of note, portable oxygen tanks found in many first-aid kits are significantly smaller than a D-size cylinder and expected to last for much shorter durations. Any excursion that brings oxygen should also carry a pulse oximeter, not only to appropriately identify patients in need of oxygen therapy but also to titrate therapy in order to conserve supply. All wilderness medicine providers, even with proficiency using a variety of common airway and oxygen delivery devices, should familiarize themselves with the specific equipment packed for the trip. For example, some expensive oxygen kits lack self-inflating bag-mask devices and contain (oxygen-powered) manually triggered ventilation devices (MTV) that may be unfamiliar to many providers.

Table 102-4 provides a list of proposed medical kits for specific purposes as detailed in other chapters.

Table 102-4 Proposed Medical Kits for Specific Purposes With Chapter References

Medical Kit Type	Reference Location	Chapter
Sample contents of a wilderness airway management kit	Box 19-5	19
Facial trauma medical kit	Box 20-1	20
Wound care first-aid kit	Table 21-8	21
Tactical personal supply module	Table 27-8	27
Tactical basic medical module	Table 27-9	27
Tactical intermediate medical module	Table 27-10	27
Tactical major trauma module	Table 27-11	27
Pain management first-aid kit	Box 47-3	47
Wilderness eye emergency kit	Box 48-1	48
Technical rescue medical kit	Appendix	56
Minimal equipment for survival first-aid kit	Appendix D	59
Medical kit for jungle travel	Box 60-1	60
Desert survival kit	Box 61-1	61
Whitewater first-aid kits	Appendix A	62
Expedition medical kit	Appendix	80
Basic emergency kit	Box 111-1	111

SPECIALIZED EQUIPMENT FOR ENVIRONMENTAL AND RECREATIONAL HAZARDS

A host of activities, including mountain climbing, water activities, and winter expedition travel, have inherent risks that may warrant specialized equipment. This section discusses specialized items

BOX 102-7 Specialized Equipment for Environmental and Recreational Hazards

High Altitude
Gamow bag and accessories
Pulse oximeter
Oxygen canisters, nasal cannulae, face masks, oxygen tubing, and connections

Cold and Avalanche Exposure
External thermal stabilizer bag
Res-Q-Air
Hot Sac
Intravenous fluid warmer
Chemical warmers (e.g., Grabber)
Electric foot warmers (e.g., Hotronic)
Low-reading thermometer
Space Thermal Reflective Survival Bag
Adhesive climbing skins
Ice axe
Adjustable ski or probe pole
AvaLung avalanche vest
Tracker DTS
Avalanche Beacon

Water Sports (Low Impact)
CPR Microshield
Water disinfection equipment (i.e., filter, iodine or chlorine, SteriPEN)

Water Sports (High Impact)
Cervical spine immobilizer
Pelvic immobilizer (e.g., SAM Pelvic Sling)

Bicycling
All-terrain cyclist kit
Occlusive dressings

Tropical and Third-World Travel
Pressure immobilization equipment (for snakebite)
Permethrin-containing insect repellent
Mosquito nets
Oral rehydration electrolyte powder packs
Water disinfection equipment (i.e., filter, iodine or chlorine, SteriPEN)

Mountain Climbing and Hiking
Prefabricated splints and pelvic immobilizer (sling)
Slishman Traction Splint (not available in United States)
Slishman Rescue Harness
Ankle brace (e.g., Aircast)

that may be needed for certain high-risk recreational activities (Box 102-7 and Appendix C).

Two pieces of potentially lifesaving equipment with applicability in almost all environments include communication and navigation devices. In the past, satellite phones and global positional system (GPS) devices were prohibitively expensive; now one can purchase or rent a GPS device or satellite phone for a reasonable cost. Many smartphones are GPS enabled and with the necessary applications are able to function for this purpose, with the caveat that battery life can be significantly limiting. There are several GPS-equipped emergency alert communication devices that can be activated solely for the purpose of emergency rescue and medical aid. When activated, these devices, as with in-home medical alert systems, globally locate the device using GPS technology and then connect the user (qualitatively or via bidirectional audio) with a 24/7 support network to direct an appropriate response.[45] These devices can be purchased at a reasonable cost, and network support can be maintained for less than one would pay for satellite telephone services. In most countries, including low- and middle-income countries, cellular telephones have good reception, sometimes even in remote areas. Many of these devices require open space to send and receive, so forested areas can severely impair their function. Once again, using satellite or cell phones to activate a rescue can expedite patient care, but neither device should be regarded as a substitute for proper preparation and sound judgment during wilderness travel. Chapter 106 provides additional discussion of specialized navigation and communication equipment.

High-Altitude Exposure

Mountain climbing not only poses a risk for traumatic injury but also subjects the climber to altitude-related illnesses, possibly requiring portable oxygen or a pressure bag (e.g., Gamow bag).[4,15] The Gamow bag is a portable hyperbaric chamber resembling a large sleeping bag with a window (Figure 102-3). It has been shown to be effective for treatment of high-altitude pulmonary and cerebral edema. Constructed of nylon, the bag can be folded, and has a packing weight of 6.6 kg (14.5 lb). Inflated, it is 2.1 m (7 feet) long and has a diameter of 64 cm (21 inches). The bag is pressurized with a foot pump at a rate of 10 to 20 strokes per minute and has relief valves pressurized to approximately 1 kg (2 lb) per square inch, allowing venting of expired air. With pressurization, the Gamow bag simulates a descent of approximately 1000 to 2800 m (3281 to 9186 feet). In a situation such as a remote clinic with electricity, a mechanical compressor can be used to avoid the fatiguing task of foot pumping. In addition, a breathing bladder has been introduced. One end of this large nylon bag connects to a face mask, and the other end connects to one of the pressure-relief valves of the Gamow bag. The patient inhales uncontaminated air from the Gamow bag, and the exhaled air flows down a plastic tube into the bladder. This obviates the need for manual foot pumping of the bag for 15 to 30 minutes until the bladder becomes full; it is then necessary to operate the foot pump again to repressurize the bag. The bladder is an excellent adjunct for expeditions at very high altitude that are far from medical evacuation and when a prolonged period of resuscitation is anticipated. The recently developed Gamow tent operates on the same principle as the Gamow bag; it is almost 50% larger and has added height that allows a patient to sit upright.

These devices are expensive and intended for expeditions that are going to extreme altitudes (i.e., >4267 m [14,000 feet]) or dangerous situations (e.g., ice climbing on a steep glacial crevasse) that prevent rapid descent. Before using any therapy for hypoxia, physicians should be familiar with expected oxygen saturations for humans at various altitudes.

Cold Exposure

Extreme cold exposure may necessitate provision of warmed IV fluids and humidified oxygen in addition to usual supportive care. Travelers engaging in low-risk trips can use a sleeping bag wrapped with a space emergency blanket to provide a capsule that preserves heat and allows thermal recovery. The space blanket is made of a lightweight material capable of reflecting and retaining more than 80% of radiated body heat. Another helpful product is the Grabber Warmer. Useful for prevention of frostbite, this small pad undergoes a chemical reaction on exposure to air, producing heat. Grabber brand warmers can maintain a temperature of 66° C (150° F) for 7 hours or more. They can

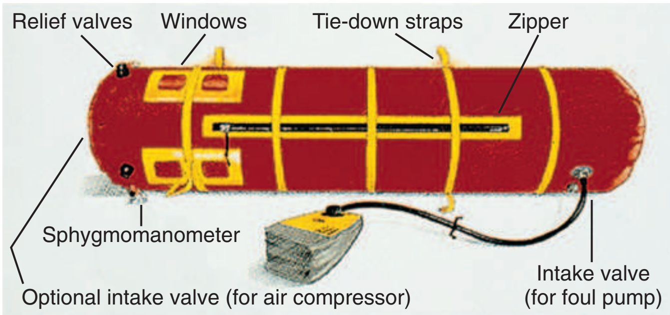

FIGURE 102-3 Gamow bag. Attached is the foot pump required to pressurize the compartment to 2 lb/in^2. Four windows are strategically located to permit observation, and entry is through a lengthwise zipper.

be placed in gloves, shoes, and pockets for prevention of frostbite, but should be used as directed to avoid burns because of the high temperatures that can be generated. They have also anecdotally been used (off-label) to warm IV fluids by coiling IV tubing around the warmer. In forested areas, a large plastic bag filled with leaves can provide insulation.

People involved in cold-water search, rescue, or other high-risk cold-water endeavors should consider purchase of a Hypothermic Stabilizer Bag. This product consists of an internal, high-pile fabric that wicks water to allow quick drying of hypothermic patients. The thermal properties far exceed those of an equivalent-thickness conventional down sleeping bag, and the product requires no additional insulation underneath it for support and comfort. A key feature allows the ability to perform CPR through an access window over the chest. The stabilizer's outer cover is made of water-resistant material and has carrying handles to facilitate safe patient transport.

For more remote or risky expeditions distant from medical rescue or assistance, several sophisticated products could be useful. Of value in circumstances of high avalanche danger is a lightweight vest with a breathing tube (e.g., AvaLung),[35] which permits extraction of oxygen and redirected release of carbon dioxide when an individual is trapped under snow (Figure 102-4). Such a device may prolong survival chances until the victim is found by another person appropriately outfitted with a snow shovel and an avalanche beacon or probe. For victims of severe exposure hypothermia, elevation of core temperature and prevention of further body heat loss may be critical. Inhalation of warm humidified air is now possible with portable field units, such as the battery-operated Res-Q-Air. The unit is simple to operate, has a temperature-control valve, and runs for 1 hour on battery power. It is small (27 × 9 × 3 cm [9 × 3 × 2 inches]), and weighs approximately 2 kg (4.5 lb). In the event that emergency IV fluids may be required, the Soft Sack IV Fluid Warmer can be used. This product comes in a soft, rugged, portable case and has its own battery power source. Temperature within the bag is maintained at 37° C (98° F) to keep IV fluids warm, and the bag has a protective sleeve to place over IV tubing to preserve warmth.

A Note on "Space Blankets"

"Space blankets" are plastic sheets, coated with a highly reflective material, that provide effective reflection of radiated body heat. Radiant heat loss is a minor component of heat loss as compared with conductive, convective, and evaporative losses. A space blanket provides virtually no insulation against conductive heat loss. Without concomitant bulky insulation, it is nearly useless when placed against any cold surface. As listed in Box 102-3, the personal medical kit should include a poncho or large plastic yard waste bag (these are available in bright orange from a variety of sources, such as OutdoorSafe). Although they are equally ineffective against conductive heat loss, these large yard waste bags are more durable over time when folded and better suited as a full body vapor barrier and enclosure. Space blankets often deteriorate along crease lines, even when stored properly. In emergency situations, the waste bags are easily worn as ponchos and stuffed on the inside with leaves, moss, grass, or other naturally obtainable bulky insulation, which makes them highly effective thermal conductive barriers.

FIGURE 102-4 The AvaLung is a lightweight vest designed to improve avalanche survival. Victims are able to draw air from even a dense snowpack through the front using an air-exchange mouthpiece. A one-way valve permits exhalation of carbon dioxide, which is expelled through the back of the vest. *(Courtesy Black Diamond, Ltd.)*

Water Disinfection

The key design features of a water disinfection system for backcountry travel include (1) adequate pore size of the filter to remove bacteria and protozoan cysts (i.e., ≤0.2 mm); (2) filter element that either has activated charcoal or is impregnated with silver or iodine for local antibacterial action; (3) pump-feed mechanism that forces water through the filter housing; (4) device that can be easily disassembled and cleaned for proper maintenance; and (5) product that is light, durable, simple to use, and can provide enough volume of clean water needed for the traveling party. Noteworthy filters that have most of these desirable features include those from Katadyn, PUR, and MSR WaterWorks. Disinfection with or without filtration may be achieved chemically with the use of iodine, chlorine, or ultraviolet (UV) radiation. Each method has benefits and shortcomings (see Chapter 88). Before the expedition, trip or medical leaders must investigate the potential likely pathogens to be eliminated, initial level of debris in the anticipated water sources, and volume of water (needed by the travel party) to be disinfected, as these are key factors for method selection. It is always advisable to have capacity for a backup method of water disinfection, such as boiling.

Bicycling

Cycling poses significantly increased risk for soft tissue injuries that may require occlusive water-based gel dressings for optimal wound care. Several prepackaged medical kits for cyclists are available. Individuals who want to modify a basic first-aid kit for treating cycling injuries should consider supplies needed to treat abrasions and minor burns. Proper wound management requires a protective pad that is nonadherent, cools the skin, and absorbs exuded fluids. Breathable water-based gels (e.g., Spenco 2nd Skin) are good for this purpose.

Mountain Climbing and Hiking

In wilderness travel above the tree line, inclusion of more advanced splinting products should be considered, but many common materials (e.g., cardboard and water bottles) provide excellent immobilization. A structural aluminum malleable SAM Splint weighs approximately 113.4 g (4 oz). The foam-coated aluminum strip unfolds to provide rigid longitudinal support. It can also be configured as a cervical collar, although an injured neck may require additional immobilization. At least two SAM Splints are required to stabilize an entire extremity. The SAM Sling is a force-controlled circumferential pelvic sling belt that is used for reduction and stabilization of pelvic fractures. The Slishman Traction Splint is a lightweight splint made from a pulley system and collapsible ski pole used as a lower-extremity traction device for femur and hip fractures. The Kendrick Traction Device is similar but uses a dedicated pole and nylon straps; it can also be used for dislocated shoulder reductions. Ankle injuries are common, and air-inflatable or gel-filled splints (e.g., Aircast) provide stability and fit comfortably in a wide range of footwear.

Protection Against Mosquito-Borne Illness

Personal mosquito netting is a requirement when traveling in tropical areas with mosquitoes, even when appropriate pretravel

BOX 102-8 In-Vehicle Emergency Supplies

First Aid, Rescue, and Survival

Comprehensive medical kit (see Box 102-4)
Large burn dressings
Boards for splint construction
Backboard, short or folding long (e.g., Junkin; see Appendix C)
Bags, large plastic
Collapsible shovel
Blankets—wool and space blankets or plastic yard waste bags (see text, Cold Exposure)
Climbing rope and hardware*
Candles, long burning
Flares
Flashlights and batteries in watertight storage
Headlamps
Food and water
Matches (waterproof) or butane-type lighter
Radio, citizens' band
Satellite phone
Global positioning system (GPS) device (e.g., Garmin *e*Trex, smartphone app or watch)
Rope
Saw with metal-cutting blade
Small stove, pot or coffee can, and utensils
Tarp, plastic
Toilet paper
Whistle

Automotive

Aluminum foil to cover windows
Cables to jump-start battery
Chains with tighteners, with repair links and special pliers†
Fire extinguisher
10-minute flares (at least six; can also serve as fire starters)
Industrial or welding gloves
Engine oil and extra can
Shovel, metal or Lexan, with short or collapsible handle
Tool kit
Small axe
Tow chain or cable
Wheel chock or wedge blocks
Siphon hose or hand-crank gas pump
5- and 10-gallon water cans
Propane tank with regulator and hoses
Solar panels or rolls
Car cigarette lighter adapters and cables
Country-appropriate electrical plug adapters
Spare automotive battery
Gasoline-powered generator
Propane or butane cigarette lighters
Tire pump
Flat-tire repair kit
Spare tire (2)
Tie-down straps
Extra gas (20 L)
High-lift jack and plate for jack

*Mountain terrain supplies (special training needed).
†Winter weather supplies.

vaccinations and antimalarial prophylaxis have been given. Mosquitoes are vectors for many serious illnesses, and mosquito netting is a simple and effective barrier. Netting impregnated with permethrin mosquito repellent is widely available in outdoor shops, as are long-lasting spray preparations for persons who want to treat existing clothes and equipment. Many compact and sturdy hammocks are manufactured with built-in mosquito netting. A second hammock suspended under the shadow of the rainfly allows dry storage of field gear and clothes off the ground in areas with frequent rain.

ITEMS STORED IN THE VEHICLE

When feasible, a complete emergency kit should be stored in a vehicle or at base camp (Box 102-8). This kit should also provide material necessary to manage accidents encountered along the highway and to cope with the environment if the occupants are stranded by automotive trouble or natural disaster. Several large burn dressings and a board with strapping to restrain the head and neck will fit in a standard vehicle trunk or other recess. Although only large vehicles can accommodate the usual full-length backboard, a folding backboard is available from Junkin Safety Appliance (see Appendix C in this chapter). The remaining contents of an emergency kit will fit in a medium (18 cm wide × 37 cm long × 27 cm high [6 × 12 × 9 inches]) or large (24 cm wide × 55 cm long × 43 cm high [8 × 18 × 14 inches]) military surplus ammunition box, watertight plastic box (e.g., OtterBox), or soft medic bag (e.g., CamelBak) of similar size (Figure 102-5).

MEDICAL REFERENCE MATERIAL

Ensuring access to familiar, readily understood, and comprehensive medical reference material is an important component of

FIGURE 102-5 First-aid kits for vehicles. Medications are stored in zipper-lock bags with dosing instructions. Each kit has an inventory card. Small kits such as these are appropriate for short excursions and while driving in a caravan.

pretrip planning but does not replace appropriate training and preparation. Traditional medical reference materials have limited utility in remote settings due to weight and size constrictions but may be extremely useful when not in the field. Numerous pocket guides exist, but often lack comprehensiveness. Books such as this one can be obtained as a field guide (*Field Guide to Wilderness Medicine*) or downloaded in electronic format as an application for mobile phone or tablet devices (https://itunes.apple.com/us/app/field-guide-to-wilderness/id713382694?mt=8). In addition, a variety of other electronic resources and mobile applications are readily available and sometimes free, including applications ("apps") for drug reference (e.g., *Physicians' Desk Reference,* http://www.pdr.net/), ePocrates (http://www.epocrates.com/products), and infectious disease guides (e.g., Sanford Guide, http://www.sanfordguide.com/); Johns Hopkins Guides (http://www.hopkinsguides.com/hopkins/ub); and downloadable clinical practice manuals for resource-constrained settings (e.g., *Integrated Management of Adolescent and Adult Illness* manual[23]). Careful attention must be given to battery life and charging capability of mobile devices if electronic resources are the primary format for reference material in the field. In certain circumstances, it may be prudent also to carry printed copies of drug and other information specific to the medications in the trip first-aid kit as well as to known existing medical conditions in the travel party.

Mobile Health (mHealth) and Emerging Technologies

The number of portable, consumer electronic medical devices has skyrocketed in recent years. Many of these products are designed for and require a mobile smartphone for use, thus the term *mHealth*. These products range from portable diagnostic devices such as Bluetooth ECGs capable of email transmission, to videoconference-telemedicine consult apps, to mobile phone–based pulse oximeters and thermometers. Despite potential promise of improved diagnostics and treatment of patients, as yet the applicability of these devices in remote settings is uncertain. Careful consideration before purchasing must be given to battery requirements and device accuracy (many are not validated or formally approved for patient care), among other concerns. It is also important to keep in mind that most consumer medical devices are not certified to be used for continuous patient monitoring. As a result, these devices often turn off automatically after set periods and do not have alarms to signal abnormal values.

MEDICATIONS USEFUL IN THE WILDERNESS SETTING

PRIORITY PRESCRIPTION AND OVER-THE-COUNTER MEDICATIONS

Expedition medical officers must confront several key questions before selecting medications to incorporate into a first-aid kit:

1. What medications am I (or other members of the party) trained to administer and distribute?
2. What medications are likely to be lifesaving?
3. What medications are most likely to be needed based on the trip itinerary and personal medical histories obtained?
4. How much space exists in the first-aid kit?

Table 102-2 lists OTC and prescription medications that should be considered for wilderness excursions. This list is intended to serve as a framework from which a medical officer can begin to prioritize both OTC and prescription medications. Many medications (e.g., atropine, epinephrine, dexamethasone, nifedipine, nitroglycerin) have significant systemic effects and should generally be limited to physicians, nurses acting under the direction of a physician, or designated medical providers with appropriate training.

Primary care physicians taking care of travelers will often be asked to prescribe medicines that will be used or withheld on the basis of the judgment of someone who is not a physician (i.e., the traveler or trip leader) (Figure 102-6). Patients should be educated about appropriate and inappropriate use of medicines and encouraged to consult a local physician or communicate with a physician from their country of origin before taking any prescription medications or even certain OTC medications.

FIGURE 102-6 Medications. See Table 102-2 for a list of over-the-counter and prescription medications often considered for various types of wilderness expeditions. *(Courtesy Matthew R. Lewin.)*

When assembling medical kits, always include copies of the manufacturer's package insert with each medicine or ensure offline electronic access using a smartphone or other device. Expedition members should visit their personal health care providers to obtain prescriptions before departure. Although sharing of medications within a group of travelers is common, it is not an activity that the prescribing physician should endorse or be responsible for unless the doctor is acting as an adviser to the entire group. All physicians should be aware of their potential liability when traveling with, prescribing medications for, or advising a travel group from a remote location.

An additional challenge facing the expedition medical officer is allocation of opioid-containing analgesics, sleep aids, and other controlled medications. Expedition members naturally hope to be as comfortable as possible and to sleep well, although these may be unreasonable expectations at times. Likewise, medical designees want to provide adequate treatment for pain and anxiety. Because of the potential for inappropriate use of these medications, it is advisable to limit access and consistently apply predetermined policies for the use of opioids and anxiolytics. All controlled substances should be kept in a secure compartment such as a zippered locking bank bag if space permits, and inventory should be regularly monitored.

Injectable drugs are rarely needed for management of wilderness-associated trauma and illness, because most emergencies can be managed by either oral or transdermal application of medicines. Intravenous medications are temperature sensitive, fragile, expire quickly, and require monitoring of vital signs because of potency and immediate onset of action. In certain circumstances, such as lengthy, remote expeditions with high-level medical support, inclusion of several injectable medications may be justified. Numerous analgesics can also be given intramuscularly.

Opioid analgesics can be used to treat pain if combining first-line analgesics (e.g., NSAIDs and acetaminophen) is inadequate. At least one oral opioid should be included in an expedition first-aid kit if a licensed provider is available.[41] Caution must be used in all travelers who are to receive opiates, but especially those with altered mental status or significant coexisting respiratory disease. Respiratory depression with limited ability to manage the airway or provide supplemental oxygen can be fatal. Oral opioids may be appropriate for moderate to severe pain. Opioids and dehydration can predispose an individual to constipation, which is an uncomfortable and potentially dangerous problem. Any patient initiating opioid therapy should be advised to also start a bowel regimen. Docusate sodium (Colace) and senna (Senokot) are acceptable first-line agents, although caution must be used with gel capsule formulations in hot environments, because melting is a common issue. Any expedition carrying opioids should also carry a reversal agent (e.g., naloxone). Travelers with chronic pain syndromes should seek appropriate analgesics and adequate supplies from their personal physician before departure.

Whenever possible, medicines should be purchased as tablets rather than capsules because of the tendency of capsules to break apart or dissolve (Figure 102-7). Under extremes of temperature, creams may become unusable, and in such environments, oral medications are preferred. For example, creams for genital yeast infections have a tendency to separate, whereas oral antifungals (e.g., fluconazole), although more expensive, are compact, stable, and may be discretely and hygienically administered.

Purchasing medications on arrival may be necessary and may save money, but must be done with caution. A study of the quality of antibiotics in a developing country found that, in approximately 30% of the products studied, the drug was either not present or present in lower dosages than stated.[38] If treatment failure poses a significant health threat, the traveler should make every effort to obtain medications from a reliable source. Although many medications that require prescriptions for purchase in high-income countries, including opioids, are available over the counter in low- and middle-income countries, the advice of a local physician may still be helpful.

Whether expired medications should be used depends on stability and safety. It is a dubious practice, but one that is widespread. The term *stability* refers to the tendency of a drug to become less potent over time. Manufacturers provide an expiration date up to which point the drug will lose more than 10% of its potency, if kept in its original closed container. After the container has been opened, the expiration date no longer applies. Retail pharmacies typically label repackaged drugs with a "beyond-use" date that is generally 1 year from the date the prescription was filled. Many drugs maintain potency of more than 90% for long after the expiration date. For example, ciprofloxacin can remain stable for several years after the expiration date, even under conditions such as high temperature and humidity. Passing an expiration date does not necessarily indicate that the drug becomes harmful for human use. Nevertheless, a known exception is tetracycline antibiotics, which degrade into toxic metabolites that can damage the kidneys.[9] For medications that are dosed to effect (e.g., those used to treat pain, gastric, respiratory, and psychiatric symptoms), decreases in potency usually present minimal risk to the patient. For medications with specific recommended doses (e.g., antibiotics, therapies for high-altitude illnesses), decreased potency could result in ineffective treatment of a serious condition. (See the text Appendix, Drug Stability in the Wilderness.)

PASSING THROUGH CUSTOMS WITH MEDICATIONS

Each medication should be labeled with the patient's name, prescribing physician's name, dosing schedule, indications, and warnings. In most parts of the world, individuals carrying properly labeled medications receive little attention at customs. For persons leading a group and carrying the community medication supply, appropriate documentation is important. To facilitate passage through customs, all medication bottles should be labeled appropriately, including "For use by the ________________ Expedition only." Medical designees should carry multiple copies of their credentials and letters of purpose from their sponsoring institutions. A letter from the sponsoring institution or company that designates the carrier of the medications as the group's medical officer or physician will usually suffice.

Special caution must be used when traveling with scheduled or controlled substances because these may require special documentation or even may be illegal in the destination country. Impeccable documentation and group discussions with participating travelers before departure are critically important because certain countries have strict laws that may include harsh legal action, including long-term imprisonment or even capital punishment.

Inevitably something will be overlooked, confiscated, or needed unexpectedly. A visit to a local hospital or clinic may require creative pantomime and drawing. These visits provide helpful local medical contacts and identify appropriate sites for donation of medications and equipment, when appropriate, on return.[54] Sterile items such as disposable needles, IV tubing, and catheters may be much less expensive. It should not be taken for granted that these will be available or fit correctly on items purchased in preparation for international travel.

A dictionary of the local language is essential. Many developing countries have hospitals and training modeled after countries

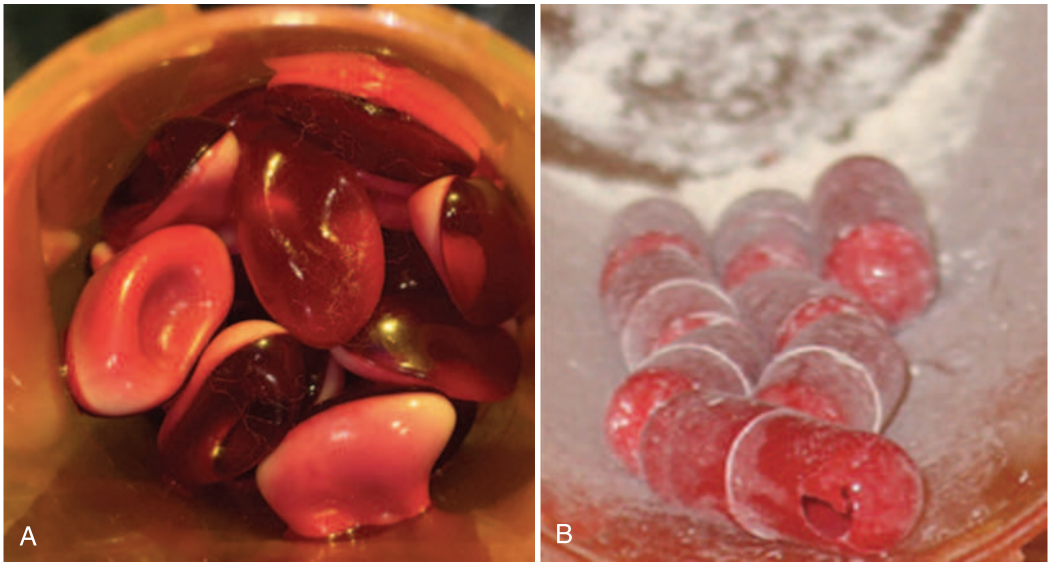

FIGURE 102-7 Gel tabs (**A**) and gelatin capsules (**B**) are susceptible to damage from heat and vibration. Consideration should be given not just to the medication, but also the dosage form.

that once occupied them. Thus, when traveling in Central Asia (e.g., Kazakhstan, Mongolia), a Russian dictionary is helpful, because a high percentage of pharmacists and physicians in this area speak Russian and read Cyrillic. Similarly, local medical providers in many parts of Africa and Southeast Asia are familiar with or fluent in French.

PREPARING FOR COMMON MEDICAL PROBLEMS IN THE WILDERNESS

Thresholds for administering medications—including analgesics, sleep agents, and antibiotics—during travel depend on practice style, supplies, and evacuation options. Treatment thresholds tend to be lower (i.e., more aggressive) in the wilderness than at home. To ensure timely care, all trip members should feel comfortable seeking consultation or clarification from the expedition's medical designee. A secure log of all patient encounters is important for both patient and physician. Preparation for common medical problems in the wilderness setting is discussed next, followed by consideration of certain challenges encountered in some low-income countries.

GASTROINTESTINAL, GENITOURINARY, AND REPRODUCTIVE CARE

Travelers should anticipate significant changes to normal hygiene practices that can potentially have negative impacts on health and morale. With adequate planning, participants can generally mitigate the potentially negative consequences of these changes. Groups camping in a delicate ecology or near freshwater should use a lightweight and portable commode with sturdy disposable plastic bags. This practice has become law when working or traveling in certain areas, such as federal land in the United States. Urine containers may be appropriate if prolonged adverse weather is a possibility. Funnel-like devices that connect to urine containers (e.g., Lady J; see Appendix C) may be helpful for women. People embarking on long journeys should be aware that their normal bowel habits are likely to change. Lack of public sanitation may compel the more fastidious to bring their own supplies of toilet paper, baby wipes, and items for treatment of perianal itching and hemorrhoids, such as pads saturated in witch hazel (e.g., Tucks) and other familiar brand-name formulations (e.g., Anusol, Preparation H). Women should predict their needs for absorbent pads and tampons based on their menstrual cycles. Knowing how and being able to squat is of vital importance and can be more difficult for men. Concepts of privacy might have to be discarded in lieu of necessity.

Some women who use oral contraceptive pills may change their cycles to avoid menstruating on long journeys. Women should discuss this possibility with their personal physicians several weeks before departure. In addition, a urine pregnancy test should be included in most medical kits.

Diarrhea and Abdominal Pain

Although most cases of diarrhea and abdominal pain are relatively benign and manageable even in a remote setting, the differential diagnosis is broad. Consideration must be given to infectious (e.g., enteric gram-negative rods, typhoid, giardiasis) and noninfectious (e.g., constipation, peptic ulcer disease, appendicitis) causes, because benign conditions, such as constipation, if not addressed early and appropriately, can cause significant impediments for travelers.

Gastrointestinal distress and traveler's diarrhea can occur during any significant geographic change (e.g., in Mexico, bismuth subsalicylate is sometimes advertised for Mexicans traveling to the United States to avoid "Uncle Sam's revenge"), but more likely when traveling in low- and middle-income countries that lack adequate water sanitation infrastructure. Whatever the etiology, careful selection of foods and drinks can decrease the risk for infection. Bottled or boiled drinks and cooked or peeled foods are less likely to contain pathogens. Conversely, cold drinks, ice cubes, and raw or undercooked foods are more likely to contain pathogens. Fomites can be highly contaminated with feces even if people are fastidious; flies land on feces and transport pathogens from plate to plate. Treatment of traveler's diarrhea should focus on fluid replacement, consideration of antibiotics, and symptomatic treatment. Each participant should be encouraged to report the first loose stool. For select pathologies, treatment at the onset of symptoms can cut duration of symptoms from 3 days to 1 day and minimize spread of infection to others within the group. Bacterial pathogens cause about 80% of acute traveler's diarrhea, which explains why antibiotic treatment is so effective. Patients with diarrhea should increase fluid intake and avoid sharing or preparing drinks or food for others.

Patients with diarrhea who are very young or very old, have significant underlying disease, or are unable to tolerate oral fluids should seek local medical attention and evaluation; parenteral fluids may be necessary to treat these individuals. As previously mentioned, for conscious travelers with mild to moderate dehydration and no ileus, adequate rehydration can generally be accomplished using commercially available oral rehydration supplements (ORS). Oral glucose-electrolyte solutions[20,37] with equimolar glucose and sodium and osmolality of 200 to 310 mOsom/L have been shown to be as effective as IV fluid therapy in treating moderate hypovolemia associated with certain diarrheal diseases. Commercially available ORS that are in line with WHO recommendations can be obtained as powder packs for easy resuspension calculations using 1-L travel bottles.[36]

Chapter 82 provides a more extensive discussion of the principles of treatment for infectious diarrhea.

All women with abdominal pain without an obvious explanation should receive a pregnancy test. If the test is positive, the patient should seek immediate medical attention, given the risk for ectopic pregnancy. Women who know they are pregnant must notify trip medical staff and should consider ultrasound studies before travel to identify the location and number of pregnancies.

Medical attention should be considered for anyone with atypical abdominal pain. Proton pump inhibitors (PPIs; e.g., omeprazole, pantoprazole) and histamine-2 (H_2) receptor antagonists (e.g., famotidine, ranitidine) are typically prescribed for acid reflux and dyspepsia, but both medications cause hypochlorhydria (i.e., decreased levels of stomach acid and elevated stomach pH), which compromises defense mechanisms of the upper GI tract. Use of these medications may predispose travelers to bacterial and parasitic intestinal infections.[42] Patients taking H_2 receptor antagonists and PPIs should be aware of their potential to increase incidence and perhaps severity of GI infections. Temporarily stopping these medications during travel should be considered on a case-by-case basis.

All travelers should receive hepatitis A immunization prior to travel to endemic regions.

Sexually Transmitted Infections

Sexually transmitted infections are common among travelers; trip medical personnel should be able to recognize and treat common conditions. Trip medical personnel should also be prepared to decrease transmission by including ample supply of lubricated and nonlubricated synthetic condoms in the medical kit and making this supply accessible.

Expedition participants considering sexual activity with a new partner should be encouraged to carry condoms. Condoms without lubrication can also serve as waterproof pill carriers, small tourniquets, and makeshift canteens (these have sometimes been used by the British military). Chancroid is particularly prevalent in the developing world and can act as a vehicle for more serious and less treatable infections, such as HIV and herpes simplex. All travelers of reproductive age should receive vaccinations for hepatitis B and consider human papillomavirus (HPV) vaccination.

ORAL HYGIENE AND HEALTH

Mild sore throat and a foul taste are common when traveling in the mountains and in cool weather, probably because of mouth breathing, enhanced loss of moisture from the upper respiratory tract, and medication effects. Both problems can be addressed by using either hard candies or medicated lozenges (e.g., Cepacol, Chloraseptic). Saline spray can keep nasal passages hydrated. Because treatment of early caries and loose fillings (which may trap expanding air) can prevent dental demise, each party member should have a dental examination before the trip. During the trip, frequent brushing may seem impractical, but having multiple brushes available and a few small tubes of toothpaste make this less so. Flossing after meals, rinsing well with water, and chewing sugar-free gum also help to maintain oral hygiene.

Toothache is common at high altitudes and during ascent from deep dives. For painful cavities or decay, temporary filling materials (e.g., Cavit) can be obtained in small squeeze tubes and applied to a tooth with a wet cotton applicator to prevent sticking. A dental emergency in any environment, hot or cold, should not occur because of lack of preparation.

FRACTURES AND DISLOCATIONS

Splints can be improvised from cardboard, plaster, cloth, duct tape, water cans, and a phenomenal array of other materials. A number of lightweight splinting products, including moldable splints, ankle braces, and pelvic immobilizers, are available (see Box 102-7 and Mountain Climbing and Hiking, earlier). There are several types of cold packs, including chemical, flexible, and rigid. Chemical cold packs are available at most wilderness and outdoor outfitters and should be used with caution when there is a break in the skin. In general, these packs are intended for single use only. Some cold packs have the potential to cause frostbite; improper application can cause or worsen injury. Gel packs are stored in the freezer and might be seen only in large expeditions with solar- or fuel-powered generators. For areas in which a cold mountain stream is accessible, submerging the injured extremity (or legs tired from a day of hiking) is helpful.

SLEEPING AND STAYING AWAKE

Difficulty sleeping during travel is common and often caused by stress associated with a new environment or jet lag. Decreased sleep negatively impacts not only trip enjoyment but also physical performance and judgment, thereby significantly increasing a traveler's risk of injury. Medications that aid induction and maintenance of sleep can be useful, as can nonpharmacologic sleep aids, such as ear plugs, eye masks, and relaxing music. Nonpharmacologic methods should always be first line. Oral diphenhydramine is generally a safe and effective soporific. A 25- to 50-mg dose can result in sedation for approximately 6 hours. Diphenhydramine also causes mild mental impairment lasting about 2 hours, and because of its anticholinergic effect, can cause urinary retention in predisposed individuals. The medical kit may carry benzodiazepines to treat seizures. They are also effective sedatives and may be used with discretion as a sleeping medication if nonpharmacologic methods and diphenhydramine are ineffective. Patients should be warned about potential adverse effects and the possibility for abuse with benzodiazepines and other sleep remedies. Benzodiazepines should not be used with alcohol and are contraindicated in pregnancy (Pregnancy Category D), except for emergencies such as seizures. Physicians prescribing benzodiazepines to women should document the last menstrual period or require a pregnancy test in addition to a detailed discussion of the risks and benefits of these medications when sexual activity and pregnancy are possibilities.

Additional problems with sleep are experienced at high altitudes, where hypoxia, frequent awakenings, and periodic breathing are almost universal. Zolpidem (Ambien), temazepam (Restoril), acetazolamide, and a variety of other medications have each been examined for treatment of sleep problems at altitude. Drugs such as zolpidem and temazepam have been shown to subjectively improve sleep quality and decrease nocturnal variations in oxygen saturation in participants at 5300 m (17,388 feet). In addition, acetazolamide and theophylline have been shown to decrease periodic breathing. Acetazolamide can significantly reduce nocturnal hypoxia from periodic breathing.[12,52] Climbers and trekkers who have difficulty sleeping at altitude should consider a trial course of acetazolamide. If acetazolamide is ineffective, zolpidem or temazepam may be useful. Patients should be aware that the effect of benzodiazepines on daytime performance at high altitudes is unknown. In addition, patients should be cautioned against the use of temazepam, alprazolam (Xanax), or other benzodiazepines during technical ascents because of the risk for impaired judgment and performance. Nevertheless, a supply of these medications should be available for emergency use.

Some travelers will encounter situations that require staying awake for an extended period; long drives, rescues, and night watch are a few possible scenarios. For these situations, caffeine-containing drinks or OTC stimulant medications may be invaluable. Caffeine is also useful for temporary relief of caffeine withdrawal headaches and is available in 200-mg tablets, roughly equivalent to 2 cups of strong coffee. Caffeine use should be discouraged among patients with a history of seizures, high blood pressure, or heart disease. Because of the diuretic effect, patients using caffeine will need to consume additional fluids to stay well hydrated. Newer (but expensive) drugs, such as modafinil (Provigil), are becoming popular but have not been formally evaluated in the wilderness setting. In emergency situations, stimulants such as prescription amphetamine derivatives (e.g., dextroamphetamine and amphetamine [Adderall] and methylphenidate [Ritalin]), have been used successfully but carry significant risk of physical and psychiatric adverse effects, as do all stimulants. Consumption of energy drinks with alcohol is considered a risk factor for problematic drinking and impulsivity.[44]

BLISTERS AND FOOT CARE

Participants should bring footwear they have already worn and found comfortable. Socks should be kept clean and dry. At a minimum, a second pair is usually necessary, but in most cases, multiple pairs should be brought.

Identifying and addressing painful areas on the feet early can prevent blisters. There are many ways to prevent blisters by minimizing friction and pressure at "hot spots" using basic elements of the medical kit. Petroleum jelly on a gauze pad, covered by duct tape, is a reliable method of preventing or treating blisters. In addition, duct tape placed on the inner lining of shoes decreases friction between the sock and shoe; it can also be placed directly on the surface of the skin. A long-acting local anesthetic such as bupivacaine can provide exceptional relief if there is no alternative to walking, and a blister injury must be overcome. Local anesthesia may allow further tissue trauma to go unrecognized, and thus is not a solution for blisters encountered at the beginning of a multiday trip. Finally, a small square of silk, paper currency, or candy wrapper can be glued to the heel or to another pressure point. This durable method of blister care is another example of a simple, inexpensive alternative to commercial preparations, which may not be available or sufficiently durable in suboptimal conditions. Similarly, methylacrylate–based glue can be used to repair skin fissures (Figure 102-8), and abrasives can be used to reduce the size of thick, cracked callouses. People who anticipate problems with blisters should consider reading John Vonhof's book, *Fixing Your Feet,* which provides detailed information about ways to protect the feet during extended travel. (See Appendix A in this chapter and Chapter 25.)

Nail clippers are an important addition to the medical kit for people on extended journeys. For shorter trips, trimming toenails before departure reduces likelihood of injury to the toenail and surrounding soft tissue. However, caution must be taken to evert the distal nail edges among people who are prone to ingrown toenails. Hikers whose feet sweat excessively may benefit from talc or medicated powder (e.g., tolnaftate [Tinactin]; see Table 102-2). Travelers in cold and aquatic environments are especially prone to dry skin. Petroleum jelly and skin creams and lotions (e.g., Eucerin, Lubriderm, Keri) may help forestall microtrauma and epidermal cracking.

FIGURE 102-8 Methyl acrylate glues may be useful for closing skin fissures and small lacerations. Skin glues should not be used to close lacerations in cosmetically significant areas (e.g., eyebrows, eyelids).

WOUNDS

Cleanliness and hemostasis are the cornerstones of good wound care, whether in an emergency department or a remote setting. Although this chapter discusses numerous potential wound care supplies, in practice, inclusion of a few simple supplies and good improvisational skills can help ensure adequate wound management under most wilderness conditions.

The medical kit should include tactical tourniquets or a blood pressure cuff to help stop bleeding. Traditional medical teaching during the last half-century has focused on avoiding tourniquets in favor of direct pressure, arterial pressure points, and elevation. It was taught that arterial occlusive tourniquets could lead to limb ischemia and loss in an "uncontrolled" out-of-hospital setting. Although inadequately applied tourniquets can increase bleeding (if only venous but not arterial flow is occluded) and cause neurovascular injury (especially with prolonged use), military data from recent conflicts have demonstrated the safety and efficacy of appropriately applied, arterial occlusive tourniquets.[3,27,29] Direct pressure is still the preferred method for hemorrhage control, but when not feasible, such as limb amputation or during technical evacuation with limited manpower, tourniquets can be lifesaving. With smaller hemorrhages, nasal sprays containing vasoconstrictors can help provide hemostasis. For some injuries, particularly those that involve the scalp, closure of the wound with staples will rapidly provide hemostasis; a small "ten shot" skin stapler (e.g., ConMed Reflex, 3M Precise) is a useful addition to the medical kit.

Water for irrigation should be clean and ideally sterile, but copious irrigation with nonsterile water is preferable to no irrigation if an adequate supply of sterile water is not on hand. IV fluids may need to be conserved if rescue is not imminent. Forcefully ejecting irrigation solution from a 20-mL syringe through an 18-gauge needle generates pressures adequate to dislodge bacteria and microscopic particles from contaminated wound surfaces (Figure 102-9). A squeezable bottle with holes punched in the top or a plastic bag with small holes suffices for lower-pressure irrigation. When appropriate, surgical excision of crushed, devitalized, or severely contaminated tissue can be achieved with sharp eyelet or suture-cutting scissors from the medical kit's surgical or bandage-cutting tools.

Surgical tools may be crudely disinfected by rubbing vigorously with a prepackaged towelette containing alcohol, chlorhexidine (Hibiclens), povidone-iodine (Betadine), or benzalkonium chloride. After cleaning the instruments with alcohol or chlorhexidine towelettes, igniting the residual alcohol will provide additional disinfection. Flame sterilization until red hot or boiling may also be acceptable. Although less efficient, immersion in boiling water (for about the same duration as one boils drinking water for disinfection) can also help disinfect materials. Use of these techniques may be considered when more reliable techniques are unavailable but should not be confused with sterility.[36a] Data on the safety and efficacy of these methods are lacking.

Wound care adjuncts, including Tegaderm adhesive dressings and Spenco 2nd Skin, can be extremely useful in wilderness settings. Tegaderm is a transparent adhesive covering for clean wounds that provides a barrier to water, dust, and dirt while allowing oxygen to penetrate. It is available in a variety of sizes and can remain in place for several days provided no wound complications arise. Spenco 2nd Skin is a polyethylene oxide gel laminate that reduces friction damage to the skin underlying blisters and burns; the product may offer additional protection

FIGURE 102-9 Water for irrigation should be clean and ideally sterile. Copious irrigation with nonsterile water is preferable to no irrigation.

by redistributing pressure and absorbing exudates. These are just two examples of many potential wound care dressings that can be helpful in remote settings.

Necessary quantities of dressings, gauze, and suture material can be calculated in a similar manner used for calculation of medication quantities (see sample calculations in Strategies for Packaging Medical Kits, earlier). However, prevalence of traumatic injury during travel should be considered. Thus, it is not necessary to bring enough packing for 10 lacerations if there are 10 people on the trip.

BITES AND STINGS

Travelers should know the signs and treatments of allergic reactions and be prepared to intervene. Epinephrine preparations, an antihistamine such as diphenhydramine (Benadryl), and oral corticosteroids are essential components of the medicine supply. As discussed earlier, individuals with a history of allergy to insect stings should carry their own epinephrine. For trained medical professionals, an inexpensive alternative to preloaded syringes is to carry a 1-cc syringe with needle and a 1-mg ampule of 1:1000 epinephrine (0.1% or 1 mg/mL) (Figure 102-10). The benefit of this approach is that a 1-mL vial provides at least three doses of epinephrine in the event of a severe reaction or reactions in multiple patients. Glass epinephrine ampules require careful handling and storage out of light.

Topical corticosteroids are especially useful for insect bites and contact dermatitis and may alleviate suffering and obviate the need for systemic drugs. Maximally potent fluorinated corticosteroid cream preparations (e.g., betamethasone, fluocinolone, fluocinonide, halcinonide) are recommended for use under the harsh circumstances of wilderness travel (see Table 102-2). Short-term use rarely causes complications, although, for the face, moderate-potency preparations, such as triamcinolone, are preferred over maximally potent formulations.

Snakebite treatment is discussed in Chapters 35 and 36.

Travelers expecting frequent exposure to snakes or dangerous marine animals, such as stonefish, might consider obtaining antivenom specific for the area of travel or knowing the location of the closest facility with the antivenom. All antivenoms, including the new formulation for rattlesnakes (CroFab), carry a significant risk for both severe allergic reaction and delayed serum sickness and thus should be administered only by people who are properly trained and equipped to handle these situations. Using an injectable cholinesterase inhibitor (e.g., neostigmine in combination with anticholinergic drug, such as atropine or glycopyrrolate) may delay or reverse the effects of a neurotoxic envenomation, such as that of a cobra or krait.

FIGURE 102-10 Three different preparations of epinephrine. *Left,* 1-mg vial of epinephrine 1:1000 and insulin syringe *Middle,* Single-use (0.3 mg, 0.3 mL, 1:1000) autoinjector device, the EpiPen. *Right,* Single-use injectable delivery device, 1:10000, 1-mg dose.

SUNBURN, SNOWBLINDNESS, AND SUNGLASSES

All travelers should use both barrier protection (e.g., hat, long sleeves) and sunscreen with an SPF of at least 30 with full ultraviolet A (UVA) and UVB light protection. Efficacy of sunscreen is diminished by sweat, water, wind, dirt, and friction. A hat and long-sleeved clothing plus sunscreen will prevent severe sunburn in most environments. Zinc oxide and titanium dioxide sunblocks or “face masks” provide additional protection in snow, high altitudes, and deserts. Modern and readily available formulations can provide remarkable sun protection without the traditional opacified coating of the skin usually seen with zinc and titanium creams. Sunscreens with compounds such as avobenzone and octocrylene should be sought, because these can protect over a broader range of the UVA and UVB spectrum.[50]

In 1997, the incidence of snowblindness (photokeratitis) among trekkers and porters in central Nepal was about 3%.[6] Snowblindness, a burn injury to the cornea, results from cumulative exposure to sunlight (see Chapter 48). If there is significant risk of eye pathology, an expedition is strongly encouraged to bring fluorescein and an appropriate light source for thorough ophthalmologic examination (see Table 102-3). Topical ophthalmic anesthesia provides pain relief and facilitates examination, but should not be given repeatedly because of increased risk for ulcer formation (see Table 102-2). Several therapies may have a role in snowblindness, including topical nonsteroidal antiinflammatory drug (NSAID) drops, antibiotic drops, and asking the traveler to rest with eyes closed in a dark location. Snowblindness is very painful, but full recovery usually occurs within 24 to 72 hours. Optimal eye protection can be achieved by wearing sunglasses with 100% UV light protection. The major variables to consider when buying sunglasses are durability, light transmission, photochromicity (i.e., darkening with increasing sun intensity), and polarization.

Although plastic lenses are lightweight, they scratch easily and are generally not recommended for extensive wilderness trekking. Glass lenses with the best photochromic properties can be coated for greater than 99% UV absorption, but are heavy, susceptible to breakage, and moderately susceptible to scratching. The most durable lenses are made of polycarbonate; these are lightweight and shatterproof. For this reason, polycarbonate is usually the preferred material for serious wilderness sports. Polycarbonate models that absorb at least 99% of UV light are manufactured by such brand names as Orvis, All Weather, Bolle, Coyote (polarized), Gargoyles, Gentex, Learjet, Oakley, Ski-Optics, Suncloud, Transitions (photochromic), and Wings. Although polarization does not protect from UV light, it reduces glare and increases contrast, making it highly desirable for winter mountaineering, skiing, and aquatic wilderness sports. External clip-on plastic polarizers are also available, and some soft contact lenses absorb UV radiation.

Because light reflects off snow and sand, sunglasses with side protection are recommended in these environments. Side shields, nose guards, and eye patches can be fashioned from almost any material. Because sunglasses are often forgotten, misplaced, or broken, for long trips, every member of the expedition should carry two pairs of sunglasses. Expedition physicians should carry extra pairs. Retention (i.e., neck) straps are recommended for virtually all outdoor activities. For water sports, a lanyard may be attached from the glasses’ frame and over the back to a belt loop. In addition, the physician should know how to improvise sunglasses from available materials (e.g., by making two horizontal slits or multiple dots in an ocular barrier, such as duct tape), because loss of vision in even one member can quickly endanger the entire party.

Eye protection should be worn at all times when working with or in the vicinity of others using hand tools, machinery, or flammable substances. A loupe or other handheld lens can be very helpful for identifying ulcerations and removing corneal foreign bodies. Sandstorms are also a common source of foreign body eye irritation. Ski and swim goggles offer good eye protection for areas where particles from tools or storms are flying at high velocity. Goggles are more effective than sunglasses with side shields for repelling dust and sand particles swirling and ricocheting in high winds.

PAIN

Pain control in remote settings should follow a multimodal approach. Medication side effects (e.g., constipation with opiates, risk of acute kidney injury with NSAIDs in a dehydrated, injured patient) and limitations in supplies (e.g., not having potent opiates or large quantities) can best be overcome with this strategy. Most individuals and groups should consider carrying at least one NSAID (e.g., ibuprofen), acetaminophen (paracetamol), and an oral opioid (e.g., oxycodone).[41] The combination of acetaminophen with an NSAID is more effective than either medication alone and may achieve analgesia comparable to some opioids. Furthermore, the combination of NSAIDs and acetaminophen can significantly reduce opioid requirement for cases of severe pain. Many drug formulations contain acetaminophen, and thus careful attention is required to avoid toxic doses of this drug (see Analgesics in Table 102-2).

When discussing analgesia in remote environments, one must include mention of ketamine. This medication can be used in oral (PO), IM, or IV forms and is unique among potent analgesic medications in that it has relatively limited respiratory or cardiovascular depression even when used at higher doses.[33] Ketamine's mechanism of action is distinct from the analgesic medications previously listed and is primarily mediated through the *N*-methyl-D-aspartate (NMDA) receptor. Additionally, it provides a state of hypnosis in addition to analgesia, which can be particularly useful for more painful procedures, such as minor surgeries, suturing, and fracture reductions, or extrications. Despite its favorable safety profile and long history of use in remote medical settings, ketamine should be used only by those with necessary licensure and experience. Increased secretions, hallucinations, and increased intracranial pressure are among many adverse effects that impact its safe use.

Transmucosal, transdermal, and intranasal narcotics can also be used for analgesia in the wilderness setting, although provider familiarity with dosing and availability of alternative therapies has limited popularity of these methods[41] (see Table 102-2).

SPECIAL CONSIDERATIONS

In low- and middle-income countries, donations of leftover, nonexpired medications, even in modest quantities, to a local hospital or clinic are usually greatly appreciated. Meeting with a local pharmacist or clinic before departure can be helpful for arranging a donation and engendering good will. However, donation of expired medications to even the most impoverished regions is generally considered unacceptable.[47]

Related to donation of medications is the issue of providing medical care to local people encountered during an expedition. Often, the medical designee, recognizing a significant illness in a local person, will want to provide care. Such interventions are generally beneficial and without significant cost to an expedition. The medical designee should keep in mind that this care is temporary in almost all cases and may diminish the perceived value of local healers or the existing medical system. In addition, lacking medical translation experience, the group's translator may not be able to communicate instructions effectively to patients, which may lead to dangerous misunderstandings. For example, nitroglycerin sublingual tablets might be given to a nomad with stable angina for "chest pain." The recipient might perceive this as a general pain medication and give it to a child with headache or another adult with aortic stenosis.

The medical designee will be expected to provide care for both native and foreign members of the expedition and must plan accordingly, unless the hosting team is accompanied by a local health care provider. Because these issues will directly affect the assembly of the medical kit, they should be discussed with the group leader in detail before departure.

A SAMPLE JOURNEY

The month is March, and the goal is a 4-day climb to the summit of Mt Shasta (elevation, 4317 m [14,162 feet]) in the Cascade Mountain range. There are 17 established routes. However, during the winter, these are limited, and the team has decided to climb Avalanche Gulch, a popular route. The team consists of 10 cross-country skiers, some with significant climbing experience and others with very little. The base camp will be at 2134 m (7000 feet).

Two weeks prior to the trip, the trip leader asks all participants to complete a pretrip medical evaluation form (Appendix B). After review of the collected forms, all participants appear to have acceptable levels of baseline fitness, and no major health contraindications are discovered. The trip leader asks two participants with preexisting medical conditions to ensure adequate supply of their prescription medications and asks all participants to review recommendations for packing, including clothes, personal first-aid kit, and other appropriate gear as previously discussed. Additionally, all participants are encouraged to complete pretrip, daily aerobic and strength-training routines to ensure optimal fitness at the time of travel. Several members of the group have completed an American Red Cross advanced first-aid course, and all group members are encouraged to attend an avalanche seminar offered to the public by the National Ski Patrol System.

Before disembarkation, a briefing with all participants is held to discuss plans, contingencies, and potential risks involved. Historical weather patterns, current forecasts, and current terrain conditions are obtained from Internet sources and local park rangers and discussed at the briefing. Were a skier to become disabled en route, one of the others would remain with the victim while another two would ski out to the nearest telephone or source of help (it is no longer than an 8-hour downhill ski from the farthest point along the route in good weather). Helicopter evacuation to the nearest hospital would usually be accomplished within the next 2 to 4 hours, making the maximum interval to medical care 12 hours, weather permitting. Based on a review of historical incidents in the region, weather can delay evacuation up to several days. All team members are made aware of a satellite phone contained in the trip leader's pack. The trip poses increased risks related to trauma, cold injury, avalanche danger, snowblindness, and high-altitude illness. With the possibility of an overnight stay until rescue arrives, medicine selection focuses on pain control for traumatic injury and acute mountain sickness. Appropriate topical medicines include sunscreens and those for managing corneal injury from snowblindness. Systemic medicines of value include a limited supply of high-priority broad-spectrum antibiotics to treat infection of soft tissue injuries, plus specialized medicines for prevention and treatment of acute mountain sickness.

The trip leader must decide how much acetazolamide (Diamox) should be carried. If the acetazolamide supply is intended for both prophylaxis and treatment, if there are 10 members, and if the maximum anticipated time to rescue is 24 hours, a conservative calculation (i.e., assuming all members require treatment and that evacuation can be accomplished within 24 hours) can be estimated as follows:

Prophylaxis: 1 pill (125 mg) twice a day during 4 days of ascent for 10 people = 80 pills

Treatment: 2 pills (250 mg) twice a day for 1 day awaiting rescue for 10 people = 40 pills

Total: Prophylaxis + Treatment = 80 + 40 = 120 pills

Finally, emphasis must be placed on the recreational and environmental hazards likely to be encountered during travel. In this example, the dangers relate mainly to high altitude and cold exposure. Box 102-7 lists specialized equipment that may be of value under the conditions described. Because the peak altitude is only 4317 m (14,162 feet) and the nearby medical center has prompt helicopter evacuation abilities, a Gamow bag would not likely be useful for treating high-altitude illness. However, because of unpredictable weather and visibility, addition of the

Gamow bag to the medical kit could be considered, weight and bulk permitting. In addition, the need to carry technical equipment to provide warmed IV solutions or humidified oxygen is offset by a prompt helicopter rescue. Frostbite can occur rapidly, and each individual may want to carry a personal supply of chemical hand warmers (e.g., Grabber Warmers) because of their low weight and ease of packing. In addition, certain repair equipment should be carried (see Table 102-1). Overall, thoughtful advanced consideration of proximity to care, duration, and probability of various illnesses and injuries will guide decisions about medication selection and quantities when preparing for a wilderness outing.

APPENDIX A Information Sources on Wilderness Emergencies and Suggested Reading

American River Touring Association, 24000 Casa Loma Road, Groveland, CA 95321; 800-323-2782; http://www.arta.org. This is a nonprofit organization that sponsors basic and leadership courses for river rafting and kayaking.

Emergency Response Institute, 4537 Foxhall Drive NE, Olympia, WA 98516; 360-491-7785; http://www.eri-intl.com. The Institute publishes books and sponsors symposia about search and rescue, emergency preparedness, survival, and outdoor leadership.

National Association for Search and Rescue (NASAR), PO Box 232020, Centreville, VA 20120-2020; 703-222-6277; http://www.nasar.org. This educational association provides conferences, symposia, and training that address search and rescue and emergency response, including communications. It also sponsors *Rescue* magazine, which is published by JEMS Communications, 1947 Camino-Vida Roble, Suite 200, Carlsbad, CA 92008; 619-431-9797.

National Climatic Data Center, 151 Patton Avenue #120, Asheville, NC 28801-5001; 828-271-4800; http://www.ncdc.noaa.gov. The Center provides historic weather summaries for U.S. and many foreign cities; there is a small fee for materials. Telephone first to determine the availability of relevant data.

National Ski Patrol System (NSP), 133 South Van Gordon, Suite 100, Lakewood, CO 80228; 303-988-1111; http://www.nsp.org. This organization sponsors training programs that address winter emergency care, avalanches, and ski mountaineering, some of which are open to the public. It also sells equipment and first-aid supplies through a catalog to its members.

National Weather Service, 1325 East West Highway, Silver Spring, MD 20910; http://www.weather.gov/. The National Weather Service site nearest the travel site can provide forecasts and in many regions provides broadcasts over National Oceanic and Atmospheric Administration Weather Radio on frequencies between 162.40 and 162.55 MHz, including 3- to 5-day forecasts and avalanche warnings.

Outward Bound Training Institute; 800-779-7935; http://www.outwardbound.com. This nonprofit educational organization uses mountain, river, and ocean wilderness settings to provide stimuli for personal development; separate leadership training courses are also available.

The Travel Doctor, 7515 Greenville Avenue, #600 Dallas, TX 75231; http://www.thetraveldoctor.com. An excellent website for travel alerts and for learning about the pitfalls of travel to different international locales. The Travel Doctor also lists prescription medications that are useful for various travel-related illnesses.

Undersea and Hyperbaric Medical Society, 10531 Metropolitan Avenue, Kensington, MD 20895; 301-942-2980; http://www.uhms.org. This is a nonprofit organization that sponsors workshops and meetings about the prevention and treatment of diving injuries and illnesses that are treatable with hyperbaric oxygen. It also publishes a bimonthly newsletter, *Pressure,* and two research publications, *Undersea Biomedical Research* and *Journal of Hyperbaric Medicine.*

Wilderness Education Association, 900 East 7th Street, Bloomington, IN 47405; 812-855-4095; http://www.weainfo.org. The Wilderness Education Association is a nonprofit educational organization that specializes in training and certifying outdoor leaders.

Wilderness Medical Society, 2150 S 1300 E, Suite 500, Salt Lake City, UT 84106; 801-990-2988; http://www.wms.org. This nonprofit organization of medical and related professionals is devoted to prevention and treatment of wilderness injuries and illnesses. The Society publishes the quarterly newsletter *Wilderness Medicine Letter,* which covers wilderness medicine meetings, literature review, field management, and position statements. It also publishes *Wilderness and Environmental Medicine* (formerly *Journal of Wilderness Medicine*), which is the official academic publication of the Society. Teaching simulations and educational lecture series are also available through the website.

Wilderness Medical Society (WMS) Practice Guidelines. Since 1987, the WMS has published Practice Guidelines for Wilderness Emergency Care on a variety of topics; published in *Wilderness and Environmental Medicine* and available online through pubmed.org.

Emergency Medicine Residents' Association (EMRA), Wilderness Medicine Division; http://www.emra.org/committees-divisions/wilderness-division/. Provides a select number of simulation scenarios and other resources.

APPENDIX B

Pretrip Medical Evaluation Form for Wilderness Travel

PARTICIPANT INFORMATION		
Name:	Email:	
Age:	Sex: ☐ M ☐ F	Weight:
Height:	Phone #:	
Home address:		
TRIP INFORMATION		
Trip Dates:	Location:	
Planned activities (climbing, cycling, etc.):		
EMERGENCY CONTACT		
Name:	Relationship:	
Address:	Phone:	
City/State/Zip:	Email:	
PRIMARY CARE PHYSICIAN CONTACT		
Name:		
Address:	Phone:	
City/State/Zip:	Email:	
MEDICAL HISTORY		
1. Allergies to food or medications (include reactions such as rash, shortness of breath):		
2. Allergies to insects and other:		
3. Current Medications (List prescription and over-the-counter medications; include dosing and scheduling; attach sheet if needed):		

4. Have you ever had any of the conditions listed below? Please check the appropriate boxes.

Diabetes?	☐ Yes	☐ No
Mental illness (anxiety, depression, other)?	☐ Yes	☐ No
Epilepsy, seizures, convulsions?	☐ Yes	☐ No
Neurologic problems (stroke/TIA)?	☐ Yes	☐ No
Heart or lung problems?	☐ Yes	☐ No
Acute mountain sickness?	☐ Yes	☐ No
Kidney or genitourinary problems?	☐ Yes	☐ No
Deep vein thrombosis (blood clot)?	☐ Yes	☐ No
Injuries or joint problems?	☐ Yes	☐ No
Fainting episodes?	☐ Yes	☐ No
Bleeding or clotting disorders?	☐ Yes	☐ No
Visual or hearing impairments?	☐ Yes	☐ No
Asthma or COPD?	☐ Yes	☐ No
Ulcers?	☐ Yes	☐ No
Metal implants?	☐ Yes	☐ No
Gastrointestinal problems?	☐ Yes	☐ No

If you answered “yes” to any of the questions above, please provide details of your condition in the space provided on the next section of this form, Medical History.

5. Medical History (List prior and current medical problems and injuries including surgeries and hospitalizations):

6. Do you have any family history of death or disability in a first-degree relative (parent or sibling) under the age of 50 from a known heart condition or any sudden death in a first-degree relative under the age of 50 for unknown reasons? ☐ Yes ☐ No	
7. How often do you drink alcohol? ☐ Never ☐ Few times per month ☐ Few times per week ☐ Daily	
8. Do you currently smoke cigarettes, or have you previously smoked regularly? ☐ Yes ☐ No	
9. Please list any recreational drugs that you currently or recently have used: ☐ None	
10. List any phobias that may affect your ability to participate in trip activities:	
11. Are you able to jog 1 mile in less than 12 minutes *and* perform the level of activity planned for the trip without chest pain, feeling faint, or struggling? ☐ Yes ☐ No	
12. Are you currently or possibly pregnant? ☐ Yes ☐ No	Last menstrual period: ____/____/____
VACCINATION HISTORY (Please Attach Copy of Original Vaccination History)	
Hepatitis A: ☐ Yes (Date:(____/____/____) ☐ No ☐ Unsure	**Typhoid:** ☐ Yes (Date:(____/____/____) ☐ No ☐ Unsure
Hepatitis B: ☐ Yes (Date:(____/____/____) ☐ No ☐ Unsure	**Meningitis:** ☐ Yes (Date:(____/____/____) ☐ No ☐ Unsure
Yellow fever: ☐ Yes (Date:(____/____/____) ☐ No ☐ Unsure	**Rabies:** ☐ Yes (Date:(____/____/____) ☐ No ☐ Unsure
MMR: ☐ Yes (Date:(____/____/____) ☐ No ☐ Unsure	**Tetanus:** ☐ Yes (Date:(____/____/____) ☐ No ☐ Unsure
APPLICANT SIGNATURE	
I certify to the best of my knowledge that all information I have provided on this form is accurate and will notify the trip coordinator should any information change prior to my planned excursion. I recognize that it is my personal responsibility to discuss my health and fitness level with my primary care physician and to decide appropriateness and risks as pertains to the planned trip. I have been given the opportunity to ask all questions as pertains to the risks and benefits of the proposed activity.	
Signature of participant:	Date:
CERTIFYING PHYSICIAN SIGNATURE *(IF APPLICABLE)*	
I certify that I have reviewed the medical information provided to me by the participant listed above and (check one): ☐ I have *not* found any medical conditions that preclude this participant from the proposed trip. ☐ I have found medical conditions that preclude this participant from the proposed trip.	
Signature of Certifying Physician *(if applicable)*:	Date:
Office Phone:	

APPENDIX C Suppliers Listed in Chapter

Many of the products cited in this chapter can be found in outdoor equipment retail stores or pharmacies. The sources listed below are for specialized products that are referred to in the text.

Black Diamond Equipment, Ltd, 2084 East 3900 South, Salt Lake City, UT 84124; 801-278-5552; http://www.bdel.com. Black Diamond Equipment is the manufacturer of the AvaLung, which is the first and only active avalanche safety device that may enable the avalanche victim to breathe while waiting to be excavated.

Besse Medical, 9075 Centre Pointe Drive, Suite 140, West Chester, OH 45069; http://www.besse.com. Besse is a distributor of vaccines, pharmaceuticals, and medical supplies.

CamelBak Products, LLC, 2000 S. McDowell, Suite 200, Petaluma, CA 94954; http://www.camelbak.com: Tactical and medic backpacks are superb and can be customized.

Campmor, PO Box 700, Saddle River, NJ 07458; 888-CAMPMOR (888-226-7667); http://www.campmor.com. Campmor provides the Lady-J urinal guide and other camping equipment.

Chinook Medical Gear, Inc, 3455 Main Avenue, Durango, CO 81301; 800-766-1365; http://www.chinookmed.com. Chinook is one of the most complete catalog retailers for wilderness medical supplies and the carrier of the Gamow bag. It is a good beginning resource for the person who is in need of a wide variety of medical supplies.

ConMed Corporation, 525 French Road, Utica, NY 13502; 315-797-8375; http://www.conmed.com. ConMed is the maker of skin staplers and other surgical instruments.

Garmin International Inc, 1200 East 151st Street, Olathe, KS 66062; 913-397-8200; http://www.garmin.com. Garmin is the maker of a wide variety of easy-to-use global positioning system devices and instructional videos for GPS education.

Gilbert Surgical Instruments, PO Box 458, Bellmawr, NJ 08031; 856-933-2770. Gilbert is the manufacturer of the Abelson emergency cricothyrotomy cannula and other respiratory care instruments.

Grabber Performance Group, 4600 Danvers Drive SE, Grand Rapids, MI 49512; 800-518-0938; http://www.grabberwarmers.com. Grabber is the manufacturer of a variety of packaged miniature heaters with accessories that are useful for preventing cold-related injuries of the hands, feet, and face.

International SOS, Inc, 11601 Wilshire Boulevard, 5th Floor, Suite 525, Los Angeles, CA 90025; 310-828-2081; http://www.internationalsos.com. International SOS specializes in international medical and evacuation insurance.

Junkin Safety Appliance Co, 3121 Millers Lane, Louisville, KY 40216; 888-458-6546; http://www.junkinsafety.com. Junkin manufactures several folding aluminum full-length backboards, splints, and stretchers that weigh as little as 6.8 kg (15 lb). Other safety equipment produced by this company includes fire blankets and cervical spine immobilizers.

King Systems, 15011 Herriman Boulevard, Noblesville, IN, 46060; 800-642-5464; http://www.kingsystems.com.

Marmot Mountain LLC, 2321 Circadian Way, Santa Rosa, CA 95407. Marmot Mountain is a manufacturer of outdoor clothing and equipment.

MARSARS/Great Eastern Marine, Inc, 205 Myrtle Street, Shelton, CT 06484-4015; 203-924-7315 or 866-426-2423; http://www.marsars.com. MARSARS is the manufacturer of water and ice rescue equipment; a hypothermic stabilizer bag and additional accessory heat packs are available.

Mountain Safety Research, 4000 1st Avenue South, Seattle, WA 98134; 800-531-9531; http://www.msrcorp.com. This company is the manufacturer of high-performance and lightweight stoves as well as the WaterWorks filtration system.

National Ski Patrol System, Inc (NSP), 133 South Van Gordon, Suite 100, Lakewood, CO 80228; 303-988-1111; http://www.nsp.org. NSP provides various first-aid supplies and equipment for winter skiing and mountaineering that are sold by catalog to its members.

Oakley, Inc, 1 Icon, Foothill Ranch, CA 92610; 800-431-1439; http://www.oakley.com; customercare@oakley.com. Oakley specializes in outdoor-wear sunglasses for a variety of activities.

Otter Products, Bldg 1, Old-Town Square, Suite 303, Fort Collins, CO 80524; 888-695-8820; http://www.otterbox.com and http://www.watertightcase.com. Otter manufactures a variety of watertight cases that are useful for everything from personal digital assistants to large medical kits.

Outdoor Research, 1000 1st Avenue South, Seattle, WA 98134; 800-421-2421; http://www.orgear.com. Outdoor Research sells a diverse array of tote bags, medical travel kits, and stuff sacks that are useful for international travel.

OutdoorSafe, PO Box 62039, Colorado Springs, CO 80962-2039, 719-593-5852; info@outdoorsafe.com.

Patagonia, Inc, PO Box 150, Ventura, CA 93002; 805-643-8616; http://www.patagonia.com. Patagonia is the manufacturer of Capilene underclothing as well as a variety of outdoor clothing.

Pelican Products, Inc, 23215 Early Avenue, Torrance, CA 90505; 310-326-4700 within California, 800-473-5422 outside of California; fax, 310-326-3311; http://www.pelican.com; sales@pelican.com. Pelican is the manufacturer of watertight freight boxes as well as bright and durable headlamps.

Recreational Equipment (REI); 800-426-4840; http://www.rei.com. REI is a provider of Thermax underclothing as well as a variety of sunglasses, outdoor gear, and clothing.

Res-Q Products, Inc, PO Box 661, Quathiaski Cove, BC, Canada VOP 1N0; http://www.hypothermia.org (educational site) or http://www.hypothermia-ca.com. Res-Q Products is the maker of Res-Q-Air and IV Hot-Sack plus its accessories; the company is a provider of sophisticated equipment for the serious expedition traveler to areas of extreme cold.

SAM Splints, 4909 South Coast Highway #245, Newport, OR 97365; 541-867-4726; http://www.sammedical.com/ (accessed 2/8/16). This company is the maker of the SAM Folding Splint (4 oz) and many other splinting and first-aid products that are made for outdoor travel and first aid.

Slishman Traction Splint; http://www.rescue-essentials.com/slishman-traction-splint-sts/ (accessed 2/8/16). This splint is available from Bound Tree Medical in the United Kingdom; it is not currently available for sale in the United States.

Travel Medicine Inc, 351 Pleasant Street, Suite 312, Northampton, MA 01060; 800-872-8633; http://www.travmed.com. Travel Medicine specializes in educational books and handy supplies for international travel; it is the source of insect repellents, clothing, and nets for mosquito protection.

Zarges Aluminum Boxes, Soanar Inc, Mayer Krieg Components, 9 Civic Square, Croydon, Victoria 3136 Australia; 61 2 9741 0192; http://www.soanar.com. This company manufactures extremely durable, lightweight, watertight aluminum freight boxes that are ideal for the storage of medical and communications equipment.

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CHAPTER 103

Emergency Oxygen Administration

ERIC L. DOUGLAS AND PAUL G. FIRTH

Effective emergency medical care often requires skillful administration of oxygen (O_2). Medical personnel must be familiar with oxygen's therapeutic value, indications, hazards, and techniques for maximizing delivery.

Oxygen is required for cellular metabolism, and thus for life. O_2 is a colorless, odorless, and tasteless gas that makes up 21% of Earth's atmosphere and is obtained commercially by fractional distillation of air.[4,5] Convenient delivery mechanisms allow administration of supplemental O_2 in prehospital settings. Oxygen use and storage pose some risk. Oxygen is not flammable, but rapidly accelerates fuel combustion.

INDICATIONS

Indications to use supplemental O_2 include the following[3,6]:

- Shock
- Tissue hypoxia
- Hypoxemia
- Pulmonary gas exchange impairment caused by trauma, edema, asthma, infection, or embolism
- Acute myocardial infarction (MI), cerebrovascular accident (CVA, stroke)
- Decompression illness (DCI), including both decompression sickness (DCS) and arterial gas embolism (AGE)
- Moderate to severe acute mountain sickness (AMS)
- High-altitude pulmonary edema (HAPE)
- High-altitude cerebral edema (HACE)
- Carbon monoxide (CO) poisoning
- Respiratory or cardiopulmonary arrest
- General anesthesia

Oxygen should be considered for any condition that reduces oxygenation or tissue perfusion. By reversing hypoxia and hypoxemia, O_2 may reduce edema around injury sites. In a diving-related emergency, high concentrations of inspired O_2 create a large pressure gradient between the inhaled gas and excess nitrogen in the body, helping to remove built-up nitrogen and possibly relieve symptoms of DCS.

Oxygen should be administered by providers trained in its use. The U.S. Food and Drug Administration (FDA) "regards oxygen to be a prescription drug. Nevertheless, FDA recognizes that there are many circumstances under which it would be impractical to insist that oxygen be administered only under the supervision of a physician."[20]

The FDA acknowledges the importance of oxygen in medical emergencies, stating, "The label for medical oxygen should bear the statement, 'For emergency use only when administered by properly trained personnel for oxygen deficiency and resuscitation. For all other medical applications, Caution: Federal law prohibits dispensing without prescription.'"[18]

CONTRAINDICATIONS

In an acutely hypoxic patient, there is no absolute contraindication to administration of supplemental O_2. In patients with severe chronic obstructive disease (COPD), prolonged administration of O_2 may cause hypercapnia, so close monitoring of ventilation is important.[15]

PULMONARY OXYGEN TOXICITY

If a high concentration of supplemental O_2 is administered for many hours, pulmonary O_2 toxicity is possible, particularly if a diver with DCI subsequently requires hyperbaric oxygen therapy (HBOT). First symptoms of pulmonary O_2 toxicity are caused by tracheobronchitis, which is characterized by substernal burning, chest tightness, and cough. Continued exposure may result in dyspnea and adult respiratory distress syndrome (ARDS). Pulmonary O_2 toxicity is usually reversible with cessation of O_2 therapy or reduction in inspired concentration.[12]

Inspired O_2 partial pressure and the individual's susceptibility are key factors influencing rapidity of O_2 toxicity development. In some individuals, continuously breathing 100% O_2 at normal atmospheric pressure (1 atmosphere [atm]) may cause symptoms to appear as soon 6 hours; however, most people can safely breathe O_2 at a fractional inspired concentration (FIO_2) of 1.0 for 12 hours. Rate of onset of symptoms can be reduced by using periodic "air breaks," during which the patient breathes air for 5 to 10 minutes.

CENTRAL NERVOUS SYSTEM OXYGEN TOXICITY

Central nervous system (CNS) O_2 toxicity can only occur when a person is exposed to O_2 at ambient pressures greater than 1 atm (e.g., while diving underwater or during HBOT in a hyperbaric chamber). In hyperbaric settings, the term *absolute pressure* (ATA) can be useful. ATA is the total ambient pressure (standard atmospheric plus any additional pressure) on the system being calculated or measured. Inspired partial pressure of O_2 (PIO_2) is calculated by multiplying FIO_2 by ambient pressure in ATA ($PIO_2 = FIO_2 \times ATA$). Signs and symptoms of CNS O_2 toxicity are most likely to appear at PIO_2 greater than 1.6 and may include sweating, bradycardia, mood changes, nausea, visual field constriction, twitching, syncope, and seizures. During HBOT, implementation of periodic 5-minute air breaks reduces the likelihood of CNS O_2 toxicity. Oxygen seizures occur at 1.3 per 10,000 treatments for HBOT at 2.4 ATA (0.7 per 10,000 when hypoglycemic seizures are excluded).[7] With air breaks and a resting patient, treatment with 100% O_2 at almost 3 ATA is possible. If the individual were performing physically exerting exercise (e.g., swimming), such high concentrations would not be safe because it would raise the incidence of oxygen seizures to an unacceptable level.

EQUIPMENT

CYLINDERS

Medical O_2 cylinders are made of aluminum or steel and come in a variety of sizes (Table 103-1 and Figure 103-1). The working pressure of steel medical O_2 cylinders is 2015 pounds per square inch (psi). The working pressure of aluminum O_2 cylinders is either 2015 psi or 2216 psi, depending on the size, construction, and design.

Oxygen cylinders in the United States are usually painted green or have distinctive green shoulders (i.e., the top of the cylinder nearest the pillar valve). European Union (EU) standard requires all oxygen cylinders to have white shoulders. The cylinder's body can be green or black.

Cylinders come in two practical field sizes: D (50 cm [20 inches] in length; carries 360 L of oxygen) and E (75 cm [30 inches] in length; carries 625 L of oxygen). Time during which oxygen can be delivered is calculated by dividing tank capacity by flow rate.

In the United States, any pressure vessel transported on public roads is subject to U.S. Department of Transportation (DOT)

TABLE 103-1 Common Portable Medical Oxygen Cylinder Specifications

Cylinder Size	Alloy	Working Pressure (psi)	Volume (L, ft^3)	Length (cm, in)	Diameter (cm, in)	Weight (kg, lb)
M9	Aluminum	2015	8.7, 246.3	27.7, 10.9	11.1, 4.4	1.8, 3.9
D	Aluminum	2015	15, 424.7	41.9, 16.5	11.1, 4.4	2.5, 5.5
D*	Steel	2015	14.5, 410.4	42.5, 16.75	11.1, 4.4	3.4, 7.5
Jumbo D	Aluminum	2216	22.9, 648.3	43.2, 17	13.3, 5.3	4.1, 9.0
E	Aluminum	2015	24, 679.4	65.0, 25.6	11.1, 4.4	3.6, 8.0
E*	Steel	2015	24.1, 682.0	65.4, 25.75	11.1, 4.4	4.8, 10.5

Note: Aluminum cylinder specifications provided by Luxfer Inc.
*Steel cylinder specifications provided by Pressed Steel Tank Co.

regulations. The DOT requires that cylinders undergo visual and hydrostatic testing every 5 years. Cylinders that do not pass are destroyed, and those that pass are appropriately stamped and labeled.[17] Gas suppliers will not fill cylinders that have not been appropriately tested and stamped.

VALVES

Valves for medical O_2 cylinders sold in the United States are designed to accept only medical O_2 regulators to avoid the possibility of using a medical O_2 regulator with an incompatible gas (e.g., acetylene). Two types of valves are available in the United States: CGA-870 and CGA-540. CGA-870 is also known as the "pin-index" valve and used on smaller, portable cylinders (e.g., D, E). CGA-540 is used primarily on larger, nonportable cylinders (e.g., H, M), such as those mounted in ambulances.

Outside the United States, a number of other medical O_2 valve types are manufactured and used. Adapters are available to make a U.S. pin-index regulator fit on an Australian bull-nose valve. Using adapters is discouraged by the U.S. Compressed Gas Association (CGA).

FIGURE 103-1 Oxygen cylinders come in a variety of sizes and capacities. Cylinder decisions should be based on the amount of time a person will likely need to provide care until the injured person can be brought to emergency care. *(Courtesy Divers Alert Network.)*

Some O_2 cylinders come with built-in O_2 regulators. These cylinders offer simplicity but may limit flow options.

REGULATORS

A regulator functions to reduce peak pressures within the tank to a usable O_2 flow rate. It is typically mounted directly to the cylinder with a compatible valve. A regulator consists of a pressure gauge, pressure-reducing valve, and flowmeter. It reduces the high pressure of the oxygen inside the tank (>2000 psi) to approximately 50 psi and allows delivery at flow rates between 1 and 15 liters per minute (L/min). Regulators are primarily of three types: constant flow only, demand/flow-restricted oxygen-powered ventilator (FROPV) only, or multifunction, which has both constant flow and demand/FROPV capability (Figure 103-2A).

A pressure gauge allows the user to monitor the amount of O_2 in the cylinder. In a tank with a maximum operating pressure of 2000 psi, a reading of 500 psi indicates that there remains one-quarter of the tank's O_2.

Other features may include a *diameter index safety system* (DISS) fitting for an FROPV (to prevent accidental connection of an inappropriate delivery device), constant flow controller device (either knob or gauge), or both, as with the multifunction regulator (Figure 103-2B).

DEVICES FOR ASSISTED VENTILATION

If a patient is not adequately oxygenating or ventilating, assisted ventilation devices can be used. When used on a nonintubated patient, these devices all depend on adequate mask seal to ensure optimal O_2 delivery and ventilatory support. Use of a device minimizes direct patient contact and reduces risk for disease transmission. Personal protective equipment (e.g., gloves, goggles) and standard precaution practices should always be employed.

Bag-Valve-Mask Device

A bag-valve-mask (BVM) device consists of a mask, bag, and valves that direct flow of air and O_2. As with the FROPV, different mask sizes can be used to accommodate different faces or be attached directly to an endotracheal tube (ETT). The volume of the bag is 1600 mL in most commercially available models (Figure 103-3).

Adult BVM devices should have the following features: (1) non-jam inlet valve system that allows a maximum O_2 inlet flow of 30 L/min; (2) either no pressure-relief valve or, if present, a pressure-relief valve capable of being closed; (3) standard 15-mm/22-mm fittings; (4) an O_2 reservoir to allow delivery of high O_2 concentrations; (5) nonrebreathing outlet valve that cannot be obstructed by foreign material; and (6) ability to function satisfactorily under common environmental conditions and temperature extremes.[14]

The BVM works best with supplemental O_2 but will function on room air if O_2 supply is depleted. In intubated patients, experienced health care providers may be able to "feel" decreased lung compliance.

The BVM requires training and practice to use effectively. Even with proper training, it is difficult to maintain adequate

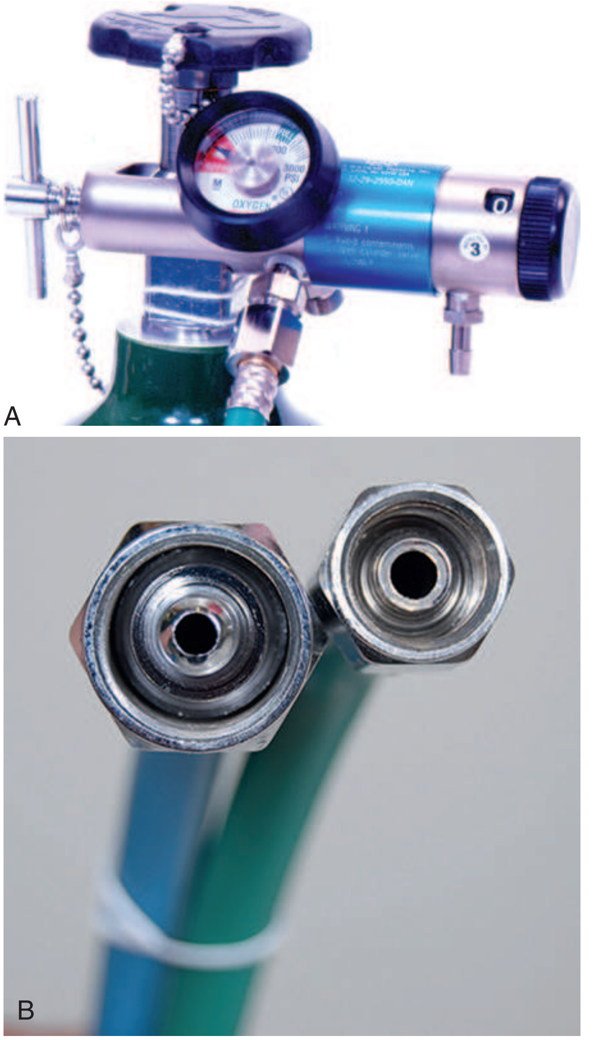

FIGURE 103-2 **A,** Multifunction regulators allow one to provide oxygen using a constant flow device, by demand-type device, or both at the same time. **B,** Diameter index safety system (DISS) prevents accidental connection of an inappropriate delivery device. *(**A** courtesy Divers Alert Network; **B** from Darby M, Walsh M:* Dental hygiene, *3rd ed, St Louis, 2010, Saunders. Courtesy Dr. Mark Dellinges and Cory Price.)*

mask seal, maintain airway patency, and ventilate sufficient volumes (600 to 1000 mL) when only one rescuer is available. DOT National Standard Curricula (NSC) for first responders, emergency medical technicians (EMTs), and paramedics recommend the BVM be used first with two rescuers (one maintaining mask seal and patency of the airway, the other squeezing the bag). NSC recommends that use of a BVM with one rescuer should be the last choice (after all other devices and techniques) in ventilating a patient.[17]

A BVM has no overpressurization relief valve. Although rarely a concern in nonintubated patients (because of difficulty establishing a tight seal), this can be a problem in intubated patients.

To use a BVM:

1. Attach the O_2 tubing from the BVM to the constant flow barbed outlet on the O_2 regulator. Expand the bag (which is often stored collapsed).
2. Set the constant flow controller to 10 to 15 L/min.
3. Establish airway patency by direct visualization. Suction or manually clear as able.
4. Position one rescuer at the patient's head to maintain the airway and ensure mask seal.
   a. The second rescuer should ventilate the patient by squeezing the bag with both hands. Gentle, steady force on the bag should result in chest rise.
   b. If excessive force on the bag is required, or chest does not rise, have the first rescuer reassess airway patency. Reposition mask and airway. Attempt to ventilate again.
   c. If ventilation still remains inadequate, check for airway obstruction; consider using an airway adjunct (e.g., nasal trumpet, oral airway) and initiating an airway obstruction protocol.
5. Ventilations should last 1 second as part of cardiopulmonary resuscitation (CPR).
6. Alternate 30 chest compressions with two ventilations.
7. Ventilate with sufficient speed and force to make the patient's lower chest and upper abdomen rise.
8. It is not necessary to empty the bag with each ventilation.
9. When providing care for an intubated patient, it is not necessary to pause and alternate ventilations with compressions. One rescuer should deliver compressions at a rate of 100 per minute, and the other rescuer (or rescuers) should deliver 8 to 10 breaths a minute (one breath about every 6 to 8 seconds).

Resuscitation Mask

A pocket-type resuscitation mask is a clear, flexible plastic mask designed to fit over the patient's mouth and nose while the health care provider ventilates by exhaling forcefully through the "chimney" (Figure 103-4). Typically, a one-way valve directs the rescuer's breath into the patient while directing the patient's exhaled breath away from the rescuer. This simple device requires minimal training and is lightweight, easily packed, and available both with and without an outlet for supplemental O_2. Presence of an O_2 inlet is preferred.[14] For the purpose of delivering adequate tidal volumes, trials have found mouth-to-mask ventilation superior to BVM devices.[17]

An adequate seal is best achieved with a mouth-to-mask device when the rescuer is positioned at the top of the patient's head. Rescuers seal lips around the coupling adapter of the mask and ventilate using both hands to hold the mask securely in position and maintain airway patency with head tilt.[19] This technique is the preferred position when two rescuers are present. When only one rescuer is present, the rescuer must be positioned at the patient's side.

When using the pocket-style resuscitation mask to deliver O_2:

1. Remove the O_2 tubing from a nonrebreather mask.
2. Stretch out the hose to be certain there are no kinks.

FIGURE 103-3 Bag-valve-mask (BVM) devices are often used to resuscitate an injured person using 100% O_2. BVM devices are relatively inexpensive and very effective, although they can be tiring for the user and require specific training. *(Courtesy Divers Alert Network.)*

FIGURE 103-4 Resuscitation mask allows rescuers to resuscitate an injured person either with their exhaled breath or with supplemental oxygen. *(Courtesy Divers Alert Network.)*

3. Attach the O_2 tubing to the constant flow barbed outlet on the O_2 regulator.
4. Connect the other end of the tubing to the O_2 inlet on the resuscitation mask.
5. Set the constant flow controller to 10 to 15 L/min.
6. The rescuer should ensure a proper mask seal by positioning the mask over the patient's mouth and nose, lifting the jaw up into the mask.
7. The rescuer should inhale away from the mask and then breathe into the one-way valve on the mask to make the patient's lower chest and upper abdomen rise.
8. Ventilations should last 1 second as part of CPR.
9. Alternate 30 chest compressions with two ventilations.
   a. If the ventilations do not go in, reposition the patient's airway.
   b. If the ventilations still do not go in, check for airway obstruction, and initiate an airway obstruction protocol.

FROPV/Positive-Pressure Demand Valve

Older-style positive-pressure demand valves (PPDVs), such as the LSP 063-05 or Elder CPR Demand valve, function both in positive-pressure mode (pushing the button to ventilate a non-breathing patient) and demand mode.

It is a misconception that a PPDV will easily cause pulmonary overpressurization injury; this valve has fallen out of favor with some health care providers. In positive-pressure mode, all PPDVs manufactured in the United States have an overpressure relief valve that stops the flow of gas at 55 to 65 cm H_2O (a pressure at which lung overpressurization is unlikely). MTV-100 FROPV (LSP/Allied) has two overpressure-relief valves, the first set at 60 cm H_2O and the second at 65 to 80 cm H_2O.*

Earlier PPDVs were designed to meet the American Heart Association (AHA) Emergency Cardiac Care Committee (ECC) CPR guidelines before 1986, which called for "four quick initial breaths and then two quick breaths after every 15 compressions."[9] This faster rate of ventilation was equivalent to 160 L/min.

In 1986, CPR standards were changed to "two slow breaths, each 1.5 seconds in duration."[9] The standard changed again in 1992 to "two slow, full breaths, with a duration of 1.5 to 2 seconds each" (equivalent to 40 L/min).[9]

In 1993, the FROPV was introduced. Its specifications include a flow rate of 40 L/min while being used in positive-pressure mode and 115 L/min in demand mode, eliminating difficulties associated with earlier models (Figure 103-5).

A mask adapter is a standard 15-mm fitting that fits a variety of masks and can also be used directly with an ETT. A FROPV requires a supply of pressurized O_2. In intubated patients, the health care provider will not be able to "feel" decreased lung compliance.

When using an FROPV:

1. Connect the FROPV to the DISS threaded port on the O_2 regulator.
2. It is not necessary to adjust the O_2 flow rate on the regulator.
3. Position one rescuer at the patient's head to maintain the airway and ensure a mask seal.
4. The second rescuer should ventilate the patient by depressing the button on the FROPV.
5. The second rescuer should also place a second hand on the patient's upper abdomen and lower chest to monitor chest rise.
6. Ventilations should last 1 second as part of CPR.
7. Alternate 30 chest compressions with two ventilations.
   a. If the ventilations do not go in, have the first rescuer reposition the patient's airway.
   b. If the ventilations still do not go in, check for airway obstruction, and initiate an airway obstruction protocol.

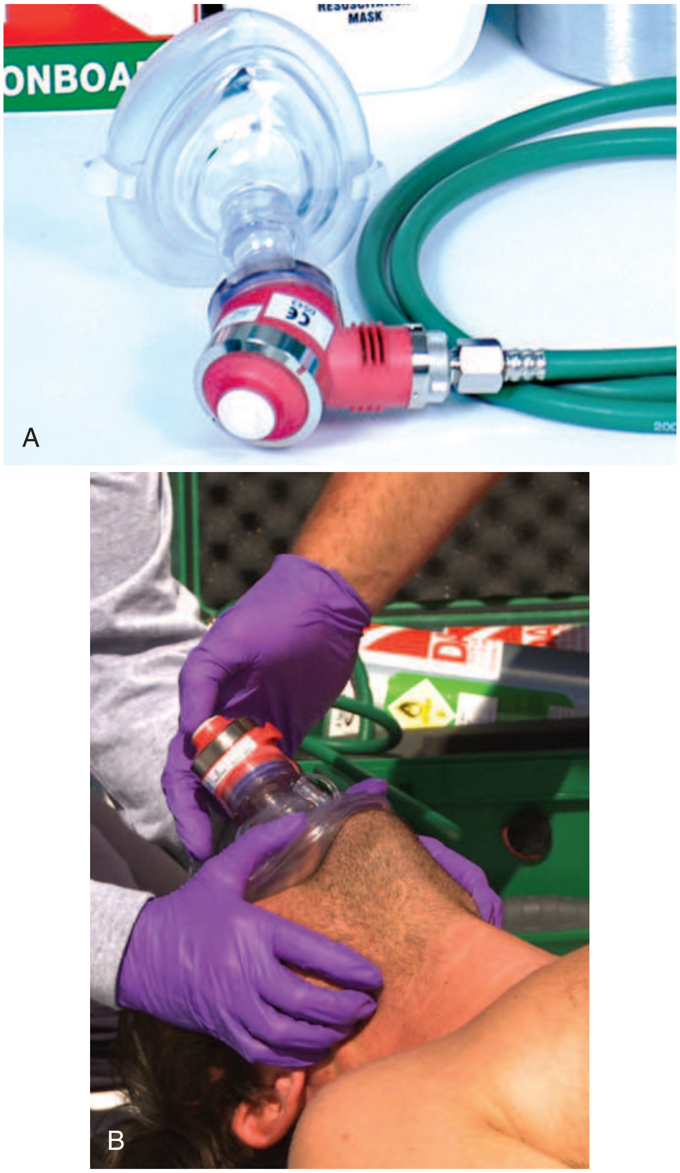

FIGURE 103-5 **A,** Flow-restricted oxygen-powered ventilator (FROPV) allows the rescuer to resuscitate an injured person using 100% O_2. FROPV devices have pressure restrictions to reduce the likelihood of harm to the patient. The ventilators are more expensive and require additional training, although they are less tiring for rescuers than a BVM device **(B)**. *(Courtesy Divers Alert Network.)*

*Specifications from Allied Healthcare, Inc./Life Support Products.

Demand-Only, or FROPVs in Demand Mode

Use of demand mode requires spontaneous respirations. To use in demand mode, hold the mask to the patient's face. Negative pressure of inhalation opens the valve and then gas flows (Figure 103-6). Flow stops when the person stops inhaling, similar to other demand systems, such as scuba and aviation regulators. This is the first choice for O_2 delivery when there is critical need for a high concentration of inspired O_2 or gas supplies are limited.

When using a demand-only valve:

1. Connect the demand valve to the DISS threaded port on the O_2 regulator.
2. It is not necessary to adjust the O_2 flow rate on the regulator.
3. Ask the patient to breathe normally from the mask.
4. Monitor the patient to ensure breathing.
5. Watch the clear mask to make sure it fogs with each exhalation.
6. If the patient is not conscious or is breathing adequately to activate the demand-only valve, it is necessary to switch to a constant flow delivery device, such as the nonrebreather mask.

CONSTANT FLOW DEVICES FOR ADEQUATELY BREATHING PATIENTS

Nonrebreather Mask

A nonrebreather mask consists of a mask, reservoir bag, and series of one-way valves, one separating reservoir from the mask and others on the sides of the mask. O_2 constantly flows into the reservoir bag, then is inhaled. One-way valves on the sides of the mask keep ambient air from coming into the mask and diluting the O_2. Expired air goes out of the mask through valves and is prevented from entering the reservoir (Figure 103-7).

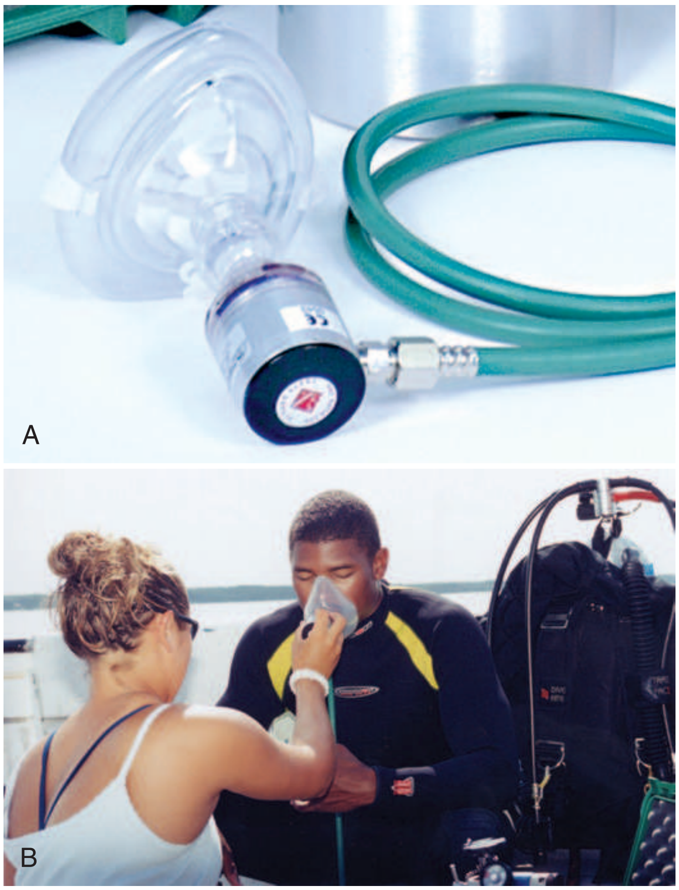

FIGURE 103-6 **A,** Demand valves deliver 100% O_2 to an injured person when he or she inhales, much like a scuba diving regulator. **B,** This device can be used only by conscious, breathing persons. It has the advantage of delivering high concentrations of gas and limiting waste compared with a constant flow device. *(Courtesy Divers Alert Network.)*

FIGURE 103-7 A nonrebreather mask **(A)** is the simplest O_2 delivery device. It can deliver high O_2 concentrations; however, rescuers must be careful to ensure a good mask seal, or the concentration of inspired O_2 will drop **(B)**. It also wastes gas because O_2 flows even when the injured person is exhaling or not breathing. *(Courtesy Divers Alert Network.)*

Efficiency of this system depends on mask fit, face seal, and proper functioning of valves. Under ideal conditions, this mask (when fitted with all three valves) may deliver an FIO_2 of up to 0.95. Field studies show it may deliver FIO_2 as low as 0.60, but it is still the most effective constant flow device available (except for demand regulators and O_2 rebreathers).

To use the mask, it is attached to the O_2 supply at a flow rate of 10 to 15 L/min. The reservoir bag must be inflated or "primed" before placing it on the patient; some new models are designed to be self-priming and will fill automatically when connected to the O_2 flow. Priming is done by placing a finger on the valve between the reservoir and mask while the reservoir inflates.

Masks are available with either one or two one-way valves. If the mask has only one valve (labeled as "with safety outlet"), it is a *partial rebreather* and will deliver reduced FIO_2.

Nonrebreather masks provide the highest FIO_2 of constant flow devices, but tend to waste O_2 and may not deliver a high FIO_2 under less-than-ideal conditions. Patients wearing a nonrebreather mask must never be left alone and should be carefully monitored. O_2 supply must be maintained. If not, suffocation can result.

When using a nonrebreather mask:

1. Open the nonrebreather mask packaging; stretch out the tubing to make sure there are no kinks.
2. Connect the tubing on the nonrebreather mask to the constant flow, barbed outlet on the O_2 regulator.
3. Set the constant flow controller to 10 to 15 L/min.
4. Place a thumb over the one-way valve between the mask and the reservoir bag.
5. Allow the bag to fill completely before placing the mask on the patient.
6. Position the mask over the patient's mouth and nose.
7. Pinch the nose clip over the patient's nose.
8. Pull on the elastic straps to tighten the mask to the patient's face, and pull the skin into the mask.
9. Ask the patient to breathe normally from the mask.
10. Monitor the patient to ensure breathing.
11. Watch the clear mask to make sure it fogs with each exhalation.

Nasal Cannula

A nasal cannula may be used when a patient will not tolerate a mask or when high inspired O_2 concentrations are not required.[17] A nasal cannula delivers FIO_2 of only 0.24 to 0.29.[16]

Flow rates for a nasal cannula are limited to 1 to 6 L/min. Flow rates exceeding 6 L/min are uncomfortable and may result in drying of the nasal mucosa. To use the nasal cannula, place prongs in the patient's nares and loop the tubing over the top of the ears to hold it in place. Adjust the tightness at the neck to a comfortable level.

Other constant flow masks, including partial rebreather, simple face, and Venturi masks, deliver only low levels of FIO_2 and are not recommended for prehospital use.[17] Automatic transport ventilators are not practical for remote emergency medicine.

When using a nasal cannula:

1. Open the cannula packaging; stretch out the tubing to make sure there are no kinks.
2. Connect the tubing to the constant flow, barbed outlet on the O_2 regulator.
3. Set the constant flow controller to 4 to 6 L/min.
4. Position the prongs in the patient's nostrils.
5. Position the hose behind the patient's head and tighten the straps.
6. Ask the patient to breathe normally through the nose.
7. Monitor the patient.
8. If oxygen supplies are limited, titrate O_2 flow to improved symptoms. At high altitude, maintain O_2 saturation above 90% to 92%.

OXYGEN REBREATHERS

Insufficient oxygen supplies are a common problem. All the O_2 delivery devices discussed make inefficient use of limited O_2 supplies and will require multiple portable cylinders if the transport time exceeds 1 hour (Figure 103-8). Breathing room air, a person inhales 21% O_2 and exhales 16% O_2. Under perfect conditions, using supplemental O_2, a patient would inhale 100% O_2 and exhale 95% O_2 and 5% carbon dioxide (CO_2). Rebreather devices are designed to reuse that exhaled O_2-rich air, and remove CO_2 and exchange it for additional oxygen.

Rebreather devices all have the same basic components: mask, breathing circuit (similar to anesthesia equipment), and canister with an absorbent chemical, usually soda lime.

Soda lime chemically removes CO_2 from the exhaled gas, allowing O_2 to be rebreathed.* Supplemental O_2 is added at approximately 1 L/min to replace metabolized O_2. Using this system, an O_2 tank that would supply a nonrebreather mask for 45 minutes, or an on demand device for approximately 1 hour, can provide a patient an FIO_2 of 0.85 to 0.99 for more than 8 hours. If oxygen supplies are limited, this device may prove invaluable.

FIGURE 103-8 A typical oxygen kit created for the marine/aquatic environment includes a multifunction regulator to care for more than one injured person, along with delivery masks and a watertight case to protect the equipment. *(Courtesy Divers Alert Network.)*

Manufacturers recommend first oxygenating the patient before setting up the unit, then flushing the system of air, and applying the unit to the patient. Air breaks may minimize the risk for pulmonary oxygen toxicity.

Chemical reaction between CO_2 and soda lime produces heat and water, providing warmed and humidified O_2. In cold climates, this is an advantage. In hot climates, consider passing the breathing circuit hoses through cold or ice water to cool the gas.

Rebreather devices require significant training and contain parts (typically the breathing circuit and absorbent canister) that are often single-patient use. Adequate mask seal is required to function effectively; otherwise, dilution of inhaled gas with air results in a lower FIO_2. Compared with a constant flow mask, increased breathing resistance may be experienced.

Common resuscitators are systems by Wenoll, Circulox, and OXI-Saver Resuscitator.[13]

EMERGENCY OXYGEN ADMINISTRATION AT HIGH ALTITUDE

Atmospheric pressure and partial pressure of oxygen (PO_2) decrease with altitude (see Chapter 1, Table 1-2). Oxygen can be used to treat high-altitude pulmonary or cerebral edema. Definitive treatment is descent to a lower altitude. Supplemental O_2 is indicated if it will not delay descent, or if immediate descent is not possible. Increased partial pressure of available O_2 is achieved by increasing the O_2 concentration or increasing the barometric pressure.

Many climbers use O_2 when climbing above 8000 m (26,247 feet). O_2 sets for climbing, typically continuous flow open circuits with rebreather reservoirs, are suitable for emergency O_2 delivery. Pulse demand and rebreathing circuits have achieved only limited popularity because of concerns about reliability in extreme environments. A mask producing expiratory resistance or continuous positive airway pressure (CPAP) could hypothetically improve gas exchange in climbers with severe high-altitude pulmonary edema.[1]

Portable hyperbaric chambers that increase barometric pressure and therefore available O_2 are used to treat various high-altitude syndromes.[11] A patient is placed within the bag, which

*$2NaOH + CO_2 = Na_2CO_3 + H_2O$ + Heat (from WR Grace, Inc).

is inflated and pressurized, simulating a descent of 500 to 2000 m (1640 to 6562 feet). Continuous air is introduced by a high-volume foot pump and exhausted through pressure-relief valves[21] (see Chapter 2 for further details).

General anesthesia is occasionally needed for emergencies at very high altitudes. Although a trained anesthetist can safely administer general anesthesia to an acclimatized patient,[10] it is generally prudent to descend to lower areas.

OXYGEN GENERATOR SYSTEMS

Oxygen generators produced O_2 using a chemical process. O_2 concentrators typically use electrical power and are not readily portable for field use. These devices often produce 3 to 4 L/min over a 15-minute cycle, with a peak flow of up to 6 L. Although insufficient for some emergency needs, these rates can be employed to fill an O_2 cylinder to operational pressure. In established remote clinics with electrical supply, O_2 generators provide abundant O_2 stores without need for distant and costly resupply.

HOW TO ADMINISTER OXYGEN FROM A TANK (CYLINDER)

1. Place the cylinder upright. Open and close the tank valve slowly ("crack the tank") with a wrench to remove debris from the outlet.
2. Close the tank valve and attach a regulator to the tank. Tighten the regulator to the tank securely by hand. Never use a regulator without the proper oxygen washer. *Never use tape to hold a loose regulator in place.*
   a. Ideally, the depressurized regulator should remain attached to the tank at all times. This ensures that the equipment is ready to use and free of debris.
3. Open tank valve slowly, one full turn.
4. Attach an O_2 delivery device to the regulator, either to the DISS threaded port or to the constant flow nipple on the end of the regulator. Attach a breathing mask or nasal cannula to the other end of hose or tubing, if it is not already attached.
5. Adjust the constant flow controller to the desired flow rate in liters per minute when using a constant flow mask.
   a. When using a demand-style mask connected to the DISS threaded port, it is not necessary to adjust the flow rate.
   b. A regulator marking of "low" indicates 2 to 4 L/min, "medium" is 4 to 8 L/min, and "high" is 10 to 15 L/min. Flow rate for a nonrebreather mask should be no less than 6 L/min; flow rate for a nasal cannula should be no more than 6 L/min.
   c. To ensure proper oxygenation, the recipient should receive high-flow O_2 (10 to 15 L/min) whenever feasible.
6. Position the mask or cannula on the patient's face. Adjust for comfort. Observe the patient to be certain that the device is tolerated, and that the reservoir bag fills properly.

For more detailed information on airway management, see Chapter 19.

Precautions

- Never allow an open flame near an O_2 delivery system.
- Do not expose an O_2 tank to excessive heat (52°C [125°F]) or freezing cold. This prohibition may be difficult to apply when O_2 tanks are carried on mountain-climbing expeditions.
- Never direct the top of a tank valve toward anyone; a loose regulator can be blown off the top of the cylinder with tremendous force.
- Do not drop or roll a cylinder.
- Close all valves when the cylinder is not in use.

SPECIAL CONSIDERATIONS IN NONBREATHING OR INADEQUATELY BREATHING PATIENTS

Caregivers ventilating nonbreathing patients need to consider ventilatory rate, volume, flow rate or speed, pressure, and oxygenation. Ventilations should be provided at 12 per minute for an adult (>8 years old) and 20 per minute for children and infants.[9] Health care providers may administer rescue breaths with or without supplemental O_2. If a lay provider finds a patient not breathing, full CPR should be initiated.

Volume for adult ventilations is 700 to 1000 mL. If a ventilation device do not have an overpressure-relief valve or greater volumes are administered, pulmonary barotrauma (overpressurization injury) could result. Ventilatory volumes less than 800 mL may be insufficient to inflate the alveoli, and thus gas exchange may be inadequate. Each ventilation should last 1 second (equivalent to 40 L/min). Faster ventilation rates force open the esophagus and push air into the stomach. Gastric insufflation greatly increases the risk for regurgitation and aspiration of gastric contents.[9]

A differential pressure as low as 90 to 110 cm H_2O has been demonstrated sufficient to rupture alveolar septa and to allow gas to escape into interstitial spaces.[2,3] Care must be taken not to exceed these pressures when ventilating a patient. Humans can easily generate pressures exceeding 120 cm H_2O by exhaling forcefully, and thus, according to ECC CPR guidelines, one should "blow until the chest rises" to accommodate various sizes of patients. Of devices for ventilating adult patients, only PPDV/FROPV devices have an overpressure-relief valve.

The goal of assisted ventilation is to provide O_2 to patients. With direct mouth-to-mouth or mouth-to-mask breathing, FIO_2 will be 0.16, or 16% O_2. Adding O_2 at a flow rate of 15 L/min may increase FIO_2 with a pocket mask to up to 50%. A BVM on room air is 0.21, and with O_2 at 15 L/min, up to 0.9, depending on equipment and skill of the ventilator. An FROPV delivers close to 1.0, or 100% O_2.[3,9]

Both volume and O_2 delivered by ventilation depends on airway patency and quality of mask seal. In a nonintubated patient, poor mask seal is the single most common cause of inadequate ventilation. With each ventilation, take great care to ensure airway patency and good mask seal. Use of an oropharyngeal, nasopharyngeal, or combination airway can greatly improve upper airway patency.

Current AHA guidelines recommend that if supplemental O_2 (minimum flow rate of 8 to 12 L/min with O_2 concentration of 40%) is available, rescuers skilled in BVM ventilation should attempt to deliver a tidal volume (V_T) of 6 to 7 mL/kg, or approximately 400 to 600 mL over 1 second. Because actual V_T delivered is impossible to determine, V_T can be titrated to provide sufficient ventilation to maintain O_2 saturation and produce visible chest expansion. V_T should be sufficient to cause the chest to rise. This smaller V_T may be associated with development of hypercarbia. If oxygen is *not* available, rescuers should attempt to deliver the same V_T recommended for mouth-to-mouth ventilation (10 mL/kg, 700 to 1000 mL). This V_T should result in obvious chest rise.[14]

An FROPV delivers the greatest FIO_2, making it the only device that is limited to 40 L/min flow rate (1 second in duration). Because it has an overpressure-relief valve, it may be the best choice for ventilating a person in respiratory arrest, whether or not the person is intubated. A BVM unit used by two rescuers (one to maintain the mask seal, the other to squeeze the bag) is the best alternative and preferred choice for ventilating a person in respiratory arrest.[8,17] Preferences for ventilating a person in respiratory arrest are as follows:

1. BVM unit with two rescuers and supplemental O_2
2. Resuscitation mask with supplemental O_2
3. FROPV
4. BVM unit with one rescuer and supplemental O_2
5. Mouth-to-mouth ventilation is the last choice and not an option for professional rescuers because of the risk for disease transmission.

HAZARDS

Oxygen does not burn, but it greatly accelerates combustion. Concentrated O_2 facilitates conversion of sparks or embers (e.g., lit cigarettes) into vigorous fires. O_2 should only be used in open, well-ventilated areas and never in the presence of burning materials. Use care when handling O_2 equipment to avoid allowing contaminants (e.g., petroleum products) to come in or around the orifices on the cylinder or regulator through which O_2 flows. Cylinders should not be exposed to temperatures above 52°C (125°F).

LEGAL ISSUES

The FDA regulations regarding O_2 administration equipment state that to qualify as "emergency medical oxygen administration equipment," a device must "be capable of administering a flow rate of at least 6 L/min for a period of at least 15 minutes."[19] Equipment not meeting this minimum standard may not be sold in the United States as emergency medical O_2 administration equipment.

According to FDA regulations, a medical O_2 cylinder can be filled "for emergency use only when administered by properly trained personnel for O_2 deficiency and resuscitation." For all other medical applications, "Caution: Federal law prohibits dispensing without prescription."[18]

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

CHAPTER 104
Telemedicine in the Wilderness

JUSTIN T. PITMAN, ASHLEY KOCHANEK WEISMAN, AND N. STUART HARRIS

Telemedicine is broadly defined as the practice of medical care through any medium that separates a patient and care provider. The prefix *tele* derives from ancient Greek, "at a distance," and *medicine* from the Latin *mederi*, "to heal." Although technologic purists might balk at histories of missive-related medical consults (noted as distantly as ancient Greek and Egyptian texts) as "telemedicine," the essence of caregivers engaging in clinical assessment at a distance from their patients gives even this ancient epistolary practice reasonable claim to the first practice of telemedicine. Although the essentials of that exchange have not changed in the last 4000 years, what have changed are speed, quantity, quality, and accessibility of data that may be transmitted between patient and caregiver. In the last 20 years, the means of data acquisition and ease of transmitting vast volumes of data inexpensively from any point on the globe have expanded tremendously. Real-time data are now routinely transmitted between hospitals and distant caregivers, including video interviews, complete electronic medical records, detailed physiologic monitoring, electrocardiograms, electroencephalograms, and state-of-the-art images (e.g., ultrasound, radiography, computed tomography, magnetic resonance). Once digitized and using current communication networks, data may be readily transferred from the International Space Station (ISS) to Houston's Mission Control Center (MCC) or from Mt Everest Base Camp to any academic center (Figure 104-1).

Telemedicine techniques can provide critical services in the most remote and austere wilderness conditions, emphasizing its importance for wilderness medicine and care rendered in other austere settings. In developed urban areas, telemedicine is often used for reasons of convenience. In rural areas, telemedicine networks "take the doctor to the patient," regardless of the distance between them. Through a range of rural telemedicine projects, diagnostic and treatment expertise can be applied to a vast, sparsely settled geographic range (e.g., Alaska health networks for remote villages). Telemedicine allows greater equity of access to health care, especially for persons for "whom time and distance constitute formidable obstacles to the receipt of care."[5] Telemedicine proves a means of overcoming limitations in medical care posed by geography, financial constraints, and weather. As Bashshur and Lovett[5] predicted in 1977, telemedicine's major promise for the future is to bring health services to people "wherever it now is not possible or feasible to bring people to health services." For many in wilderness locations, this is exactly what would be intended. As recently as 15 years ago, computing technology for such devices was prohibitively expensive and only accessible by groups or individuals with large budgets. However, over the past decade, technologic evolution has produced smaller, more powerful, yet energy-efficient devices that are now within an attainable price range. With such profound and widespread accessibility, telecommunication from mobile and remote locations is now frequently practiced.

EVOLUTION OF TELEMEDICINE

Although we think of modern telemedicine as a product of recent technology, the underlying concept of communicating medical information from a distance can be traced back several centuries. Perhaps the earliest documented evidence of health information transmission originates from the African continent. Villagers used smoke signals as a way to convey the presence of serious disease or illness and serve as a warning to others to keep their distance. It has been noted from ancient Greek and Egyptian texts that practitioners used to convey information to patients through the use of a runner. Bonfires were used throughout Europe in the 1600s to transmit information regarding the bubonic plague.[10]

Until the mid-1800s, information transfer between two distant parties relied on nonelectrical means of conveyance, including smoke signals, bonfires, drum code, runners, riders, and letters. The first electronic transmission, sent via telegraph by Samuel Morse in 1844 between Baltimore and Washington, DC, signaled the birth of modern electronic telemedicine. During the American Civil War, telegraph was used to transmit information regarding casualty lists and to order medical supplies.[48] In 1875, Alexander G. Bell's first communication via telephone was to his assistant, Mr. Watson.[13] As recorded in Bell's journal, "I then shouted into the M [mouthpiece] the following sentence: 'Mr. Watson—come here, I want to see you.'" Bell had accidentally spilled battery acid on his leg and, by telephone, was able to call Mr. Watson to provide medical aid. The telephone was rapidly and widely adopted for ease of use and immediately embraced by physicians as the mainstay for both physician-physician and physician-patient communication. In 1906, Dr. Willem Leister Einthoven successfully transmitted an electrocardiogram (ECG) over telephone lines, likely the first example of telecardiology.[14]

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FIGURE 104-1 Ultrasound on International Space Station. Astronauts and cosmonauts practice zero-gravity abdominal ultrasound from Earth orbit. *(Courtesy National Aeronautics and Space Administration, Washington, DC. From Dulchavsky SA, Kirkpatrick AW: The surgeon's use of ultrasound in thoracoabdominal trauma. In Cameron JL, Cameron AM, editors:* Current surgical therapy, *10th ed, Philadelphia, 2011, Elsevier, pp 900-905.)*

The advent of two-way radio communication soon followed. For the first time, users could communicate between distances without a hard-line connection. In 1924, *Radio News* magazine ran a futuristic cover story, "The Radio Doctor—*Maybe!*" In this story, Hugo Gernsback, an American inventor, writer, and magazine publisher, postulated development of a machine, the "teledactyl," or "distant fingers"[18] (Figure 104-2). Using the teledactyl, he hypothesized that a physician would not only be able to view his patient remotely via a two-way view screen, but using robotic arms and fingers, physically examine the patient and generate a diagnosis as if the two were present within the same room. In 1935, an Italian group led by Professor G. Guida in Rome established the International Radio Medical Center, which offered radio medical assistance to crews at sea. With government funding, it later expanded services to provide 24-hour physician support to sailors, aviators, and rural populations in Italy.[2] By the late 1930s, radio-based medical communication was extensively used in remote and wilderness areas. To serve rural populations, Australia developed the Royal Flying Doctor service, which fielded teleconsultations from remote individuals using two-way radios powered by bicycle pedal–driven dynamos.[42]

New technology soon allowed for miniaturization, mass production, and affordability of telephone and radio devices, a huge advance for future wilderness applications. In 1947, Norman Holter transmitted the first portable radio-electrocardiogram.[22] Although the machine weighed almost 38 kg (85 lb), it could be strapped to a person's back and monitor heart rate and rhythm during activities and in locations never before studied, whether the patient was cycling at full speed, skiing at altitude, or hiking in heat[36] (Figure 104-3). By 1950, radiologists in Pennsylvania and Canada had used telephone lines to transmit radiographic images. Soldiers and national parks services used portable radios to call for medical assistance and helicopter dispatch from distant field locations. Sailors were using radio to transmit ECGs and x-ray images from distant ocean sites.[33]

In the 1960s, television and video technology were first used to perform telemedicine. Physicians and medical staff at the Nebraska Psychiatric Institute used two-way closed-circuit television (CCT) to connect the institute in Omaha and the state mental hospital in Norfolk, 112 miles away, enabling consultations between specialists and general practitioners.[10,30,48] By 1967, Bird and colleagues established a two-way audiovisual microwave link between Massachusetts General Hospital and Logan International Airport.[10,48] This service was set up for remote physicians to augment medical care of an on-site 24/7 nurse-staffed clinic.

President John F. Kennedy's decision to fund the National Aeronautics and Space Administration (NASA) in 1961 proved pivotal for development of radio, satellite, and television telemedicine technologies that would eventually be applied to astronauts, adventurers, and average citizens. As a critical step in landing a man on the Moon, NASA had to answer a fundamental question: Could a human body function in space? This sparked development of new satellite-based telemedicine systems. NASA built monitoring systems capable of constantly recording real-time physiologic parameters (heart rate, respiratory rate, blood pressure, temperature) and transmitting these data to physicians regardless of the astronauts' position in Earth orbit. As flight time shifted from hours (Earth orbit) to days (lunar orbit), NASA recognized the need for the ability to diagnose and treat in-flight emergencies and began to develop more advanced medical support systems.

This realization also highlighted the need to achieve remote health monitoring for non-space-related situations. NASA, the U.S. Indian Health Service, and the Lockheed Corporation jointly sponsored the Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC).[48] The project began with two Native American paramedics driving a van to deliver care to rural communities with the assistance of physicians connected by two-way microwave transmission from the regional Public Health Service Hospital.[17] This program provided the combined benefits of the "telemedicine trifecta": (1) triage decisions, (2)

FIGURE 104-2 "Teledactyl." Diagnosis by radio: cover of *Radio News*, April 1924; "The Radio Doctor—*Maybe!*" (by Hugo Gernsback). The illustration portrays a family physician using two-way radio communication to speak with, visualize, and examine the patient.

FIGURE 104-3 Tele-electrocardiography. Norman Holter demonstrating his radio-electrocardiograph while riding a bicycle in 1947, the first documented use of portable ECG monitoring. The device weighed 38 kg (84 lb). *(From Ioannou K, Ignaszewski M, MacDonald I: Ambulatory electrocardiography: The contribution of Norman Jefferis Holter, BC Med J 56(2):86-89, 2014.)*

guidance through obtaining a medical history and simple procedures, and (3) specialist consultation. NASA established standards for television telemedicine applications. NASA also led a collaboration to determine the minimal television system requirements for effective care. Their goal was to achieve the same diagnostic accuracy in a patient who was interviewed and examined by a nurse with the guidance of a remote physician (i.e., telemedicine) as in an in-person patient-physician encounter.[8,19] This project recognized that telemedicine requires the same rigorous scientific proof and quality control standards as does bedside medicine. NASA also spearheaded the first international telemedicine cooperation. In 1989, using the "Space Bridge to Armenia and Ufa," Russia provided audio, visual, and facsimile-based medical consultation to clinicians caring for earthquake victims in Armenia hospitals and later to burn victims in a railway fire in Ufa, Russia.[21] These collaborations set the precedent for international telemedicine efforts that would serve hundreds of wilderness expeditions and robust, permanent base stations in austere environments of Mt Everest and Antarctica.

Radio, television, and satellite systems created faster two-way networks that enabled telemedicine to reach remote settings. However, the links were limited; NASA scientists, Royal Flying Doctor service, and psychiatrists in Nebraska could not engage in real-time consultation outside of established channels. Several groups of American computer scientists noted this problem of limited connectivity and created a new network of computer-based interface message processors, precursors to modern routers. Their goal was to allow simultaneous communication among dozens of academic centers over a single network. In 1969, their project, initially called ARPANET, was deployed and quickly evolved from a system using a few dozen scientists with room-size computers communicating over telephone lines at a bandwidth of 56 kilobits per second (kbps), to become the current Internet, where more than 2.8 billion users communicate with handheld devices linked via cable modem at 160 megabits per second (Mbps).[38]

Faster, higher-resolution data transfer allows telemedicine to be available to an exponentially greater number of patients, adventurers, and physicians around the globe. Although data transmission time is directly proportional to distance (unidirectional transmission from Earth to Mars takes on average 14 minutes), technology exists for communication throughout the Solar System, allowing for future theoretical human exploration with medical support of Mars and other planetary bodies. On the ground, these capabilities have also rapidly changed. In 1987, a telephone line connection enabled x-ray and detailed ultrasound echocardiographic images to be transmitted from rural Nova Scotia to pediatric cardiology consultants for diagnosis and treatment advice.[15] Less than 15 years later, dial-up connection made two-way video consultation with specialists available to ailing scientists in Antarctica 24 hours a day.[7] As the World Wide Web and cellular data access have become globally available through handheld devices, it is now the case that digitized photos, radiographic images, ECGs, and audio files are universally available for education and medical advice. A trekker may download a range of advanced health care applications to a smartphone via the airport wireless Internet connection before departure and then carry the telemedicine-empowered smartphone to a remote location (Table 104-1).

TELEMEDICINE SYSTEMS ENGINEERING

The increase in telemedicine's scope is fueled by improvements in computer technology and communication networks. Telemedicine can be divided into three broad categories: store-and-forward, remote monitoring, and live streaming audio or video interaction (Table 104-2). In store-and-forward systems, patient data or consultant advice are saved and stored in an electronic medium. When timing is appropriate, these data are then uploaded via telephone, hard disk, or wirelessly, then transferred for later review. This allows for the two parties to be physically separated in both space and time and still communicate relevant data. This separation has several drawbacks. In particular, it limits caregiver ability to obtain real-time clinical history or physical examination and to provide immediate assistance with diagnosis and treatment. Currently, typical applications of store-and-forward include the use of a Holter monitor or loop recorder for arrhythmia detection, where cardiac electrical activity is stored over a period of time and as needed, uploaded from home for

TABLE 104-1 Wilderness First-Aid Smartphone Apps*

Application (App)	Device	Cost
Army First Aid by Double Dog Studios	iPhone	$1.99
First Aid by Red Cross	iPhone, Android	Free
GotoAID by Jaargon, Ltd	iPhone, Android	Free, $4.99
Pocket First Aid & CPR by American Heart Association	iPhone, Android	$1.99
SAS Survival by trellisys.net	iPhone, Android	Free, $5.99
Wilderness First Aid by Wildside Medical Education LLC	iPhone, Android	$0.99
Wilderness Survival by Jason Vance	iPhone	$1.99

*Price and app availability are subject to change.

TABLE 104-2 Types of Communication in Telemedicine Systems

Type	Mechanism	Examples	Limitations
Store-and-forward	Data stored on patient machine and uploaded to specialist. Specialist recommendations sent back.	Holter/loop monitor Radiographic images Dermatologic images	Clinical history Physical examination Time-sensitive information Inexpensive
Remote monitoring	Physician monitors patient data remotely using technologic devices.	Heart disease Diabetes Asthma	Clinical history Physical examination Moderately expensive
Live-stream communication	Live two-way communication between patient and clinician replacing in-person evaluation.	Live diagnostic consultations Procedural guidance Triage decision making Live physiologic monitoring	Reliable data infrastructure Expensive

clinical review in the office at a later date. Other uses include tele-radiology and tele-dermatology. Tele-radiology uses patient images captured in one location and then uploaded to a central server for radiologist review either from home, another state, or another country. With tele-dermatology, experts provide downloadable visual diagnosis aids for generalists to use when they encounter an unknown lesion or rash, as well as provide ability to upload digital photo documentation that can then be forwarded over the network for remote dermatology consultation.

Remote monitoring provides a means for a physician or medical provider to monitor and subsequently manage a patient from afar and is particularly helpful managing chronic diseases such as asthma, diabetes, dyslipidemia, or heart disease. Based on patient-gathered metrics (e.g., blood pressure, blood sugar, or lipid levels), remote clinicians can quickly and accurately adjust patient medications.

Lastly, telemedicine can be used to employ real-time connections, including telephone, video conferencing, and live physiologic monitoring. Real-time telemedicine is used to connect patients and physicians in rural settings with distant specialists. In acute settings, real-time telemedicine helps save lives by allowing diagnosis, triage, and treatment from highly qualified practitioners. A volunteer emergency physician staffing a remote Himalayan medical clinic may be concerned regarding a pediatric patient with fever, atypical soft tissue swelling, and rash, and via the telephone may contact a remote pediatrician to discuss physical exam findings, differential diagnoses, and whether the patient requires more urgent evaluation. In another example, to evaluate a patient with traumatic injuries, a distant clinician using a live audiovisual link could guide a field care provider inexperienced in ultrasound through the components of a focused assessment with sonography in trauma (FAST) examination and determine whether the patient may require immediate evacuation and operative intervention. Video conferencing with specialists can be used for routine consultations or follow-up appointments.[11,17] It can save patients and families time and money, improve patient satisfaction, and reduce the environmental impact of medical practice.[20]

Telemedicine systems all contain three basic data functions: acquisition, transmission, and reconstruction and interpretation (Table 104-3). Within each of these areas, any device capable of the qualities of that grouping can be used as part of a system. With current digital systems, increasing frequency of "plug and play" simplicity can be expected (Figure 104-4). For example, for data acquisition, digital medical devices and methods include voice and streaming video over the Internet, ultrasound, ECG, and text documents with past medical history, which are transmitted through any of a range of media (typically, satellite phone connection for remote, austere environments) and then reconstituted at a secondary site (usually accomplished on a standard personal computer). Although options for addition of two-way voice, real-time audio, and other methods can be made, these three essential elements exist as the backbone of every telemedicine system. Certain devices require a means of reconfiguring data (e.g., ultrasound device might need to be plugged into video-streaming device to digitize and compress the signal for transmission), but these typically can be easily and inexpensively accomplished (Figure 104-5). By mixing and matching the different components of the telemedicine system, it can be reconfigured easily to perform a myriad of tasks, whether gathering remote field data, providing local care givers with expert consultation to aid the management of chronic illness, or assisting in the decision-making process and acute management of injury or illness in an austere location.

Current devices allow certain physiologic systems to be easily monitored and data to be stored and transmitted. The devices can record physiologic signals necessary for research purposes, including electroencephalograph (EEG), ECG, respirations, spirometry, oximetry, electromyogram (EMG), and more with compact hardware that can fit in the palm of one's hand.[6] Novices, guided by experts thousands of miles away, have successfully used ultrasound systems, linked by satellite phone to a video-streaming device and laptop computer, to stream video through the Internet to assay for pulmonary edema in high-altitude climbers on Mt Everest.[37] In this example, the authors report on a telemedicine system constructed using a standard,

TABLE 104-3 The Three Required Components of a Telemedicine System

Data Acquisition	Data Transmission	Data Reconstruction and Interpretation
Physical examination by local provider Real-time history by patient Text documents Electrocardiogram Anatomic imaging (CT, MRI, ultrasound, radiography) Physiologic monitoring Electroencephalogram	Satellite phone Cellular/smartphone Internet Visual (semaphor) Radio-wave	Receiver compatible with transmitting system, most typically a computer with a display

CT, Computed tomography; *MRI*, magnetic resonance imaging.

FIGURE 104-4 Smartphone telemedicine. Miniaturization of biologic sensors and medical devices allows remote monitoring or diagnostics for use in the field. **A,** The Philips Lumify, a portable ultrasound designed for a mobile smart device. **B,** WelchAllyn iExamine, an iPhone-compatible funduscope. **C,** AliveCor Heart Monitor, a smartphone-based ECG machine. **D,** Sanofi iBGStar, an iPhone-based glucometer. *(**A** courtesy Philips Ultrasound Inc, Andover, MA; **B** courtesy WelchAllyn, Skaneateles Falls, NY; **C** courtesy AliveCor, San Francisco; **D** courtesy Sanofi, Bridgewater, NJ.)*

commercially available, portable ultrasound system coupled with a two-way communications system. They describe a system remarkable in its capability and ease of use. In this study, the ultrasound operators were nonphysician climbers without ultrasound experience. A 2-minute orientation to the ultrasound machine, probe orientation, remote commands, and examination conduct was given over a satellite phone by a remote ultrasound expert just before the examination. The remote expert communicated with the climbers using bidirectional audio, reviewed streaming video output from the ultrasound, and guided the examination with the aid of a cue card to which the climbers referred (Figure 104-6). In this and other investigations, compelling evidence shows that "coupling portable ultrasound with remote expert guidance telemedicine provides robust diagnostic capability in austere locations."[37]

Each of these components of the telemedicine system can further be defined by their speed and resolution. A major defining parameter in any telecommunication network is bandwidth. *Bandwidth* is the amount of data transmitted per unit time and often the rate-determining step in a telemedicine system.[11] Speed of data transfer is usually measured in bits per second (bps). A bit is a single value in a line of computer code, and either represents 0 or 1. A byte is 8 bits in size and represents the smallest addressable memory unit; it takes 8 bits or 1 byte to form a single character of the alphabet (Table 104-4). A network connection that allows for a 1 megabit per second (Mbps) or 1000 kilobits per second (Kbps) can transfer data at the rate of 125 kilobytes per second (KBps) (Table 104-5). Transferring a 5-megabyte (MB) photograph over a 14-Kbps connection (14.4-Kbps dial-up modem) takes approximately 45 minutes. Sending the same file over a 10-Mbps connection (broadband cable modem) takes 3.8 seconds (Table 104-6). Tele–diabetic retinopathy screening requires about 5 MB per compressed diagnostic video, ultrasound requires approximately 120 KB to transmit 5 key frames per second, or about 100 MB of compressed data for a full echocardiogram, and live video conferencing with diagnostic-quality resolution requires speeds of 1 to 2 Mbps or more.[40] Meeting these bandwidth benchmarks requires capable underlying technologic infrastructure or that caregivers carry significant telecommunication equipment. For example, expeditions on Mt Everest and along the Amazon River have carried their own equipment to link with orbiting satellites.[4,27] As recently as 2014, attempts to use "3G" wireless for telehealth in rural South Africa proved unsuccessful because there was not a functional 3G cellular network, but instead a very slow general packet radio service.[9] Before deployment,

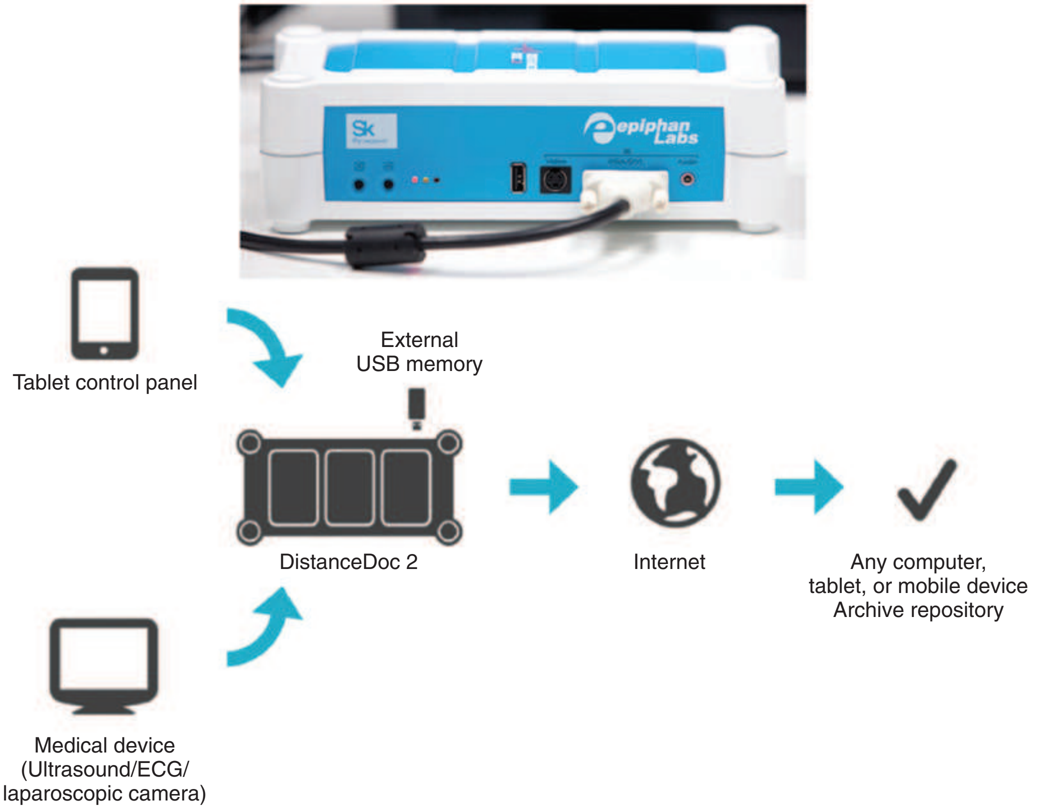

FIGURE 104-5 Telemedicine made easy. Shown is the DistanceDoc, a device that allows for real-time capture of images and video from any medical device or tablet with a compatible video output. The medical device or tablet video output is connected to DistanceDoc video input. Captured images and video can then either be saved to a USB stick/internal storage or compressed and transmitted via the Internet for real-time diagnostic evaluation. *(Courtesy Epiphan Labs, Skolkovo, Russia.)*

FIGURE 104-6 Telemedicine on Mt Everest. This climber is performing a thoracic ultrasound examination on a fellow climber in a tent at Advanced Base Camp using telemedical guidance. They are being led in this examination through a real-time audiovisual connection with a remote expert, visible on the computer screen on the top of the barrel in the background. *(From Otto CM, Hamilton DR, Levin BD, et al: Into thin air: Extreme ultrasound on Mt. Everest,* Wilderness Environ Med *20(3):283:289, 2009.)*

TABLE 104-4 Memory Conversion

Memory	Abbreviation	Value	Size
bit	b	1	0 or 1
byte	B	1	8 bits
kilobit	kb, Kb	103	1000 bits
kilobyte	KB	103	1024 bytes
megabit	Mb	106	1000 kilobits
megabyte	MB	106	1024 kilobytes
gigabit	Gb	109	1000 megabits
gigabyte	GB	109	1024 megabytes
terabit	Tb	1012	1000 gigabits
terabyte	TB	1012	1024 gigabytes

TABLE 104-5 Network Bandwidth

Network	Minimum	Maximum
Dial up	2.4 Kbps	56 Kbps
ISDN	64 Kbps	128 Kbps
DSL	128 Kbps	9 Mbps
ADSL	1.5 Mbps	9 Mbps
Cable	512 Kbps	20 Mbps
Wireless	Variable depending on source	
T-1	1.544 Mbps	1.544 Mbps
T-3	43 Mbps	45 Mbps
OC3	155.52 Mbps	155.52 Mbps
Satellite	492 Kbps	512 Kbps

Data from Beal V: Types of internet connections. Webopedia, 2014. www.webopedia.com/quick_ref/internet_connection_types.asp.
Kbps, Kilobits per second; *Mbps*, megabits per second.

TABLE 104-6 Network Transfer Rate and Theoretical Maximum Download Speed Chart*

Network Speed	Transfer Rate (MB/s)	1 MB	5 MB	10 MB	50 MB	100 MB	500 MB	1 GB	10 GB
14.4 Kbps	0.0018	9:15	46:17:00	1:32:35	7:42:57	15:25:55	77:09:37	154:19:105	1543:12:35
28.8 Kbps	0.0036	4:37	23:08	46:17:00	3:51:28	7:42:57	38:34:48	77:09:37	771:36:17
56 Kbps	0.007	2:22	11:54	23:48	1:59:02	3:58:05	19:50:28	39:40:57	396:49:31
128 Kbps	0.016	1:02	5:12	10:25	52:05:00	1:44:10	8:40:50	17:21:40	173:36:40
256 Kbps	0.032	0:32	2:36	5:12	26:02:00	52:05:00	4:20:25	8:40:50	86:48:20
512 Kbps	0.064	0:15	1:18	2:36	13:01	26:02:00	2:10:12	4:20:25	43:24:10
1 Mbps	0.125	0:07	0:39	1:18	6:30	13:01	1:05:06	2:10:12	21:42:05
2 Mbps	0.25	0:03	0:19	0:39	3:15	6:30	32:33:00	1:05:06	10:51:02
5 Mbps	0.625	0:015	0:08	0:16	1:20	2:40	13:20	26:40:00	5:26:01
10 Mbps	1.25	<0:01	0:04	0:08	0:40	1:20	6:40	13:20	2:13:20
20 Mbps	2.5	<0:01	0:02	0:04	0:20	0:40	3:20	6:50	1:06:40
50 Mbps	6.25	<0:01	<0:01	0:01	0:07	0:15	1:18	2:36	26:08:00
100 Mbps	12.5	<0:01	<0:01	<0:01	0:04	0:08	0:40	1:20	13:20

*Time listed as hh:mm:ss.
Kbps, Kilobits per second; *Mbps*, megabits per second; *GB*, gigabytes.

thorough assessment of field location infrastructure should be performed to evaluate availability and reliability of telecommunication networks; this is essential for successful implementation of telemedicine.

Telemedicine involves several logistical and ethical considerations on the part of the network and physicians providing consultation. The logistics particularly pertinent to wilderness locations are discussed later. Both parties should be aware of and should agree to certain responsibilities and availability, and should discuss a backup plan for unscheduled blackout times. Although disruptions in connectivity in remote settings can occur without warning, it is ethically unsound to begin providing a level of care that requires telemedicine and be unable to complete that care plan because of a predictable disruption in telemedicine service. This issue is further complicated in cases of medical expeditions that use telemedicine to provide medical services to isolated communities for a short time. Similar to the medical mission model, temporary telemedicine services can provide great benefit, but caution should be exercised to defer evaluations and treatments that will require follow up beyond the duration of the expedition.

On-scene medical providers and the tele-physician should be aware of the capabilities of the facility they are speaking with and give advice accordingly. Legal responsibility for patient care is shared between the on-site and telemedicine teams. Each should provide a standard of care to the best of their abilities and acknowledge the limitations of tele-practice as these arise. If at all feasible, informed consent should be obtained in the setting of procedures or decision making, explaining the use of telemedicine to assist an on-site provider. The need for lifesaving procedures may make this impossible, but every effort should be made to discuss care options with the patient in their native language before undertaking a procedure in the field or an evacuation that carries explainable risk. The ideal network for telemedicine is a secure one that preserves privacy of the patient-physician interaction, or the blindedness of observers performing clinical research. (See core guidelines for telemedicine operations at www.americantelemed.org.)

Before deployment of a telemedicine system for rural, international, or expedition use, careful thought regarding specific needs and medical goals is critical. Depending on the location of use, multiple factors must be considered, including budget, local infrastructure, unique environmental threats (cold, altitude, salt, water exposure), size, and weight restrictions (Box 104-1). Specific environmental factors to consider include sunlight availability to power solar grids, waterproofing in areas with exposure to rainfall, equipment tolerance of the cold/hypobaric conditions of high altitude, and general ruggedness of equipment to survive exposure to harsh environmental exposures to dust, wind, and other elements. Equipment specifications must be scrutinized to determine whether modifications are necessary before deployment. Caregivers must be cognizant of their destination's network communication and power grid infrastructure capabilities. If a reliable electrical infrastructure will not allow safe and reliable equipment use, alternative power supplies (batteries, solar/wind power, portable generator) will be required to operate the telemedicine system. Caregivers must be knowledgeable about the type and speed of the network connection, because speed will likely be a significant bottleneck for data transmission. If only a telephone or local area network (LAN) line connection is present, data transmission may be limited to audio, document, or e-mail, whereas cable or 3G cellular capability may allow real-time audiovisual communication and live data streaming (Figures 104-7 and 104-8).

Before investing in telemedicine technology, consideration should be given to the specific injuries and illnesses likely to occur during the deployment and what the use of telemedicine will be expected to achieve.[47] It should be determined if data requirements are most easily satisfied using a store-and-forward method, remote monitoring, or live streaming mechanism. Setting up an advanced tele-stroke neurologic consultation service for remote areas requires real-time audiovisual connectivity with two-way communication ability to allow rapid diagnostic and treatment conversations. The data and power requirements for such a service can be time and money intensive. Conversely, a wilderness expedition leader who intends to rely on infrequent use of a satellite telephone to make a triage decisions regarding management and evacuation of injured mountaineers has much less technologic demand.

For telemedicine to be successful, each participant's level of medical training should be determined and integrated appropriately. Although some procedures and treatments can be conveyed using verbal communication to a layperson (e.g., how to use a needle to perform decompression needle thoracostomy in a patient with a tension pneumothorax), others may require significant medical expertise (e.g., surgeon remotely guiding a general practitioner through an appendectomy). Certain skill sets are unable to be transferred via audio or video conferencing. It is important to recognize that if medical equipment is being brought along, there should be an individual(s) capable of using it.

Developing effective telemedicine systems in the wilderness requires one to be methodical and to take each of these features into consideration. First is a complete needs assessment. What are the expedition's most critical or common medical needs? Would they benefit from store-forward, physiologic monitoring, or live streaming telemedicine? What is the region's

BOX 104-1 Telemedicine Needs Assessment

How to Choose a Telemedicine System

1. Where will the telemedicine system be deployed?
   Environmental factors:
   - Availability of sunshine (e.g., solar power production influenced by cloud cover, natural terrain: north side of mountain in northern hemisphere)
   - Rainfall/exposure (waterproofing needs)
   - Wind/dust/vibration (ruggedness of equipment)
   - High altitude (hypobaria and cold can disable some devices)

   Is equipment suitable for deployment in particular environmental conditions?
   Does equipment require special attention or modification to maintain functionality?
2. What is the level of network and power grid infrastructure and its reliability?
   Is there reliable power, and is an alternative source needed (generator, batteries, solar array, wind power)?
   Is there access to a communications network?
   - Telephone/LAN line
   - Cellular/3G/4G LTE
   - Wireless
   - Satellite

   Network reliability and speed will dictate data transmission bottlenecks and limit efficacy of telemedicine networks requiring fast data transfer.
3. What are the objectives of telemedicine network?
   - Research
   - Rural/international medical care
   - Adventure/expedition medical care

   What is the simplest and most reliable system to accomplish predetermined goals?
4. What are the size, weight, and cost limitations of system components?
   Telemedicine system must fit within size, weight, and budgetary constraints, which may represent significant restrictions on type of system.
5. What injuries/medical illnesses are expected?
   Injury/illness pattern expected:
   - In particular destination (e.g., alpine vs. desert environment)
   - In particular activity (e.g., mountaineering vs. scuba diving)
   - Chronic illness within community or expedition/crew

   Knowing expected needs of telemedicine system can allow for appropriate selection.
   Triage decision (Evacuation: Yes/No)
   Advanced medical care/procedures
   Chronic illness management
6. What is the medical training of expedition or crew members?
   What level of medical expertise is immediately available?
   Certain knowledge/skill sets cannot be transferred via communication.
   Medical equipment brought should match skill level of individuals.

infrastructure and the team's ability to care for and maintain equipment? What is the greatest bandwidth that can be achieved with reasonable consistency? Will the system be used for emergencies only, or routine medical care? What will be the availability and responsibility of on-site providers and telemedicine consultants? Once the expedition is capable of carrying out telemedicine, the most successful systems stress thorough understanding of the content, time, cost, and quality of proposed remote medical interactions and information exchanges, as well as in-person alternatives.[12,16,34]

MODERN TELEMEDICINE

Modern telemedicine fills three major information gaps in wilderness and rural medicine: remote specialist consultation, remote monitoring of patients, and patient and physician education. Common telemedicine specialties include radiology, cardiology, dermatology, and psychiatry, with pediatric branches of these specialties especially well represented. Among emergency specialty consultations, tele-neurology is well established and provides real-time diagnostic examinations and expert advice

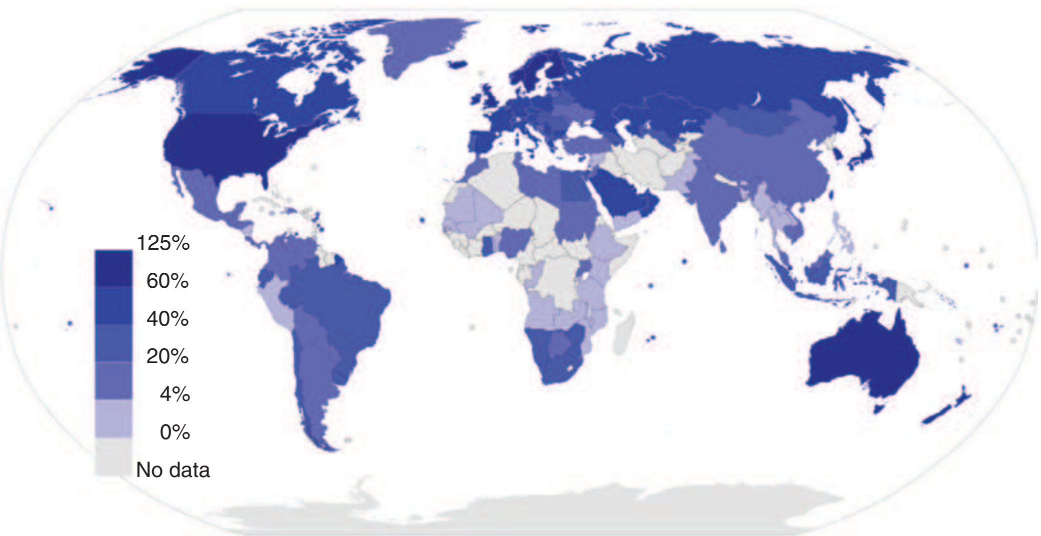

FIGURE 104-7 Global cellular 3G/LTE broadband global accessibility as of 2012. Despite the increasing size of cellular broadband networks, many areas of the world still do not have access to cellular broadband Internet connectivity. *Darker shades of blue* represent areas with high accessibility; *lighter shades* demonstrate limited access. *(Courtesy Jeff Ogden: Mobile broadband internet penetration world map,* Wikimedia Commons, *2013.)*

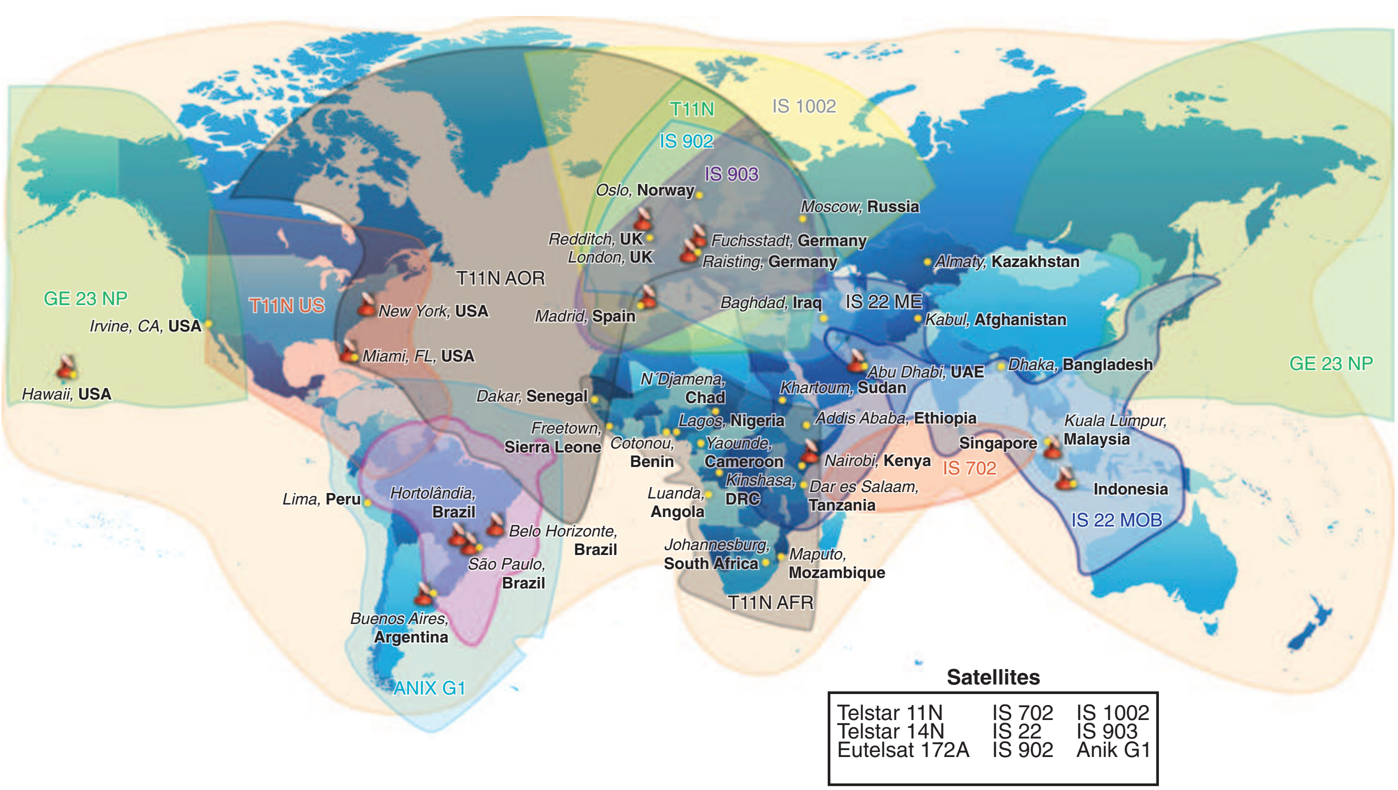

FIGURE 104-8 Satellite broadband global accessibility. With orbiting geosynchronous communications satellites, broadband Internet is now accessible from nearly every inch of the globe. *(Courtesy TEC Offshore: VSAT. TEC Offshore Marine Services Communications, 2015.* www.tecoffshore.com/communications/vsat/.*)*

regarding use of thrombolytic drugs for acute ischemic strokes. Other specialists who have joined the field of telemedicine include burn surgeons, orthopedists, pediatric traumatologists, and neurosurgeons.[41,43] Technology can be as complex as a dedicated video conferencing network utilizing international satellite systems, or as simple and publicly available as smartphone cameras and multimedia messaging service.[44] True telesurgery remains in developmental phases, but in 2002, surgeons in New York City put forth a compelling proof of concept by successfully completing laparoscopic cholecystectomy on a patient in Strasbourg, France via signals sent over asynchronous transfer mode (ATM) telecommunications technology to a surgical robot.[28]

Telemedicine has been rapidly adopted in intensive care units (ICUs), rehabilitation centers, and nursing facilities for remote monitoring of physiologic parameters and specialist consultations.[24] Its role in monitoring patients at home (with a goal of keeping them healthy and at home) is being fine-tuned. Modern physicians can currently monitor patient physiology to a degree and detail at a distance that Norman Holter could hardly have imagined. From home, heart failure patients can transmit daily heart rate, weight, blood pressure, and even pulmonary artery pressure to clinicians and can receive clinical advice according to algorithms that help predict exacerbations.[1,3]

Finally, telemedicine currently plays a growing role in patient and clinician education. Procedural teleconferences, such as the Boston International Live Endoscopy Course, use high-definition video and two-way audio to provide live broadcasts of thousands of procedures with real-time, interactive teaching to gastroenterologists worldwide. Similar conferences exist for surgeons and interventional cardiologists. Clinician education has improved medical student learning from live surgery teleconferences. Internet-based programs, podcasts, and simulations allied with free, open access medical education enable clinicians to access new information and question colleagues and experts.[46,35]

TELEMEDICINE IN THE WILD

Wilderness medicine draws from the telemedicine applications of specialty consultation and procedural guidance, remote physiologic monitoring, and education. It matches the needs of austere environments and expeditions with the capabilities of telemedicine technology to keep mountaineers safe, handle emergencies, and contribute to our understanding of human physiology in extreme wilderness environments. Antarctica and Mt Everest Base Camp are two notably extreme environments with highly sophisticated medical care and telemedicine support that have utilized telemedicine in several capacities and served as examples for others. Antarctic expeditions in the early 1900s recognized the need for remote medical care and brought medical supplies and expedition medical doctors with their crews. An Australian expedition in 1911-1914 pioneered the use of wireless communications to provide telemedicine support between the doctor at a sub-Antarctic base location and far-forward explorers on the ice.[25] Over time, duration of human stays on Antarctica has grown from a few challenging weeks to year-round scientific investigation. Correspondingly, the role of telemedicine has grown to help study and improve health in humans under the physical and psychological stress of continual darkness and freezing cold. Detailed research by the Australian National Antarctic Research Expeditions (ANARE), facilitated by robust medicine and telemedicine communications, has linked vitamin D deficiency to hormonal changes related to bone and behavioral health.[23] On subsequent expeditions by Australian and American teams, issues ranging from severe accidents to complications of chronic medical disease arose, for which remote expert physicians helped save lives. In the 1950s, Americans and Australians constructed permanent research facilities that included a medical ward staffed by an on-site physician with radio-based medical support. In 1961, Australian team physician Russel Pardoe under the guidance of a surgeon in Melbourne made lifesaving use of the Morse code–based telemedicine system to perform a burr hole with a modified dental drill in a patient with a cerebral hemorrhage.[25] As the population of scientists and staff in Antarctica has grown to the thousands, telemedicine technology has evolved from Morse code to continuously available high-speed Internet via geosynchronous satellites, without the blackouts that plagued Antarctic communications through the 1990s.[7]

To date, remote applications of neurology, cardiology, oncology, surgery, and anesthesiology have been used to diagnose, treat, and make evacuation or supply-drop decisions for such conditions as stroke, heart attack, breast cancer, orthopedic trauma, and gallstone pancreatitis. Telemedicine is particularly lifesaving and cost-effective in winter, when evacuation can be extremely dangerous, if not impossible. On-site general physicians used telemedicine guidance to diagnose and treat conditions such as surgical repair of ligamentous knee injuries under anesthesia, self-biopsy, and administration of chemotherapy for breast cancer. This avoided evacuation without delaying clinical care.[7,45] The United States manages three Antarctic hospitals that have been linked to tertiary medical centers (University of Texas Galveston and University of Colorado) with high-speed two-way video and audio to facilitate ongoing medical care and research.

Formal medical care and telemedicine began later in the Himalayas. Twenty years after Sir Edmund Hillary's 1953 first ascent of Mt Everest, a coalition of medical professionals and guides founded the Himalayan Rescue Association and began providing care at a high-altitude hospital with radio connection for evacuation assistance. True telemedicine on Mt Everest arrived in 1998 with a Yale University/NASA collaboration. The Everest Extreme Expedition (E3) achieved the following three goals:

1. Establishing a daily medical clinic and connecting Mt Everest Base Camp with Yale New Haven medical center in real time via two satellite telephones with sufficient bandwidth to support audio and video.
2. Physiologic monitoring of climbers at high altitudes using wearable devices.
3. Performing numerous experiments related to high-altitude physiology.

The E3 team's temporary clinic saw approximately 150 patients during their stay and used telemedicine to perform medical "rounds" each day on clinic patients and remotely monitored climbers, bringing the standard of high-altitude health care impressively close to that of lowland tertiary medical care. Numerous tests included ultrasound, digital funduscopy, cardiac and pulmonary auscultation, and even a Gram stain. These were transmitted to Yale for live, detailed evaluation, enabling numerous diagnoses (e.g., high-altitude retinopathy, pneumonia, high-altitude pulmonary edema, rotator cuff impingement) and guiding treatment.[4] Although the E3 expedition was temporary, its success stimulated additional telemedicine projects and connections between Mt Everest Base Camp and academic medical institutions for research and patient care. A subsequent series of studies by the Xtreme Everest Research Group employed telemedical physiologic monitoring and real-time data transmission to conduct high-altitude physiology research to expand understanding of hypoxia among climbers in austere environments.[29]

Another major wilderness application of telemedicine is expedition medicine. It is becoming more common for commercial and scientific expeditions to include a wilderness medicine physician in the team and to connect the team to telemedicine resources for further safety. As one of the world's premier wilderness education institutions, the National Outdoor Leadership School (NOLS) decisions involving need for acute communication and access to medical expertise in the backcountry are illustrative. As policy, NOLS now requires one electronic communication device (typically a satellite phone) as standard issue to be carried by instructors on every course. Satellite phones allow instructors with varying degrees of medical training (typically wilderness first responder or wilderness emergency medical technician) to discuss cases with expert medical control while still in the field. In addition, some form of electronic position-indicating radio beacon (EPIRB) is being employed on certain courses. EPIRBs allow rapid notification and exact localization of a potential patient if an emergency evacuation must be planned. In the Indian Himalayas, when a NOLS student suffered an open tibia fracture during a fall on glacial moraine, medical management and decision making provided from NOLS world headquarters in the United States allowed rapid stabilization and initiation of treatment. When poor weather prevented immediate evacuation, ongoing medical expertise from afar provided oversight until evacuation to definitive medical care was feasible. Another notable recent example of extensive, live telemedicine support in an area with unpredictable infrastructure and weather was the Martin Strel Amazon swim expedition in 2007. Over the course of the 66-day swim from Peru to the Brazilian coast, the group used intermittent Skype and e-mail-based telemedicine to maintain frequent and helpful contact at low bandwidth by using light, durable equipment suited for the small size of their watercraft and the humid, wet environment. As in the Yale-Everest project, the team used these modalities to conduct daily tele-rounds to keep on-site and remote medical team members abreast of daily events, weather conditions, vital signs, and physical exam findings to assess the overall health of the swimmer, a strategy that the lead physicians and swimmer believed was essential to safe and successful completion of the journey.[27]

Telemedicine is a key aid to triage and evacuations decisions on expeditions. Technologies such as continuous or intermittent physiologic monitoring, live streaming video examinations, or e-mail conversations with on-site clinicians can help remote physicians assess indications for evacuation. As ultrasound machines and smartphones with video cameras become smaller and more portable, tele-ultrasound is increasingly available and helpful in wilderness settings. Lung ultrasound in particular, with its ability to diagnose and quantify lung pathology (e.g., pneumothorax, pneumonia, pleural effusion, pulmonary edema), is simple enough to teach to nonphysicians; even a school-aged child can perform an acceptable examination when being guided by smartphone teleconference with a remote physician.[31] Cardiac and abdominal ultrasound with remote interpretation and guidance are under investigation and will likely provide helpful data regarding altitude-related pulmonary edema, pneumonia, pneumothorax, pericardial effusion, reduced cardiac function, intra-abdominal bleeding, and fracture.[32] Further study must be done to determine reliability of remote guidance for nonphysicians to perform these studies.

Additional roles for telemedicine in expeditions and military operations are found in store-and-forward smartphone applications (apps) that help on-site clinicians manage unfamiliar clinical conditions. Several apps are available to assist in triage during combat and disaster situations. One such application includes digital representation of a human body that solicits input of injuries and treatments and subsequently reviews these situations (real and simulated) to improve decision making.[39] Another smartphone app can be used by military field medics in the assessment of neurocognitive function after a blast injury or performance degradation from environmental factors to determine whether a soldier remains cognitively fit for duty.[26] The World Health Organization (WHO) and U.S. Centers for Disease Control and Prevention (CDC) offer numerous digital references for triage, disaster relief, first aid, vaccination, and infectious disease maps. Additionally, this textbook and several other wilderness medicine and first-aid references are available in digital form and can be carried to any location hospitable to smartphone, tablet, or e-reader.

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CHAPTER 105

Wilderness and Global Communications and Techniques

STEVEN C. CARLETON

Communications to facilitate safe wilderness travel can be as simple as two-way voice transmission over handheld walkie-talkies or as complex as real-time telemedicine using a laptop computer and satellite Internet connection. Highly capable communications equipment can be reliably operated independent of the electrical grid, but this convenience extracts a cost. Gear can be expensive, fragile, bulky, and complex to operate. Portable gear may be limited in broadcast power and thus in range of transmission. Preplanning is essential. Commercial subscriptions and licensure are required to use many of the technologies of greatest utility, and national regulations must be addressed if the equipment is to be imported and used legally in countries other than the country of origin. With rare exceptions, land-based cellular phone technology is not useful in the wilderness setting; the infrastructure required for call routing is simply too limited (90% of Earth is beyond the reach of cellular phone signals).

TWO-WAY LOCAL COMMUNICATION

Local communication in wilderness relies primarily on frequency-modulated (FM) voice radio in the very-high-frequency (VHF, 30 to 300 megahertz [MHz]) and ultra-high-frequency (UHF, 300 MHz to 3 gigahertz [GHz]) portions of the radio spectrum. Unlike commercial amplitude-modulated (AM) and shortwave radio (i.e., 300 kilohertz [KHz] to 30 MHz), these frequencies do not usually benefit from ionospheric effects to increase range and are not reliable for long-range transmissions.

The most common misperception about portable radio transmission involves range. From a practical standpoint, communication with handheld radio devices should be considered to be "line of sight." The radio horizon to which these devices can effectively communicate is influenced by wattage of the transmitter, heights of the transmitting and receiving antennas, orientation of the antennas, and presence of obstructions to propagation (e.g., foliage, terrain features).[2,18] A simple equation defines the maximum theoretical range between a transmitter and receiver, where D is the distance to the radio horizon in miles; Hr is the height of the receiver in feet; and Ht is the height of the transmitter in feet[21]:

$$D = 1.33\left[\sqrt{(2\ \mathrm{Hr})} + \sqrt{(2\ \mathrm{Ht})}\right]$$

For a transmitter and receiver being held with the antennas 1.8 m (6 feet) off of the ground, the maximum theoretic range would be approximately 14.5 km (9 miles). The actual maximum range would reliably be only a fraction of this. By comparison, the theoretical range for communication between a ground-based transmitter and a satellite in low Earth orbit (LEO) would be several thousand miles, and the practical range would be a substantial fraction of this, as long as obvious overhead obstructions (e.g., cliff walls, forest canopies) were avoided.

As a general rule, when free of visual obstructions, the radio horizon can be considered as the distance to the visual horizon plus 10% to 15%. Propagation is maximized when antennas are elevated above ground as much as possible and visual obstructions between the transmitter and receiver are avoided. Propagation with handheld radios is also optimized when antennas are held vertically. Transmissions from the depths of a river valley might only be receivable at a distance just beyond the ridgelines of the valley's horizons, with even greater limitations if the valley is forested. In addition, there are levels of output power insufficient to reach the theoretical radio horizon because of degradation of the signal (by the inverse-square law that governs all electromagnetic radiation [*path loss*]) and from ground absorption of radio waves.

When traveling in a group, the ability of members to communicate over distances of several kilometers can greatly facilitate safety. Simple radio gear can be used to locate and rescue lost or injured members or to communicate information that allows the lost or injured person to self-rescue. The Federal Communications Commission (FCC) has allocated many frequency bands for both nonlicensed and licensed use by individuals for short-distance communication within the United States. Relatively inexpensive, lightweight, highly portable, and reliable radio transceivers are available for handheld use. For optimal communication within an expedition, the channels or frequencies to be used for various purposes must be defined in advance. Establishing regular check-in times and communication schedules helps to maintain group situational awareness, rapidly recognize problems (e.g., by failure to communicate on schedule), and maximize battery life.

FAMILY RADIO SERVICE

Family Radio Service (FRS) represents a group of 14 discrete frequencies in the UHF spectrum at 2.5-KHz intervals from 462.5625 MHz to 462.7125 MHz and from 467.5626 MHz to 467.7125 MHz. The FCC has designated FRS for use by individuals and businesses for short-range, two-way communication within the United States and its territorial islands.[19] Licensure is not required, and there are no age restrictions on usage. Transmission output power is limited to 0.5 watts, transmission mode is limited to FM voice, and transmitters cannot be legally modified after purchase. Two-way communication using FRS radios is *simplex* in type, meaning that the transmitting and receiving frequencies are identical. It is estimated that there are 50 to 80 million FRS radio transceivers in circulation,[3,4] ranging in price from $20 to $400, depending on their features. Radios from different manufacturers are interoperable.

The most commonly cited limitation of FRS radio is congestion of the channels as a result of number of units in use. This is less likely to be factor in a wilderness setting. Misperceptions exist about FRS's range of reliable communications. Manufacturers often claim communication ranges of 16 to 48 km (10 to 30 miles). Although true in idealized circumstances, these conditions are unlikely to be encountered in wilderness applications. From a practical standpoint, FRS communication is reliable over distances up to several kilometers. FRS radios are generally small enough to fit in a pocket and operate with disposable batteries or rechargeable battery packs. The operating life is greatest with fresh disposable batteries. Figure 105-1 shows a pair of typical FRS/GMRS hybrid radios (*A* and *B*).

GENERAL MOBILE RADIO SERVICE

General Mobile Radio Service (GMRS) is a service designated by the FCC for two-way FM voice communication by individuals and their immediate family members within the United States and its territorial islands.[22] Most GMRS transceivers are hybrids, sharing seven of the 467-MHz frequencies (i.e., channels 8 [467.5625 MHz] through 14 [467.7125 MHz]) with FRS and having

FIGURE 105-1 Several inexpensive handheld radios for short-distance communication. **A** and **B,** Hybrid Family Radio Service (FRS)/General Mobile Radio Service (GMRS) transceivers. **C,** 900-MHz (33-cm band) frequency-hopping spread spectrum (FHSS) radio. A common coin is pictured to provide scale. All three radios can be powered by rechargeable battery packs or disposable AA batteries. The FRS/GMRS radios require a license from the U.S. Federal Communications Commission (FCC) to transmit on the higher-wattage channels unique to the General Mobile Radio Service.

an additional 16 channels from 462.5500 MHz to 462.7250 MHz that are unavailable to FRS users. Unlike FRS, GMRS is licensed through the FCC. Licensure requires the applicant to be a U.S. citizen, over 18 years old, and not acting as an agent of a foreign government. An application must be approved, and a $65 application fee and $25 regulatory fee paid; online submission is available at http://wireless2fcc.gov.[7] Approval of an online application generally takes only a few days. The license is valid for 5 years. The GMRS license permits members of the holder's immediate family to communicate with the licensee without the need for separate licenses. Communication outside this restriction would require that each have a separate license.

GMRS transmitters are permitted to use up to 5 watts of output power on channels not shared with FRS. This allows clear communication with handheld units over a considerably greater range than with FRS, but still only a few miles. On the shared channels, transmitter power is intended to be restricted to the same 0.5 watts as for FRS. However, many hybrid transceivers require the user to switch manually to the lower power setting on the shared channels. Failure to do so violates FCC rules but does not disable the GMRS radio from transmitting on these frequencies at the higher wattage. In this circumstance, inequality in transmission power could result in the operator of an FRS radio being able to receive from a GMRS transmitter, but being unable to reply to the GMRS operator given the distance involved. GMRS radios built by different manufactures are interoperable (Figure 105-1A and B). In my tests using commonly available, inexpensive GMRS transceivers, clear communication in lightly forested terrain with low intervening hills was possible to a range of 4 to 5 km (2.4 to 3 miles). GMRS radios cannot be modified to extend range.

Handheld communication in GMRS is generally simplex in nature, but these radios can also be used in conjunction with mobile and fixed relay stations (i.e., repeaters) to greatly increase their range. In this circumstance, the radios operate in *duplex* mode, meaning that the transmission frequencies of the handheld unit and the repeater differ. By convention, these two frequencies are separated by 5 MHz to avoid the two signals talking over one another. As such, channels with 462-MHz frequencies are paired with channels having 467-MHz frequencies when repeaters are used. The frequency on which a receiver listens for a relayed message must correspond with that of the repeater station and not that of the original transmission. This salutary feature of GMRS can be exploited in the wilderness setting only where fixed or mobile repeaters are available. A single unit combining a mapping global positioning system (GPS) receiver with an FRS/GMRS hybrid radio exists that transmits FM voice as well as GPS coordinates of the user. This feature allows remote GPS tracking.[8] This function can be easily emulated manually if the person transmitting has a separate GPS receiver and simply reads the GPS coordinates during transmission. This practice should be part of the preplanned radio routine when check-in calls are made among expedition members during wilderness travel.

900-MHz BAND

In 2000, the FCC approved low-power, unlicensed, publicly available voice communications in the UHF band between 902 MHz and 928 MHz. Simultaneously, they issued a requirement that technical measures be taken to avoid the chaos of overuse found on other channels.[3,4,25] The solution to avoid channel overcrowding is a method called *frequency-hopping spread spectrum* (FHSS), which created an almost unlimited number of virtual channels within the 900-MHz band.[4] Radios using this digital technology continually shift among frequencies, spending less than 1 second at any given frequency. This largely eliminates multiple concurrent conversations being overheard on a given channel in areas with heavy radio traffic. Handheld FHSS radios are available at a cost of $30 to $250 (Figure 105-1C). These can use both disposable and rechargeable batteries, are highly portable, and have a practical range of about 1 to 2 km (0.6 to 1.2 miles). Repeaters for FHSS radio do not exist, and the range of the handheld units cannot be extended. The software algorithms that control the frequency hopping are proprietary, and these radios are not interoperable among manufacturers. Some models are capable of sending brief text messages to compatible receivers as an alternative to voice communication.

2-METER AND 70-CENTIMETER AMATEUR RADIO SERVICE

There are numerous highly capable, highly portable, handheld amateur radio service (i.e., ham) radios—called *handheld transceivers* or *handy talkies* (HTs)—that transmit in the VHF spectrum at 144 MHz to 148 MHz (i.e., the 2-m band), in the UHF spectrum at 420 MHz to 450 MHz (i.e., the 70-cm band), or in both (i.e., dual band) (Figure 105-2).[5] HTs typically cost from $120 to $500, depending on features. Most have removable antennae allowing the stock "rubber ducky" antenna to be easily replaced with more capable 0.625-wave, telescoping, base-loaded antenna. These greatly improve receiver performance but are slightly less portable. Most HTs use rechargeable metal hydride or lithium ion battery packs; however, optional battery trays that accept AA batteries are available for many models. The transmitter output is typically 1.5 to 5 watts. Many units can optionally transmit at lower power to extend battery life when the necessary range is short. Most dual-band units support both simplex and duplex modes, including VHF to UHF and UHF to VHF duplex. Radio communication with HTs primarily involves FM voice transmission, but these units are capable of receiving Morse code via carrier wave and voice by single side-band transmission.

The principle advantage of HTs over the handheld radios discussed earlier is range. Although the propagation characteristics of the radio waves transmitted from these devices are similar to those of the other frequencies, the receiver sensitivity and antenna efficiency tend to be better in HTs than in FRS, GMRS, and FHSS radios. Typical 2-m HT-to-HT range on flat terrain is 5 to 10 km (3 to 6 miles). When used with a repeater that has been strategically placed on elevated terrain, HT-to-repeater ranges of dozens of kilometers may be achieved, and subsequent relay from repeater to repeater can then extend the range for long-distance communication. However, as with GMRS radios, repeaters are unlikely to be available in the vast majority of wilderness settings. HTs tend to be ruggedly built, and some

FIGURE 105-2 A selection of small, handheld handy talkies (HTs). These radios communicate on the 2-m (144-MHz) and 70-cm (420-MHz) amateur radio service bands. HTs are more capable and rugged than FRS, GMRS, and FHSS radios, but their use requires FCC licensure through a process that includes testing on radio theory, equipment, procedures, and regulations. The radios pictured here use rechargeable lithium ion batteries.

models are even submersible. Most can receive a broad range of the radio spectrum in addition to the transmitter frequencies, allowing weather broadcasts, commercial AM broadcasts, marine VHF, air band, and commercial FM radio to be monitored.

Radio communication in the United States using frequencies allocated to the amateur radio service requires FCC licensure. The most basic class of license that is sufficient for operation in the 2-m and 70-cm bands is the Technician Class license. There is no age limit or fee for licensure. Being granted a Technician Class license requires correctly answering 26 of 35 multiple-choice questions on a test covering radio theory and equipment and the regulations governing radio communication.[7] The test is administered by an FCC-approved examiner from the applicant's local area. Considerable course work or reading is required to pass the examination, but knowledge of Morse code is not required. A two-page form (FCC Form 605) must be completed and can be submitted online at http://wireless2fcc.gov. The applicant must assert he or she is not acting as an agent for a foreign government. If 2-m or 70-cm HTs are used for expedition communication, each individual using a transceiver requires a separate license.

Choice of radio equipment for wilderness communication will be guided by cost, range, battery life and type, regulations governing radio communication in the country of intended use, and licensure considerations. From the standpoint of pure utility, 2-m/70-cm dual-band HTs offer an excellent blend of range, cost, durability, and size. However, relatively few U.S. citizens hold amateur radio licenses, and the majority of individuals participating in a wilderness trip will have neither the time nor the background to acquire a Technician Class license before traveling. FRS and 900-MHz FHSS radios are inexpensive and do not require a license but have range limitations unsuitable for expeditions if members may be separated by more than a few kilometers. GMRS offers a workable compromise; the transmission power enables communication over a practical range, and licensure is simple and not prohibitively expensive.

All the forms of two-way radio communication discussed can be as simple as tuning to a prearranged channel, pushing the transmit button, and speaking into the radio microphone. The equipment for each type of service may have other functions to increase convenience and flexibility of operation, but these are not necessary for basic transmission and receipt of messages.

Other radio services available for portable use include citizens band, marine-VHF, and business-band radio. These are less practical than the alternatives previously discussed and offer no compelling advantages for terrestrial wilderness use.

A novel approach to short-range radio transmission recently became available that utilizes the user's smartphone as a communication interface. The device, goTenna, is a 2-watt VHF radio transceiver that operates at 151 MHz to 154 MHz. It pairs via Bluetooth LE with the operator's Android or iOS phone and allows transmission of text messages up to 160 characters in length, and sharing of GPS locations with any other individual within range who also has a device. Neither cellular service nor satellite communication is required for text communication. A free app allows users' locations to be displayed on previously downloaded offline maps, and text communication to be private between two individuals, shared between up to 10 members of a group, or "shouted" to any nearby person who has a unit. The range of communication varies with location; it is advertised to be approximately 4 miles in most backcountry terrain. goTenna units are sold in pairs for approximately $200 US, recharge using a USB cable, and weigh less than 2 ounces.

TWO-WAY LONG-DISTANCE VOICE COMMUNICATION

The ideal device for wilderness communication would offer the portability and convenience of a cellular telephone with worldwide coverage. As mentioned previously, land-based cellular telephony is inadequate for this task; however, satellite-based telephone services are well established and approach this ideal. It is now fairly routine to be able to call any telephone number (e.g., fixed phones, cellular phones, other satellite phones) from almost any location on Earth that has unobstructed access to the sky. Licensure is not required for use, but satellite telephones are expensive, the cost of on-air minutes is high, and their use requires preplanned subscription. Satellite phones are also expressly forbidden in some countries. These devices are unsurpassed for utility and flexibility, allowing access to any resource that is available by regular telephone, including Internet connectivity.

Numerous commercial services are available for satellite telephony. Several have near-global reach, whereas others are restricted to particular geographic areas determined by the location of their geostationary Earth orbit (GEO) satellites. All involve the use of handsets with folding antennas that are size-compatible

FIGURE 105-3 **A,** Typical satellite telephone. The antenna on most satellite phones folds for travel and must be extended and held vertically to optimize performance. Satellite phones are becoming smaller as technology evolves. **B,** Representative Broadband Global Area Network (BGAN) terminal. This device is plugged into the USB port of a laptop and oriented so that the integral antenna faces the GEO satellite for the region in question to provide satellite Internet service. A BGAN terminal allows standard voice communication and data transfer for text or e-mail and has the capacity to stream larger volumes of data at transfer rates that allow smooth, real-time video to be transmitted and received. Applications for telemedicine are promising. *(A Iridium 9555 Satellite Phone courtesy Chroma Communications, Inc; https://satellitecommunications.ca/product/iridium-9555-satellite-phone.)*

with wilderness use (Figure 105-3A). Commercially available phones do not meet military standards for ruggedness, and the manufacturers make no particular claims regarding resistance to weather, water, dust, vibration, or being dropped. The latest-generation handsets cost from $500 to $1500, depending on available features; these can also be rented for temporary use at daily, weekly, or monthly rates. As for cell phone service, there is a bewildering array of rental and purchase plans and rate plans that may involve prepaid minutes or pay-as-you-go airtime. In general, calls to landline phones and cell phones are less expensive than calls to other in-plan satellite phones, whereas calls to satellite phones supported by other vendors are the most expensive. The principal service providers are described in the following sections.

IRIDIUM

The Iridium system has a constellation of 66 operational satellites in near-polar low Earth orbit (LEO). Iridium provides true global coverage. The number of satellites allows calls to be readily linked from an overhead satellite to three others and subsequently to ground stations or "gateways" in Hawaii and Arizona, reducing the potential for dropped calls. Each individual satellite has a maximum view time of about 10 minutes to a user on the ground, and passes the call to another linked satellite as the signal weakens. Because of the relatively low orbital altitude (476 miles), delay from transmission to reception (latency) is small and tends not to interrupt a normal mode of conversation.[16] Used, older-generation Iridium phones can be purchased for about $750, whereas the newest handsets cost $1400. Phones can be rented for rates that range from $3 to $10 per day. Most rate plans require a monthly fee in addition to a per-minute charge; a basic plan may cost $40 per month, with airtime costing an additional $1 to $1.75 per minute. The first generation of Iridium satellites are scheduled to be replaced beginning in 2015 by a new constellation of 66 operational satellites with six orbiting and nine ground-based spares (Iridium NEXT).

GLOBALSTAR

The Globalstar satellite system provides broad coverage but excludes the majority of the Arctic and Antarctic, sub-Saharan Africa, and parts of Asia. Globalstar uses a constellation of 60 satellites (48 operational) in LEO with an orbital inclination of 52 degrees. The system offers the same low call latency and satellite linkage as Iridium.[9] The Globalstar system is censored in China.

Globalstar-compatible handsets generally cost from $500 to $1000 and can be rented at rates comparable to those for other service providers. Recently, Globalstar began offering, through their SPOT subsidiary, handsets that are available from brick-and-mortar outdoor equipment stores. Globalstar per-minute rates vary by the region from which the call is made. There may be roaming charges in some regions.

INMARSAT

Inmarsat, based in Britain, makes use of three GEO satellites spaced more or less evenly about the planet for its current satellite telephony and Internet services. Coverage is broader than that of Globalstar but less than that of Iridium and excludes the majority of the Arctic and Antarctic as well as much of Alaska, Greenland, and Siberia. The high altitude of the GEO satellites introduces some delay into voice communication, resulting in latencies between transmission and reception of up to 0.5 second. However, the incidence of dropped calls is lower with GEO than with LEO satellites. Inmarsat appears to be concentrating its service efforts on satellite Internet connectivity.[13]

THURAYA

The Thuraya system is based in the United Arab Emirates and operates three GEO satellites that provide service to virtually all of Europe, much of Asia, Australia, and all but the southernmost portions of Africa.[27] Thuraya satellite phones are available for purchase for approximately $600 to $900 and can be rented for about $80 to $100 per week or $180 to $300 per month, exclusive of airtime. Outgoing calls cost between $2 and $12 per minute, depending on the type of phone being called; incoming calls do not incur charges. Thuraya offers an accessory for a popular brand of smartphone (SatSleeve) that converts the handset into a satellite phone with voice, e-mail, social media, and short-message service (SMS) functionality. Service is limited to the same service area as for their dedicated satellite phone handsets.[28]

Handsets for satellite telephone services discussed here generally provide 2 to 6 hours of talk time and 20 to 40 hours of continuous standby time on a battery charge. If a satellite service is selected with attention to geography and legal restrictions, and if the phone is safeguarded against damage, battery power is available, and the user can afford the charges, a satellite telephone offers the wilderness traveler the utility of a cellular phone.

SATELLITE MESSAGING DEVICES

A novel approach to satellite communication for wilderness travel is the introduction of *satellite messengers/communicators*.[6,26] These are portable, battery-powered devices that contain two elements: (1) a radio that receives continuous positional information from the Navstar GPS satellite constellation and (2) a transmitter, or transceiver, that communicates with LEO communication satellites (Figure 105-4A and B). Use requires purchase of monthly or yearly subscription plans from the companies that manufacture the devices and operate the associated communication satellites (SPOT, Inc., through their parent company, Globalstar; DeLorme, Inc., in cooperation with Iridium). These plans provide various levels of emergency response and communication. Basic satellite messengers allow travelers to be tracked online (Figure 105-4C); to "check in" with position, date, and time; to send preprogrammed one-way messages; and to initiate a rescue response by pressing an "SOS" button in case of emergency. Messages, tracking information, and requests for search and rescue (SAR) are transmitted to a monitoring center operated by the service vendor, then to the e-mail addresses or cellular phones of contacts designated by the user. Requests for emergency response also prompt notification of the user's emergency

FIGURE 105-4 **A,** Satellite messenger with a common coin provided for scale. Note that the user interface consists of only four buttons and four indicator light-emitting diodes. The "HELP" and "9-1-1" buttons are recessed to prevent accidental activation. During routine use, the unit is turned on and given several minutes to establish a GPS fix, and the "OK" button in pressed to send the current coordinates and a preplanned check-in message to the cell phones or e-mail addresses of individuals designated by the user. Battery power is sufficient for hundreds of such check-in messages. **B,** Satellite communicator that permits simple GPS navigation as well as the functions described in **A.** This device also allows two-way satellite text communication using a virtual keyboard. **C,** Demonstration of the GPS tracking function supported by the device shown in **B.** GPS coordinates are sent via satellite at intervals determined by the user to a Web page that plots the user's location on a map or satellite image for each check-in time. Messages from the user can be appended to each plotted point to allow emergency contacts, family members, expedition support personnel, or media to follow the progress of a wilderness excursion.

contacts and are routed to the GEOS International Emergency Response Coordination Center, which contacts governmental emergency providers in the locale from which the transmission originated.[26] The button that initiates an emergency response is designed to minimize the possibility of accidental activation. If this occurs and is recognized, the user can rescind the request for emergency assistance by various methods. Nonetheless, numerous accidental emergency activations have occurred and represent a wasteful, potentially dangerous unintended consequence inherent to a one-button, automatic request for help.

Later-generation devices allow two-way text communication via SMS, transmission of brief e-mails, and posting of tracking information and messages to social media. Two-way communication allows transmitted tracking data to be augmented with timely status updates from the user and has the potential to reduce accidental SAR activations by allowing follow-up communication after the request for help is received. Most units capable of two-way communication pair via Bluetooth with a smartphone or tablet, which then serves as the communication interface. The advantages of convenience and familiarity offered by these external interfaces may be hampered by their fragility and limited battery life. Several models have the ability to function as standalone communicators using an on-screen, virtual keyboard as the communication interface (Figure 105-4B). These units also have full GPS functionality, allowing continuous determination of position, waypoint navigation, and some limited mapping features.

SATELLITE INTERNET

Few wilderness expeditions require access to the Internet to transmit e-mail, text, or two-way real-time voice and images. However, these functionalities exist and can be exploited for expedition media updates, technical assistance, telemedicine, and reassurance of the traveler's family and friends (see Chapter 104).

Data-enabled satellite telephones can be connected by cable to a computer to allow the phone to act as a wireless modem and permit Internet connectivity. This method of connection in effect is standard dial-up service, with data transfer rates of 2.4 kilobytes per second (KBps).[17,23] Some vendors have optional external data modules that compress the data and transmit through dedicated data servers, allowing effective transfer rates of up to 9.6 KBps over the 2.4-KBps connection. Such speeds are sufficient for transmitting and receiving e-mail or text but are impractical for transmission of large image files or real-time video. Inmarsat markets a dedicated satellite Internet service called the *Broadband Global Area Network* (BGAN) that was designed for such high-volume data streaming.[12]

A variety of manufacturers make dedicated satellite Internet terminals for use with the Inmarsat BGAN service (see Figure 105-3B). These terminals cost several thousand dollars, are comparable in size to a laptop computer, work exclusive of a satellite telephone, and have batteries that can be recharged by optional solar cells or other power sources. Battery life is 2 to 3.5 hours for voice calls or data streaming, with a continuous standby time of 36 hours. BGAN terminals can be rented. Several levels of service are offered by Inmarsat, including a standard data connection for browsing and e-mail, and multiple levels of dedicated streaming connectivity that provide data transfer rates from 32 KBps to 512 KBps.[11] These services are billed at monthly rates. For standard service, this rate may include an allocation of a specified amount of data (in megabytes [MB]) that can be transmitted without additional charge, or may be a base rate onto which any data transmissions are added as an additional fee. Typical fees are approximately $5 to $7 per MB. Data streaming with the dedicated services is generally billed by time. Transmission of 1 MB of data over a 200-KBps connection takes approximately 40 seconds.

BGAN terminals connect to a computer by a cable. The antenna, which is integral to the terminal case, is aimed in the direction of the GEO satellite serving the region. The terminal is configured using included software, and the Internet connection is established through the satellite. Once connected, browsing and data handling are the same as with any other networked computer.[11] Cautions about use of this technology are identical to those for satellite telephones: these devices are heavy, bulky, power hungry, expensive, and illegal in some locales. BGAN is best suited to expeditions that operate from a base camp or vehicle and have a source of external power. Recently developed technology has overcome these obstacles, allowing true global access to the Internet, as well as voice-over Internet protocol (VoIP) communication via cellular phone.

SATELLITE WI-FI

In 2014, Iridium, Globalstar, and Addvalue (allied with Inmarsat) each introduced devices that establish a Wi-Fi "hot spot" (802.11 d/g/n standard) and communicate with their proprietary satellite networks. The Globalstar device (Sat-Fi) is intended primarily for vehicular and industrial applications. It requires a 12-V direct current (DC) external power supply and external antenna and measures 6.3 × 6.3 × 2.4 inches. This device allows simultaneous data connections for up to eight compatible devices (Windows, MacIntosh, Android, or iOS) over a 30.5-m (100-foot) radius. Connectivity requires a proprietary application (app) to be installed on the mobile devices to be used. Data transfer rates of 9.6 KBps can be achieved under optimal conditions. This rate is sufficient for text communication via SMS, e-mail, and social media, but is very slow for image transmission or web browsing. Only a single voice call can be placed at a time. 9-1-1 calling is supported in North America. The device does not automatically upload GPS positional data to permit tracking, although this functionality is planned for the near future. The device costs approximately $1000, is available from numerous online retailers, and requires one of a menu of data and voice plans. Data rates are approximately $1.00 (US dollar/USD) per minute, but burst transmission greatly reduces the time required for messages to be sent and received. Voice rates are similar to Globalstar satellite phone rates and may include roaming charges. Although the device is more portable than a BGAN unit, it suffers from many of the same limitations for individual use.[10]

The Iridium satellite wireless hot spot (Iridium GO!) is designed specifically for wilderness operation; it measures 4.5 × 3.25 × 1.25 inches, has an integral folding antenna, and is powered by internal, replaceable, rechargeable lithium ion batteries or a 5-V DC USB power supply. A full battery charge provides 7 hours of talk time and 16 hours of standby time. The unit meets military standards for ruggedness and is water and dust resistant. It establishes a data connection between a line-of-sight satellite and up to five Wi-Fi-enabled Android or iOS mobile devices that are running a downloadable, proprietary app. Connectivity is possible over a radius of 30.5 m (100 feet). The data transfer rate is 2.5 KBps under optimal conditions, a speed sufficient for text transmissions via SMS, e-mail, or social media. Download of a 100-KB image might require more than 5 minutes, and transfer of 1 MB of data might require almost 1 hour. The device is available from online retailers for $800 to $850. Service plans charge approximately $1.00 USD/min for data. Voice rates begin at $1.49 USD/min to any phone, and $0.66 USD/min to other Iridium phones. Voice rates fall as larger plans are purchased. Outgoing SMS messages are billed per message at a base cost of $0.50 USD each. Incoming messages are free. The device has a one-button emergency response activation feature. Online GPS tracking is supported similar to the satellite messengers/communicators discussed earlier.[15]

The Inmarsat-compatible device (Wideye iSavi) offers near-global coverage, except for high polar latitudes. It is intermediate in size between the Iridium GO! and Globalstar SatFi units, weighing 1.9 lb and measuring 7.1 × 6.7 × 1.2 inches. It permits data transmission rates of up to 384-KBps download speed and 240-KBps upload speed and supports voice, SMS, and social media functions. The standard, rechargeable, internal, 3 amp-hour lithium ion battery allows 2 hours of continuous transmission time and 24 hours of standby time. The device costs $1350 USD. Data plans charge $2.79 USD to $5.00 USD per MB.[1]

From the standpoint of portability, support for GPS tracking, facilitation of both voice and data communication, and emergency response initiation, satellite wireless hot-spot technology approaches a practical ideal for multifunctional wilderness communication. Initial cost may be prohibitive for the individual traveler, and service costs can be daunting if discipline is not exercised in their use. The capabilities of these devices can only be realized through a paired smartphone or tablet computer, which tend to be fragile and have relatively brief battery lives. Satellite Wi-Fi and all other forms of satellite-based communication require unobstructed access to the sky. If a traveler encounters an emergency in a slot canyon, cave, or even under a particularly heavy forest canopy, these aids may be inoperable.

EMERGENCY BEACONS

Emergency beacons are a form of one-way, satellite-based communication that initiates a SAR response from governmental agencies. They have been in use for decades and are mandated by law for oceangoing ships (i.e., emergency position-indicating radio beacons [EPIRBs]) and for aircraft (i.e., emergency locator transmitters [ELTs]). More recently, this concept has been extended to land-going individuals in the form of personal locator beacons (PLBs). Before development of practical digital radio technology, EPIRBs, ELTs, and PLBs transmitted only an analog distress tone and homing signal at 121.5 MHz that was monitored by Cosmicheskaya Sistema Poiska Avariynyh Sudov–Search and Rescue Satellite Tracking (COSPAS-SARSAT) satellites. In addition to initiating SAR operations, this signal assisted with coarse radiolocation of the transmitter. Historically, the vast majority of emergency calls triggered on 121.5 MHz were false alarms or spurious activations caused by nonemergency transmissions with overlapping frequencies. This resulted in enormous resource expenditures without demonstrable benefit because of inability to identify the source of the communication to check its veracity and thus to abort an unnecessary response.[14,24]

As technology improved, a digital beacon was added at 406 MHz that transmits a distress call that includes identifying information about the transmitter. On enabled models, the signal may also include GPS coordinates of the transmitter. PLBs require registration with national authorities in the country of origin and intended use. In the United States, the registering agency is the National Oceanic and Atmospheric Administration (NOAA).[20] International registration is available through the COSPAS-SARSAT center. Registration is free, can be made online at http://www.beaconregistration.noaa.gov or http://www.406registration.com/ibrd, allows the PLB to be linked to the identity of the user, and includes emergency contact information that can be accessed by SAR authorities on receipt of a distress call. Although false alarms from 406-MHz devices occur, the ability to identify and contact the device operator allows false alarms to be recognized and the rescue response to be aborted in approximately 70% of cases. The 406-MHz beacons' homing function is superior to that of the 121.5-MHz signals, allowing the receiving satellite to locate the source of transmission within about a 5-km (3-mile) circle.[14]

Satellite monitoring of the 121.5-MHz service was discontinued in February 2009, but PLBs that transmit on both this and the 406-MHz frequencies are still common. Commercial airliners continue to monitor 121.5 MHz, and the analog signal may be used by local SAR assets for ground-based radiolocation. Older devices that use only this frequency should be avoided.

Pocket-sized PLBs can be purchased for $300 to $600 or rented for $50 to $60 per week. PLBs typically have battery power for 20 to 48 hours of continuous operation once activated, depending on temperature. Because they communicate with satellites, PLBs avoid the range limitations encountered with ground-based, line-of-sight radio communications. They offer tremendous utility for initiating SAR operations in an emergency. However, they are inflexible. PLBs only transmit the trigger for an emergency response and the user's identification and general positional information. Media reports document frequent incidents of inappropriate SAR activations and poorly conceived expeditions by unprepared individuals who were emboldened in their travel planning by the notion that rescue was available at the touch of a button. Such an attitude ignores the cost of the emergency response and risk to rescuers and should be discouraged. As with all forms of satellite communication, use of PLBs requires unobstructed access to the sky.

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CHAPTER 106

Wilderness Navigation Techniques

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Many environmental illnesses occur as a consequence of becoming lost. Even well-prepared individuals may suffer hypothermia, heatstroke, frostbite, immersion foot, sunburn, dehydration, starvation, and a variety of other conditions if they become separated from the resources of their expedition or have an unanticipated extension of their time outdoors. The individual can minimize the possibility of becoming lost by maintaining awareness of position and direction and familiarity with local landmarks at all times during travel. This chapter discusses satellite navigation, terrestrial coordinate systems, route finding with the magnetic compass, map reading, application of celestial navigation in wilderness travel, and employment of alternative methods for recovering when lost.

All of navigation boils down to two processes: (1) determination of direction and (2) establishment of position. Awareness of position and direction permit practice of a fundamental process in navigation, the process of "dead" (deduced) reckoning. Dead reckoning is the estimation of current location based on knowledge of the direction, rate, and time of travel from a known starting point. Whenever traveling in the wilderness, dead reckoning should be practiced so that a general awareness of position is never lost. Estimates of time of travel, rate of travel, and direction of travel should be recorded whenever possible so that the last known position and subsequent movement from that position are preserved. In the wilderness setting, determination of direction and fixing of position may be simple but can be challenging. Generally, routes and landmarks are provided by a map, but local knowledge from memory may have to suffice. Direction is often derived from a magnetic compass, but other methods of direction finding can be exploited when the compass is forgotten, lost, damaged, or unreliable. Lines of position (LOPs) are established by trails or bearings to identifiable landmarks; however,

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shorelines, watercourses, firebreaks, and bearings to celestial bodies or radio sources can substitute. Position can be estimated with the careful practice of dead reckoning, determined from scratch by triangulation of bearings from landmarks, or fixed with astonishing ease and accuracy with the use of a satellite navigation receiver. None of these navigational techniques is prohibitively expensive or so equipment intensive as to be incompatible with a hiker's kit. Each method requires understanding of its practice and limitations. Nothing substitutes for preparation, but effective wilderness navigation can be practiced using nothing more than the clues offered by the environment and the wits of the navigator. For travelers in the continental United States, it is significant that no site is more than 48 km (30 miles) from a road, and thus from a potential source of help.

NAVIGATION WITH THE GLOBAL NAVIGATION SATELLITE SYSTEMS

Satellite navigation systems have been in widespread civilian use for decades after implementation of the Navstar Global Positioning System (GPS) by the United States and the Global Orbiting Navigation Satellite System (GLONASS) by Russia. The European Union has partially implemented a similar system (Galileo), as have the Chinese (BeiDou). Licensing requirements and trade agreements have pressured the manufacturers of satellite receivers to make chipsets that are interoperable among these systems. Combined GPS/GLONASS receivers are currently on the market, and receivers that will be able to access all four systems are on the horizon. Although GPS has been an appropriate generic term for satellite navigation, it is now more appropriate to refer to these collective technologies as the Global Navigation Satellite System (GNSS).[3] This term will be used for general reference to satellite navigation in this chapter unless the specific features of an individual service or device are being discussed.

Space-based navigation systems use satellites as predictable extraterrestrial references for determination of terrestrial position. Calculation of position is based on circles of equal distance from the satellites. GPS consists of a constellation of 24 active satellites arrayed in six orbital planes, with four satellites per orbital plane. The orbital planes are inclined to Earth's equator by 55 degrees. The orbital paths of the satellites are nearly circular and have an altitude of approximately 20,000 km (12,425 miles; medium Earth orbit [MEO]) with an orbital period of 11 hours and 58 minutes. At any given time, five to eight satellites are available in line of sight to a GPS receiver anywhere on the surface of the earth.[13,23]

The method of position determination using GPS depends on calculation of the range between the satellite and receiver. GPS signals are transmitted on two frequencies by each satellite: L1 (1575.4 MHz) and L2 (1227.6 MHz).[11] Transmitted information includes the precise time as kept onboard the satellite by multiple atomic clocks, a satellite *ephemeris* (i.e., a catalog of predicted positions), and data concerning corrections for atmospheric propagation of radio signals and satellite clock errors. The GPS receiver decodes the positional data for each satellite and compares the timing information transmitted by the satellite with time as kept by the receiver's onboard clock. Because distance = speed × time, the transit time of the signal allows calculation of the distance between receiver and satellite.[20] At any given instant, a GPS receiver in contact with a Navstar satellite will lie on the surface of a sphere of equal distance from the satellite. The intersection of this sphere of equal distance with the earth's surface forms a circle of equal distance. The intersection of two such circles occurs at only two points, and the intersection of three such circles occurs at a single point on the earth's surface[13,23,24,34] (Figure 106-1); this is the position of the receiver. If the intersection of the sphere of equal distance of a fourth satellite is added, the approximate altitude of the receiver can be determined. Software allows the GPS receiver to choose the optimal group of four satellites for position determination among the subset of satellites within the line of sight of the receiver.

As originally configured, two levels of service were provided by GPS; the Standard Positioning Service (SPS) and the Precise

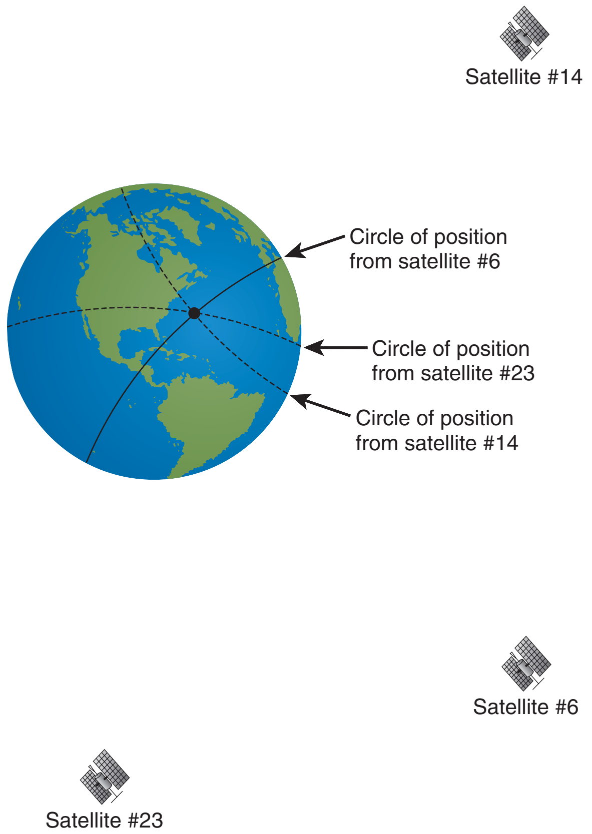


FIGURE 106-1 A Global Positioning System fix from the intersection of three circles of equal distance from three separate satellites. *(From Monahan K, Douglass D:* GPS instant navigation, *Bishop, Calif, 1998, Fine Edge Productions.)*

Positioning Service (PPS). SPS provided civilian users with positional accuracy to 100 m (328 feet) 95% to 98% of the time, to 50 m (164 feet) 65% of the time, and to 40 m (131 feet) 50% of the time. The intentional inaccuracy of SPS resulted from the introduction of timing errors into the broadcast signal from the satellites on frequency L1; this degradation of precise data from the satellites is called *selective availability* and is controllable from the ground. Selective availability was formally implemented 1 year after public availability of GPS was granted in 1994 and was discontinued in 1999. There are no plans for reimplementation, and PPS is the level of service available to all military and civilian users at the time of this writing. PPS provides positional accuracy of 15 m (49 feet), velocity accuracy of 0.1 m/sec, and time accuracy of 100 nanoseconds. To comply with the requirements of safety-of-life aviation applications, the Wide Area Augmentation System (WAAS) was developed in cooperation with the U.S. Federal Aviation Administration (FAA) and Department of Transportation. WAAS consists of 25 North American ground stations that monitor and correct errors in the GPS satellite signals caused by ionospheric interference, orbital drift, and clock errors. Corrections are transmitted on the L1 frequency by geostationary satellites and can be received by enabled receivers. WAAS was implemented for general application in 2000 and for aviation safety-of-life applications in 2003. WAAS-enabled civilian GPS receivers allow less than 3-m (10-foot) horizontal and 6-m (20-foot) vertical positional accuracy 95% of the time, with 7-m (23-foot) accuracy the remainder of the time.[15] Currently, WAAS is available only in the continental United States, including Alaska, border areas of Canada and Mexico, and the surrounding coastal waters.

GLONASS has marginally better satellite coverage than GPS in high northern and southern latitudes because of its high orbital inclination to the equator (64.8 degrees). Its positional accuracy is 30 m (98 feet). GLONASS-capable receivers are less widely available than GPS receivers, but receivers capable of operating with both systems will soon become standard. The GLONASS constellation has 30 satellites (24 active, 6 spare) in three orbital planes at 120-degree intervals in longitude.

Galileo, a cooperative venture of the European Union and European Space Agency, had its initial satellite launch in 2011. Eight satellites were in place as of March 2015, with a total of 18 to be in orbit by the end of 2015. The completed constellation will consist of 30 satellites in MEO, occupying three orbital planes with an orbital inclination of 56 degrees. Galileo is intended to become operational for general use by 2016 and will be publically available and interoperable with GLONASS and GPS. Galileo will offer 1-m (3.3-foot) accuracy in position and altitude for latitudes of 75 degrees north to 75 degrees south.[14] Coverage will extend into extreme polar latitudes, although with lesser accuracy.

BeiDou, the Chinese system, became operational in greater China in 2003, offering 100-m (328-foot) accuracy. The second phase of deployment, BeiDou-2, offered regional coverage in the Asia-Pacific area with 25-m (83-foot) accuracy in late 2012. Global coverage with a constellation of five GEO and 27 MEO satellites is anticipated by 2020.[1,8]

The raw output of a GNSS receiver is in latitude and longitude to the nearest second of arc or in Universal Transverse Mercator (UTM) grid coordinates to the nearest meter. This information is somewhat abstract in isolation, but software included with the receiver permits the user to understand absolute and relative position and perform sophisticated navigational feats in the absence of other navigational aids. Even without a map or compass, GNSS allows users to determine their current position, direction, course traveled, deviation from an intended course of travel, bearing and linear distance to predetermined targets, and velocity. Hikers with GNSS devices can literally have no idea about where they are, but if they have the coordinates of where they want to go, they can find their way to safety with remarkable fidelity. Even the simplest commercially available GNSS receivers render it almost impossible to become lost over distances likely to be encountered on a hike. These receivers dispense with complex displays and have only two buttons. At the start of a hike, the user turns the unit on, allows it a brief period to acquire a fix, then pushes a button to record the coordinates of the initial position as a *waypoint*. As the hike progresses, the receiver continually determines and displays the distance and direction to the waypoint and provides an arrow that points to the waypoint (Figure 106-2). As long as the user follows the displayed arrow on the return hike, he or she will move toward

FIGURE 106-2 A simple, single-function, Global Positioning System (GPS) receiver. The screen displays the distance to a known waypoint (designated by the "house" symbol) and has an arrow on the rim that points in the direction of the waypoint. As the user hikes in the direction indicated by the arrow, the distance counts down and, in the absence of obstructions to travel, the waypoint is gained.

FIGURE 106-3 A typical GPS receiver showing two navigation screens. The screen on the left displays the terrestrial coordinates of the user's position in the Universal Transverse Mercator format, with a moving map that shows the current position (indicated by the ▲ symbol) and several labeled waypoints. The tracks made by the user when walking the route are shown as a continuous line of small dots. A pink line shows the bearing line from the user's starting location to a selected waypoint (i.e., "DEADFALL"). The data fields display the distance to the waypoint in meters and the true bearing to the waypoint. North is at the top of the screen. The screen on the right shows the bearing and distance to the selected waypoint and a graphic representation of the direction of travel to the waypoint. The data field in the upper right corner displays the distance in meters that the hiker is off of the line between the original position and the waypoint. If the user walks a course that minimizes the deviation from this line, the waypoint will be gained. If the user is forced to detour by terrain features, he or she can return to the line to get back on course. Note the scale indicators (i.e., meter bar at the bottom left of the screen and meter ring around the current position of the hiker).

the starting location. This type of receiver will not allow the traveler to predict or avoid impassable obstacles that may lie on the straight-line course between the current position and the goal. However, most general-purpose GNSS receivers have a "moving map" feature that solves this issue, as described later. All receivers can calculate the heading of travel and thus provide the user with a method of determining cardinal directions by walking a brief straight course.

Waypoint navigation is a feature of particular utility for wilderness travel. Waypoints can be preloaded into the GNSS receiver via the keypad or downloaded from a personal computer, or they can be added on the hike with a few keystrokes as locations of interest are encountered. Most receivers have memory capacity sufficient for storage of several hundred waypoints. A group of sequential waypoints can be stored as a route, and the actual path followed between waypoints on the outbound leg of a route can be stored as tracks. *Tracks* are the virtual equivalent of the user's footprints and are displayed on the GPS screen as a string of points or a continuous, meandering line. On the return leg of a route, the receiver can display the path defined by the tracks of the user, the bearing and distance to any selected waypoint, and the current course (Figure 106-3). Many receivers inform the user that a waypoint is near by sounding a proximity alarm and then automatically switch to the next waypoint in the route. Theoretically, these capabilities allow a hiker to follow a route in conditions of near-zero visibility when using no references other than the display of the GNSS receiver. Identification of a large number of waypoints connected by tracks on a complex route essentially allows the user to follow a "breadcrumb trail" to return to the objective[34] (Figure 106-3).

GNSS reaches its greatest usefulness when used in conjunction with a map. Many inexpensive GNSS units include low-resolution base maps with a resolution of a few hundred meters. More capable receivers often include or permit downloading of high-resolution topographic maps. Receivers with mapping capabilities display the user's current position, with any stored waypoints, routes, or tracks superimposed on the map image (Figure 106-3). When a topographic map is available—whether virtual or on paper—GNSS allows users to plot their position and route at will, determine bearings to landmarks even when the landmarks are not visible, enter the location of terrain features for use as predetermined waypoints, and precalculate the distances to be traveled during a trek. The fullest use of GNSS with a map requires understanding two frequently used terrestrial coordinate systems: the geodetic coordinate system and UTM coordinate system.

The explosion in cellular telephone technology was followed a decade later by widespread civilian access to satellite navigation. This had an unintended consequence, with a negative societal impact in countries that offered 9-1-1 or equivalent emergency call services. Replacement of landlines by mobile phones hampered the ability of emergency services automatically to determine the location of mobile callers. In recognition of this problem, the U.S. Federal Communication Commission (FCC) established a 1994 standard requiring mobile phone carriers to provide 9-1-1 service that allows location of the user to be established. The inclusion of GPS-capable chipsets in cellular phones followed. Of the 228 million cell phones sold in the United States in 2011, 90% were GPS capable. Worldwide, 40% of the 1.6 billion cell phones purchased were GPS capable. The vast majority of currently manufactured GNSS chipsets are incorporated into cell phones rather than into dedicated GNSS receivers.[5] In terms of wilderness navigation, this trend is a dual-edged sword; although satellite navigation capability is extremely widespread, the majority of the devices that offer this capability are not designed for wilderness use. They are fragile, have a relatively short battery life, and have less capable antennas than dedicated navigation receivers. Reliance on cell phones as an aid to navigation has the potential to save lives, but also to embolden otherwise unprepared travelers to venture into the wild without more appropriate gear.

GEODETIC COORDINATE SYSTEM

The geodetic terrestrial coordinates of latitude and longitude evolved in response to the requirements of navigation at sea, where identifiable landmarks may be absent for thousands of miles, and unobstructed visibility in good weather may permit identification of a landfall from a considerable distance. With this coordinate system, the earth has a North Pole and South Pole that define its axis of rotation. This axis passes through the earth's center. Any plane that passes through the center of the earth describes a circle on the surface called a *great circle*. The equator is the great circle described by the plane that passes perpendicular to the earth's axis. The great circle of a plane that contains the earth's axis is called a *meridian*. Meridians always run due north and south and converge at the poles. The Prime Meridian is the great circle that passes through Greenwich, England. Greenwich was assigned the Prime Meridian by treaty in 1884 in recognition of the work on astronomy and navigation performed at the Greenwich Royal Observatory.

The angular measurement or arc between the Prime Meridian and the local meridian passing through any other point on the planet's surface is called the *longitude* (λ) of that point. Longitude is measured in degrees, minutes, and seconds of arc east or west of the Prime Meridian, from 0 degrees through 180 degrees. Longitude bears a special relationship to time. Within reasonable standards of accuracy, Earth rotates once about its axis every 24 hours. As such, Earth moves through 360 degrees of longitude in 24 hours, that is, 15 degrees each hour and 1 degree every 4 minutes. It is this fact that establishes the conventions by which sundials work, clocks run, and time and distance are defined. It also forever links the modern practice of celestial position finding to the accurate keeping of time.

The angular measurement between the plane of the equator, as measured north or south from the center of the earth to a point on the surface, is the *latitude* (L) of that point (Figure 106-4). All points at the same latitude form a *parallel* of latitude. Latitude is measured in degrees, minutes, and seconds of arc from 0 degrees through 90 degrees north or south. As such, the latitude of the equator is 0 degrees, whereas that of each pole is 90 degrees north or south. Every point on the surface of the earth is defined by a specific longitude and latitude.

A nautical mile (i.e., 1852 m, 6076 feet, 1.15 statute miles) is the distance on a great circle that covers an angle of 1 minute of arc as measured from the center of the earth. A degree of arc

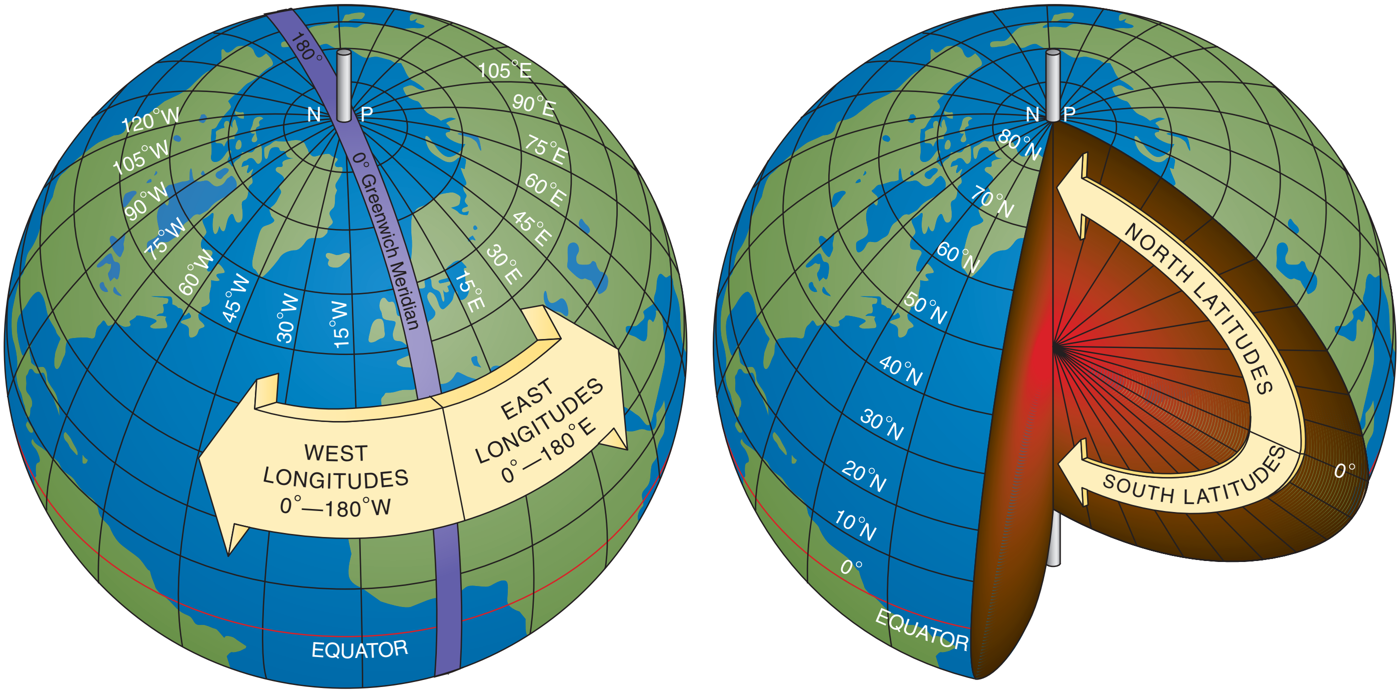


FIGURE 106-4 Meridians of longitude (including the Prime Meridian) and parallels of latitude as measured north and south of the equator in degrees of arc from the center of the earth. *(With permission from the Department of the Air Force:* Survival Training Edition AF Manual 64-3, *Randolph Air Force Base, Texas, 1969, Air Training Command.)*

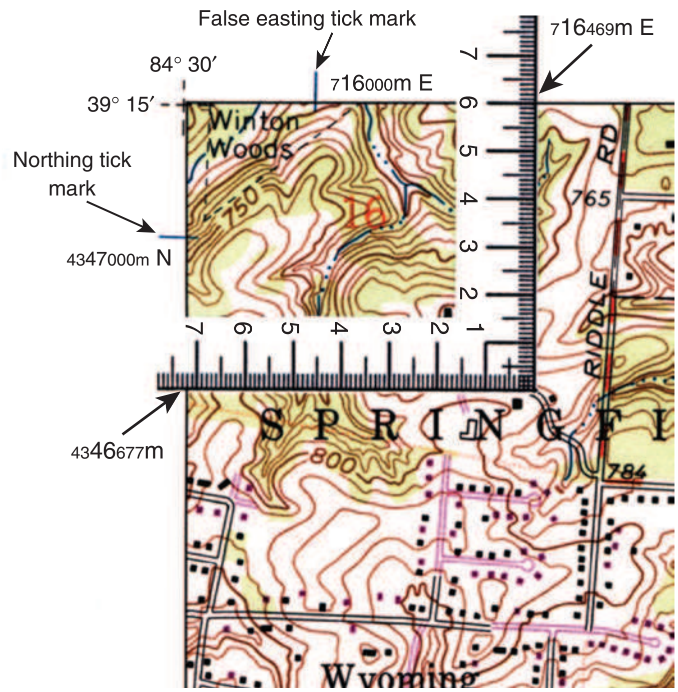


FIGURE 106-5 Portion of a United States Geological Survey 1:24,000 map showing the blue Universal Transverse Mercator tick marks on the map margin that give values for false easting ($^{7}16^{000}$ m E) and northing ($^{43}47^{000}$ m N). A 1:24000 Universal Transverse Mercator roamer scale is superimposed on the map. The points of intersection between the arms of the roamer scale and the map margin allow the grid reference for the point at the outside corner of the roamer scale to be read.

(60 minutes of arc) is thus 60 nautical miles, and 1 second of arc is equal to about 100 feet. It must be recognized that 1 minute of latitude will always equal 1 nautical mile, whereas 1 minute of longitude will only equal 1 nautical mile at the equator. At all points north or south of the equator, 1 minute of longitude will cover less than 1 nautical mile, as a result of the convergence of the meridians toward the poles. At either of Earth's poles, one could walk through 360 degrees of longitude in only a few strides.

Latitude and longitude appear along the margins of topographic maps distributed by the United States Geological Survey (USGS) and by other national governmental organizations responsible for cartography. At each map corner, the latitude and longitude of the point defined by the intersection of the horizontal and vertical map margins is recorded in degrees, minutes, and seconds (Figure 106-5). On standard USGS 7.5- and 15-minute maps, latitude and longitude notations appear on the margins at intervals of 2.5 minutes of arc and are marked with black tick marks on the inside edges of each margin.

Although it is conceptually useful, the nautically based latitude and longitude system is less well suited to land navigation, where precision on the order of tens of meters is often required and visibility may be limited by terrain features and vegetation. In addition, calculation of a new position based on the direction and distance traveled from a known starting point requires intimidating mathematics in the geodetic system, and the interconversion of minutes or seconds of arc to meters or feet is cumbersome and confusing. For these reasons, the UTM grid or the Military Grid Reference System was adopted by the United States Defense Mapping Agency in 1947 to cope with the specific exigencies of maneuvering and delivering ordnance on land.

UNIVERSAL TRANSVERSE MERCATOR COORDINATE SYSTEM

The UTM and Military Grid Reference System grids are metric, make use of the transverse Mercator map projection in common with maps distributed by the USGS, and require no conversion between distances expressed as angles and linear measures of distance expressed in meters (m) or kilometers (km). UTM divides the earth's surface from 80 degrees south latitude to 84 degrees north latitude into 60 south-to-north–running zones arrayed around the surface of the planet like narrow slices of an orange. Each zone is 6 degrees wide in longitude. The zones are consecutively numbered from 1 through 60 beginning at an index line, the International Date Line, and progressing eastward. Each zone is subdivided from south to north in 8-degree increments of latitude (except the northernmost zone, which encompasses 12 degrees of latitude [i.e., 72 degrees north to 84 degrees north]). The south-to-north divisions of each zone are labeled consecutively and alphabetically from C through X, excluding the letters I and O to avoid confusion with the numbers 1 and 0 (Figure 106-6). In UTM, terrestrial coordinates are expressed in meters east of a false origin and north of a latitude index line. The *false origin* for any zone is an arbitrarily assigned south-north line 500,000 m (1,640,420 feet) to the west of the central meridian of the UTM zone of interest. Progress to the east of the false origin is termed *false easting* or simply *easting*. In the northern hemisphere, the latitude index is the equator. In the southern hemisphere, the latitude index is the southern limit of strip C (i.e., 80 degrees south latitude). Progress to the north of the latitude index is termed *northing*.[7,23,40]

UTM coordinates are printed on all USGS maps produced during the past several decades. These appear as numbered blue tick marks occurring at 1-km intervals along the horizontal and vertical map margins. The numbers express UTM eastings and northings and thus increase from left to right and from bottom to top (i.e., to the right and up). By convention, the central meridian of each of the 60 UTM zones is assigned an easting value of 500,000 m E (500,000 m east of the false origin of the zone). Easting values less than 500,000 thus lie west of the central meridian for the applicable UTM zone, and easting values of more than 500,000 lie east of the central meridian for the UTM zone in question. Slight overlap (i.e., 80 km) between adjacent zones prevents negative easting values from occurring. Similarly, easting values of more than 1,000,000 are never encountered; they would lie beyond the overlap into the next zone to the east. For the northern hemisphere, northing values are expressed as meters north of the equator and range from zero to 10,000,000 m N (10,000,000 m north of the equator) (Figure 106-7). Negative values for northing are avoided for the southern hemisphere by labeling the equator as 10,000,000 m N and counting upward toward this number as one moves northward from the southern latitude index (i.e., 80 degrees south latitude).

On the horizontal margins of the map in the left upper and right lower corners, one of the last blue tick marks is labeled with a six-digit number in mixed large and small numerals (i.e., $^{7}16^{000}$ m E in Figure 106-5). This refers to a line that is 716,000 m east of the false origin or 216,000 m east of the central meridian of the applicable UTM zone, because the false easting value is more than 500,000 (the central meridian in this example is in UTM Zone 16 at 87 degrees west longitude). Similarly, one of the blue tick marks at the right lower or left upper vertical margins of the map image is labeled with a multidigit number (i.e., $^{43}74^{000}$ m N for the left upper border), indicating a line 4,374,000 m north of the equator in UTM row S. Note that, within the six-digit false easting value and seven-digit northing value, the numerals in larger type represent thousands of meters or kilometers. UTM tick marks on a map margin between corners are labeled with three- or four-digit numbers. The last two digits, which are in large numerals, represent whole kilometers in relation to the UTM reference value given near the corner of the map. Thus, for practical purposes, when navigating within an area of several dozens to several hundreds of square kilometers, the UTM margin tick marks on any large-scale USGS map can be thought of as a simple kilometer scale. The long and intimidating numeric labels on the tick marks can be ignored (except to recognize that they indicate 1-km increments on the map margin).

Every point on the earth's surface can be described by a unique false easting and northing value; this is described as a *grid reference*. Use of the UTM grid system for plotting position

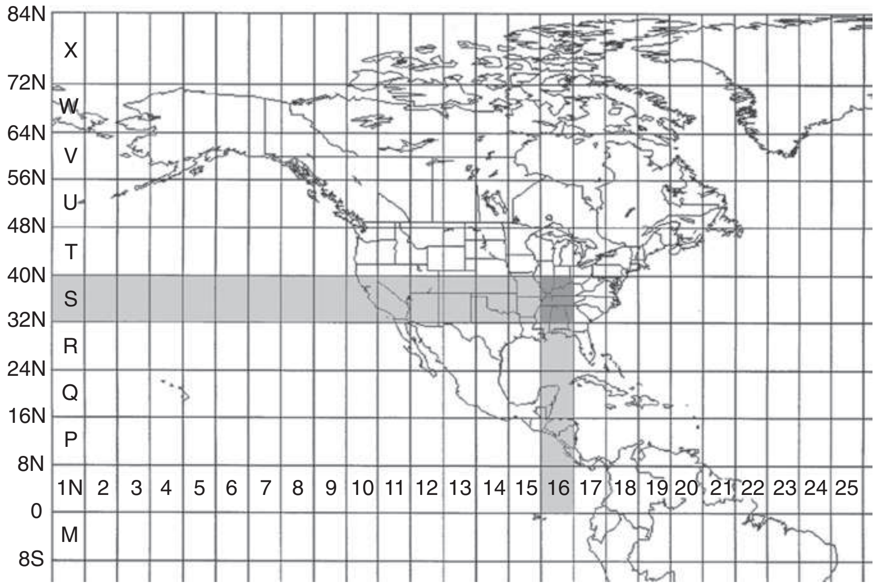


FIGURE 106-6 Map with the Universal Transverse Mercator (UTM) grid overlaid on a portion of the western hemisphere. Zone 16 and Row S are highlighted in *light gray*. The area of their intersection, designated as *16S,* is highlighted in *dark gray*. The central meridian for this zone lies at 87 degrees west longitude. The uppermost right-hand corner of the map represents the area used in the examples involving UTM coordinates discussed in the text.

based on a map is actually much simpler than its conceptual framework would suggest. Position plotting is greatly assisted by using a specialized ruler called a *roamer scale* that is compatible with common USGS map scales (see Figure 106-5). Roamer scales are included on many baseplate compasses, can be easily made from a scrap of paper, or can be printed or purchased from Internet sources. The large graduations on a roamer scale

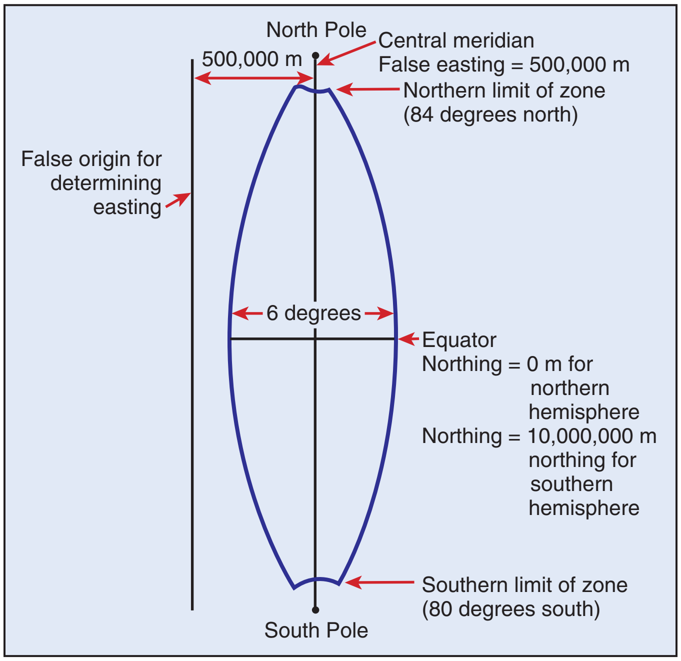


FIGURE 106-7 Diagram of a representative UTM zone showing the false origin 500,000 m to the west of the central meridian of the zone. The zone extends from 80 degrees south latitude to 84 degrees north latitude and spans 6 degrees of longitude. Note that the equator forms the index line for reckoning northing for the northern hemisphere, whereas the southern limit of the zone forms the northing index for the southern hemisphere. *(Redrawn from Cole WP: Using the UTM grid system to record historic sites.* http://www.cr.nps.gov/nr/publications/bulletins/nrb28/.*)*

generally denote 100-m increments, whereas the smaller divisions may represent a 10- or 20-m span. The steps for determining UTM coordinates for any point on a compatible map follow:

1. Mark the position of interest on the map with an "X."
2. Examine the margins of the map to become familiar with the three- or four-digit labels for the UTM ticks. For most hiking trips covered by a single map, or small number of maps, the UTM zone and row can be ignored.
3. Draw lines connecting tick marks of equal value on the top and bottom margins of the map. This need only be done for the area of the map surrounding the position of interest. Connect tick marks on the vertical margins of the map in the same manner. This will form a grid of 1-km squares on the desired portion of the map.
4. Position the corner of the roamer scale or ruler at the "X." Measure from the X to the nearest false easting line to the left, and record the easting value of the X. Measure to the nearest northing line below the X, and record the northing value of the X.
5. The unique position of point "X" is now known, and can serve as a reference point for subsequent navigation. This might include use as a GPS waypoint, as the position of a prominent landmark to be used for the triangulation of bearings, or to label a known starting point for the next leg of the hike.

When a degree of comfort with UTM coordinates is attained, navigation from point to point becomes much more intuitive than with latitude and longitude. Using the method just described, it is a simple matter to determine bearing and distance in meters between any two points on the map, to plot GPS waypoints on the map, or to identify a probable position based on dead reckoning from a known starting point. Note that it is standard for GPS receivers to be able to express the user's position in any of several formats, including as UTM coordinates. A location near my home has geodetic coordinates of 39 degrees and 15 minutes north latitude and 84 degrees and 30 minutes west longitude, as determined by a commonly available, inexpensive GPS receiver. With several simple key presses, the grid reference is expressed in UTM format as:

16S $^{07}16^{469}$
$^{43}46^{677}$

This indicates that the location is in UTM Grid Zone 16S (Zone 16, Row S). The meridians bounding Zone 16 are 90 degrees west longitude on the west and 84 degrees west longitude on the east. Row S is bounded by 32 degrees north latitude to the south and 40 degrees north latitude to the north. The latitude and longitude boundaries of the identified zone and row include southwestern Ohio. The numbers specifying the unique location within the zone and row must be read, per UTM convention, to the right (easting) and then up (northing). The first seven-digit number indicates that the site of interest has a false easting value of $^{7}16^{469}$ m E (i.e., 716,469 m east of the central meridian for the zone) or 469 m east of the 16-km tick mark on the horizontal margin of the relevant USGS map (see Figure 106-5). The second number indicates that the location has a northing value of $^{43}46^{677}$ m N (i.e., 4,346,677 m north of the equator) or 677 m north of the 46-km tick mark on the vertical map margin.

For navigation in the majority of wilderness activities, the area of interest fits within a single USGS 7.5-minute square, and accuracy to within 100 m is adequate. As such, the UTM coordinates used to describe a location can be abbreviated for simplicity, including only the whole kilometers (i.e., the larger two-digit numerals) and the small digit to their immediate right (representing hundreds of meters). Do not round the last digit upward. In the prior example, the location of interest would be described in abbreviated UTM notation as easting 16^{4}, northing 46^{6} (i.e., about 400 m east of the 16 tick mark and about 600 m north of the 46 tick mark).[7] Map usage involving the UTM coordinate system is greatly facilitated by drawing a 1-km by 1-km grid on the map using the UTM tick marks to define the whole-kilometer spacing of the grid lines.

In practice, GPS should be applied to a wilderness trek in the following manner. Before embarking on a trip, the user should choose a terrestrial coordinate system (i.e., UTM vs. latitude and longitude) and then enter into the receiver the precise coordinates of various important landmarks on the intended route of travel. The coordinates of locations of interest can be obtained from a trail guide or from a topographic map. For reasons articulated earlier, UTM coordinates offer a substantive benefit for land navigation as compared with the geodetic coordinate system. The waypoints obtained in this manner are entered, labeled, and stored within the receiver's memory. If a topographic map of the area of travel is available, a UTM grid should be drawn on the map using the method outlined previously. At the beginning of the trip, the location of the nearest town or source of assistance and the location of the trailhead where the trip is begun are entered as waypoints. The trip then progresses using the map, established trails, or the GPS receiver to follow the intended route. Tracks are recorded as the trip progresses. When pausing to camp, the position of the camp would be named and entered as yet another waypoint. At any time, the bearing and distance to any waypoint of interest are available to the user. If, in a spasm of self-reliance, the user decides to lay aside the GPS receiver and pursue traditional methods of navigation and the person becomes lost, reactivation of the receiver will allow the direction and distance to safety to be immediately determined; the tracks to the last waypoint could be retraced, or the receiver could be used to guide the person by bearing and distance to the next waypoint on the route.

Highly capable GPS receivers, including WAAS-enabled receivers, are commonly available at a price of about $100. They will fit into a shirt pocket and have sufficient battery power for 10 to 30 hours of continuous use. This is sufficient for weeks of navigation if power is used judiciously, and most models use common AA or AAA batteries. Models that incorporate onscreen topographic maps can be purchased for $200 to $700. However, GPS still suffers from important limitations. Dead batteries yield a useless receiver, so spare batteries should always be included when traveling. The receivers are relatively fragile, and many are not waterproof or even particularly water resistant. Obstruction of the sky by terrain features or heavy foliage may interfere with reception of satellite signals, which may render the receiver unable to acquire a sufficient number of satellites to provide a fix. In an era of national security risk, selective availability could be reimplemented or WAAS could be restricted, with resultant degradation of the accuracy of recreational GPS. Still, GPS is unsurpassed with regard to ease of use, accuracy, and usefulness for wilderness navigation. When applied with common sense and routine awareness of approximate location, even the simplest GPS receiver renders it virtually impossible to become lost and effectively eliminates many of the pathfinding challenges that are inherent to wilderness travel. However, reliance on GPS as the sole navigational resource for any wilderness expedition is a grave error. As with all high-technology methodology, GPS can be easily disabled. The more self-contained methods of navigation discussed in later sections should be used whenever possible to maintain positional awareness and navigational skill in anticipation of the possibility that GPS may fail.

COMPASS NAVIGATION

The directional properties of lodestone (magnetite) were recognized by a variety of civilizations during ancient times. References to the use of a directional magnetized needle at sea appear in Chinese literature dating from the 12th century CE. Descriptions of the magnetic compass in European writings followed during the 13th century, by which time it was noted that a needle stroked on lodestone pointed to the vicinity of the North Star.[4,6,12] Discovery of the magnetic compass was a seminal event in exploration of the planet; the compass allowed reasonably accurate steering in all weather and provided the directional reference that permitted development of the process of dead reckoning.

MAGNETIC DIP, DEVIATION, AND DECLINATION

The directional properties of the compass result from interactions between magnetized iron in the compass needle and magnetic lines of force generated by metals in the earth's core. These lines of force have both a vertical and horizontal component. The vertical component is termed *magnetic inclination* or *dip*. Dip causes a compass needle to incline downward from horizontal, potentially to a degree that interferes with ability of the needle or card to pivot freely. Dip is 90 degrees at the magnetic poles and 0 degrees at the magnetic equator. Most modern compasses are manufactured to compensate for the average dip that is likely to be encountered in the region of intended use. Others allow a small weight to be moved along the indicator needle to compensate for dip in any region of use.[38]

The horizontal component of the magnetic lines of force causes the compass needle to point to the earth's north magnetic pole. It is an unfortunate fact that the earth's magnetic and geographic poles do not correspond in location. The earth's magnetic lines of force are not straight lines; rather, they meander in an irregular fashion dictated by irregularities in the density of the core. The irregular directionality of the earth's magnetic field is called *magnetic declination*. The compass needle is also influenced by local magnetic forces. These forces may result from natural sources such as ore deposits or from artificial sources such as ferromagnetic metals in vehicles, equipment, and clothing fasteners. Displacement of the compass needle resulting from local magnetic influences is termed *deviation*. As a result of magnetic declination and deviation, compasses point to geographic north only when used with care in selected locations. In general, compasses point northward but not exactly due north.

Direction in compass navigation is expressed in three ways: (1) true direction, or direction measured in reference to the earth's meridians and geographic poles; (2) magnetic direction, or direction measured in reference to the earth's magnetic poles; and (3) compass direction, or direction measured by the magnetic compass. Magnetic direction varies from true direction by the sum of declination and deviation. Compass direction varies from magnetic direction by the quantity of deviation.[10,32] The definitions of magnetic and compass direction point out the necessity of minimizing preventable sources of compass deviation when taking bearings. For practical purposes, when preventable sources of deviation are minimized and the compass is used with caution, magnetic direction and compass direction can be considered to be equivalent.

Wandering lines of points with equal magnetic declination can be graphed on maps and charts; these are called *isogonic lines*. Lines representing points on the surface of the earth where the magnetic declination is zero, and where magnetic north and

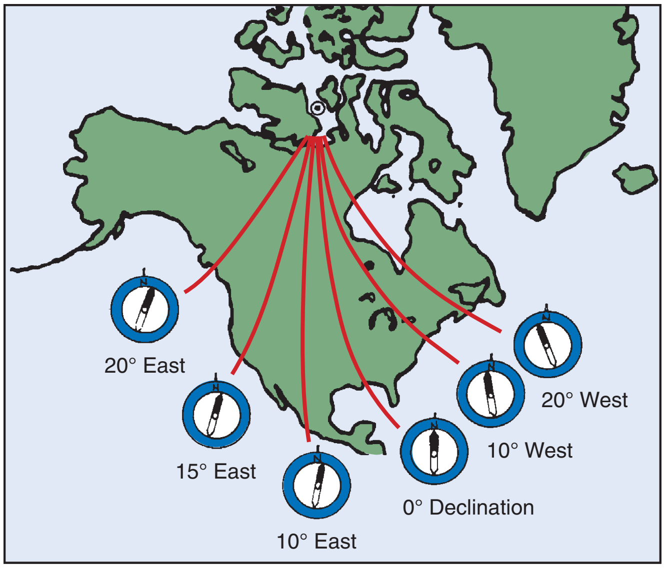


FIGURE 106-8 Schematic representation of North America showing declination at various locations as the difference between true north (i.e., "N" on the compass rim) and magnetic north (i.e., tip of the compass needle). *(From Seidman D:* The essential wilderness navigator, *Camden, Me, 1995, Ragged Mountain Press.)*

true north are aligned, are termed *agonic lines.* In the Americas, an agonic line follows a relatively straight and slanting course extending from the east coast of Victoria Island in north-central Canada through western Lake Superior, along the west coast of Florida, and traversing South America from the Gulf of Venezuela to the southeastern coast of Brazil. At locations east of the agonic line, the compass needle declines to the west (counterclockwise) of true north; at points west of the agonic line, the compass needle declines to the east (clockwise) of true north. By convention, magnetic declination is given a positive sign when east and a negative sign when west (Figure 106-8). Declination is quantified as the angle between true and magnetic north.

By way of example, in southwestern Ohio the current magnetic declination is negative 5.71 degrees, or approximately 6 degrees west. This means that a compass needle actually points 6 degrees to the west of true north and that the true bearing given by the needle is 354 degrees when the needle points to 360 degrees on the compass rim. Any magnetic bearing taken with a compass will thus be 6 degrees greater than the true bearing. To correct from magnetic to true, 6 degrees must be subtracted from any indicated magnetic bearing.

The mnemonic "Declination east, compass bearing least; declination west, compass bearing greatest" may be helpful for converting magnetic direction to true direction when taking a bearing. In other words, to convert from magnetic to true while taking a bearing from the compass, add east declination to the compass bearing, or subtract west declination from the compass bearing. When taking a true bearing from a map and converting it to a compass bearing to follow in the environment, subtract east declination from the true bearing, or add west declination to the true bearing. Interconversion between magnetic and true bearings is an essential skill for compass navigation. Failure to recognize this relationship will result in significant errors when following a map route by compass, because directional references on the map are based on true direction. At a location where the magnetic declination is 10 degrees, travel over a straight course derived from a map and guided by a compass will result in a 0.18-mile error for each 1 mile traveled if declination is not considered.[22]

Magnetic declination for any location can be determined by referencing the *Isogonic Chart for Magnetic Declination* produced every 5 years by the USGS, or by accessing the National Oceanic and Atmospheric Administration (NOAA) website at www.ngd.noaa.gov. In the United States, magnetic declination varies from 23 degrees East in Washington State to 22 degrees West in Maine (see Figure 106-8).[10] On standard USGS 7.5-minute and 15-minute squares, magnetic declination is indicated by a pointer next to the indicator for true north at the bottom of the map. If one does not have access to an isogonic chart, declination for any location in the northern hemisphere can be empirically determined with reasonable accuracy by comparing the magnetic bearing of north with the true bearing, as indicated by the direction to the star Polaris. Polaris lies up to 45 minutes of arc (i.e., 0.75 degrees) away from true north at some times of day, but this offset is negligible for wilderness navigation situations. Declination at any location can also be determined by comparing the magnetic bearing of a prominent landmark with the true bearing between the observer's known location and location of the landmark as read from a map.[7]

COMPASS TYPES

The three compass types used in land navigation are the fixed-dial compass, magnetic card compass, and baseplate compass (Figure 106-9). The simplest compass is the fixed-dial, which uses a magnetized needle that is balanced on a pivot and enclosed in a case and that is graduated around its periphery into 360 degrees. The magnetic card compass uses a magnetized needle or wire fixed to a circular card that is graduated around its periphery from 0 degrees to 360 degrees. The housing of the compass is marked with a line called the *lubber line* that allows magnetic bearings to be determined when the line is pointed at an object of interest. The lensatic compass used by the military, which has a lens for magnification of the compass card and sights for alignment to distant objects, is a typical magnetic card compass. The most useful compass for land navigation is the baseplate compass,[22,25,35,39] which consists of a fixed-dial compass (or capsule) mounted to a baseplate in a manner that allows the capsule to rotate in relation to the baseplate. The baseplate is marked with a line used to indicate the direction of travel. This line functions in a manner identical to the lubber line of the magnetic card compass. The capsule of the compass has an orienting arrow inscribed on its lower surface that points to the graduation denoting north on the capsule rim. On different models, this graduation may be labeled "0°", "360°", or "N". Rotation of the capsule such that the compass needle is superimposed on the orienting arrow and points to "N" on the capsule rim allows the user to easily read the magnetic bearing indicated by the direction-of-travel line. As long as the direction-of-travel line is followed and the needle remains superimposed on the orienting arrow, the user is assured of maintaining the desired magnetic bearing during travel.

Many baseplate compasses allow the orienting arrow to be adjusted relative to the rim of the capsule to compensate for

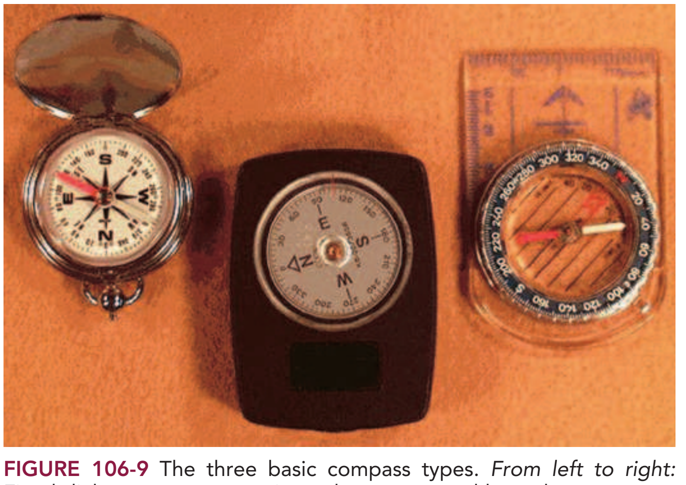


FIGURE 106-9 The three basic compass types. *From left to right:* Fixed-dial compass, magnetic card compass, and baseplate compass. Note the deviation in indicated north resulting from local magnetic influences.

magnetic declination. When the orienting arrow of such a compass is adjusted to point to the bearing of magnetic north, the "N" graduation on the capsule rim will indicate true north when the compass needle aligns with the orienting arrow. All bearings as read on the capsule rim will now represent true—rather than magnetic—direction. Baseplate compasses have other features particularly suited for use with a map, including plotting scales, a straightedge, and often a protractor and magnifier.[39]

Correction for declination when using a fixed-dial or magnetic card compass requires addition or subtraction of the declination, as appropriate, from the magnetic bearing indicated by the compass rim or lubber line.

COMPASS USE

A magnetic compass is used to establish cardinal directions, bearings for use in route finding, and back bearings for use in returning to a known starting location. The term *back bearing* refers to the reciprocal of the bearing followed on the outbound leg of a journey (i.e., outbound bearing minus 180 degrees) or the reciprocal of a measured bearing to a prominent terrain feature. Any route can be subdivided into legs that can be defined by magnetic bearing lines. Ideally, each leg should pass between prominent and identifiable landmarks that will remain recognizable even in the dark or in poor weather. However, even when weather or lighting conditions prevent visual acquisition of the landmark from a distance, careful compass work should permit the user to reach an objective. Early during the course of travel over each leg, the observer should visually check the back bearing of the direction of travel to become familiar with the view of the starting point as it will appear on the return journey. If possible, the bearing and back bearing of each leg of a route, and the landmarks defining each leg, should be recorded on paper rather than trusted to memory.

Use of a compass in this manner permits the user to return easily to the desired direction of travel if an obstacle to the intended route is encountered. The course around the obstacle is recorded as a series of legs of known direction and estimated (by stride) length. When permitted by the terrain, right-angle detours are the simplest to follow. The user returns to the intended route by traveling the reciprocal of the course of the detour for the same distance as that required for bypass of the obstacle[9] (Figure 106-10). Return to the intended course is greatly augmented by using natural ranges. A natural range is formed by two landmarks that lie along the same bearing line, with one end indicated by a landmark of intermediate distance from the viewer and one at a greater distance (e.g., a large tree or rock formation several kilometers from the viewer and the silhouette of a hill or mountain on the horizon). As the traveler deviates from the intended course, the near and far landmarks will fall out of line. When the traveler returns to the intended route, the objects forming the natural range will return to alignment.

Use of a compass with a map allows the user to orient the map to the environment and relate bearings taken from the map to bearings measured with the compass. Correction for declination is essential when the compass is used for this task if true bearings are to be used when plotting a route. However, there is no absolute need for the use of true bearings in navigation; it is important only that the map and compass agree. Agreement can be accomplished either by correcting the compass to the map or by correcting the map to the compass. If a baseplate compass with declination adjustment is used, it is relatively simple to correct the compass to the map and use true bearings for all subsequent travel. With all types of compasses, however, it is easiest to use magnetic bearings exclusively. If the declination is known or can be determined observationally, magnetic meridians can be drawn on the map to be used in place of the true meridians represented by the map margins (Figure 106-11). These magnetic meridians will form an angle with the true meridians equal to the declination angle. A map modified in this manner permits magnetic bearings (rather than true) to be taken from the map for use when following a course. The internal consistency of this method is always much less confusing than the method requiring conversion between true bearings and compass bearings. Because of the ease with which bearings may be taken from the map when it is marked with magnetic meridians, maps for use in navigational sports (e.g., orienteering) are prepared exclusively with magnetic meridians. Choice between the use of true versus magnetic bearings should be made in advance of travel to permit modification of the map. Plotting magnetic meridians on a map requires a pencil, straightedge, flat surface, and protractor; these items are unlikely to be available during a field emergency.[38,39]

To orient a map with a baseplate compass corrected for declination, the compass capsule is rotated such that "N" on the capsule rim is aligned with the direction-of-travel arrow. An edge of the baseplate parallel to the direction-of-travel arrow is then placed on one of the vertical borders of the map. The map, with the compass in place, is then rotated until the compass needle is superimposed on the orienting arrow on the base of the capsule. True north on the map is now aligned with true north on the planet.

To orient a map that has been modified with magnetic meridians using an uncompensated baseplate compass, the compass capsule is rotated until "N" on the capsule rim aligns with the direction-of-travel arrow. An edge of the compass parallel to the

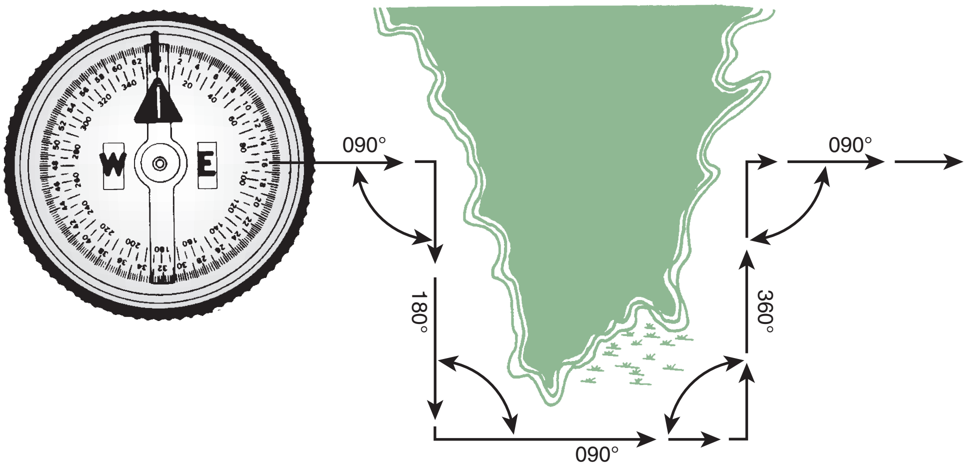


FIGURE 106-10 Use of a compass to return to an intended route when faced with an obstacle. A course 90 degrees to the intended course is walked for a known number of steps, the obstacle is bypassed, and the original course is regained by walking the reciprocal course of the initial detour for the same distance. *(From the Department of the Army: Map reading and land navigation, Field Manual 21-26, Washington, DC, 1987, Headquarters, Department of the Army.)*

FIGURE 106-11 United States Geological Survey 1: 24,000 (7.5-minute) map modified with magnetic meridians *(dark lines).* The magnetic meridians reflect the 8 degrees west declination of the area represented on the map. The compass has been placed with its edge parallel to a magnetic meridian, and the compass capsule rotated such that the orienting arrow on the bottom of the capsule points to north on the map. The map and compass were then rotated in concert to align the compass needle and the orienting arrow. The map is now oriented to the terrain, and directions as indicated on the capsule rim represent magnetic bearings to objects in the environment.

direction-of-travel arrow is placed on one of the magnetic meridians plotted on the map. The map, with the compass in place, is rotated until the compass needle is superimposed on the orienting arrow. True north on the map now corresponds with true north in the surrounding landscape.[22,35,38,39] If an uncompensated compass of another type is used, the north-south line of the compass face or lubber line is superimposed on a magnetic meridian, and the map and compass are rotated in concert until the indicator needle points to "N".

To plot and follow a bearing using a baseplate compass and map, the map is held horizontally, and a straightedge of the baseplate parallel to the direction-of-travel arrow is placed on a line connecting the starting and ending points of the leg. The compass capsule is then rotated until the orienting arrow points to north as indicated on the map. The map and compass are held together and rotated until the compass needle is superimposed on the orienting arrow. The intersection of the direction-of-travel arrow and the capsule rim now indicates the bearing of the leg, and the direction-of-travel arrow points to the objective (Figure 106-12). To follow the bearing, the user walks in the direction indicated by the direction-of-travel arrow while keeping the compass needle and orienting arrow in alignment.

When a map is oriented to the environment, back bearings from landmarks that are visible both on the map and in the landscape can be used to obtain a positional fix by resection or triangulation.[35] Each back bearing from a landmark represents a line of position (LOP) that can be plotted on the map. The point of crossing of two or more LOPs fixes the position of the observer (Figure 106-13). Alternatively, the intersection between the LOP represented by a bearing line and a shoreline, riverbank, road, firebreak, or ridgeline can be used to fix position on a map.

MAKESHIFT COMPASSES

A field-expedient compass can be fabricated with relative ease. Items containing iron, nickel, or cobalt are suitable for use as an indicator needle. Iron in the form of a steel needle, pin, wire, staple, or paper clip is most commonly available. Most of these items are magnetized as purchased. If not, they can be magnetized by stroking them on a magnet salvaged from an electric motor or radio speaker, on a magnetized screwdriver or similar item, or on a piece of silk. A dry cell also can be used to magnetize a needle by wrapping an insulated wire tightly around the needle and connecting the ends of the wire to the battery terminals for several minutes. There is a fire risk associated with shorting the battery terminals in this manner, and sparks and heat should be expected. Trial and error will often yield a suitable magnetizer. The indicator needle is floated in water by placing it on a wood chip, leaf, slip of paper, or small piece of cork or closed-cell foam. The container, which may be the cupped palm of the hand or a puddle, should be protected from the wind (Figure 106-14). A compass that has been so constructed will reliably indicate a magnetic north-south line. The absolute determination of direction may require external cues, such as the general direction of sunrise, sunset, or position of the sun at midday.

CELESTIAL NAVIGATION

Celestial navigation exploits the predictable relationship between the apparent positions of selected celestial bodies and surface of the earth. The influence of celestial navigation on world history is immense. Millennia before European cultures conceived of celestial navigation as a means for facilitating exploration, commerce, and military domination of the seas, the people that populated the islands of the Pacific Basin were making open-ocean voyages over thousands of miles guided by memorized "star paths."[17] The use of simple altitude-measuring devices (e.g., Greek gnomon, Arab kamal, Chinese stretch board) for the qualitative determination of latitude was practiced by mariners in antiquity. As the Age of Exploration dawned, competing governments of Western Europe devoted enormous energy to systematization of celestial navigation, funding legions of astronomers for development of coordinate systems and accurate tables of stellar, solar, lunar, and planetary positions. Instruments such as the mariner's astrolabe, quadrant, octant, and sextant permitted accurate and reproducible quantitative measurement of the altitude of celestial bodies, and accurate clocks became available to permit ready determination of longitude.[4,44]

Celestial navigation has its greatest usefulness and easiest application at sea. Standard celestial practice depends on availability of a sea horizon as a reference point for measurement of altitude. The horizon reference for land navigation is necessarily artificial (i.e., a plumb bob, bubble level, or level reflective

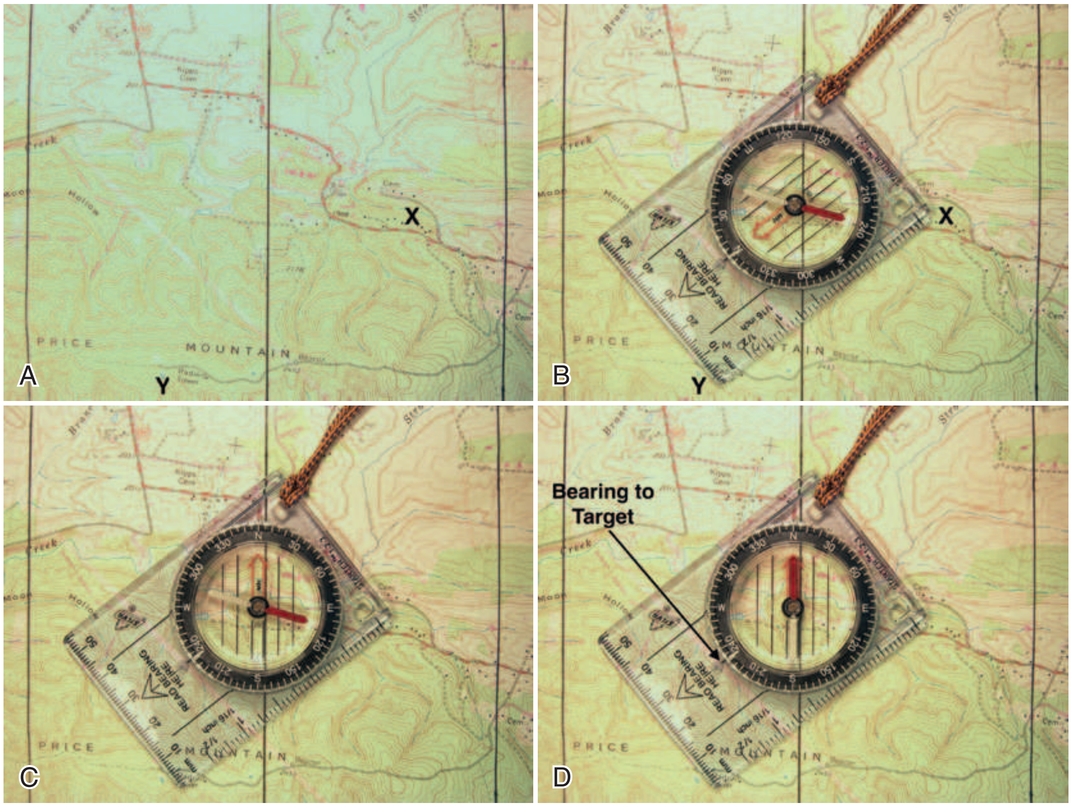


FIGURE 106-12 The steps for plotting and following a bearing using a map and compass. **A,** The current position (road junction at *X*) and destination (watch tower at *Y*) are identified. **B,** The compass is then placed on the map with an edge along the line connecting *X* and *Y*. **C,** The compass capsule is rotated so that the orienting arrow points north as indicated by the magnetic meridians drawn on the map. The compass is now oriented to the map. **D,** The compass and map are now held horizontally and rotated until the magnetic needle is superimposed on the orienting arrow. The map is now aligned to the environment, and the bearing to *Y* is indicated at the intersection of the compass capsule and the direction-of-travel arrow (232 degrees in this example). As long as the needle is kept superimposed on the orienting arrow, the direction-of-travel arrow will point toward the destination.

surface). Positions resulting from celestial fixes, even with scrupulous technique, are only approximations of the navigator's actual position. Errors of several miles are common. This is of little consequence in the open ocean, even as landfall approaches; the target destination is generally large enough to be seen from many miles away. This degree of imprecision may prove troublesome on land, but accuracy of celestial navigation should still suffice for many wilderness situations.

Although developed for use on trackless seas, celestial navigation has a long and rich tradition of use on land. With this type of navigation, Lewis and Clark established the positions of landmarks during their exploration of the American West. Various expeditions that explored the North and South Poles depended entirely on celestial observations to determine direction and position. Celestial navigation techniques can be applied in a wilderness setting at a variety of levels. Traditional celestial navigation, in which sextant observations lead to the fixing of terrestrial

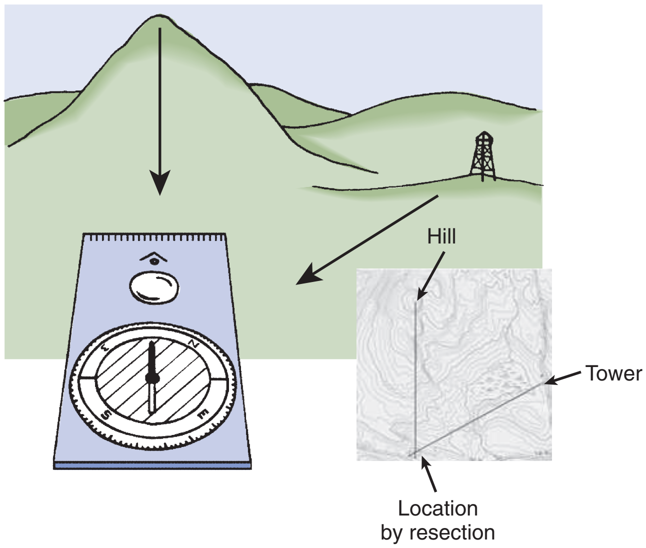


FIGURE 106-13 Establishing a magnetic fix by crossing the back bearings from two prominent landmarks. This process is known as *resection*.

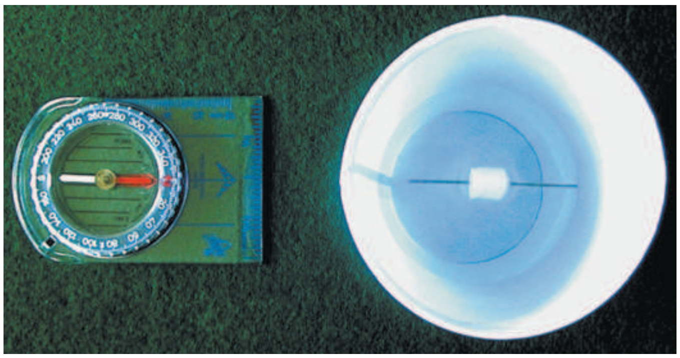


FIGURE 106-14 A makeshift compass constructed from a plastic cup, straight pin, and foam packing peanut. Note the correspondence between north as indicated by the makeshift device and the commercial compass.

position, can be accomplished with relatively little equipment but requires considerable preplanning. This methodology is unlikely to be adopted for use by the vast majority of wilderness travelers. However, simplified celestial techniques requiring little or no equipment are well suited to field-expedient navigation and can provide accurate directional information in the absence of a compass. In particular, understanding movement of the sun and several prominent stars can allow accurate route finding without recourse to technology. To understand the relationship between the position of a celestial body and the position of an observer on Earth, it is necessary to relate the coordinate systems that are used to describe celestial position and the appearance of the sky from the earth's surface (i.e., the horizon coordinate system) to the geodetic system previously discussed.

CELESTIAL COORDINATES

To a terrestrial observer, the sky appears to be an immense hollow sphere with the earth at its center, and the stars painted on its inner surface. The sphere rotates about the earth once daily. The sun, moon, and planets wander across the background of stars on concentric spheres of their own. This is exactly how the universe was described by Ptolemy during the second century CE and is called the *geocentric model.* This theory was highly popular with the Catholic Church; challenging it led to persecution of many intellectuals during the era of the Spanish Inquisition. It held sway until the 16th century, when it was replaced, gingerly, with an equally incorrect heliocentric (i.e., sun-centered) model. The geocentric model, although false, is a useful construct for ordering the heavens and is the model used for definition of celestial coordinates.

The celestial coordinate system plays off the geodetic terrestrial coordinate system. The terrestrial poles are projected outward to the surface of the imaginary celestial sphere to form the north and south celestial poles. The terrestrial equator is similarly projected outward to form the celestial equator, which is also known as the *equinoctial.* The celestial correlate to latitude is declination; this is unrelated to magnetic declination in compass use (Figure 106-15). The declination of a celestial body is the angle measured from the center of the earth (and geocentric universe)

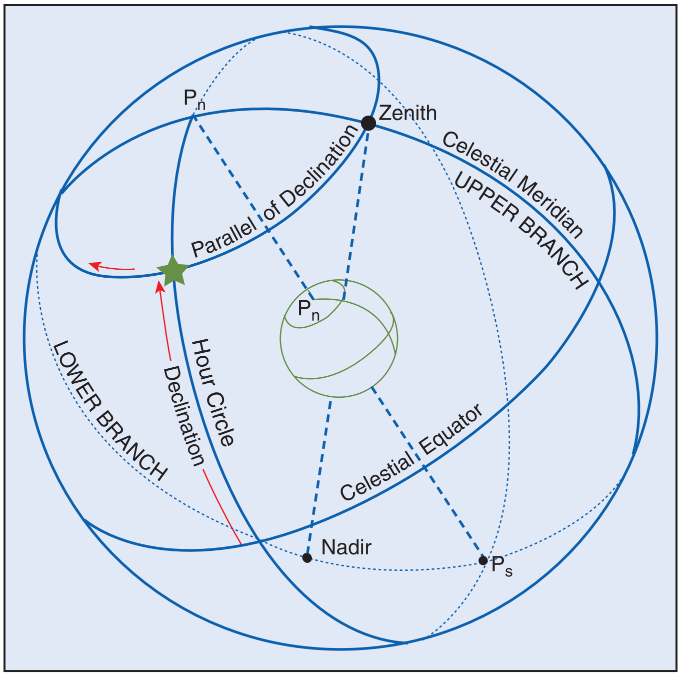


FIGURE 106-15 Diagram showing the celestial meridian of an observer on the earth's surface and the celestial meridian corresponding to the hour circle of an observed star. *(From Bowditch N:* The American practical navigator: An epitome of navigation, *Washington, DC, 1984, Defense Mapping Agency Hydrographic/Topographic Center.)*

north or south of the celestial equator from 0 degrees through 90 degrees of arc. Declinations north of the celestial equator are positive (+), whereas those south of the celestial equator are negative (−). The declinations of the celestial poles are thus +90 degrees and −90 degrees, respectively, whereas that of the celestial equator is 0 degrees. The declinations of the sun, moon, four navigational planets (Venus, Mars, Jupiter, and Saturn), and 57 navigational stars are listed in the daily pages of the *Nautical Almanac.*[12,21]

The celestial correlate to longitude is less intuitive and requires explanation. Projections of terrestrial meridians onto the celestial sphere form celestial meridians. Projection of the Greenwich meridian onto the celestial sphere forms the Greenwich celestial meridian. Projection of an observer's meridian onto the celestial sphere forms the local celestial meridian (Figure 106-15). A meridian on the surface of the celestial sphere that contains a celestial body and the celestial poles and is perpendicular to the celestial equator is called the *hour circle* of that body. Hour circles converge toward the celestial poles in a manner identical to meridians on Earth. As the celestial sphere rotates about its polar axis, the hour circles of all celestial bodies appear to rotate above a terrestrial observer, rising in the east, sweeping overhead, and setting in the west. A reference hour circle on the celestial sphere called the *first point of Aries* or the *hour circle of Aries* substitutes for the terrestrial Prime Meridian. The first point of Aries is represented by an hour circle that intersects the celestial equator at the point where the sun crosses it at the moment of the spring equinox. The angular measurement between the hour circle of a celestial body and the Greenwich celestial meridian is called the *Greenwich hour angle* (GHA) of the body. GHA is the celestial equivalent of longitude and is measured westward from the Greenwich celestial meridian from 0 degrees through 360 degrees. The Greenwich hour angle of Aries (GHA^{Aries}) is the angle between the Greenwich celestial meridian and the hour circle of Aries at any given second in time. The GHAs for Aries and for the sun and moon, Venus, Mars, Jupiter, and Saturn are listed for each hour of each day of a year in daily pages of the *Nautical Almanac*. Interpolation tables permit determination of hour angles for each second of the year.[21,32]

The GHAs of the 57 navigational stars are defined by their predictable and nearly constant relationship to the hour angle of Aries. The angular measurement between the hour circle of Aries and the hour circle of any of the navigational stars is called the *sidereal hour angle* (SHA) of that star. The GHA of each of the navigational stars is thus equal to the sum of the hour angle of Aries and the SHA of the star in question ($GHA^{star} = GHA^{Aries} + SHA^{star}$).

For the practice of celestial navigation, the hour angle of a celestial body is ultimately defined in reference to the observer's local celestial meridian. The angular measurement between the local celestial meridian and the hour circle of a body is the *local hour angle* (LHA) of that body. The LHA, as with the GHA, is measured westward from the local celestial meridian from 0 degrees through 360 degrees. The LHA of a celestial body equals the GHA of the body plus the observer's longitude if east, or minus the observer's longitude if west ($LHA = GHA + East\ \lambda$; $LHA = GHA - West\ \lambda$). When a celestial body is on an observer's meridian, its GHA equals the longitude of the observer's position.[4]

HORIZON COORDINATE SYSTEM

The horizon coordinate system defines celestial position from the point of view of the earthbound observer. The point on the celestial sphere directly over the observer's head is called the *zenith*; the point on the celestial sphere directly beneath the feet of the observer is called the *nadir.* The zenith and nadir lie on a line that includes the observer's terrestrial position and the earth's center. The plane that passes though the center of the earth perpendicular to this line is called the observer's *celestial horizon.* The celestial horizon lies parallel to the observer's visible horizon. Any great circle on the celestial sphere formed by a plane passing perpendicular to the celestial horizon is called a *vertical circle* (Figure 106-16). Vertical circles converge at the

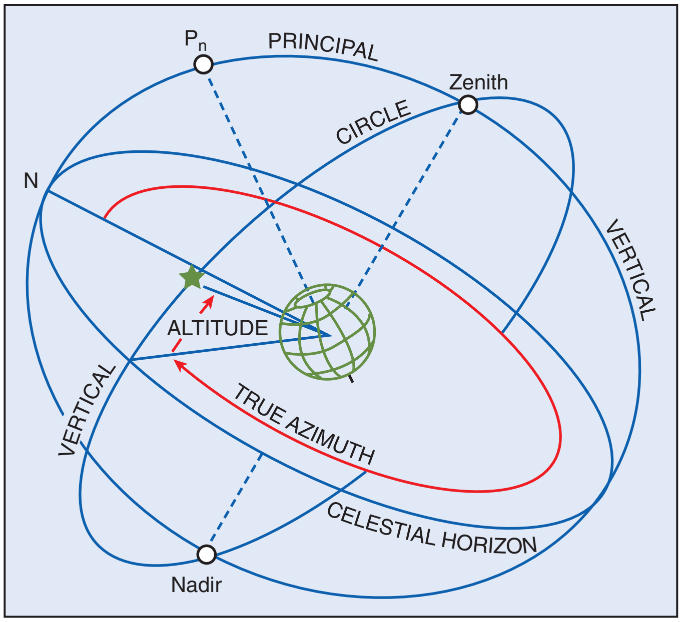


FIGURE 106-16 Schematic representation of the horizon coordinate system showing the observer's zenith and nadir, the celestial horizon, the prime and principal vertical circles, the elevated pole *(Pn)*, and the altitude and azimuth of the body being observed. *(From Hobbs RR:* Marine navigation: Piloting and celestial and electronic navigation, *ed 4, Annapolis, Md, 1998, Naval Institute Press.)*

observer's zenith and nadir in a manner analogous to convergence of the terrestrial and celestial meridians at their poles. Three of the infinite number of potential vertical circles for any surface position are of particular importance: (1) the *principal vertical,* which is the vertical circle lying on the observer's celestial meridian; (2) the *prime vertical,* which is the vertical circle passing through points due east and west of the observer; and (3) the *vertical circle* containing a celestial body of interest (Figure 106-16).[21]

The angular measurement between an observer's celestial horizon and a celestial body is the *altitude* of that body. Altitudes are expressed in degrees, minutes, and seconds of arc from 0 degrees (the horizon) through 90 degrees (the zenith). In the traditional practice of celestial navigation, altitudes are measured using a sextant, octant, or quadrant. Altitude, as measured by an instrument in reference to the horizon, is termed *sextant altitude* (Hs), regardless of the type of instrument used. Hs, once corrected for various atmospheric and geometric factors, is then called *observed altitude* (Ho). The corrections to be applied are tabulated in the *Nautical Almanac*. The true altitude of a body can be calculated for any given terrestrial position at any instant of time using application of spherical trigonometry. This altitude is called *calculated altitude* (Hc).[4]

The other determinant of the observed position of a celestial body is angular measurement along the celestial horizon between true north and the vertical circle including the body. This angle is called the *azimuth* (Zn) of the body and is measured clockwise from 0 degrees through 360 degrees (see Figure 106-16).

CELESTIAL LINES OF POSITION

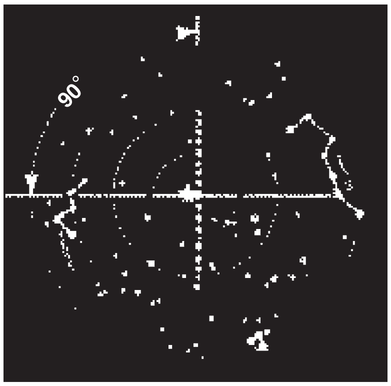
Methods for Latitude

The simplest celestial LOP is derived from the noon sight or meridian altitude of the sun. This method dominated celestial navigation from the 17th century until the late 1800s. The noon sight is simple but inflexible. It is very adaptable to wilderness navigation, requiring minimal mathematics and little equipment. The noon sight allows direct determination of latitude by measuring altitude of the sun at the moment that it passes the observer's meridian. The instant of solar meridian passage, which is called the *local apparent noon* (LAN), is that moment when the sun achieves its greatest altitude. The sun is observed with the sextant for a brief period of time preceding LAN until the altitude ceases to increase and begins to fall. The maximum sextant altitude so determined is corrected using *Nautical Almanac* data to yield Ho, which is then converted to zenith distance (ZD). Zenith distance is the angular distance between observer's zenith and the body; thus, ZD = 90 degrees − Ho. The algebraic sum of ZD and the declination of the sun (d; from the *Nautical Almanac*) at the approximate time of observation gives the observer's latitude with the use of the following formulae[12,26]:

1. L = ZD + d, when L and d have the same sign and L>d.
2. L = d − ZD, when L and d have the same sign and d>L.
3. L = ZD − d, when L and d have different signs.

Because declination of the sun changes very slowly on an hourly basis, accuracy is acceptable if the sun's declination is known for merely the approximate time of observation. The noon sight requires only the sun's declination and precise altitude. Determination of latitude by meridian passage can be accomplished by observation of any celestial body of known declination, although observation is easiest with the sun.

Another extremely simple observation to determine latitude involves measuring the altitude of Polaris (also known as α *Ursae Minoris,* the *Pole Star,* or the *North Star*). Because Polaris rotates about the true north celestial pole on a very short radius (i.e., <1 degree of arc), at two times each day, the altitude of Polaris will be equal to the altitude of the true pole, and that altitude will equal the latitude of the observer. The altitude of Polaris most closely approximates the altitude of the pole—and thus latitude—when the constellations Ursa Major (the Big Dipper) and Cassiopeia are positioned as indicated by Figure 106-17. For the remainder of the day, there will be a predictable discrepancy



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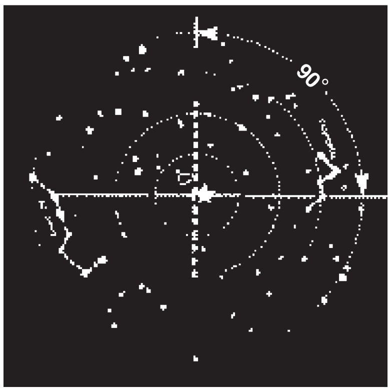

No correction

FIGURE 106-17 Diagram indicating appearance of the north circumpolar sky at the two times of day when the observed altitude of Polaris is equivalent to the latitude of the observer. *(From the Department of the Air Force:* Survival Training Edition AF Manual 64-3, *Randolph Air Force Base, Texas, 1969, Air Training Command.)*

between the measured altitude of the star and the latitude of the observer. The *Nautical Almanac* has a brief table that corrects for this discrepancy, allowing an observer to determine accurate latitude by the altitude of Polaris at any time when the star is visible and a suitable horizon is available. The Polaris sight requires Greenwich Mean Time (GMT) to within several minutes, a precise measurement of altitude, and data from the *Nautical Almanac*.[4,12]

The latitude obtained by the noon sight or Polaris sight represents the simplest available celestial LOP. This line can be used to determine a fix if coupled with a sight that yields longitude, or with another LOP obtained by any other method. For land navigation, this second LOP might represent a linear surface feature, compass bearing, or radio bearing that crosses the determined latitude line at a single point.

Methods for Longitude

Determination of longitude is considerably more involved than determination of latitude, requiring precise timekeeping, meticulous observation, extensive preplanning, and detailed tables of celestial data. The seminal advance in the search for a method of determining longitude was invention of the chronometer by John Harrison in 1735. With an accurate timepiece, longitude could be directly determined by measuring the altitude of any celestial body of known coordinates at a precisely known instant of time. This method, which is called *time sight,* revolutionized exploration but involves formidable mathematics. A simpler alternative exists that is adaptable to the wilderness setting. This traditional technique for establishing longitude is called *equal altitude method*. Equal altitude method requires accurate timekeeping, the ability to measure altitude with precision, and data from the *Nautical Almanac*. At a convenient interval before the meridian passage of the body (i.e., 1 to 2 hours), the altitude of the body is taken, and GMT is noted. The sextant is left at the altitude setting of the first observation. After the body passes the meridian, it is observed until it falls to the exact altitude of the first reading, and the time is again noted. Meridian passage will have occurred at the midpoint between these two times, and the GMT of meridian passage is then known. At the moment of meridian passage, LHA of the body equals zero, and GHA of the body (from the *Nautical Almanac*) equals the observer's longitude.

In theory, the instant of meridian passage could be found by noting the moment the body reached maximum altitude, achieving the same result. This is highly inaccurate in practice because of the extremely slow rate of change of altitude in the minutes immediately surrounding the LAN.[26] Other elegant and highly accurate methods exist for determining longitude and position. These use Sumner lines, a particularly flexible form of celestial LOP discovered by Thomas H. Sumner in 1837, and the altitude-intercept method discovered by Marcq Saint-Hillaire in 1875. These methods have a rich and colorful history and serve as the principal methods for celestial position finding at sea. However, these techniques are unlikely to be practiced by the land navigator and are not discussed further here. Interested readers are referred to several references for further study.[4,12,21,26,43]

CELESTIAL METHODS FOR DIRECTION FINDING

SHADOW METHODS

The axis of rotation of the earth is inclined at about 23.5 degrees from the orbital plane of the solar system. It is this phenomenon that results in the seasons; in the variable path of the sun through the sky with each season; and in the terrestrial definitions of the tropics, the temperate zones, and Arctic and Antarctic zones. The apparent path of the sun is lower in the sky, and shadows cast by the sun are longer at any given time of day in winter than in summer. A plot of the tips of the shadows cast in daylight by a vertical object (i.e., a gnomon) on any given date results in a curved line called a *declination curve*. The declination curve is so named because shadow lengths are proportional to the declination of the sun on the date of the plot. The shadows used to plot a declination curve are shortest at noon, when the sun is at its greatest altitude, and longest near sunrise and sunset. A family of declination curves can be plotted empirically for various dates and can then be used in subsequent years to predict shadow lengths for future dates and times. The shadows themselves can be plotted to indicate direction of the sun, which gives the approximate time of day. This is the principle by which sundials were constructed before the discovery of trigonometry. A family of declination curves will be useful for any point on the earth's surface near the same latitude as the location at which they were plotted. The curves will not be accurate at more distant latitudes, because the altitude of the sun changes with the latitude of the observer. This lack of universality can be overcome by moving the gnomon to compensate for changes in latitude. Since the advent of plane and spherical trigonometry, declination curves and gnomon positions can be calculated for any date and location.[36]

The sundial is most often used to tell time, but it can also be used as a sun compass to indicate direction. Shadows cast in the morning hours point westward, whereas those in the afternoon point eastward. Variations between the rising and setting points and due east or west are predictable for any date and latitude (see Direction by Amplitudes, later). The shortest shadow cast by the sun occurs at LAN and always lies on a due north-south line. Alternatively, a north-south line can be found by bisecting the angle between two points on a declination curve that are at equal distances from the gnomon. Knowing this, a sun compass can be constructed that indicates true direction with a high degree of accuracy whenever the shadow tip of the appropriately positioned gnomon lies on the declination curve for the approximate date of observation. Figure 106-18 shows such a sun compass, called a *Universal Pocket Navigator,* with a scale to compensate for the latitude of the user.[36] A copy of this sun compass, a pin or a toothpick that is more than 2.5 cm (1 inch) in length, and sunshine are all that is necessary to determine the cardinal directions with an accuracy greater than that typically achievable with a magnetic compass (Figure 106-19).

In the absence of a copy of Figure 106-18, the same principle can be applied to construct a sun compass on the fly. Any flat surface (e.g., a chip of wood, piece of bark, scrap of paper) is placed horizontally in the sun, and a gnomon of convenient length is stuck in the surface in a vertical position. The tip of the shadow cast by the gnomon is marked at various times beginning shortly after sunrise, and a curve is traced between the marks. At some point, the sun will pass the meridian, and the shadow will begin to lengthen again. A line between the base of the gnomon and the point of closest approach of the curve represents solar noon and runs due north to due south. Whether the shadow at noon points north or south depends on whether the observer is in the northern hemisphere, southern hemisphere, or the equatorial tropics. The actual direction indicated by the shadow is easily determined by noting the general direction of sunrise, which is on the eastward side of the sun compass. The remaining afternoon portion of the curve can either be completed freehand as a mirror image of the morning curve or by continued observation and marking of shadow tips (Figure 106-20). On subsequent days, the sun compass is reoriented to true north by rotating the horizontal surface until the tip of the gnomon's shadow touches the curve. A sun compass prepared in this manner is highly portable and remains accurate for many days, until there is significant change in the latitude of the traveler or in declination of the sun. New curves can be prepared on the same compass as needed.

Other methods of direction finding with the use of shadows exist but are significantly less accurate. The direction of travel of a shadow tip over 1 hour or so will point generally eastward throughout the day.[9] The accuracy of this method is degraded in direct proportion to the length of time before or after noon that the observations take place and in inverse proportion to the declination of the sun. Errors of more than 30 degrees are possible when conditions are unfavorable, such as at higher latitudes and during winter, when the path of the sun is low in the sky. However, errors incurred during morning hours will tend to be

SELECTOR CHART								
	NORTHERN HEMISPHERE							
Latitude	Dec 22	Jan 22 Nov 22	Feb 22 Oct 22	Mar 22 Sep 22	Apr 22 Aug 22	May 22 Jul 22	Jun 22	Latitude
0°	0–N	0–M	1–K	0–J	0–I	1–G	2–F	0°
10°	2–N	3–M	4–K	3–J	2–I	3–G	4–F	10°
20°	6–N	6–M	7–K	5–J	4–I	6–G	7–F	20°
30°	10–P	10–N	11–K	9–J	9–H	11–F	12–E	30°
40°	20–P	18–N	14–L	12–J	12–H	13–F	14–E	40°
50°	30–Q	29–Q	23–L	18–J	18–G	21–D	21–C	50°
60°	Wait for rescue party			25–J	25–F	28–B	29–A	60°
	Jun 22	Jul 22 May 22	Aug 22 Apr 22	Sep 22 Mar 22	Oct 22 Feb 22	Nov 22 Jan 22	Dec 22	
	SOUTHERN HEMISPHERE							
	In the southern hemisphere, the arrow points to the south, and west (a.m.) is interchanged with east (p.m.)							

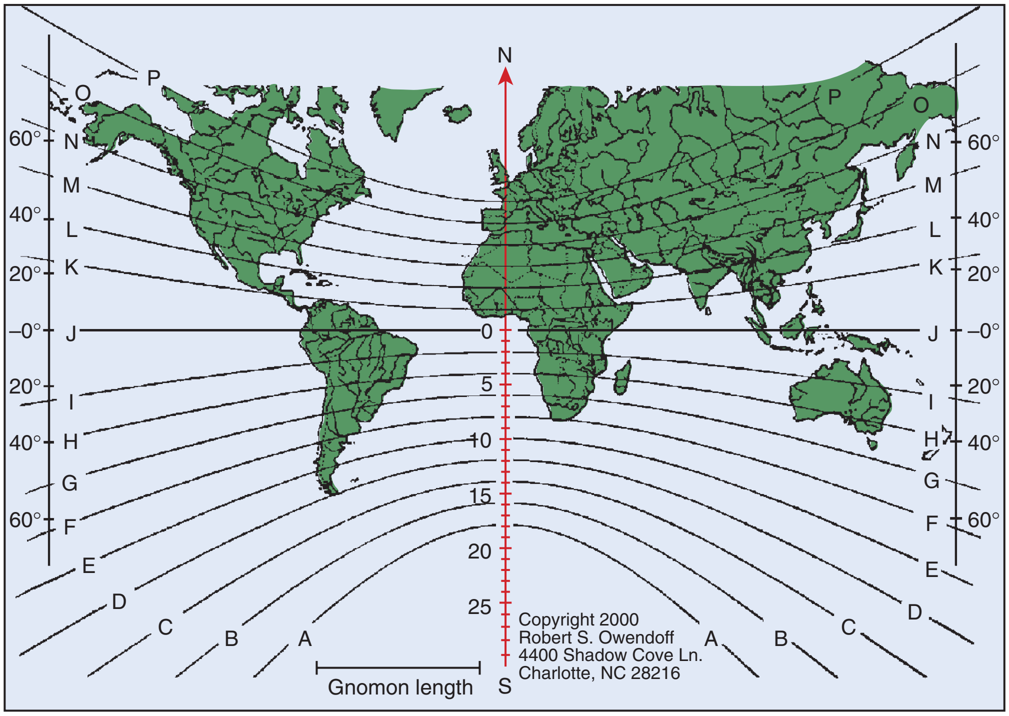

FIGURE 106-18 The Universal Pocket Navigator. Enter the Selector Chart with arguments for approximate date and approximate latitude as determined from the background map. Stick a pin or toothpick vertically in the center line at the cross-mark indicated by the Selector Chart to serve as a gnomon. The tip of the gnomon should stand above the figure by the length indicated by the gnomon scale. Hold the figure horizontally, and rotate your body until the shadow of the tip of the gnomon lies on the appropriate lettered curve (as listed in the Selector Chart). The arrow now points north. *(From Owendoff RS:* Better ways of pathfinding, *Harrisburg, Pa, 1964, Stackpole.)*

canceled by reciprocal errors incurred during afternoon hours, as long as the rate of change in latitude while traveling is relatively slow during the period of observation.[36] The shortest shadow cast by a vertical gnomon throughout the course of the day lies on a north-south line at all latitudes. The point of closest approach of a declination curve to the gnomon may be difficult to determine accurately when the rate of change of the sun's altitude around LAN is slow. As an alternative method, a line bisecting the angle between any two shadows of equal length cast by a vertical gnomon will lie on a north-south line at all latitudes.

An ordinary analog wristwatch or pocket watch can be used to provide a rough north-south direction using the shadow technique. Because a conventional watch has a 12-hour cycle of rotation, the hour hand rotates at 30 degrees per hour, which is twice the rate of the apparent angular movement of the sun. Thus, if the hour hand of the watch is aligned with the shadow of a vertical object (i.e., the hand is pointing directly at the sun), the bisected angle between the hour hand and 12 o'clock on the dial yields a line that runs generally north to south. At times before 0600 or after 1800, the larger of the two possible angles between the hour hand and 12 o'clock should be used. This method is fraught with errors that increase in magnitude when the sun's altitude is high (i.e., in tropical or subtropical latitudes or during late-spring, summer, and early-fall months). It is also subject to errors that result from differences between zone time

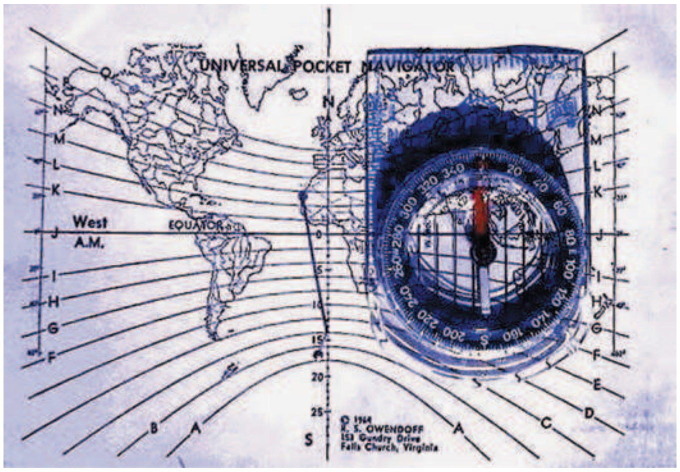

FIGURE 106-19 Use of the Universal Pocket Navigator to find north. The Selector Chart was entered with the date of October 25 and the assumed latitude of 40 degrees, yielding declination curve L and gnomon position 14. Note the correspondence between magnetic north and north as indicated by the center line of the figure. The magnetic declination at the sight of observation was about 5 degrees west. The Universal Pocket Navigator reading corresponds with true north.

and local time and from the equation of time (i.e., the difference between mean solar time and true solar time). However, the watch method can be useful as a direction finder if the potential for inaccuracy is kept in mind and if techniques are used to reduce avoidable errors. Correspondence between direction determined by the watch method and true direction will be greatest between latitudes of 40 degrees to 60 degrees during the winter months. Accuracy is improved if the watch is set to local solar time at the approximate longitude of observation rather than zone time (Local solar time = GMT + east longitude expressed in time *or* GMT − west longitude expressed in time [where 15 degrees of longitude = 1 hour]). Directional errors are further reduced by tilting the watch face to lie in the plane of the sun's apparent path rather than in the horizontal plane.[16,36,38] A digital watch may also be used if the indicated time is drawn as an analog clock face on paper or in the dust.

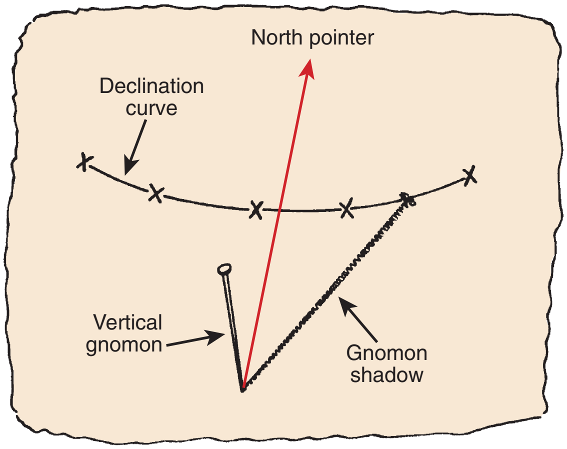

FIGURE 106-20 A makeshift sun compass inscribed on a scrap of paper. The declination curve has been empirically determined by tracing a line through points representing the tip of the gnomon shadow at various times throughout the day. On subsequent days, rotation of the figure such that the shadow tip touches the curve will orient the line connecting the base of the gnomon to the point of closest approach of the curve to point north. *(From Owendoff RS:* Better ways of pathfinding, *Harrisburg, Pa, 1964, Stackpole.)*

DIRECTION BY AMPLITUDES

Amplitude of a heavenly body is the angular measurement between the body when it is on the horizon and the observer's prime vertical circle. When the body is rising, amplitude is reckoned from due east; when the body is setting, amplitude is reckoned from due west. Amplitude is designated as north or south, depending on the relative position of the body on the horizon and the prime vertical circle. Amplitude will always be north when the declination of the body is positive, and vice versa. For objects of constant declination (i.e., the "fixed stars"), amplitude is constant. For the sun, moon, and planets, amplitude varies with the seasonal variations in the declination of these bodies. Knowledge of the amplitude of the sun for various dates is useful as a means of determining direction at sunrise and sunset. Amplitude of the sun is zero on the dates of the spring and fall equinoxes, and the sun rises due east and sets due west of an observer at any latitude between the Arctic Circle and Antarctic Circle on those dates.[4,12]

The formula for calculating the amplitude of any body at rising or setting (i.e., when altitude = 0) is known as Napier's rule[4,30,31]:

$$A = \sin^{-1}(\sin d / \cos L)$$

The maximum amplitude of the sun for any given latitude is calculated by entering the maximum declinations of the sun occurring at the solstices (i.e., ±23.5 degrees) into the formula.[4] The amplitude for any date is calculated by entering the declination of the sun on the date of interest. Note that directions as established by amplitudes are true (rather than magnetic) directions.

For most of the year in most of the world, the sun's amplitude lies within 30 degrees of due east and west. During fall and winter in the northern hemisphere, the sun rises and sets south of east and west, whereas in the spring and summer the opposite is true. Maximum amplitudes occur at the solstices, whereas minimum amplitudes occur at the equinoxes.

A useful table of amplitudes for the sun or other selected celestial body can be easily calculated by Napier's rule and carried on an index card to provide a directional reference in the area of intended travel. The approximate latitude of the area of travel can be determined from a map. The declinations of the body to be used for the dates of travel can be located in the *Nautical Almanac* or found on any of several websites. A ready-made table of amplitudes covering latitudes from 0 degrees to 77 degrees and declinations from 0 degrees to 24 degrees is available in Bowditch's *The American Practical Navigator,*[4] Volume II, as Table 27.

DIRECTION BY OBSERVATION OF CIRCUMPOLAR STARS

Polaris provides the most reliable directional indicator in the night sky and can be used to indicate direction within a degree of true north at any location above 10 degrees north latitude. Use of the star becomes progressively more difficult as its altitude increases above 60 degrees north because of the difficulty relating the star's azimuth to the horizon. A stick with a string tied to the end and weighted with a bolt or washer can be used to find the point on the horizon representing north in this setting. The stick is held such that the string hangs in a line from Polaris to the horizon. The point of intersection of the string with the horizon indicates north.[6]

The Big Dipper (Ursa Major) can be used to identify Polaris or true north by extending a line from the "Pointers" (i.e., α Ursae Majoris or Dubhe and β Ursae Majoris or Merak) toward the north celestial pole. These stars form the leading edge of the Dipper. The distance between them multiplied by five indicates the approximate position of Polaris. When the Dipper is low in the sky or below the horizon, a similar process can be followed in identifying north from the constellation Cassiopeia. Cassiopeia has the appearance of a flattened letter "M" when above the pole, and "W" when below. If a line drawn between the stars forming the feet of the "M" (i.e., β Cassiopeiae or Caph and ε Cassiopeiae) is assigned length *y,* a perpendicular line of length

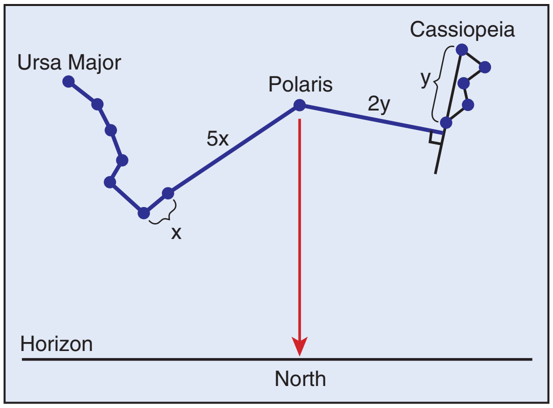

FIGURE 106-21 The azimuth of Polaris is always within 45 arc minutes of true north. Lines as indicated from the "pointers" of the constellation Ursa Major, or from the trailing star of the constellation Cassiopeia, can also be used to find north when Polaris is obscured by clouds or below the horizon. *(From Burch D:* Emergency navigation, *Camden, Me, 1986, International Marine Publishing.)*

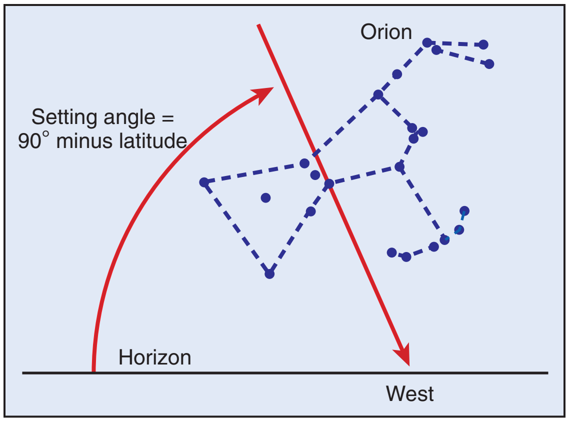

FIGURE 106-23 Determination of true west by observation of the setting point of the star Mintaka (with declination 0) in the belt of the constellation Orion. The rising point of the same star indicates true east. *(From Burch D:* Emergency navigation, *Camden, Me, 1986, International Marine Publishing.)*

$2y$ extending from the trailing star indicates approximate north (Figure 106-21).

In the southern hemisphere, there is no conspicuous star that marks the south celestial pole. However, the distinctive asterism of the Southern Cross can be used to point to the approximate location of the pole and thus to indicate south. The Southern Cross consists of four stars, and the declination of the crossbar is approximately –60 degrees. The long axis of the cross lies on a line that passes within 3 degrees of the south celestial pole. The distance to the approximate pole from the star forming the base of the cross (i.e., α Crucis or Acrux) is approximately five times the length of the long axis of the cross (Figure 106-22). At latitudes where the cross is visible but the south celestial pole is below the horizon, the long axis of the Southern Cross indicates south when the constellation is vertically oriented.[6,9,39]

When the Southern Cross is below the horizon or too low in the sky for reliable observation, the bright stars Canopus (α Carinae) and Achernar (α Eridani) can be used to find south. If a line between these stars is considered to represent the base of an equilateral triangle, the apex of the triangle points to the approximate location of the south celestial pole[6,9] (Figure 106-22).

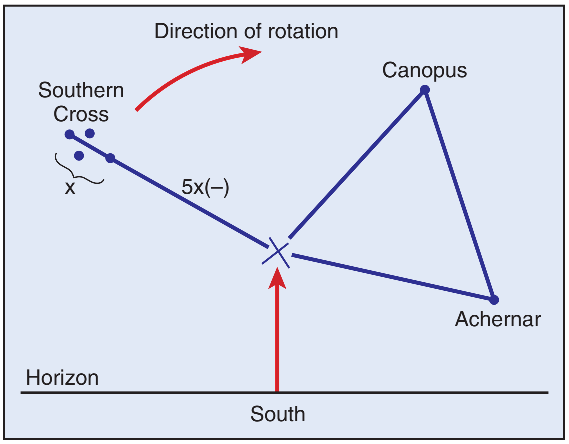

FIGURE 106-22 Determination of south by circumpolar stars. The long axis of the Southern Cross lies along an approximate radius extending from the south celestial pole at the distance indicated in the figure. The apex of an equilateral triangle with the stars Achernar and Canopus forming the vertices of the base also approximates the position of the south celestial pole. *(From Burch D:* Emergency navigation, *Camden, Me, 1986, International Marine Publishing.)*

DIRECTION BY OBSERVATION OF OTHER STARS

It should be clear from the amplitude formula that any object with a known declination of less than ±5 degrees could be used to give a reasonably accurate indication of east at the time of rising or west at the time of setting. By virtue of its brightness and of the familiarity of the constellation in which it is located, the star δ Orionis (i.e., Mintaka; declination, –0 degrees and 18 minutes) is particularly useful in this regard. Mintaka is the leading star in the belt of the constellation Orion; it rises due east and sets due west at any latitude from which it is observed (Figure 106-23). Unfortunately, the visibility of Mintaka at rising or setting is limited to the months of October through April. When the star is obscured by haze or by clouds at rising, or the time of rising is missed, location of the rising can be extrapolated. Within 1 to 2 hours of the rising time, hold a straightedge connecting the star to the horizon at the rising angle of the star, where rising angle is equal to 90 degrees minus the latitude. The point at which the straightedge touches the horizon indicates the position the star occupied when on the horizon. Because the rising and setting angles of any body are the same, the same technique can be used to determine the point on the horizon where the star will set.[6]

The constellation Scorpius is prominent in the southern sky at mid–northern latitudes during the summer. This constellation contains a distinctive reddish star, Antares (i.e., α Scorpii), at the position of the neck of the scorpion. To the east of Antares, the tail of the scorpion hangs toward the horizon. Three stars (i.e., ε, μ, and ζ Scorpii) just before the sharp bend in the tail of the figure form a nearly straight line. The stars that are the head and claws of the figure (i.e., β, δ [Dschubba], and π Scorpii) lie in a fairly straight line located immediately to the west of Antares. Configuration of the constellation is such that the stars forming the linear array of the tail point due south when the line of the head and claws has passed the meridian and is perpendicular to the horizon (Figure 106-24).[6]

In the Caroline Islands of the South Pacific, the bearings at rising and setting times of 32 prominent stars are memorized by navigators to permit determination of direction at sea. The fidelity of this "star compass" for direction finding is demonstrated by the ability of these navigators to make successful landfall on minute atolls after open-ocean voyages of hundreds of miles.[18] Memorization or recording of the rising or setting azimuths of a few prominent stars at the latitude of a planned trip will afford the same directional reference to the land navigator in case the compass or other navigational aid is lost or damaged. These azimuths could be precalculated in minutes using Napier's rule.

Finally, observation of the movement of any overhead celestial body relative to a fixed reference (e.g., a branch, guy

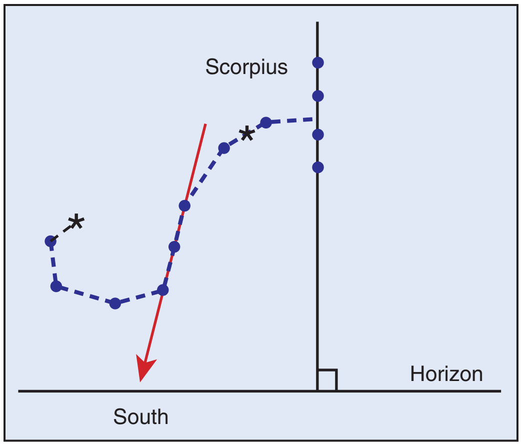

FIGURE 106-24 Determination of south by observation of the constellation Scorpius. When the best-fit line connecting the stars forming the head and claws of the figure is perpendicular to the horizon, the linear array of stars in the tail of the asterism points south. *(From Burch D:* Emergency navigation, *Camden, Me, 1986, International Marine Publishing.)*

line) over a span of 15 to 20 minutes (i.e., 4 to 5 degrees of movement) will give a reasonably accurate indication of east and west.

PRACTICAL FIELD-EXPEDIENT CELESTIAL NAVIGATION

The following discussion demonstrates the practical use of the methods just described on a hypothetical trip to one of the most remote areas in the 48 continental United States. Before leaving on a trip to the Florida Everglades in mid-May, a traveler consults a map of the intended area of travel, noting the approximate latitude (25 degrees north) of the area in question. The traveler also consults the *Nautical Almanac,* Bowditch's *The American Practical Navigator,*[4] or a website to obtain the approximate declination of the sun (18.5 degrees north) during the week of intended travel. By applying Napier's rule and using a calculator, or by consulting Bowditch,[4] the traveler notes that the sun will rise approximately 20 degrees north of due east and set 20 degrees north of due west during the trip. This information is recorded on an index card. The traveler then checks the same sources to see which easily recognized stars will be visible after sunset, near midnight, or before sunrise during the planned dates of the excursion. In this case, the traveler notes that Polaris will be visible all night and that the constellation Scorpius (see Figure 106-24) will be prominent, and almost due south, just before 1 AM. Antares, a prominent red star in Scorpius, rises shortly after twilight and has a declination of 26 degrees south. By using the formula or table, the traveler determines that the amplitude of Antares at rising will be approximately 29 degrees, and the star will rise at a bearing of about 119 degrees and set at a bearing of about 251 degrees; this information is also recorded on the index card. On the morning of arrival at the destination latitude, the traveler places the index card on a flat surface in sunlight and sticks a pin into the card so that it protrudes 1 inch above the face of the card. A sun compass is constructed by the method described earlier (see Figure 106-20), and the card and pin are then placed in a pocket.

The traveler paddles to a remote location in the park on a cloudy day and travels farther than anticipated because of an unusually high tide. He has a spill from the canoe en route, and while in the middle of the Everglades, becomes stranded when the tide recedes. He discovers that his compass and map are missing and that his watch is broken, but the index card is still in his pocket. The weather worsens, and the traveler loses all directional reference and is forced to camp. That evening, the eastern horizon clears, and Antares is observed rising at low altitude. The traveler retrieves the index card, recalls the rising amplitude of the star, and scratches a line pointing toward the rising point in the dirt and labels it "119°". He then draws a complete compass rose in the dirt and labels all of the cardinal directions. In the morning, the sky is obscured, but the traveler recalls that a highway crosses the Everglades to the south-southeast. The drawn compass rose is consulted, and a small rise is noted on the horizon south of his position. Through a combination of paddling and dragging the canoe, the traveler moves toward the rise but is forced well to the west of its position by the terrain, and it is lost from view after several hours. The traveler continues moving southward as judged by the position of the brightest area of clouds, presumably representing the position of the sun. Several hours later, the sun breaks through the clouds, and the traveler retrieves the index card, pins it flat to the seat of the canoe with the pin protruding 1 inch above its surface, and rotates the card until the shadow tip touches the curve. The cardinal directions are now reestablished, and the traveler proceeds southeast as indicated by the sun compass. As the weather worsens, the traveler again identifies a landmark on the southern horizon and moves toward it after the shadow is lost. As night falls, the clouds thin on the western horizon, the setting sun is observed, and the cardinal directions are again established by the amplitude method. Travel progresses to the southeast. That night, the northern sky transiently clears enough for Polaris to be identified. The traveler continues southward away from the direction of the star, but becomes disoriented. During a rest period, the traveler lies on the ground and observes the movement of overhead stars for 15 minutes through a break in the overcast, reacquiring the cardinal directions. He continues southward and notices lights in the direction of travel; he then reaches the highway and is rescued by motorists.

The successful outcome in this example resulted from preparation in advance of travel and familiarity with the navigational clues offered by the environment. Being lost in the middle of a desert or in mountainous terrain during winter may represent a more desperate situation than that just described, but the methods used for recovery would be identical if sophisticated navigational aids were unavailable.

NAVIGATION WITH A POCKET RADIO

Radio transmission and reception are inherently directional. This is particularly evident with reception in the broadcast band (i.e., 500 to 1600 KHz) and is a principle that is more apparent in inexpensive portable radios than in larger, more expensive models. Exploitation of this characteristic was used extensively in aviation navigation from the 1930s through the 1950s. There are anecdotal reports of successful sailings from the west coast of the United States to Hawaii using only an amplitude-modulated (AM) radio and jet contrails as navigational aids.

The internal antenna of the typical pocket AM radio is formed by a ferrite bar wrapped in multiple loops of copper wire. This ferrite-loop antenna responds most strongly to radio-waves when oriented perpendicular to them. Reception is minimized when the axis of the bar is oriented parallel to the transmitted radio-waves (i.e., pointed at the transmission tower of the station). The point of minimum radio reception (i.e., *null point*) can be used to find the direction to a source of radio transmission with surprising precision.[6,38] Use of this technique assumes that a broadcast band station is audible and that the geographic location of the radio transmission can be identified by listening to the station. When these conditions are met, the procedure for establishing a direction line that runs through the broadcast source and the observer is relatively easy. Radio homing does not determine true direction but can identify the direction to safety. When used in conjunction with a map, radio bearings act as LOPs, and multiple bearings to different stations can result in a fix. The procedure for navigation by radio bearings follows:

1. If not known, determine orientation of the radio's internal antenna. This can be done by opening the case and looking for the antenna (i.e., a dark-gray or black bar wrapped in fine copper wire) or by rotating the radio while listening to a station and determining the plane of rotation that results in a null point (rotation about the long axis of the antenna will

not change the reception, whereas rotation perpendicular to the long axis will result in nulling).

2. Select an audible AM station and listen until the location of the station is identified. Hold the radio in a manner that allows the long axis of the internal antenna to act as a pointer. Rotate the radio parallel to the ground until the radio signal becomes faintest or disappears. Nulling of the signal can be augmented by tuning to the fringes of the station frequency if the reception is strong.
3. The actual direction to the source of radio transmission will be one of the reciprocal bearings of the LOP connecting the observer and the station location. The bearing that actually points to the radio source can be determined if the observer has even a crude understanding of his or her position relative to the station (e.g., generally north of vs. generally south of). The bearing to the broadcast source can also be determined by serially checking the null point of the station while traveling. The angle over which nulling occurs becomes greater as the signal weakens with increasing distance from the source. Thus, if the angle over which the signal nulls is widening as travel progresses, the observer is moving away from the radio source. If the angle over which the station nulls narrows as travel progresses, the observer is moving toward the source.
4. If a compass is available, determine the azimuth of the null point. Keep the compass far enough from the radio to avoid influencing the needle with the radio's metal parts. A compass allows the magnetic bearing to the station to be determined. This bearing can then be followed to safety without further use of the radio.
5. If a map and compass are available, orient the map using the compass and draw a line though the broadcast source on the map at the azimuth of the null point. Extend this line to the edges of the map. Your location is somewhere on or near this line. If you have a map but no compass and can properly orient the map by natural cues, place the radio on top of the broadcast location on the map, and rotate it until the signal nulls. Draw a line parallel to the internal antenna through the broadcast location, and extend it to the map margins. Again, your position lies somewhere on this line. When two or more stations can be tuned and identified, the LOPs connecting the observer to each radio source will cross, and a fix can be obtained at the point of crossing. The uncertainty of this fix will be least when the angle between two position lines is close to 90 degrees or when the angles among three position lines are close to 120 degrees.

ORIENTEERING AND GEOCACHING

Orienteering is a competitive sport in which an unfamiliar course is navigated using map and compass. Usually, participants are required to find a number of controls (i.e., identified sites) in a set sequence; this is called *point-to-point orienteering*. In a variant, participants have a fixed amount of time to visit as many controls as possible in any sequence; this is called *score orienteering*.[2] Orienteering is usually practiced as a cross-country footrace over a distance of kilometers or miles, but shorter courses can be set up in paved or inhabited areas for participants of differing abilities. Appropriately constructed courses can be negotiated on foot, on skis, or by bicycle or wheelchair.

Orienteering had its genesis in military land navigation exercises. The term *orienteering* was coined in Sweden in 1900 to describe a ski relay race over a distance of more than 160 km (100 miles). By the close of World War I, orienteering clubs conducting competitive meets were well established in Scandinavia. The sport rapidly gained popularity in Europe and was introduced in North America during the late 1940s. By the 1970s, the International Orienteering Federation was established to codify standards and rules.[2] Orienteering is now practiced by many thousands of people on all continents.

Orienteering has spawned several offshoot sports. *Rogaining* is a team form of score orienteering practiced over a 24- to 48-hour period, requiring overnight camping as a component. Participants set out from a central base to find as many controls as possible during the allotted time span. Return to the base for meals, rest, refreshment, or socializing is permitted. *Adventure racing* is a form of team orienteering practiced over long distances and time spans of days to weeks; it may involve running, hiking, biking, and canoeing as components.[27]

THE ORIENTEERING MEET

Orienteering meets are usually sponsored by local clubs operating under guidelines established by the International Orienteering Federation, United States Orienteering Federation (USOF), or other national federations. Events may be advertised in local newspapers or on websites maintained by the sponsoring clubs. Most events offer multiple courses to accommodate participants of varying skill and fitness levels. An internationally standardized color-coding system identifies the technical difficulty of each course (Table 106-1).[37]

The only required equipment for competitive orienteering is an orienteering compass, pencil or pen, and appropriate athletic clothing. Participants register for a course, pay a fee, and receive a start time, course map, printed description of the controls along the course (e.g., "at bend in creek"), and control card that will be marked with a coded hole punch attached to each control point. The map displays magnetic meridians, eliminating the need to correct for declination. The map may also have the controls and lines connecting them printed on it (Figure 106-25), or participants may be required to copy these features onto their map from a master map.

Several minutes before the appointed start time, the participant reports to the starting line. The starter tears a stub from the control card to allow a tally of participants on the course. The participant orients the map to the environment using the compass and visual landmarks and starts the course when told by the starter. The starter records the starting time with the participant's name or number for comparison with the finish time and

TABLE 106-1 Color-Coded Events: Standards for Competitors

Color	Length (km)	Control Sites	Type of Leg	Technical Level	Time (min)	Age (yr)
String	0.5-1.0	On the line	Along the string	Easy	10-15	3
White	1.0-1.5	On major line features and at junctions	Along line features, no route choice	Easy	15-40	6-12
Yellow	1.0-2.5	On line features and at easy adjacent features	Along line features, minimal route choice, no compass legs	Easy	20-45	8
Orange	2.0-3.5	On minor line and easy point features	Route choice with compass legs and collecting features near controls	Medium	35-55	10
Red	4.5-6.0	Same as Orange	Same as Orange	Medium	50-80	10
Green	3.5-4.5	At small point and contour features	Fine compass and contour legs, more physical	Hard	25-55	10
Blue	4.5-6.5	Same as Green	Same as Green	Hard	50-75	10
Brown	6.5	Same as Green	Same as Green	Hard	60-85	10

Modified and with permission from Renfrew T: *Orienteering*, Champaign, Ill, 1997, Human Kinetics.

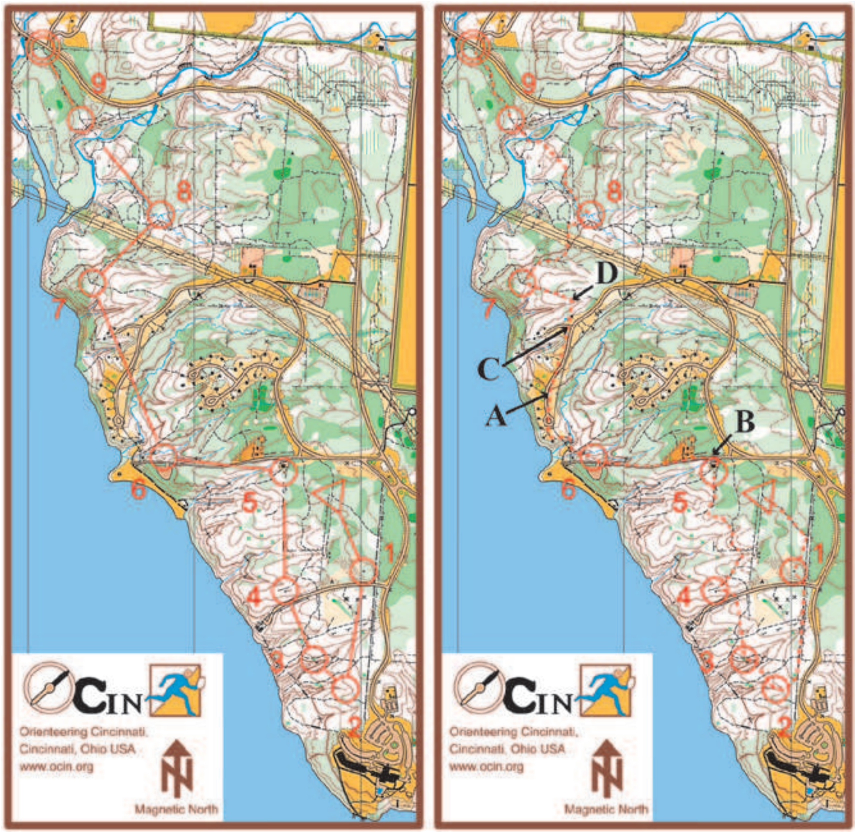

FIGURE 106-25 Paired orienteering maps for a typical yellow-level course showing the starting point as a *triangle,* the control points as *numbered circles,* and the finish point as a *double circle.* Note the magnetic meridians printed on the map as a directional reference. In the map on the left, bearing lines connect the controls but may not represent the fastest, least strenuous, or safest routes of travel. The actual route followed is shown in the map on the right. Note the use of the road segment *(A)* between Controls 6 and 7 as a handrail. The road immediately to the north of Control 5 *(B)* represents a collecting feature should the participant overrun the control. The branch in the road between Controls 6 and 7 *(C)* forms an attack point for reaching the path that leads to Control 7. On this leg, the participant deliberately aimed off to meet the path at a point known to be east of the target *(D)* so that the path could be followed in the proper direction toward the objective. *(From Michael Minium, Orienteering Cincinnati, Inc., and the United States Orienteering Federation, 2005.)*

determination of elapsed time to run the course. When running the course, the participant continually reorients the map to the environment using the compass, and the environment to the map by comparing visual cues with map features. The participant chooses a route between control points by considering terrain features and the presence or absence of readily identifiable landmarks that may assist with navigation. As the participant approaches the area of a control, the area is scanned for descriptive features and the orange and white flag that identifies the site; the control point is then located, and the participant punches his or her control card with the punch attached to the control as proof of having been there. The participant then reorients the map and progresses to the next control in sequence. This process is repeated until the course is completed. As the participant crosses the finish line, the time is recorded, and the number on the control card is checked against the stub that was collected by the starter. The card is then inspected to establish that all the control points were visited, and the course time is calculated and recorded. At the completion of the meet, the winners of each course are determined and announced, and prizes may be awarded.[2,37]

Several concepts that receive particular emphasis in orienteering are extremely useful for general map and compass navigation.[28,37] A *handrail* is a linear feature on the map that can be easily recognized in the terrain and used as a guide toward an objective. Typical handrails include paths, roads, streams, fences, shorelines, firebreaks, ridgelines, and abrupt contour changes. When a handrail is encountered, the navigator can move along it with speed until the chosen route deviates from it or the objective is encountered. An *attack point* is a prominent and obvious feature in the terrain from which an objective can be easily located; this may be a knoll, bend in a path, narrowing in a stream, or another point feature. An attack point can be chosen in advance of travel, allowing the bearing and distance from the point to the objective to be calculated in advance. When the attack point is reached, discovery of the ultimate objective is greatly simplified. A *collecting feature* is an easily recognized terrain feature that lies beyond a desired objective. If the collecting feature is encountered, the navigator knows that the target has been passed and can retrace his or her steps to the last known position for a second attempt at the objective. *Aiming off* is a technique for reducing confusion when navigating toward a particular point that lies on a handrail feature. A common problem with land navigation involves encountering such a linear feature and then not knowing which way to turn to follow the handrail to the objective. Aiming off involves introducing a deliberate error into the bearing to the handrail so that it will be encountered at a point that is absolutely known to be to the left or right of the intended target. The navigator then follows the handrail in the direction that corrects the error and is certain to lead to the objective (see Figure 106-25).

Handrails, collecting features, attack points, and opportunities for aiming off should be determined in advance of travel by studying the map and the visible terrain. This permits selection of a route that facilitates speed, safety, and ease of travel. These features should be recorded rather than trusted to memory. Critical evaluation of the map for such features greatly increases the navigator's awareness of terrain as well as his or her competence in map reading.

ORIENTEERING FOR CHILDREN

Successful orienteering depends on an ability to apply basic land navigation skills with speed and accuracy. The skills required for completion of even simple orienteering courses are completely translatable to following a wilderness route. Note in Table 106-1 that string courses—in which participants literally follow a string, ribbon, or length of yarn strung from one control to the next—are available as an introduction for the very young. Courses classified as white, yellow, and orange are also of a length and technical level that are appropriate for children. As such, orienteering offers perhaps the most reliable and accessible avenue for teaching map and compass skills to children. Map reading, orientation of a map with a compass, orientation of a map to the environment, route selection, terrain recognition, and outdoor safety are all concepts that are compatible with training in a classroom or backyard setting. These skills can then be applied in any large indoor space or at a local park.[28]

Most orienteering clubs offer programs for teaching children. The USOF sponsors a four-step program to foster progressive mastery of necessary skills in a logical sequence.[41,42] The program begins at the Little Troll level and involves string courses. Participants complete five USOF-sponsored courses with adult assistance. At the conclusion of each course, the child receives a sticker that he or she affixes to a special card. The completed card is redeemed with the USOF for a Little Troll patch, and the child then progresses to the Chipmunk level. As Chipmunks, participants learn to be more comfortable in an outdoor setting and are introduced to map symbols, the concept of control sites, and the procedures of running a course. After completion of five USOF-sponsored white courses with adult assistance, the child receives a Chipmunk patch and advances to become a Rabbit. At the Rabbit level, knowledge of map symbols and colors is expanded, safety awareness is increased, and the child learns to orient the map to the terrain, mark his or her current location, select routes to follow, and follow a path between controls. Some adult assistance continues at this level. After completion of seven sponsored white courses, the child receives a Rabbit patch and advances to training as a Roadrunner. Training at this level occurs without direct adult assistance, although an adult follows the child on each course. Roadrunners are required to know safety rules and learn to adjust the orientation of the map as they cover the course, make independent route selections, and orienteer in sequence from control to control. After completion of another seven white courses, the child receives a Roadrunner patch and progresses to solo orienteering.[41] The International Orienteering Federation supports a similar progressive training program for children called the *Swedish Step System*.[37]

In orienteering, correction for declination is not required because the maps are prepared with reference to magnetic meridians, creating internal consistency between the map and compass. Separate training in the conversion of magnetic and true bearings is required to allow the practice of safe and comprehensive map and compass navigation.

GEOCACHING

The sports of orienteering and rogaining prohibit the use of GPS technology. The recently developed sport of *geocaching* offers an excellent opportunity for training in the use of terrestrial coordinates and GPS receivers. Geocaching is essentially a treasure hunt in a challenging environment. The sponsors of a cache leave a container or object in a concealed location identified only by latitude and longitude, or UTM coordinates. Locations of caches, relevant maps, and location descriptions are published on websites maintained by cache sponsors. Persons seeking the cache use the provided information and a GPS receiver to locate the site. When the cache is located, the participant may record the date of discovery in an enclosed logbook, if provided, and the cache is replaced. Note that the cache may be located in an easily discovered spot or in an extremely challenging position such as on a cliff face, in a tree, buried, or underwater. Many variations on the basic theme exist, including caches that contain coordinates for locating the next cache in a sequence and caches that contain hints for locating a final cache after accumulation of clues from several other caches.[19] Geocaching is greatly facilitated by the use of a WAAS-enabled GPS receiver because of increased accuracy available with this technology.

CONCLUSION

The body of literature covering the topic of navigation is immense. Many techniques for determining direction and position exist in addition to those described in this chapter, and several references catalog these methods.[4,6,16,26,30,43,44] It is sufficient to the task of navigation if the aforementioned methods are understood in terms of their practical application, even if why they work remains obscure. Practice is essential, and the reader is encouraged to increase his or her familiarity with the motion of celestial bodies, inconstancy of Earth's magnetic field, and use of a variety of common navigational aids (e.g., compass, topographic map). Inexperienced persons anticipating a backcountry trip are strongly encouraged to increase their navigational skill by participating in the sports of orienteering and geocaching. A review of land-navigation techniques, advance study of the area of intended travel, and familiarity with the appearance of the day and night skies during the planned time of travel should be routine components of preparation for any wilderness expedition.

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CHAPTER 107

Principles of Meteorology and Weather Prediction

JOHN MIODUSZEWSKI AND D. NELUN FERNANDO

GENERAL CIRCULATION AND ATMOSPHERIC PROFILE

CLIMATE CONTROLS AND RADIATION BALANCE

Equatorial regions receive a net surplus and polar regions receive a net deficit of solar radiation because of differences in solar angle and beam dissipation at the poles and the equator. This heat imbalance drives the ocean-atmosphere circulation. Heat is transported in the atmosphere primarily through convection, conduction, and advection. Convection and conduction are important in vertical atmospheric heat transport. Latent and sensible heating are the key mechanisms by which convective and conductive transport are enacted. Horizontal heat transport is achieved primarily through migration of air masses and eddy circulation.

Average global circulation on a simplified basis consists of three circulation cells. This structure is found in both hemispheres. The cell that straddles the tropics (0 degrees to ~30 degrees), known as the *Hadley cell,* is characterized by rising motion on its ascending limb along the equator and sinking motion on its descending limb at the subtropics (~30 degrees). A second cell, known as the *Ferrel cell,* has an ascending limb at the midlatitudes and descending limb at the subtropics. The third cell, known as the *polar cell,* is characterized by rising motion at the midlatitudes and subsidence at the poles.

This circulation structure results in a climate with intense convective precipitation in the regions along the rising limb of the Hadley cell. This region is identified as the *intertropical convergence zone* (ITCZ) because it is a zone where intense heating leads to convective motion and low pressure. Low-level or surface convergence and upper-level divergence result in convective precipitation in this zone. Regions along the descending limb of the Hadley cell—approximately 30 degrees north and 30 degrees south—tend to be warm and dry as subsiding air warms and dries out the air column. It is no coincidence that most deserts are found at this latitude. The midlatitudes (40 degrees to 50 degrees)—the rising limb of the Ferrel cell—have cells of low pressure and receive precipitation from storms and frontal systems. Polar regions along the subsiding limb of the polar cell are characterized by cold and relatively dry climates.

The three-division structure results in surface winds blowing from the east (easterly) out of the subtropical high-pressure zone to the low-pressure zone at the equator; winds from the west (westerly) out of the subtropical highs to the midlatitude low-pressure zone; and polar easterlies flowing from the polar high-pressure zone to the midlatitude low (Figure 107-1). Such an east-west wind direction, as opposed to north-south, prevails because of the Coriolis effect, which acts on the pressure gradient force and deflects winds to the right in the northern hemisphere and to the left in the southern hemisphere.

The tricell structure is only a simplified representation of the general atmospheric circulation. In reality, the Ferrel cell does not persist throughout the year, as does the Hadley cell. The pressure gradient at the polar front is so intense that it results in eddies that are instrumental in poleward heat transport, particularly during winter, when the equator-pole pressure gradient is at a maximum. The midlatitudes are the regions most influenced by air masses. Eddy circulation is predominant at the boundary, the *polar front,* between the Ferrel cell and the polar cell.

ATMOSPHERIC PROFILE

Lapse Rate

Temperature generally decreases with altitude in the troposphere, as evidenced by decreasing temperature as one ascends a mountain. The rate at which air cools as it rises depends on the amount of moisture in the air, as well as dynamics of the atmosphere. This rate can be estimated to be 6.5° C for every 1000-m gain in elevation, or 3.5° F for every 1000 feet.

Moisture

Humidity reflects the amount of moisture in the air, usually measured by relative humidity and dew point temperature. Relative humidity is a ratio of the amount of moisture in the air to the amount the air can hold at that temperature. Atmospheric moisture is often given as relative humidity, which must be accompanied by a temperature to be a valuable indication of the air's moisture content.

Dew point temperature is the temperature at which the air becomes completely saturated. If air is cooled to this temperature at the surface, fog will form. If air is forced to rise and cools to this temperature, clouds will form.

Heat capacity is the amount of energy required to increase the temperature of a substance. This is important because of the great difference in heat capacity of land and water. Water heats and cools much more slowly than does land, which has important implications for weather in the interior of continents, especially compared with coastal areas.

CLIMATIC REGIONS CONTROLLED BY LATITUDE: TROPICS, MIDLATITUDES, AND POLES

MIDLATITUDE AND POLAR CLIMATES

Most weather systems, such as midlatitude cyclones and thunderstorms, form at the frontal boundaries between air masses of different densities and are steered by upper-level winds, typically to the east in the midlatitudes and west above 60 degrees. This is in contrast to tropical cyclones, which are not influenced by air masses and only form over the ocean. Midlatitude cyclones are a powerful means by which air can be transported across latitudes. These differing air masses meet at boundaries called *fronts.*

Cold and warm fronts are typically oriented around a cyclone, as shown in Figure 107-2. The colder, polar air mass advances equatorward behind the cyclone at the cold front, while the warmer air mass advances poleward ahead of it behind the warm front. Typically, the faster-moving cold front catches up to the warm front as the cyclone matures and "occludes," and the cyclone begins to lose its strength as the temperature differences from which it derives its energy dissipate. Occasionally, neither air mass will be able to dislodge the other, and the front will become stationary. Stationary fronts are conducive to prolonged periods of precipitation and can serve as a focus for moisture transport and subsequent precipitation as new areas of low pressure move along the front.

These areas of low pressure have favored storm tracks that shift during the year and as larger-scale atmospheric conditions

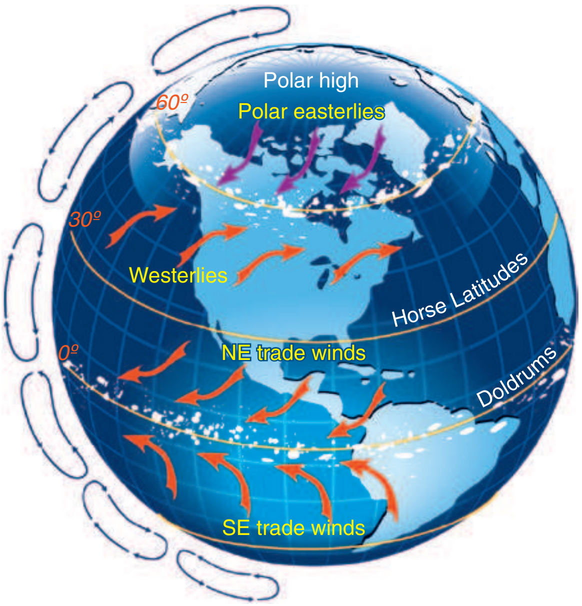


FIGURE 107-1 General circulation of the atmosphere. *(Courtesy Deborah Mioduszewski.)*

change. Often, atmospheric patterns emerge where cyclones take the same track, moving through the same areas for up to several weeks. Conversely, locations removed from these storm tracks may experience persistent fair weather associated with an accompanying anticyclone. Cyclones often form and move along the polar front, where there is a sharp contrast in temperature and moisture. During winter, the precise track of a cyclone will determine whether rain, snow, or a mixture will fall in a given location, with snow more likely on the poleward side of the cyclone and rain on the equatorward side.

These cyclones bring the most noticeable changes to sensible weather in the mid- and high latitudes. In addition to precipitation ranging from drizzle and fog to severe thunderstorms, temperature and humidity levels vary greatly in different parts of the storm. Warm and moist air is advected in behind the warm front with a shift in the wind, causing extremely uncomfortable weather in the summer and thaws in the winter. Colder, dryer, and usually breezy or blustery weather accompanies passage of a cold front as air from higher latitudes is advected in behind a departing cyclone.

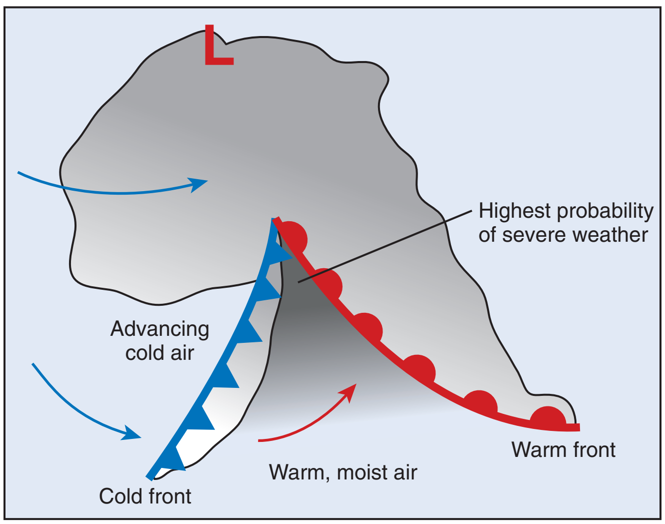


FIGURE 107-2 Midlatitude cyclone model. *L*, Low pressure. *(Courtesy Deborah Mioduszewski.)*

Midlatitude cyclones can bring ice and snow with cold temperatures. Snow occurs when the entire atmosphere is below freezing, whereas sleet (ice pellets) and freezing rain occur when there are intrusions of warmer air in the lower atmosphere. These cyclones are considered to be a blizzard when strong winds accompany the snow. These strong winds result from the gradient in surface pressure across the area and are primarily caused by the strength of the low-pressure system, with rapidly strengthening storms often generating the strongest winds. When winds are strong enough, blowing snow can generate whiteout conditions that reduce visibility to near zero and can be disorienting to anyone caught outdoors.

Ice storms often occur as snow is transitioning to rain behind a warm front and as the lighter warm air slides in above the colder air mass. This changes the precipitation to sleet, freezing rain, and finally rain when the surface temperature rises above freezing. If the surface temperature cannot rise above freezing, an extended period of freezing rain occurs and is particularly hazardous. Even the thinnest glaze of ice can be treacherous, but prolonged freezing rain accumulates as a heavy layer of ice that weighs down everything above the ground. This occurs during cold-air *damming* events when low-level cooler air is dammed against mountains and cannot be displaced, most often in the leeward side of mountain ranges (e.g., Appalachian Mountains). Ice storms are most disruptive when the temperature remains below freezing as the storm ends and remains there for days afterward.

When and where the transition between precipitation types occurs is very difficult to forecast precisely, even for meteorologists, but trends in temperature, pressure, and wind direction can provide clues. Rising temperature and dew point during snow or a mix, particularly with a south or southwest wind in the northern hemisphere, indicate that the warm front is likely approaching and precipitation will soon transition to rain. Rain with temperatures near freezing and a falling barometer may indicate an approaching cold front, in which case a change to snow is likely as the front passes when the pressure begins rising again, the wind shifts, and temperature drops.

SUBTROPICAL AND TROPICAL CLIMATES

The subtropics lie poleward of the Hadley cell, at about 35 degrees north and 35 degrees south. The subtropics are characterized by warm and dry climates. Weather in the subtropics is primarily influenced by frontal systems during the winter and spring seasons. Tropical weather systems can affect weather in the fall, particularly in the coastal lower latitudes of the subtropics. The summers tend to be hot and dry, and summer heat waves are common. These heat waves can persist for days, aided by the positive feedback among dry soils, temperature, and atmospheric subsidence (sinking air). If the antecedent winter and spring seasons were dry, it is more likely that the oncoming summer will be dry, given that land-surface processes play a significant role in driving convective processes in the subtropics.

Tropical climates are found along the rising limb of the Hadley cell. Temperature is high throughout the year, with the average coldest temperature not below 18°C (64.4°F). Convective processes and convective precipitation, typically experienced as brief periods of intense rainfall from showers and thunderstorms, dominate the climate of the tropics but are not the sole climatic phenomena found there. Monsoons and tropical cyclones can also account for a significant amount of precipitation that falls in parts of the tropics.

MONSOONS

The term *monsoon* refers to the seasonal reversal in atmospheric circulation and associated precipitation in tropical and subtropical regions. Reversal of wind direction takes place with seasonal migration of the ITCZ, which induces a temperature difference between the land surface and ocean. The land-ocean temperature difference induces a land-ocean pressure gradient that drives the monsoonal winds. Regional components of the monsoon include the tropical and subtropical regions of Asia, Australia, Africa, South America, and southwestern North America. The onset of monsoonal rains varies among and within these regions.

TROPICAL CYCLONES

Intense convective heating, particularly in the tropics, creates regions of low atmospheric pressure characterized by clouds, showers, and locally windy conditions. If low-pressure systems form over warm oceans of the tropics and subtropics at least 5 degrees from the equator, they have the potential to develop into cyclones, which are intense, rotating low-pressure systems. Winds flow counterclockwise in the northern hemisphere and clockwise in the southern hemisphere around cyclones. Cyclones, hurricanes, and typhoons all refer to the same phenomenon. The convention is to use *typhoons* to identify severe cyclones in East Asia, *hurricanes* for severe cyclones in North America, and *cyclones* for severe cyclones over the Indian Ocean region. Cyclones form in all the major ocean basins, except the South Atlantic and Southeast Pacific. Minimum factors needed for cyclones to develop are sea surface temperatures exceeding 28° C (82.4° F) and a minimal amount of vertical wind shear. Extratropical cyclones form at frontal boundaries. After formation, tropical cyclones tend to move westward and poleward. Some cyclones, particularly in the midlatitudes, recurve and enter the westerlies. Tropical cyclones tend to dissipate on making landfall. Cyclones are classified by their intensity as follows:

- Tropical depression: winds up to 64 km/hr (39.8 miles/hr)
- Tropical storm: winds of 64 to 118 km/hr (39.8 to 73.3 miles/hr)
- Severe tropical cyclone, hurricane, or typhoon: winds greater than 118 km/hr (74 miles/hr)

These are further categorized using the Saffir-Simpson scale, ranging from category 1 to category 5 (most severe) (Table 107-1).

Tropical cyclones have spiraling bands, often termed “rain bands,” of convective clouds (Figure 107-3). Intense upward motion and thus the heaviest rainfall occur within these rain bands and in the eyewall, which encircles the calm eye at the center of the storm. Wind speeds increase with each rain band toward the center of the cyclone as the pressure decreases. The wind is typically strongest in the quadrant of the cyclone where the wind direction is the same as the cyclone’s motion, and weakest on the opposite side (Figure 107-3). The destructive winds of a cyclone are strongest at the coast and well above the surface, where frictional effects are minimized.

In addition to destructive winds, the greatest hazards from tropical cyclones on land include heavy rainfall and storm-surge flooding. Heavy rain and consequent flooding are always threats with cyclones, regardless of strength. This is exacerbated in mountainous regions, where mudslides and flash floods frequently result. Rainfall potential depends primarily on the cyclone’s speed and access to atmospheric energy and moisture, which are typically well predicted by meteorologists but impossible to predict without these tools. The storm surge occurs primarily as the storm’s persistent wind pushes water ahead of it and is experienced on the coast as a relatively gradual rise in water as the storm’s center approaches. Storm surge is historically the deadliest of a cyclone’s hazards but can be avoided by seeking higher ground, if possible.

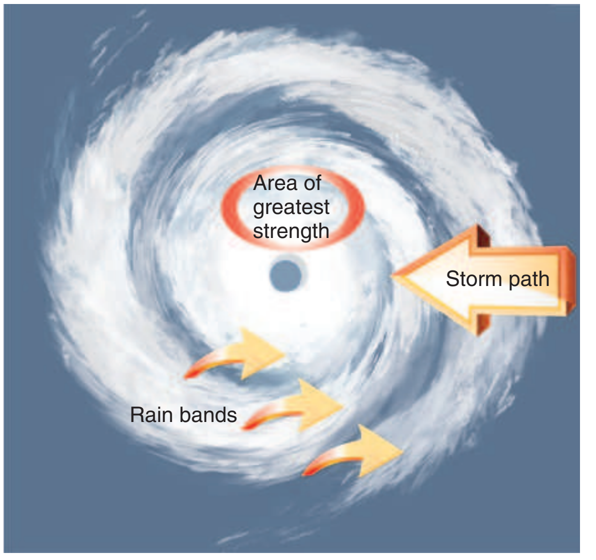


FIGURE 107-3 Tropical cyclone, motion and structure (northern hemisphere). *(Courtesy Deborah Mioduszewski.)*

THUNDERSTORMS

Thunderstorms result from atmospheric instability caused by intense convective heating processes in the tropics, and with convergence of air masses of different temperatures in midlatitudes, particularly in continental climates. Cumulonimbus clouds are characteristic features of thunderstorms, as are lightning and thunder, wind gusts, and heavy rain.

Flash flooding, the rapid flooding of low-lying areas, can occur in any location given a long enough period of heavy rain. The probability of such an event depends on the strength of the wind in the midlevels of the atmosphere as well as the moisture available to precipitate, which cannot be predicted on the ground. Intense, slow-moving, and persistent thunderstorms in upstream regions of river catchments with sharp elevation gradients may induce flash flooding in downstream regions where little or no rain falls, such as the Big Thompson Canyon Flood that killed 143 people in Colorado in 1976. Therefore, hikers should pay particular attention to the topography of the local area and the possibility of rapid, unexpected rises in nearby streams. In these regions, it is critical to have access to real-time weather alerts and ideally weather radar to monitor such storms.

One of the major dangers associated with thunderstorms is lightning (see Chapter 5). Lightning can strike more than 32 km (20 miles) away from the parent thunderstorm, which may appear far enough away to present the illusion that there is no risk. When a thunderstorm is in the area, seek shelter away from high ground, water, and open spaces. Distance to a lightning strike can be calculated by counting the number of seconds between the flash of lightning and the thunder, keeping in mind that sound can travel a mile in 4.5 seconds.

TABLE 107-1 Saffir-Simpson Scale of Tropical Cyclone Intensity

		Wind Speed		Storm Surge		
Category	Pressure (mb)	km/hr	miles/hr	m	ft	Damage
1	≥980	119-154	74-95	1-2	4-5	Minimal
2	965-979	155-178	96-110	2-3	6-8	Moderate
3	945-964	179-210	111-130	3-4	9-12	Extensive
4	920-944	211-250	131-155	4-6	13-18	Extreme
5	<920	>250	>155	>6	>18	Catastrophic

Hail may be encountered in some thunderstorms, though rarely reaching a size that is dangerous to people. Hail is formed in strong thunderstorm updrafts that can support ice chunks as the hail nuclei are accreted with more ice before becoming heavy enough to fall to the ground. Ideal conditions for hail formation are often best in continental climates and near mountain ranges, where a larger depth of the cumulonimbus cloud is below freezing and conditions promoting strong updrafts are enhanced. As such, hail occurs globally, but most frequently in central Europe, the foothills around the Himalayas and European Alps, and particularly across North America's Great Plains and Rockies. The hazards of large hailstones and long-lasting storms are much more serious for agriculture, livestock, infrastructure, and personal property, where risks are primarily economic, rather than for safety and logistics in wilderness operations.

Tornadoes are extremely dangerous weather phenomena characterized by rapidly rotating air that reaches the ground beneath cumulonimbus clouds. They are preceded by a lowering of part of the cloud base, with rotation of this base (funnel cloud) often visible. All funnel clouds do not produce tornadoes, but all tornadoes are preceded by funnel clouds. Once a tornado forms, it is not dissipated or deterred by topography, land surfaces, or human construction. Tornadoes cross over rivers and mountains and strike cities as easily as they move across the prairie. Although most tornadoes are relatively weak and short-lived (<175 km/hr [108 miles/hr] and <10 minutes), violent tornadoes are typically much wider, longer lasting, and cause the most damage. Because the greatest hazard from tornadoes is wind-blown debris, the best refuge is in the interior of a sturdy shelter away from windows. A storm shelter designed and tested specifically to withstand tornadoes offers the best protection. Both underground storm cellars and interior "safe rooms" are usually available in tornado-prone regions and are designed to withstand the strongest tornadoes. If no shelter of any kind is available, the individual is advised to lie flat in a ditch or natural culvert. Climatologically, tornadoes most often occur in the interior of continents, particularly the United States and Canada, where tornadoes tend to be more frequent and stronger than elsewhere.

Waterspouts, as with tornadoes, are columns of rapidly rotating air that are visible due to condensation of water vapor in the funnel (not water being sucked up). Some are associated with supercells and therefore can be considered tornadoes over water. However, many are called "fair-weather waterspouts" because they generally are not associated with thunderstorms. Instead, they form under large cumulus clouds in light wind conditions. Their life span is typically less than 20 minutes, winds rarely exceed 113 km/hr (70 miles/hr), and they are usually found in coastal regions. However, waterspouts can still cause considerable damage and injury, and it is advisable to avoid them or seek shelter if they come ashore.

Types of Thunderstorms

Severe thunderstorms are storms with wind speeds above 93 km/hr (58 miles/hr). Updrafts and downdrafts associated with severe thunderstorms often reinforce each other and intensify the storm.

Mesoscale convective complexes (MCCs) are roughly circular, organized storm systems composed of several thunderstorms. MCCs are common occurrences over the Great Plains region of the United States and Canada, where mesoscale (10 to 1000 km [6 to 620 miles] in diameter) atmospheric processes provide conditions suitable for reinforcement of thunderstorm complexes.

Frontal/squall-line thunderstorms tend to form parallel to and ahead of cold fronts in the presence of wind shear. They form a linear band of storm cells with a life span of about ½ to 4 days and are often a clear visual indication on radar of an approaching cold front.

Supercell thunderstorms are violent storms that occur as isolated thunderstorms, each with a diameter of 20 to 50 km (12 to 31 miles). Supercells are the most common type of thunderstorms to generate tornadoes.

ARID CLIMATES

Arid climates are characterized by lack of moisture. These are found along subtropical high-pressure zones or in the interiors of large continents, where the influence of moisture-laden oceanic frontal systems is limited. Deserts are characteristic ecosystems of arid climates. Extreme heat, high diurnal temperature ranges, wind, and fire danger are important elements of desert climates.

Virga refers to precipitation that falls from clouds but evaporates or sublimates before reaching the ground. This can sometimes be seen as a rain shaft in the distance, with a veil of rain under the clouds becoming streaky and disappearing before reaching the ground. Virga is much more common in arid regions, since lower humidity of the air induces evaporation more readily, although hazards, such as lightning and strong downdrafts of wind, still exist.

MOUNTAIN CLIMATES

Lifting of air caused by the presence of mountains is known as *orographic lift,* which results in cooling of the air. If sufficient moisture is present, condensation takes place. Such convection can induce thunderstorm development on the windward side of a mountain (Figure 107-4). In the winter, orographic lift can both enhance and generate heavy snowfall in mountainous regions, particularly on the windward side of a mountain range. Average winter snowfall in the mountains is typically substantially greater than elsewhere for this reason, and the greatest potential for heavy snowfall occurs in regions with a moisture source upstream (e.g., lakes, oceans), such as northern Japan, the northwest coast of North America, and elevated locations in the lee of the Great Lakes.

In the presence of steep topography, convective processes may be limited to the windward side because the mountain ridge can form a wet-dry divide. Air flowing over a mountain ridge and downward along the leeward side warms and dries through the process of adiabatic compression. Thus, leeward winds are characteristically dry and warm. Such winds are known internationally as foehn winds and are given regional names in the United States, such as the Chinook winds in the lee of the Rockies and the Santa Ana winds that blow into Los Angeles.

Wind direction typically reverses twice a day in mountain climates. During the day, wind flows upslope from the valley toward the mountain. At night, winds blow downslope from the mountain toward the valley. Horizontal temperature differences that develop in complex terrain produce diurnal mountain winds. Overnight and into the early morning, cold air accumulates in valleys and causes a temperature inversion. By morning, valley bottoms are colder than mountain slopes, and a pressure gradient develops that drives upslope winds. Convective heating during the day dissipates the temperature inversion in the valleys.

Varied topography in mountain ranges results in a myriad of microclimates. Factors, such as exposure to sunshine, slope direction, elevation, and windward or leeward side of major weather systems, determine the varied characteristics of microclimates found in mountainous regions. Therefore, weather is generally more difficult to predict in the mountains and changes more frequently, especially in more exposed locations.

MARINE/COASTAL CLIMATES

The difference in heat capacity between land and ocean initiates a diurnal sea-land breeze circulation. During the day, land heats up faster than the ocean, establishing a land-ocean temperature difference that causes a pressure gradient. Wind blows toward the lower pressure over land to equalize the pressure difference. At night, land surfaces cool rapidly compared with adjacent oceans. The cycle is reversed at night, with winds blowing from the land toward the ocean to dispel the ocean-land temperature (and thus pressure) gradient (Figure 107-5).

Ocean upwelling (cold) currents, particularly along the west coasts of continents, modify climate in adjacent land areas. Summers and winters in such locations are mild because of the

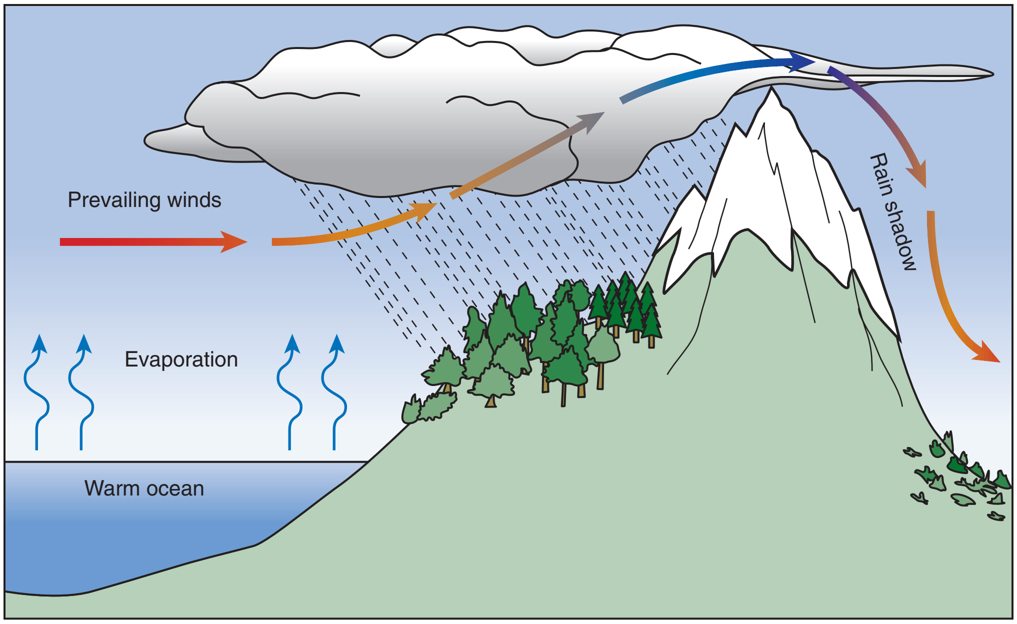


FIGURE 107-4 Orographic precipitation. *(Courtesy Deborah Mioduszewski.)*

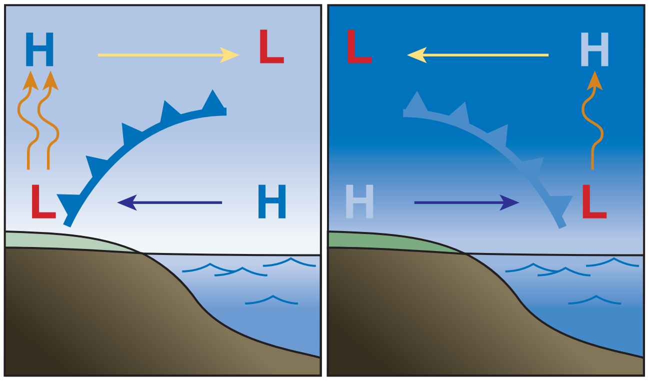


FIGURE 107-5 Land-sea breeze circulation. *H*, High pressure; *L*, low pressure. *(Courtesy Deborah Mioduszewski.)*

moderating effect of the cool water. However, these locations are also prone to low clouds, advection fog, and light rain throughout the year.

Fog is formed when the temperature drops to near its dew point or when moisture is added to the air to saturate it. *Radiation fog* is a shallow layer of fog near the surface caused by rapid cooling of the land. The air just above the land cools to its dew point and condenses, although this type of fog typically dissipates quickly in the morning as the sun rises. *Advection fog* forms when moist air is transported horizontally (advected) over a cool surface. The surface cools the moist air to its dew point, causing condensation and fog. It is most common on land when warm air advects over a snow pack and the snow cools the air to saturation. Advection fog is most common over water and adjacent coastal locations when tropical air moves over a cool ocean current. *Upslope fog* occurs when air is forced to rise. It cools to its dew point, and a cloud forms at the surface.

HUMAN COMFORT

Wind chill refers to accelerated cooling of the human body that occurs because of atmospheric motion, particularly when temperatures are low, typically below 7° C (44.6° F). Weather forecasts often report both absolute and relative (i.e., wind chill) temperatures when wind chill is a factor.

Heat index is a metric that describes "how hot it feels" when humidity is combined with actual air temperature. During summer months, particularly in more humid regions of the world, it is important to heed forecasted heat index values when planning outdoor activities. Table 107-2 provides an indication of the danger levels associated with various values of the heat index.

Haze is reduced visibility caused by suspension of particulates in the air. Such particulates may either be aerosols (e.g., carbon particles, salt) or air pollutants (e.g., nitrogen oxides, ozone, hydrocarbons). Haze generated by atmospheric pollutants is referred to as "photochemical smog" and is often exacerbated by nearby human activity, such as coal-burning power plants and automobile traffic. Additionally, a region's topography can compound this effect. An example is the Los Angeles basin, where

TABLE 107-2 Categories of Heat Index

Category	Heat Index	Possible Heat Disorders for People in High-Risk Groups
Extreme danger	54° C or higher (130° F or higher)	Heatstroke or sunstroke likely
Danger	41° to 54° C (105° to 129° F)	Sunstroke, muscle cramps, and/or heat exhaustion likely. Heatstroke possible with prolonged exposure and/or physical activity.
Extreme caution	32° to 41° C (90° to 105° F)	Sunstroke, muscle cramps, and/or heat exhaustion possible with prolonged exposure and/or physical activity.
Caution	27° to 32° C (80° to 90° F)	Fatigue possible with prolonged exposure and/or physical activity.

Modified from http://www.srh.noaa.gov/ssd/html/heatwv.htm.

TABLE 107-3 Air Quality Index (AQI)

AQI Levels of Health Concern	Numeric Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51 to 100	Air quality is acceptable. for some pollutants, however, there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects. members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health alert: everyone may experience more serious health effects.
Hazardous	301 to 500	Health warnings of emergency conditions. The entire population is more likely to be affected.

Modified from http://www.airnow.gov/index.cfm?action=aqibasics.aqi.

surrounding mountains help keep polluted air in place and close to the surface.

Air Quality Index (AQI) is a measure of daily air quality in the context of human health. In the United States, the Environmental Protection Agency (EPA) calculates the AQI for five major air pollutants: ground-level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrous oxide. The AQI has a range from 0 to 500, with lower values (up to 50) associated with good air quality and higher values (300 and above) associated with levels of air pollution hazardous to health. The EPA uses color-coded categorizations of the AQI to indicate possible health effects associated with different values (Table 107-3).

Vector-borne diseases, such as malaria, dengue, and hantavirus, have been linked to climatic events. In the tropics, dengue outbreaks occur at the onset of rainy seasons, such as the monsoons. Malaria and hantavirus outbreaks in certain regions of the tropics have been associated with the warm phase of the El Niño Southern Oscillation (ENSO), when increased temperature is conducive to vector breeding.

Stratospheric ozone prevents much of the sun's ultraviolet (UV) radiation from reaching the earth's surface. UV radiation that passes through the atmosphere is a health concern, primarily to eyes and skin. The two primary factors affecting risk for receiving unhealthy levels of UV radiation are angle of the sun and elevation. Higher levels of UV radiation are more likely at high elevations, where radiation has to pass through less of the atmosphere. The *sun angle* refers to both its varying angle throughout the day and its differing angles at different latitudes. At low latitudes, the sun angle remains high throughout the year, and therefore sunburn risk remains relatively high. At higher latitudes, the risk is especially high in late spring and early summer, when solar angle is highest. In either case, this risk is enhanced during the hours around solar noon. In addition, clouds only scatter solar radiation; they do not block it. This allows UV radiation to reach the surface diffusely, where it is still harmful. *Diffuse radiation* is radiation that has been scattered, usually by clouds, but that still reaches the ground. As a result, sun protection should be used even when the sun is blocked by clouds.

Stratospheric ozone is not evenly distributed around the world and tends to be thinner at higher latitudes, particularly during the spring. Therefore, care should be taken to wear sunscreen, protective clothing, and eyewear when engaged in outdoor activity, particularly in springtime in the mid- to high latitudes and year-round in the tropics.

WEATHER FORECASTING

OBTAINING DATA AND FORECASTS AND PREDICTING WEATHER IN THE NEAR TERM

Weather forecasting in the wilderness requires data collection, whether from online sources (ideal) or with what is readily available and observable. Crude forecasts can be made by monitoring clouds and basic weather variables, such as temperature, humidity, and wind direction, if this is all that is available. If online resources are available, reliable short-term forecasts can be obtained for most locations on Earth, typically provided by either private or public weather services. The primary use of online sources lies in the ability to monitor real-time weather information, such as radar, satellite, and observations, in addition to obtaining forecasts. The primary purpose of data collection outdoors should be to make a rough forecast of ensuing weather conditions in the near term through 48 hours.

Proliferation of smartphones in recent years has allowed more accessible Internet connectivity in the wilderness. This allows for current weather forecasts and real-time radar and satellite images. In addition, there are many weather applications (apps) for use on smartphones. For a complete listing of weather apps for iOS, see https://itunes.apple.com/us/genre/ios-weather/id6001?mt=8. For a list of recommended weather apps for Android phones, see www.androidauthority.com/the-9-best-weather-apps-for-android-256942/.

PORTABLE WEATHER INSTRUMENTS OF USE IN THE WILDERNESS

Barometer

Barometers are useful for assessing evolution of weather systems, especially in the midlatitudes. Changes in atmospheric pressure at one location are small in comparison with changes as one moves up or down in elevation; thus, barometers must be calibrated with changes in elevation if this is not already done automatically. In general, the value of the atmospheric pressure is much less significant than its trend over time. A steady drop in pressure indicates the possibility of stormy conditions in the near future, whereas rising pressure generally portends fair weather.

Thermometer

Portable thermometers provide indication of imminent changes in weather conditions, such as those arising from passage of a frontal system. They could also be consulted to ascertain the probability of freezing conditions and risk for hypothermia. Because these applications do not require a high degree of precision, there is no need for a costly, high-precision instrument.

Lightning Detector

Portable lightning detectors are useful for detecting lightning within a 64- to 120-km (40- to 75-mile) radius, depending on the instrument. Lightning detectors operate with varying degrees of accuracy and can be limited in their ability to describe storm position and movement. Because they operate by detecting the electromagnetic pulses of lightning, interference can occur when operating near many types of electronic devices, including car engines, appliances, fluorescent lights, and even cell phones. However, most lightning detectors now have incorporated systems to warn the user of interference and automatically mitigate it. In addition, the interference can often be minimized by moving a few meters from the source, so outdoor operation is recommended.

TYPES OF FORECASTS

Forecasts vary by timescale, ranging from weather forecasts to seasonal climate forecasts.

Weather forecasts assess the future state of the atmosphere and its constituent elements in reference to components such as temperature, wind, and precipitation. Weather forecasts are generated using numeric integrations of the equations of motion in the atmosphere. Such forecasts require accurate observations of the initial atmospheric state that are fed into numeric computer models. There are four types of weather forecasts:

- *Nowcasts:* up to 0 to 3 hours, or 6 hours in some locations
- *Short-range forecasts*: up to 48 hours
- *Medium-range forecasts:* 3 to 7 days in advance
- *Long-range forecasts:* more than 7 days in advance

Skill

Accuracy of weather forecasts quickly declines with time because of the inherent chaos of the atmosphere. The details of midlatitude cyclones and smaller-scale events are impossible to forecast accurately beyond a few days, even if the pattern that produced them is relatively easy to identify. In the tropics, forecast skill is higher during years when either phase of the ENSO phenomenon—La Niña or El Niño—is underway, because ENSO is the single most dominant mode of climate variability at the seasonal and interannual timescales.[2] ENSO-led seasonal forecast skill tends to be higher in winter and spring seasons. This is particularly so for tropical and subtropical regions. However, in the higher latitudes of the subtropics and in the midlatitudes, seasonal forecast skill can be confounded by atmospheric circulation patterns driven by phenomena (e.g., North Atlantic Oscillation) that operate at shorter timescales.

HOW TO INTERPRET FORECASTS

ACCESSING FORECASTS

There are many online resources for weather forecasts for a particular location. In any country, the authoritative source for weather forecasts is the National Meteorological and Hydrological Services (NMHS) of that country. Links to the weather forecasts for cities issued by most NMHS centers are available through http://www.worldweather.wmo.int/ on the World Meteorological Organization (WMO) website.

North America

In the United States, the National Weather Service (NWS) is responsible for all outlooks, forecasts, and advisories. Some of these responsibilities are handled by specialized centers within the organization. The National Hurricane Center (www.nhc.noaa.gov/) issues all updates on tropical weather in the Atlantic and eastern Pacific Oceans, regardless of the impact on the United States. The Storm Prediction Center (www.spc.noaa.gov/) handles all severe weather, including tornado and severe thunderstorm watches. Local NWS offices are responsible for issuing warnings on such events. Medium- to long-range discussions, outlooks, and forecasts are available from the Climate Prediction Center (www.cpc.noaa.gov/), and broader national forecasts and discussions for different regions of the country are available from the Hydrometeorological Prediction Center (www.hpc.ncep.noaa.gov/), which also provides guidance on quantitative precipitation forecasts and winter weather.

In Canada, Environment Canada (www.weatheroffice.gc.ca) is responsible for all outlooks, forecasting, and advisories. These include data and forecasts regarding hurricanes, sea ice, aviation, and air quality. Environment Canada issues watches, warnings, and special weather statements for all of Canada, including its waters.

International Forecasts

The WMO has a dedicated website for severe weather warnings for various parts of the world. Such forecasts are categorized by region (e.g., European Union: www.meteoalarm.eu/) or by weather phenomena (e.g., tropical cyclones or thunderstorms: severe.worldweather.org/). Forecasts of severe weather in maritime regions are available through the Global Maritime Distress and Safety System (weather.gmdss.org/).

FORECAST VARIABLES

Seasonal Precipitation Forecasts

Seasonal precipitation forecasts are presented as tercile probability forecasts in the United States. Tercile forecasts are based on the assumption that precipitation in a coming season has a 33% probability of falling within one of three possible categories: below, near, or above normal. The forecast is expressed as the probability of seasonal rainfall being below normal, near normal, or above normal, or in terms of expected rainfall anomalies.

Temperature Forecasts

Temperature forecasts are issued as expected daily minimum and maximum temperatures. In countries outside the United States, the convention is to express the two values in degrees Celsius.

Humidity

Humidity forecasts are usually issued as expected relative humidity, ranging from 0% to 100%.

Wind Direction and Speed

Wind forecasts indicate direction (eight possible directions: N, NE, E, SE, S, SW, W, and NW) and speed (expressed as kilometers per hour or miles per hour). In maritime environments, the convention is to use knots (1 knot equals 1.852 km/hr [1.151 miles/hr]).

Precipitation

Precipitation is forecast as probability of precipitation (POP) and, if applicable, quantitative precipitation forecast (QPF). POP should be interpreted as the probability that precipitation will fall at any specific point. QPF is the total amount of rain (or melted frozen precipitation) expected to fall in a specified period.

FORECAST PRODUCTS

UNITED STATES

According to the NWS, a warning is issued when a hazardous weather or hydrologic event is occurring, imminent, or likely. A warning means that conditions pose a threat to life or property. An advisory is also issued when such events are occurring, imminent, or likely, but the event is not expected to be as severe. The criteria for advisories and warnings vary among different NWS offices. Events such as heat index and winter weather, including snow, ice, and wind chill, may be perceived differently in different parts of the country. A watch is issued when the risk for a hazardous or hydrologic event is increasing, but its occurrence, location, or timing is still uncertain. As time advances, a watch could be replaced by an advisory or a warning. A watch is issued when warning-level conditions are anticipated. When a watch is issued, people should proceed with a plan of action for the predicted event and continue to be alert for further information and possible warnings.

INTERNATIONAL

Regional Specialized Meteorological Centers (RSMCs) and Tropical Cyclone Warning Centers (TCWCs), established through the WMO, provide warnings on severe weather, particularly cyclones. Figure 107-6 shows locations of the RSCMs and TCWCs.

Tropical storm warnings use the Saffir-Simpson scale. Such warnings are often accompanied by a brief description of the damage likely to occur with the passage of each storm. Box 107-1 provides examples of the narrative used by the Indian Meteorological Department, responsible for RSMC-New Delhi, to describe potential damage associated with a "deep depression" (28 to 33 knots) and a "severe cyclonic storm" (equivalent to a category 4 on the Saffir-Simpson scale).

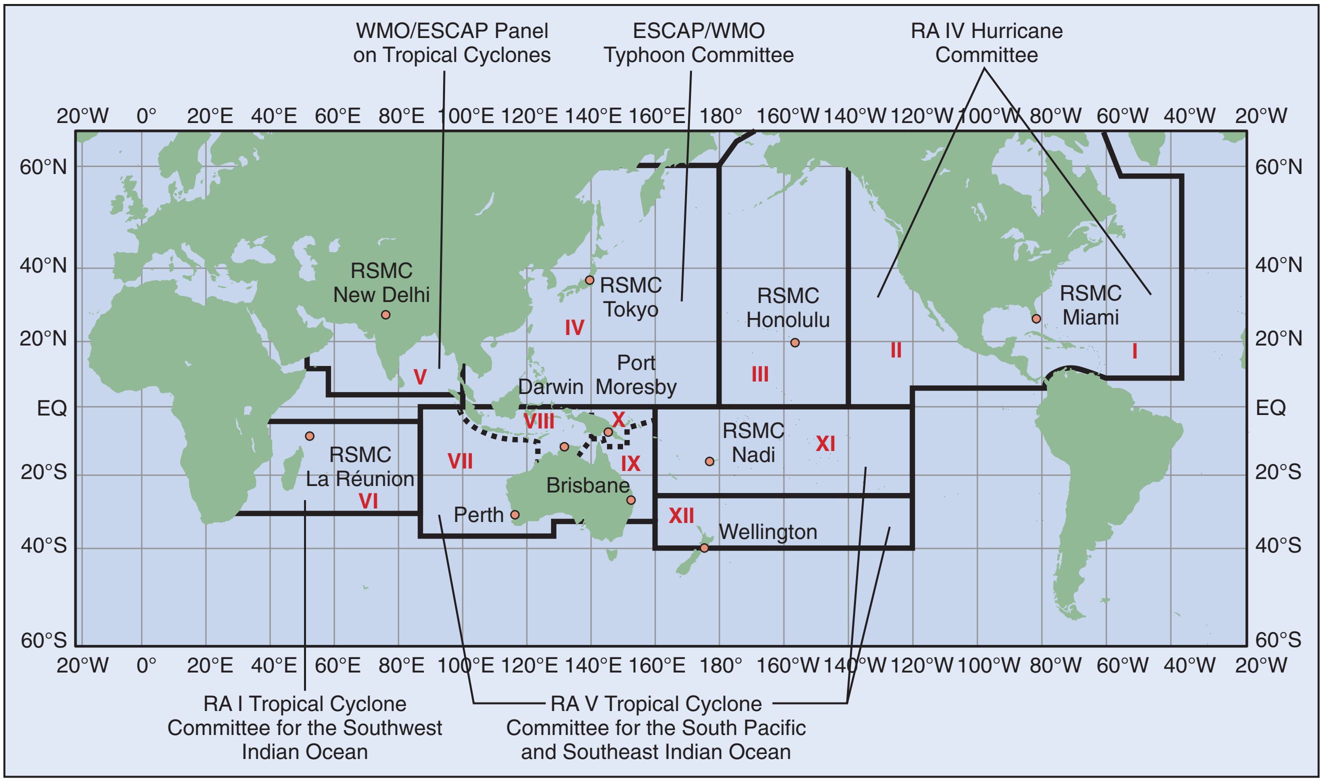


FIGURE 107-6 Location of the Regional Specialized Meteorological Centers and Tropical Warning Centers. *(From http://www.nhc.noaa.gov/gifs/wmo-tcp2.jpg.)*

HOW TO OBTAIN SURFACE OBSERVATIONS

UNITED STATES

Historic surface observations for the United States are available online through the National Climatic Data Center (www.ncdc.noaa.gov/oa/climate/climatedata.html). Station-based data are available from hourly to monthly time resolution. The data are available free of charge to e-mail users with domains ending in .edu, .k12, .gov, and .mil; otherwise, fees apply to cover processing expenses. Data are also available from automated stations and volunteer observations through the NWS. Another source of data is the volunteer network of precipitation observers known as Community Collaborative Rain, Hail and Snow; data are available at www.cocorahs.org/.

GLOBAL DATA

Surface observations from various part of the globe can be accessed through the Global Historical Climatology Network (GHCN). Such observations are available as station-based

BOX 107-1 Examples of Indian Meteorological Department Narratives

What is the damage potential of a deep depression (28 to 33 knots)?
What are the suggested actions?
Structures: Minor damage to loose/unsecured structures.
Road/Rail: Some breaches in Kutcha road due to flooding.
Agriculture: Minor damage to banana trees and near coastal agriculture due to salt spray. Damage to rice paddy crops.
Marine Interests: Very rough seas. Sea waves about 4 to 6 m high.
Coastal Zone: Minor damage to Kutcha embankments.
Overall Damage Category: Minor.
Suggested Actions: Fishermen advised not to venture into sea.
What is the damage potential of a super cyclonic storm (120 knots [222 km/hr]) and above?
What are the suggested actions?
Structures: Extensive damage to nonconcrete residential and industrial buildings. Structural damage to concrete structures. Air full of large projectiles.
Communication and Power: Uprooting of power and communication poles. Total disruption of communication and power supply.
Road/Rail: Extensive damage to Kutcha roads and some damage to poorly repaired pucca roads. Large-scale submerging of coastal roads due to flooding and seawater inundation. Total disruption of railway and road traffic due to major damages to bridges, signals, and railway tracks. Washing away of rail/road links at several places.
Agriculture: Total destruction of standing crops/orchards, uprooting of large trees and blowing away of palm and coconut crowns, stripping of tree barks.
Marine Interests: Phenomenal seas with wave heights more than 14 m. All shipping activity unsafe.
Coastal Zone: Extensive damage to port installations. Storm surge more than 5 m. Inundation up to 40 km in specific areas and extensive beach erosion. All ships torn from their moorings. Flooding of escape routes.
Overall Damage Category: Catastrophic.
Suggested Actions: Fishermen not to venture into sea. Large-scale evacuations needed. Total stoppage of rail and road traffic needed in vulnerable areas.

Modified from www.imd.gov.in/section/nhac/dynamic/faq/FAQP.htm#q51.

observations and as gridded products. Precipitation and temperature are the two variables usually available through the GHCN. The following are links to GHCN data:

- Monthly station-based precipitation: http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.GHCN/.v2beta/
- Daily station-based precipitation and minimum-maximum temperature: http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.GHCN_Daily/.version1/
- Monthly station-based temperature: http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.GHCN/.v2/
- Gridded (2° × 2° resolution) monthly precipitation and temperature: http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.CAMS/

HOW TO ACCESS AND INTERPRET WEATHER SATELLITE AND RADAR DATA

In the United States, the NWS website has links to real-time radar and weather satellite imagery. The easiest method to track the passage (and associated precipitation) of a storm is to study radar imagery of a system available for different regions of the United States (Figure 107-7).

Clicking on the region of interest takes one to a higher-resolution image, where relevant warnings (e.g., thunderstorms) are marked on the imagery (Figure 107-8).

The legend on the right enables the user to obtain an idea of the location of the highest intensity of precipitation. Table 107-4 provides an indication of the approximate rainfall intensity, which is associated with the units dBZ (known as "reflected intensities" or "decibels of Z").

Satellite images enable a user to obtain a quick, large-scale estimation of where overcast/stormy conditions are located and where clear weather prevails, with a satellite loop allowing for a general extrapolation of these conditions to locations downstream (Figure 107-9).

TABLE 107-4 Doppler Radar Scale of Intensity

dBZ	Rain Rate (inches/hr)
65	16+
60	8.00
55	4.00
52	2.50
47	1.25
41	0.50
36	0.25
30	0.10
20	Trace
<20	No rain

From http://www.srh.noaa.gov/jetstream/doppler/baserefl.htm#rainrate.
dBZ, Decibels of reflectivity (Z).

WEATHER PREDICTION IN THE WILDERNESS

CLOUDS

Clouds appear in various shapes and sizes and at different altitudes. Clouds are often classified according to their height and form (Figure 107-10):

- *High clouds:* cirrus, cirrostratus, and cirrocumulus
- *Middle clouds:* altostratus and altocumulus
- *Low clouds:* stratus, stratocumulus, and nimbostratus
- *Clouds with extensive vertical development:* cumulus and cumulonimbus

Frequency of occurrence of the different cloud types differs in the tropics and higher latitudes. Cumulus is the predominant cloud form in the tropics.[1]

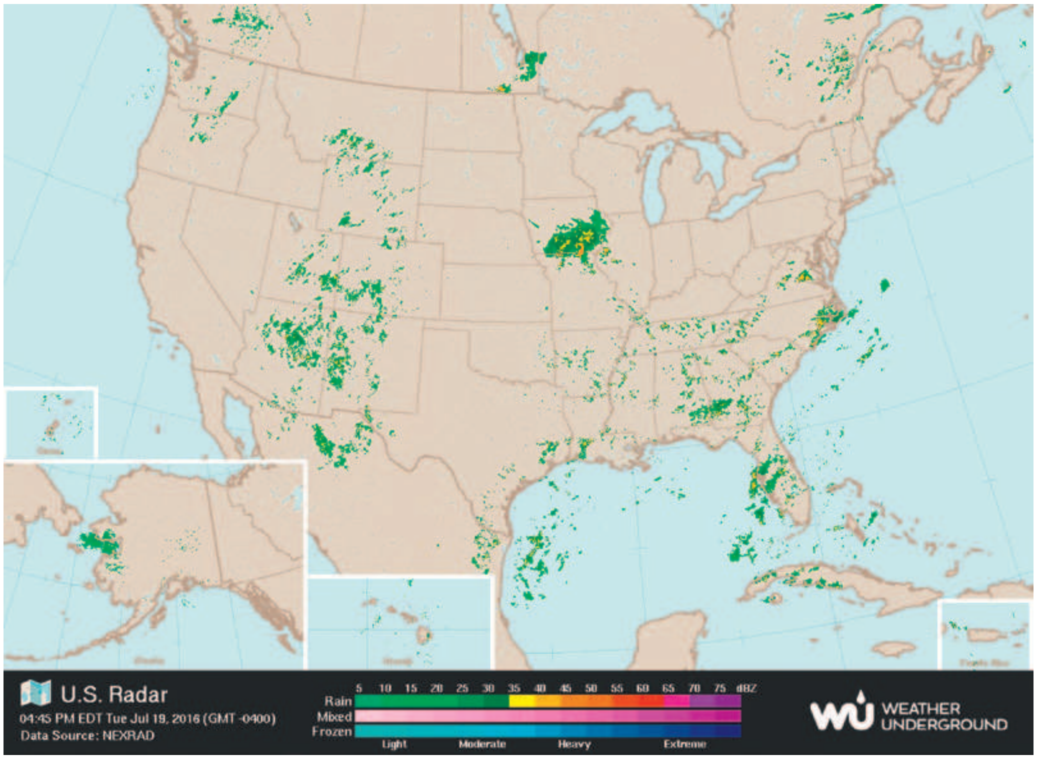


FIGURE 107-7 Example of radar imagery over the United States.

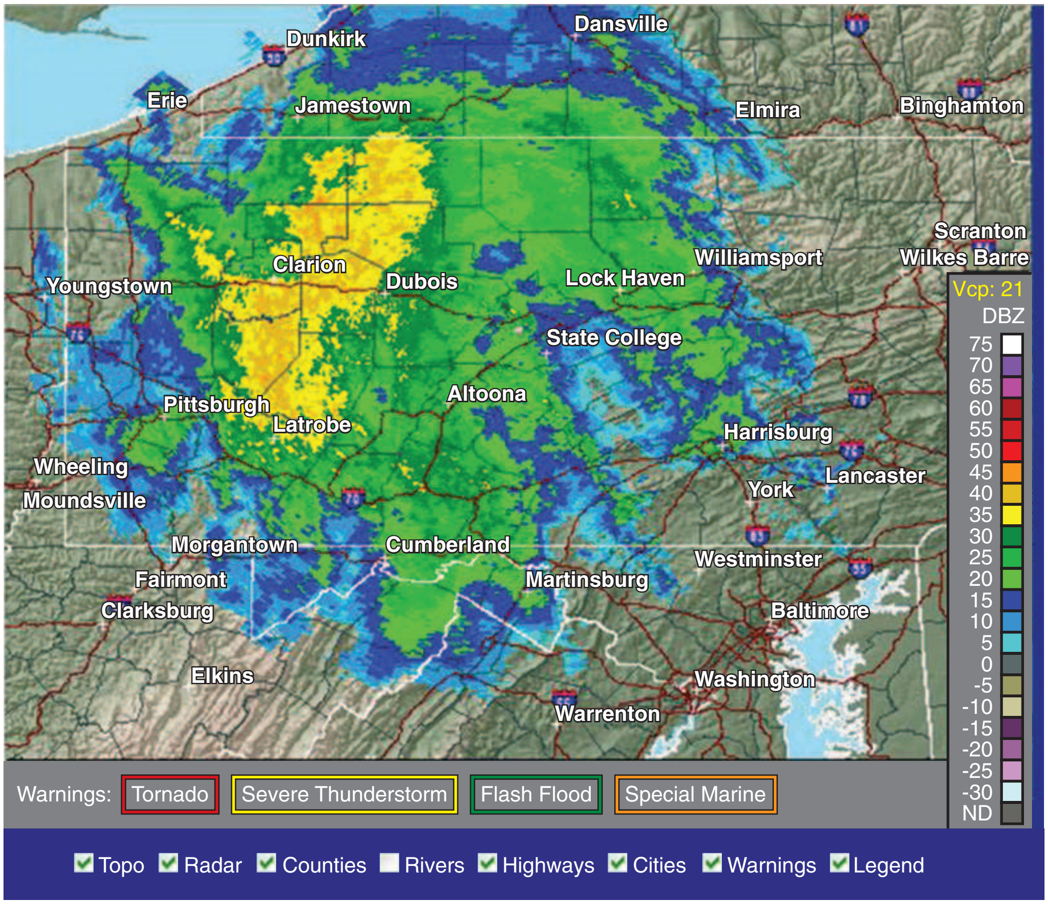
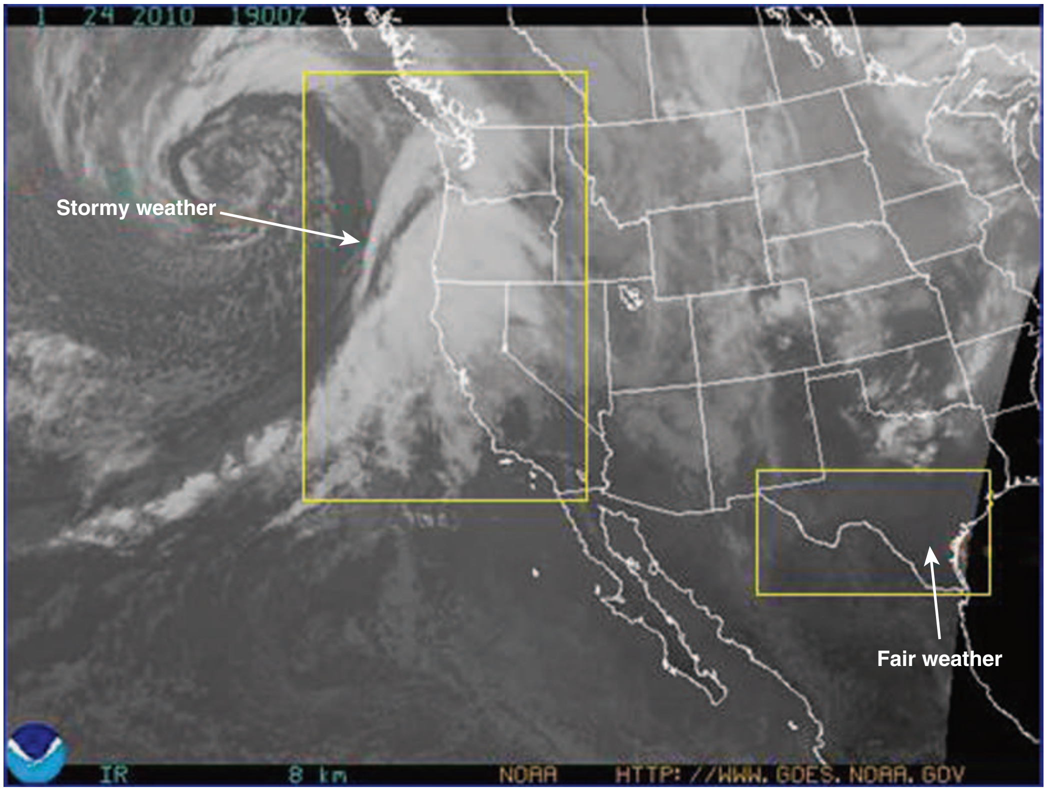


FIGURE 107-8 Example of a Doppler radar image.

GOES WESTERN U.S. SECTOR IR IMAGE



Western Conus Sector (IR Ch4)

FIGURE 107-9 Example of the usefulness of satellite imagery in capturing stormy and clear conditions.

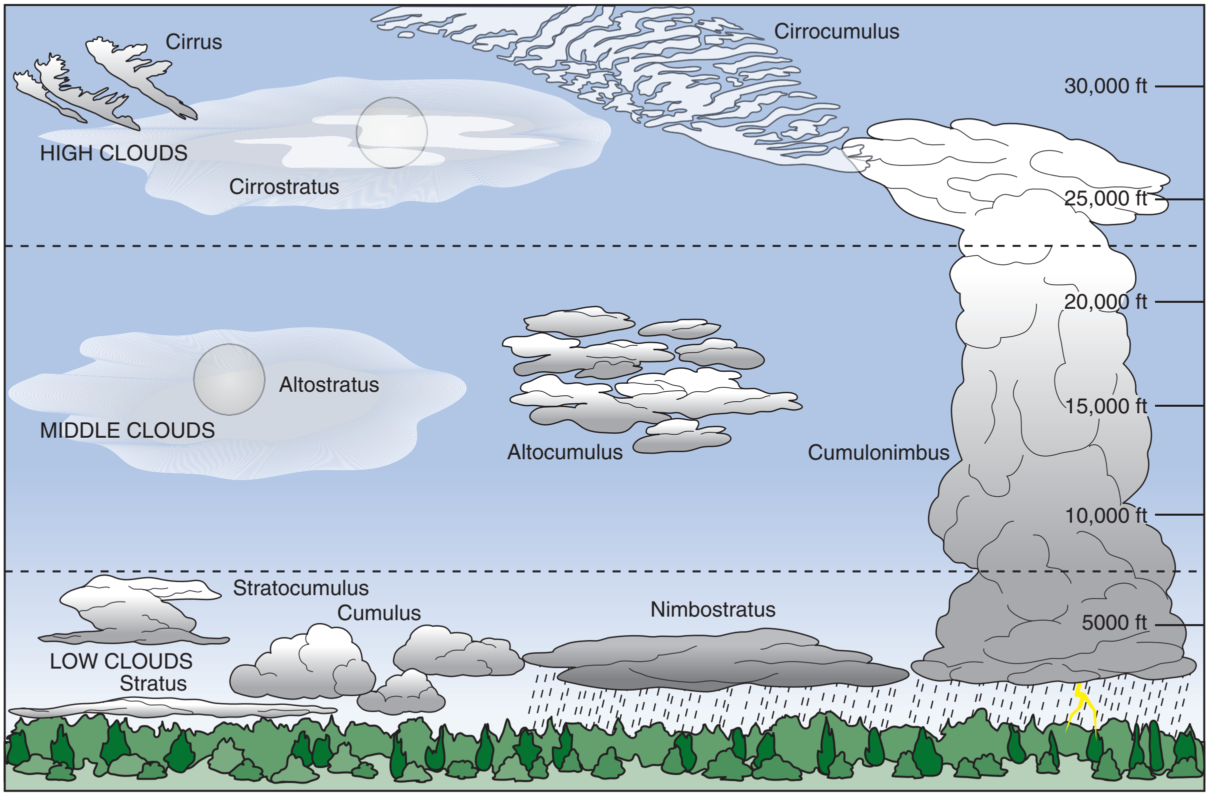


FIGURE 107-10 Guide to different cloud types.

CLOUDS AND WEATHER

Clouds are among the best indicators of changing weather in the wilderness. Figure 107-11 shows the typical progression of clouds as a midlatitude cyclone moves through to the left of the observer, whereas a simplified version would apply when it moves to the right. Cirrus clouds are often present 1 to 2 days before a storm and serve as the earliest indication that a cyclone is approaching. They should be noted as a sign that a storm might be on its way, bearing in mind that cirrus can be associated with storms that have no appreciable impact on a location, as well as with other innocuous disturbances.

When cirrus begins to transition into a deck of altostratus, it can reasonably be assumed that the clouds are associated with a storm or front that is nearing. Stratus clouds are most frequently associated with warm fronts because they are a good indication that air is being forced to rise gradually over a wedge of cooler air, as is found in a warm front. In general, stratus clouds occur as a warmer air mass is being lifted over a cooler one; the longer this occurs, the more likely the stratus clouds are to lower and begin precipitating. Therefore, as altostratus clouds lower into a low, gray deck of nimbostratus clouds, it is a good assumption that a light, steady rain or snow will follow. Nimbostratus clouds occur in the vicinity of the warm front and near the center of low pressure, where air is being lifted.

The location of low pressure can often be assessed using a simple rule called Buys Ballot's law. When the observer stands with his or her back to the wind in the northern hemisphere, the low pressure will be to the left. This rule is reversed in the southern hemisphere and works best at higher latitudes.

The weather conditions ahead of a warm front typically include winds from the east or southeast with cool conditions and a slowly dropping barometric pressure. After the front passes, the pressure continues to drop, and the wind shifts clockwise to the south or southwest, in most regions bringing in warmer and

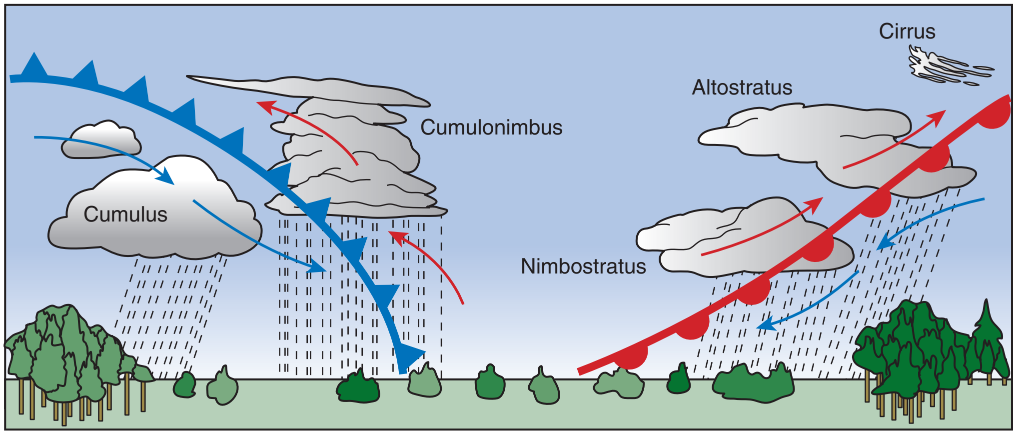


FIGURE 107-11 Progression of a midlatitude cyclone as seen from the ground.

moister air. This region of the cyclone between the cold and warm fronts is associated with the most instability, which increases the chance for showers and thunderstorms and the highest probability of severe weather (see Figure 107-2). Because there is more instability, cumulus clouds dominate this sector. In the winter, warm air can rapidly be transported into this part of the storm, changing snow and ice to rain.

Passage of the cold front is easy to observe because there are several sharp changes in weather conditions. Before its passage, wind typically blows from the south or southwest, the dew point and temperature are relatively high, and air pressure is dropping. The strongest atmospheric lift is found near a cold front, so cumulonimbus clouds with associated heavy rain and severe weather can be found at the frontal boundary. Typically, precipitation in the vicinity of a cold front does not fall for as long as it does ahead of a warm front, because the slope, and therefore area of uplift, is much steeper and narrower with a cold front. After the front passes, wind typically shifts clockwise to the west or northwest, temperature and dew point slowly drop, and air pressure rises. Strong cold frontal passages can be observed as a deck of low or midlevel clouds sharply giving way to blue sky. Clearing skies are typically observed relatively quickly after the front has passed, often with gusty winds remaining for 1 day or longer.

Dense cumulonimbus clouds in the tropics portend thunderstorms and lightning. Altocumulus and altostratus clouds are associated with disturbed weather, such as tropical cyclones, or in locations of large-scale orographic lifting.[1] Cirrus clouds often form as leftover anvils from cumulonimbus clouds. However, they can also form independently and are usually associated with upper-atmospheric cyclones. High cirrus clouds are often observed before formation of a tropical cyclone, followed by midlevel and low-level stratus clouds (see Figure 107-3). Eventually, showery precipitation from cumulus and cumulonimbus clouds arrives and increases in intensity as pressure steadily falls.

BOUNDARY LAYER STABILITY

Fronts and cyclones are not always needed for precipitation or severe weather. Strong daytime heating is all that is necessary to induce deep convection, which can occur frequently in the moister parts of the tropics and subtropics, as well as during the summer in midlatitudes. Stability of the lower atmosphere can be difficult to assess from observation, but can be useful to determine how much potential there is for thunderstorms. To achieve deep convection, air must be readily able to rise and overcome any resistance. Rising plumes of smoke or steam can give an indication of the stability of the lower atmosphere. If it rises to a certain level before spreading out horizontally, it is safe to assume that the lower atmosphere is at least somewhat stable. If nothing stops it from rising, the lower atmosphere may be quite unstable. A large amount of haze or pollution in the air is an indication of a stagnant environment where air moves very little, either horizontally and vertically. In arid regions, "dust devils" are also indication of an unstable, but dry, atmosphere. Clouds in their vertical development can be good indicators of atmospheric stability. Clouds with minimal vertical development, such as stratus and "fair-weather" cumulus, indicate a stable atmosphere. Rapidly building cumulus clouds are a good indication that the atmosphere is unstable, and showers or thunderstorms should be forecast.

BACKING AND VEERING

To aid in assessing current weather conditions, cold and warm air advection can be diagnosed by observing movement of clouds at different levels. Advection is horizontal transport of air from one location to another, bringing with it the temperature and humidity characteristics of its source region. Cold-air advection, an indication of stability and improving (but colder) weather, often follows passage of low pressure. Wind direction at different levels of the atmosphere differ in this situation; at the surface, the wind may blow from the west or northwest, but much higher in the atmosphere, the wind may be out of the southwest or west, respectively. The wind is said to *back with height*, and this is an indication of cold-air advection. Similarly, warm air advected ahead of warm fronts creates an unstable situation, because it is forced to rise over the existing air mass. At the surface, wind out of the southeast is often accompanied by a southwesterly wind at the midlevels of the atmosphere, so the wind is said to *veer with height*. Two levels of clouds with movement that veers with height is a good indication that a steady rain or snow will follow.

REFERENCES

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

CHAPTER 108

Ropes and Knot Tying

LOUI H. MCCURLEY AND THOMAS EVANS

Every wilderness traveler should be familiar with use of ropes and other tension materials (members) such as webbing and cordage. In the hands of someone who has a reasonable amount of knowledge and skill, these tools may be used to perform many functions. The ability to use software (ropes, webbing, cordage) effectively and to create the knots that make them functional is a hallmark of an avid and experienced outdoors person. These tools are often used for lashing, shelter construction, food storage (protection from wildlife), and specialized wilderness adventure activities such as climbing, canyoneering, and caving. More importantly, during an emergency, ropes, webbing, and cordage can be lifesaving resources for the person who knows how to use them properly. This chapter provides an introduction to rope, webbing, and cordage use. The interested reader should consult training manuals for further information and study.

ROPES, WEBBING, AND CORDAGE TERMINOLOGY

In terms of equipment nomenclature, rope, cordage, and webbing are classified as *software*. This term refers to the concept of soft,

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1. Atkinson GD. Forecasters' guide to tropical meteorology, 1971, reprint. Honolulu: University Press of the Pacific; 2001.
2. Goddard L, Mason SJ, Zebiak SE, et al. Current approaches to seasonal-to-interannual climate predictions. Int J Climatol 2002;21:1111.

pliable, and "knotable" material. Any software used to support a human load should be specifically designed, tested, and approved for that purpose, whether for recreation or rescue.

Cordage is a general term used to refer to various types of cords, lines, ropes, and strings intended for use as tension members. Typically, cordage is composed of flexible intertwined fibers that are woven, twisted, braided, or otherwise formed into a round structure. In practice, particularly when referring to life safety products, cordage is used in a narrower sense. Instead, the word *rope* is used to describe a thicker tension member, such as might be appropriate for use as a primary support line, whereas cordage is reserved to describe smaller-diameter ancillary items.

Webbing is flat, unlike rope and cordage, and used to tie knots in and around locations in which rope and cordage would be damaged. The flatter shape of webbing makes it more conducive for certain functions than rope or cordage.

ROPE SELECTION CONSIDERATIONS

Selecting the right rope for the job means first and foremost understanding how a rope is affected by, and performs with, the way you use it. The following discussion provides some background for balancing these needs against available alternatives.

FALL FACTORS

Fall factors can be calculated by dividing the fall distance by the length of the rope between the load and the anchor or belay. Thus, a 0.9-m (3-foot) fall on a 2.7-m (9-foot) rope would be a fall factor of 0.3; an 0.9-m (3-foot) fall on an 0.9-m (3-foot) rope would be a fall factor of 1.0; and a 0.9-m (3-foot) fall on a 30.5 m (100-foot) rope would be a fall factor of 0.03. This calculation assumes the fall takes place in free air without rope drag across the rock face or through intermediate equipment (Figure 108-1).

The danger of a high fall factor on a low-stretch or static rope is not necessarily that the rope will break, but that the high-impact forces may subject the person to great discomfort and possible injury or death. A static rope transfers more of a shock load to the anchors than does a dynamic rope, increasing damage potential. Another concern in any impact load situation is the effect such forces have on equipment, such as belay devices, rope grabs, or ascenders. Some of these devices can damage a rope when subjected to relatively low-impact forces.

At one time, the general recommendation was that a dynamic rope should be used where high fall factors were likely, whereas static rope is more suited to circumstances involving lower fall factors. However, subsequent research has shown that the concept of fall factors does not apply to static rope in the same manner as to dynamic rope, and it is better understood that force absorption is more a matter of system performance than simply a matter of rope. The study of impact forces and ways that different pieces of equipment relate to different constructions of rope when subjected to such forces is fairly complicated, but two general rules of thumb are (1) design and operate rope systems to minimize the potential for high-impact forces, and (2) exercise great caution when selecting belay methods.

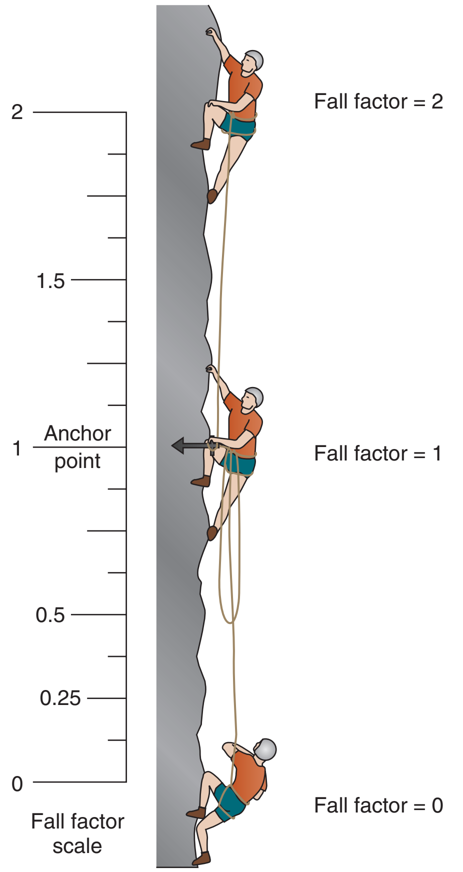

FIGURE 108-1 Fall factors.

ROPE DIAMETER

Just as no single type of rope is appropriate for all activities, no single size fits all conditions. Purchasing the largest rope in the hope that it will fit all situations because it is strong could lead to problems when working with the rope and auxiliary equipment. Rope strength and elongation are more critical, and size considerations should follow. However, ensure that hardware (e.g., ascenders, rappel devices) is designed for the chosen rope diameter.

ROPE STRENGTH

Rope strength is a misunderstood topic. Life safety rope strength is usually referred to as *minimum breaking strength*. Unfortunately, reported numbers do not necessarily reflect numbers adequate for comparison. Variations in test methods, as well as in analysis of results, provide little more than marketing fodder that can create great confusion.

One way to report strength is as the rope's "ultimate" or "maximum" breaking strength, which is the highest score of a given rope in a series of tests. An alternative is to list the average breaking strength of several tests. A more conservative method is to define breaking strength at a value that is two or three standard deviations (2 or 3 SD) below the average test result. Another method is to define the minimum as not greater than 10% below the average. Often, figures for tensile or breaking strength are reported with no explanation about whether they are average or minimum, or whether some other measure was used. Simply stated, the term *breaking strength* may refer to any one of these reporting methods or to another method altogether.

To add to the confusion, a number of factors affect test results. The rate at which the pull is applied to the rope, temperature, humidity, diameter of the object to which the rope is attached, and other factors all affect test results. Unless ropes are tested in exactly the same way, results cannot be directly compared. Consequently, only general comparisons are justifiable.

One common test method that has been adopted by several standards organizations is CI-1801 from the Cordage Institute. CI-1801 for life safety rope is specific and gives a common baseline from which to attain results. This standard also calls for a very conservative reporting method, wherein minimum breaking strength is defined as 3 SD below the mean of several break tests; this helps normalize results. In addition to type of construction, the strength of a rope comes from the amount of nylon used and the type of construction; similar rope constructions of the same diameter should have similar strengths if they have the same amount and quality of nylon.

Results from laboratory tests may differ greatly from rope performance in real-world applications, which cannot be consistently and accurately quantified. For example, a knotted rope loaded over a building edge may not have anything close to the rope strength measured in a laboratory.

SAFETY FACTORS

It is clear that a rope should be stronger than the force of the intended load, but how much stronger? The ratio of a rope's strength to the weight of the intended load is often called a *design factor*. If the strength of a rope is 1134 kg (2500 lb) and the intended load is 227 kg (500 lb), the design factor is 5:1. The design factor takes into consideration only the new condition of an item as it is designed to perform. When translating a design factor into a system safety factor, factors such as age, wear and tear, dry or wet conditions, and system rigging should be considered.

Because a rope system is only as strong as its weakest link, selecting a sufficiently strong rope is only the beginning. Generally, component design factors tend to be very high, often as high as 15:1. However, when all these components are joined into a larger system in the real world, the remaining system safety factor may be less than half that value.

The *system safety factor* is the ratio between the weak link in a system and the load to be applied. System safety factors also take into account the ways that loads are applied to a system. For example, redirectional pulleys, rigging angles, and mechanical advantage systems can all increase forces within a system.

As a rule, the higher the probability and consequences of failure, the higher should be the system safety factor.

SERVICE LIFE

The service life of a rope cannot be determined in advance. How long a rope lasts depends on many variables, including individual care, frequency of use, type of hardware used, speed of descent on rappels, exposure to abrasion, local climate, and type of loading. DuPont claims at least a 10-year shelf life for nylon, and rope tests have confirmed that an unused rope can last up to 10 years without significant strength loss. However, used ropes degrade more quickly.

Any rope can fail after poor care or under extreme conditions, such as shock loading and sharp edges. A shock load involving a 0.25 fall factor for a static rope or 1.5 fall factor for a dynamic rope will likely cause internal invisible damage to the rope, although damage may also be caused with lower fall factors. Regardless of how long a rope has been in service, it should be immediately discarded when it becomes cut, when abrasion has caused significant wear to the sheath, after a hard shock load, when chemical contamination is suspected, or any time there is doubt about it for any reason.

WEBBING

No discussion of ropes and tension members would be complete without mentioning webbing. As with rope, only webbing designed for outdoor use and fabricated to hold a human load should be used in applications supporting body weight. Webbing is engineered to meet one of two standards: climbing specification (climb spec) or military specification (mil spec) (Table 108-1). Climb spec webbing is stronger than mil spec webbing; however, both webbing types are strong.

TABLE 108-1 Webbing Minimum Breaking Strength by Size (Width) Noted in Pounds-Force (lbf) and Kilonewtons (kN)

Width	Minimum Breaking Strength
9.5 mm (0.375 inch)	950 lbf (4.2 kN)
12.7 mm (0.5 inch)	1000 lbf (4.4 kN)
14 mm (0.563 inch)	1500 lbf (6.7 kN)
16 mm (0.625 inch)	2250 lbf (10.0 kN)
19 mm (0.75 inch)	2300 lbf (10.2 kN)
22 mm (0.875 inch)	3100 lbf (13.8 kN)
25 mm (1.0 inch)	4000 lbf (17.8 kN)

TABLE 108-2 Cord Minimum Breaking Strength by Size (Diameter) Noted in Pounds-Force (lbf) and Kilonewtons (kN)

Diameter	Minimum Breaking Strength
4 mm (0.16 inch)	720 lbf (3.2 kN)
5 mm (0.20 inch)	1125 lbf (5.0 kN)
6 mm (0.24 inch)	1620 lbf (7.2 kN)
7 mm (0.28 inch)	2200 lbf (9.8 kN)
8 mm (0.31 inch)	2875 lbf (12.8 kN)

Webbing comes in two forms, flat and tubular. Generally, flat webbing is stronger but less abrasion resistant, whereas tubular webbing is weaker (but strong enough) and significantly more abrasion resistant. Consequently, most sport participants use tubular webbing. Flat webbing is one sheet of woven fibers; tubular webbing is a continuous tube of webbing that lays flat. To determine if webbing is tubular, cut an end open and see if it is possible to open the webbing. If there is a space inside, it is tubular.

Webbing can be made out of the same fibers as ropes; however, most webbing on the market is made of nylon or Dyneema. The most common size is 1-inch (2.5-cm) tubular webbing.

In general, webbing is used in locations where minimal stretch is desired, where tying a rope would or could cause damage, or in locations where a larger interface would help the software stay put. Webbing is inexpensive, so using webbing to sling trees or rocks is a good way to preserve rope by preventing abrasion and rubbing. Because webbing is flat, when wrapped around an object, considerable friction is created, thus preventing the webbing from becoming loose. As a result, webbing is a favorite for building anchors on and around objects, as well as for building etriers (webbing ladders) and other short tethers.

Because webbing is flat, it behaves differently when knotted, so knots such as the overhand bend or overhand on a bight are better choices for tying webbing. Except for climbing hitches, almost all knots in webbing derive from the overhand knot, usually the overhand bend (water knot) or overhand on a bight.

ACCESSORY CORD

Accessory cord, or just cord, superficially resembles rope but behaves much differently. Accessory cord may be found in a kernmantle construction, appearing almost identical to kernmantle rope, or in a braided construction. Experienced users know that kernmantle cordage can be used to support human loads when used appropriately, but braided cordage should not be used to support a human life. Kernmantle accessory cord used for life safety should meet an appropriate standard (e.g., UIAA, CEN, CI-1803) (Table 108-2). General utility cord may be strong but is not held to the same quality standards as kernmantle cordage.

Around camp, utility cordage has many uses (e.g., guy lines for tents, securing food in trees, tying equipment to backpacks). During a medical emergency, these cords can be used effectively to splint and otherwise stabilize patient injuries. However, cords should not be used for life support functions. Kernmantle cord is frequently used to build anchors (cordelette), tie climbing hitches (Prusik hitch; see Hitches, later), or other short, personal tethers. As with webbing, kernmantle cord is used in places where using rope could produce unwanted rope abrasion. Some prefer cordage because it is easier to tie knots using cord, and strands slide more easily over anchor hardware, thus making multipoint anchors easier to fabricate. As with rope, a wide variety of fibers may be used to make cordage, although nylon and Dyneema may be most common. For best results, use sewn rather than tied Dyneema cordage, because this fiber has a low coefficient of friction, allowing knots to slide out more easily (see Knot Safety, later).

ROPE FOR LIFE SAFETY

Not every rope is appropriate for every purpose; ropes used for life safety should be different from those used to make camp. Rope users should understand the characteristics of different ropes and should choose ropes with the desired characteristics for their intended function.

Ropes used in non–life safety applications are known as *commodity ropes* and can be found in hardware stores, discount stores, and one's garage. These ropes are suitable for use in noncritical applications, where rope failure is unlikely or would have relatively minor consequences.

No rope should ever be used to support a human life unless it has been engineered and built for that purpose. Stories abound of towropes being (fatally) used as climbing ropes, utility ropes coming apart when used as hand lines, and natural-fiber ropes rotting away to nothing. A good way to know a rope is designed for life safety purposes is to check whether it is certified to any life safety standards, such as those promulgated by the International Climbing and Mountaineering Federation (UIAA), Cordage Institute (CI), American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), Committee for European Normalization (CEN), or National Fire Protection Association (NFPA).

Various life safety ropes are manufactured for different applications because the desired rope priorities are different for rock climbers, mountaineers, cavers, rope access technicians, and rescue personnel. Although priorities vary, users consider similar variables but want different combinations of properties. Important performance considerations for life safety rope include the following:

- Strength
- Impact force transmitted during a fall
- Number of falls held
- Elongation
- Diameter
- Abrasion resistance
- Compatibility with other equipment
- Hand (knotability)
- Weight
- Flotation

Life safety rope users generally select rope based on whether they want a rope that stretches a little, a lot, or somewhere in between. As such, life safety rope is classified into three types: dynamic, low stretch, and static. Each of these three rope types is tested to different standards and criteria.

Although there are no cookie-cutter solutions to rope selection, some generalizations can be made. A climber who could potentially take a significant fall on a rope will opt for a higher-stretch rope for its ability to absorb the forces of a fall—a dynamic rope. A rescuer who wants to lower or raise a load without excess elongation may choose a rope with as little stretch as possible—a static rope. The user who wants a limited amount of stretch but would like at least some force-absorption capability may opt for a low-stretch rope. Therefore, to select the appropriate rope, it is important to understand the desired rope functions and performance characteristics.

STRENGTH

Strength requirements for life safety rope are most important to people who are using the rope for raising, lowering, ascending, or rappelling. Although most rope users never come close to pushing the strength limits of their equipment, a necessary margin of safety should be engineered into any system. In extreme environments or with heavy loads and complex systems, combined with safety margin requirements, creating systems with the desired safety margin can be a challenge.

Every system should be built to withstand greater than the actual force expected on the system. The difference between these two numbers is known as a "safety factor" and is expressed as a ratio. For example, a system capable of withstanding up to 5000 lb at its weakest point, but is expected to only see 1000 lb in actual use, is said to have a 5:1 safety factor. That is, the actual strength of the system is five times greater than the intended load.

TABLE 108-3 Rope Minimum Breaking Strength by Size (Diameter) Noted in Pounds-Force (lbf) and Kilonewtons (kN)

Diameter	Minimum Breaking Strength
7 mm (0.28 inch)	2200 lbf (9.8 kN)
8 mm (0.31 inch)	2875 lbf (12.8 kN)
10 mm (0.38 inch)	4500 lbf (20.0 kN)
11 mm (0.44 inch)	6000 lbf (26.7 kN)
12.5 mm (0.5 inch)	9000 lbf (40.0 kN)
16 mm (0.63 inch)	12,500 lbf (55.6 kN)

Safety factors are most appropriately applied to the completed system, not just the rope or other individual components. What constitutes an appropriate safety factor is at the discretion of the user. When there is a low likelihood of failure with minimal consequence, a safety factor as low as 2:1 may be appropriate. Situations that involve a high probability or consequence of failure may call for a higher safety factor.

Establishing and calculating an appropriate safety factor requires significant user sophistication and high component strengths to compensate for strength reductions that occur as the equipment is integrated into a system. According to CI specifications, static and low-stretch life safety rope must meet the minimum strength requirement outlined in Table 108-3.

IMPACT FORCE

Impact force is an important consideration, especially for sport climbers who are climbing above their protection, thereby exposing themselves to a fall with significant impact potential. Dynamic ropes are typically used for such applications. They are designed to absorb energy during a fall so that the force is not transmitted to the climber or to anchorages. Dynamic ropes are tested to verify their performance using an 80-kg (176-lb) mass and are certified to either UIAA or European Committee for Standardization (CEN) standards. During these tests, the 80-kg (176-lb) mass is attached to a 2.5-m (8.2-foot) rope, anchored over an edge, then raised 2.3 m (7.5 feet) above the anchor. It is then dropped 4.8 m (15.7 feet), with the requirement that the resulting impact force be less than 12 kilonewtons (kN), or 2698 pounds-force (lbf). Despite a rope passing this laboratory test to qualify as dynamic, it should be noted that taking a 12-kN impact is not a pleasant experience and may cause injury during a real-life fall. Typical industrial fall protection standards require fall protection equipment to limit impact forces to 8 kN or less, which is also based on an 80-kg (176-lb) mass. Climbers who weigh considerably more will generate greater forces and may require larger-diameter dynamic ropes to provide proper safety and a reasonably low impact force.

When it comes to static and low-stretch ropes, impact force is an important consideration, but impact force testing is not performed in the same way as on dynamic rope, because static and low-stretch ropes are not intended for use when significant impact may occur.

NUMBER OF FALLS HELD

Number of falls held applies only to dynamic climbing rope, on which falls are anticipated. To test for this, the impact force test described previously is repeated until the rope breaks. To qualify for UIAA or CEN certification, a rope is required to sustain a minimum of five falls. The maximum number of falls achieved without breaking the rope is known as the *fall rating*. It is important to note that for this test, the impact force requirement of 12 kN or less is measured only on the first fall. After the first fall, impact force is not measured and can be any force, as long as the rope does not break. This fall rating is basically used for comparison of one rope with another when purchasing a dynamic rope; it has little to do with the actual number of falls a given rope can take in the real world of climbing. A good-quality dynamic rope can provide service for hundreds of low-impact falls. Alternatively, just because a rope is rated at 12 or 15 falls does not mean that it should be used over and over after an extremely high-impact fall has occurred (see Fall Factors, later, for estimating the impact of high-force falls on a rope).

ELONGATION

An important attribute of nylon and polyester ropes is inherent ability to absorb force. Virtually any loading of a rope results in at least some impact force, which could damage equipment and systems if the rope does not have some stretch. Using high-quality nylon and polyester life safety rope helps protect against the effects of such loading. Although absorption of impact force generally translates into a high-stretch rope, elongation poses a practical concern when heavy loads are being raised, lowered, and positioned on a vertical plane. Ropes with too much elongation require more effort to raise, may "bounce" the load, and may cause a stopped load to creep dangerously. For this reason, ropes with lower elongation are preferred for raising, lowering, and positioning heavy loads. Aramid materials, such as Kevlar, Technora, and Twaron, are most desirable because of their resistance to heat, but a secondary characteristic of these fibers is minimal elongation. Such ropes, frequently used for emergency escape from fire, should be used with great caution. There are also accessory cords and cordelettes made with ultra-high-modulus polyethylene (UHMPE) yarns, such as Spectra and Dyneema. These materials do not offer heat resistance, but feature a high strength-to-weight ratio. However, they offer almost no elongation or energy-absorbing abilities. Caution should be used during application of such superstatic ropes, because even the slightest slip could pass high-impact forces to the rope, anchors, and user, much as would a steel cable.

DIAMETER

Most life safety ropes range in diameter from 7.5 to 13 mm (0.23 to 0.57 inch). Accurate assessment and reporting of diameter are critical for these ropes. Most of the auxiliary equipment designed for use with life safety ropes is designed to function with specific rope sizes. Rope friction, ability to be gripped, and weight are also important considerations. Balancing these factors is a matter of personal preference. Some brands and constructions of rope seem fatter than others despite being advertised as the same size. How tight or loose a rope is made will change the hand (i.e., the feel) of a rope as well as the actual diameter at any given load. In addition, there are different methods of determining rope diameter from one standard to the next. Typically, for life safety ropes, some reference load is placed on the rope, the diameter is measured in several places, and an average is provided to the purchaser.

ABRASION RESISTANCE

Life safety ropes should be built for abrasion resistance on rock, ice, and industrial surfaces. This translates to better protection against cutting and damage as well as greater security. Because ropes with the best abrasion resistance generally do not also boast the softest hand, experienced rope users are often identifiable by their preference for ropes with a tighter sheath weave and stiffer characteristics.

COMPATIBILITY WITH OTHER EQUIPMENT

Auxiliary equipment selected for use with life safety rope should be selected according to purpose and with consideration of the specific rope to be used. Rope construction is important with some devices, as is sheath material, flexibility (too much or too little), rope diameter, and even sheath slippage.

HAND

The term *hand,* when applied to a rope, refers to its flexibility and handling characteristics. A rope must be manageable and easy to work with, but these terms are very subjective. An experienced user will have different priorities than will an inexperienced user. Although a soft hand and flexibility are often preferred by inexperienced rope users, ropes with the best abrasion resistance, least sheath slippage, and greatest efficiency in systems are usually those with a stiffer hand.

QUALITY

In addition to the technical considerations involved with the manufacture of life safety rope, quality is a key factor. Some user groups of life safety rope now mandate that qualifying manufacturers meet specific quality assurance criteria, such as third-party certification to a quality standard, such as the International Organization for Standardization's ISO 9001: 2008 Quality Management Systems Requirements.

WEIGHT

In some use environments, such as deep caves or wet and cold canyons, the rope weight significantly alters how ropes are carried and used. Users working in environments where heavy or bulky ropes provide a hindrance often chose smaller-diameter ropes (lighter in weight) to facilitate their use. Those working in open environments, where strength is a priority, often use heavier ropes.

WATER RESISTANCE/FLOTATION

Users who work in or around water may prefer ropes that have water-resistant coatings to prevent absorption of water. Such coatings reduce water weight absorbed by rope and prevent water running off ropes and making users wet and cold. Water resistance is of most concern when flotation is a priority and weight of a soaked rope would be problematic. This is only an issue in certain environments, so is not a concern to users unless integral to their particular environment.

LIFE SAFETY ROPE CONSTRUCTION

Most life safety ropes in the 21st century are of kernmantle construction. The German word *kernmantle* means "core" (kern) and "sheath" (mantle). Kernmantle rope sheaths are braided around the core, and their design is crucial to the hand, knotability, and abrasion resistance of the rope. A tightly woven sheath is more durable than a loose weave, but this feature must be finely balanced to maintain knotability. Other variables include fiber denier (diameter), number of strands in the braid, and angle of weave.

MATERIALS

Before development of synthetic fiber ropes, the standard was rope made of natural fibers (e.g., manila). Natural-fiber rope degrades in strength even when carefully stored; it lacks the ability to absorb shock loads, lacks continuous fibers along the length of the rope, and has low strength compared with certain artificial fibers. For these reasons, natural-fiber ropes are no longer considered appropriate for life safety applications. Synthetic fibers, including nylon, polyester, UHMPE, aramides, and polyolefin, are more often used in modern rope making.

Nylon

Nylon is the most common and suitable fiber for general life safety use. Nylon is approximately 10% stronger than polyester, but nylon fiber may lose as much as 10% to 15% of its strength when wet. This strength loss is not permanent; the nylon regains its strength when it dries. In addition, nylon can handle about twice as much shock loading per pound as can polyester when both are wet.

Nylon strongly resists most chemicals, but certain acids and bleaches can cause degradation, especially in high concentrations. For the high-angle technician, the source of most damaging acids is batteries, including lead acid and "sealed" or "dry-cell" batteries. Users must scrupulously protect ropes from direct contact with batteries and exposure to acid fumes or residues that might be found in vehicle storage compartments, trunks, and garage floors. Industrial users should take special precautions for storage and handling because of chemicals used in their rescue environments.

Polyester

Polyester fibers are used in many ropes. Dacron has a melting point of approximately 249° C (480° F), which is in the range of nylon 6,6 with a melting point of approximately 269° C (516° F); the melting point of polyester is 265° C (509° F). Polyester fiber has a high tensile strength even when wet, has low elongation at break, and can be as effectively stabilized to ultraviolet (UV) light as can nylon. These factors make polyester rope well suited for marine applications (e.g., for boat-rigging lines), and make it an interesting choice for life safety applications. Whereas nylon is susceptible to degradation from exposure to acids, polyester is more susceptible to damage from alkali. Polyester fiber also has lower dynamic energy absorption, which means that it cannot handle shock loads or repeated loading as well as can nylon fiber.

Ultra-High-Molecular-Weight Polyethylene

Also known as high-modulus polyethylene (HMPE) and more commonly by trade names Spectra and Dyneema, ultra-high-molecular-weight polyethylene (UHMPE) fiber floats and has better abrasion resistance than do aramids, but still has too little stretch to absorb dynamic energy. UHMPE fibers have too low a melting point to be used safely with most rappelling equipment. In addition, they tend to be very slippery and do not hold knots well under high tension. These properties make them excellent marine ropes, as well as short runners and tethers for sport climbing applications.

Aramids

Aramids, commonly known by the trade names Kevlar, Technora, and Twaron, are extremely strong fibers, resist high temperatures, and have become popular for escape ropes when one requires smaller-diameter, higher-strength ropes with ability to withstand higher working temperatures than can nylon and polyester ropes. Aramids are very susceptible to internal and external abrasion. Because these fibers cannot absorb dynamic energy and are easier to break if bent too tightly (i.e., in a knot or rappel device), they are dangerous to use in most life safety rope applications.

Polyolefin

Polyolefin (polypropylene or polyethylene) fiber ropes are used when their flotation property is required, as for water rescue. They have good resistance to most acids; however, polyolefin fibers rapidly degrade, especially under UV light exposure. Because this fiber has low abrasion resistance, strength, life expectancy, and melting point, it is a poor choice for most life safety applications.

ROPE TYPE

The core of a kernmantle rope primarily determines its elongation, force absorption, and strength properties. The terms *dynamic, low stretch,* and *static* are technically misnomers in that all ropes are dynamic to some degree. However, these are industry-standard terms useful for relating the degree of elongation inherent in each rope type.

Dynamic Kernmantle Rope

A well-designed dynamic rope intended to absorb the shock load of a fall will also be very stretchy, with as much as 30% elongation at 10% of minimum breaking strength. Thus, a dynamic kernmantle rope would be very difficult to use effectively for positioning heavy loads (e.g., rescue load), contending with changing loads (e.g., loading patient midface on rock wall), or rigging into a haul system (i.e., where energy would be wasted with each pull because of the inherent elongation). This type of rope would also be very difficult to use effectively under high tension (e.g., as a highline).

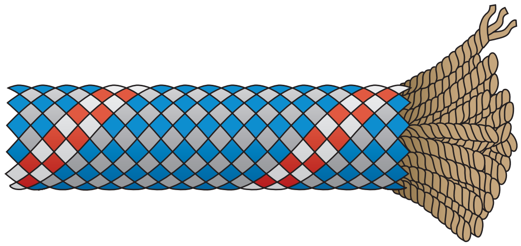

FIGURE 108-2 Dynamic kernmantle rope.

Dynamic ropes also tend to have a lower tensile strength than do static or low-stretch kernmantle ropes because of the same design characteristics that allow it to stretch. Furthermore, dynamic kernmantle designs are often softer and have a lower percentage of sheath than do static kernmantle ropes, making them more susceptible to abrasion and wear (Figure 108-2).

Static Kernmantle Rope

A static kernmantle rope is designed to be very strong and to have minimal stretch (i.e., as little as 3% to 6% at 10% minimum breaking strength). For consistent strength, inner bundles run continuously and unbroken throughout the length of the rope, usually in a near-parallel manner, to reduce stretch and spin (Figure 108-3). This load-carrying core is protected from dirt, abrasion, and cutting by a tightly braided outer sheath. Static kernmantle ropes are ideal for lowering and raising heavy loads (e.g., during rescue), work positioning, fall protection, and ascending. Static ropes should not be subjected to a fall factor of more than 0.25 unless additional force-absorption provisions are made in the system.

Low-Stretch Kernmantle Rope

Low-stretch kernmantle ropes elongate 6% to 10% at 10% breaking strength, fulfilling the needs not met by highly dynamic climbing ropes or very stable, static kernmantle designs. This is achieved using a different core construction and a better sheath-core relationship, which typically gives such ropes a softer profile than that of static lines. However, these same characteristics decrease abrasion resistance and make this type of rope less desirable for positioning. Low-stretch ropes are often used for belaying heavy loads, especially where fall factor potential is low.

KNOTS IN SOFTWARE

Medical professionals encounter many knots during the course of their careers. From the square knot in a stitched laceration to neckties at administrative functions, practical and symbolic representations of knots abound.

In modern society, knots are used as a form of expression, in art, as mathematical structures, and for security purposes. Determination of "good" versus "bad" in analysis of a knot lies solely in the knot's ability to achieve the purpose for which it was created. Therefore, you may find that several of the good and clever knots you have learned are useless when it comes to functioning in the wilderness.

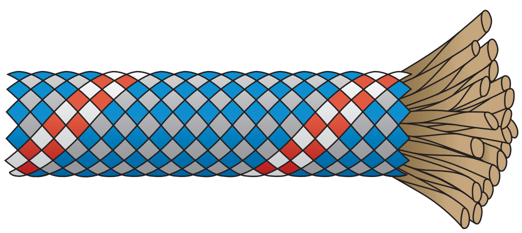

FIGURE 108-3 Static kernmantle rope.

USES

Knots are applied in the wilderness to stake out tents or shelters, tie flies to fishing lines, create suspended "bear-proof" gear caches, and occasionally tie things together.

When performing wilderness medical evacuation, knots take on great significance. Many medical professionals find themselves working alongside rescue technicians in steep terrain, where knots are used for safety of rescue personnel and patient evacuation. Improvisational medical techniques often involve knots. Knotted rope or fabric can be used to secure a splint, create a hasty patient transport device, or provide secure shelter for people in precarious environmental situations.

HOW KNOTS WORK

A knot or hitch is held together by internal friction. The friction is attained by the rope twisting and turning around itself or another object, such as a carabiner, capstan, or another rope. The geometry of the twists and turns give knots and hitches their shape, function, strength, and ultimately behavior under load. In a wilderness rescue situation, lives may depend on this skill, so experienced outdoor users should be able to select the correct knot without hesitation, tie knots correctly the first time, and tie knots with gloved hands, on muddy or icy rope, in the dark, and under stress. One should be able to determine by looking at a knot whether it is tied correctly.

Unfortunately, it has been said, "If you can't tie a knot, tie a lot," which is the genesis of the "lotta knot." In a lotta knot, the greater the mass of rope and the more twists and turns it takes in relation to itself, the higher the probability that the knot will hold. Although the theory is somewhat humorous, it is seldom effective. The lotta knot sometimes holds because the larger rope mass increases the odds of getting a bend to hold. However, there are many disadvantages to this type of knot. It uses lots of rope, is difficult to tension, and is frequently difficult to untie. It is unpredictable and may fail to perform altogether. Consequently, outdoor users should strive to learn tried-and-true knots because they are faster, more efficient, and safer to use. One hallmark of a seasoned outdoor user is basic knotcraft.

When working with software, it is critical to be aware of the material type into which the knot is tied. Some fibers have a low coefficient of friction (e.g., Spectra, Dyneema) and require special considerations when tying knots. Similarly, knots that are effective on rope do not always perform well in webbing.

KNOT TERMINOLOGY

To communicate more effectively, knot users employ discipline-specific terminology. Learning these terms will allow you to communicate more efficiently and effectively in the backcountry. For examples of these terms, see Figure 108-4.

The *working end* is the section of software used to tie the knot.

The *standing part* (or *end*) is the section not actively used to form the knot or rigging.

The *running end* (or simply the *end*) is the free end of the software.

A *line* is some software in use. For example, a rope used to rappel is called a *rappel line*.

A *bight* of rope is formed when the rope takes a U-turn on itself so that the running end and standing end run parallel to each another. The U portion, where the rope bends, is referred to as the *bight*.

A *loop* of rope is made by crossing a portion of the standing end over or under the running end. Note that a loop closes, as compared with a bight. Thus, many knots that form a loop from a bight in the standing part of the rope are named *something on a bight,* (e.g., figure-8 on a bight).

The *tail* of a rope is the typically short, unused length of rope that remains when a knot is tied.

FIGURE 108-4 Knot terminology.

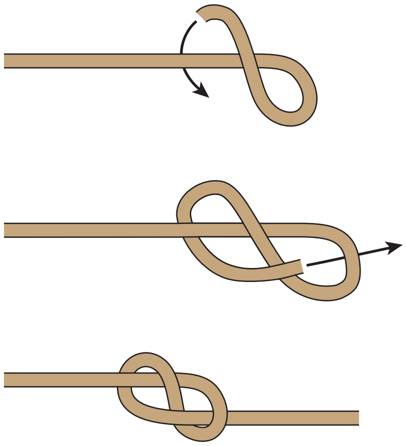

FIGURE 108-5 Figure-8 knot.

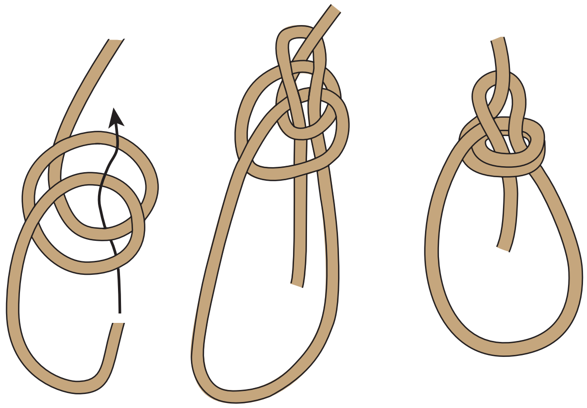

FIGURE 108-7 High-strength bowline or double bowline.

CATEGORIES OF KNOTS

The most practical way to select a knot is to evaluate what function the knot will perform. For our purposes, knots have five basic functions: (1) stopper knots; (2) end-of-line knots; (3) midline knots; (4) knots that join two ropes; and (5) safety knots.

There are knot subsets for the terminology purist. A knot tied around something (e.g., a tree, a standing rope, the rail of a litter) that conforms to the shape of the object around which it is tied, and does not hold its shape when the object around which it is tied is removed, is called a *hitch*. A knot that connects two ends of software is called a *bend*. A *loop* is a section of rope that crosses itself, and a *tied loop* is a knot that forms a fixed eye or loop in the end of a rope. Regardless of the name, basic rules apply to any of these ties.

Stopper Knots

A stopper knot is often used in rappelling. Before a rope end is lowered or thrown down for a rappel, a stopper knot is tied into the end to prevent the rappeller from rappelling off the end should the rope not reach the ground. Rappelling off the end of a rope is one of the most frequent causes of climbing injuries and is entirely preventable with stopper knots. Stopper knots perform a similar function as part of other applications.

The most common stopper knots are the *figure-8 knot* (Figure 108-5) or the barrel knot. When two ropes are used in tandem, the stopper knot should be tied into both lines together. A simple overhand knot (Figure 108-6) may also be used for this purpose, but its relatively low bulk makes it less desirable than a figure-8 knot.

Stopper knots, such as the figure-8 and overhand knots, are the foundations of many other knots for wilderness use. It is important to learn these before progressing further.

END-OF-LINE KNOTS

Perhaps the most common knot use is to make a loop in the end of a rope to anchor, tie in, or attach the rope to something. Bowline knots, borrowed from mariners, have been used by mountaineers for years. However, this knot can "capsize" into a slipknot quite easily when the tail is pulled; therefore, the *high-strength bowline knot* (Figure 108-7) is often preferred for life safety applications. Other variations on the bowline knot that include added safety for live loads are the simple *bowline with safety* (Figure 108-8) and the *bowline with Yosemite safety* (Figure 108-9).

A handy way to tie a mainline and backup line together for attachment to a live load, such as a litter with patient and attendant, is the *interlocking long-tail bowlines* (Figure 108-10), which consist of two simple bowlines with small loops tied to interlock, while leaving long tails for additional attachment to the litter and attendant.

Another bowline variation is the *bowline on a coil* (Figure 108-11). With its several large loops, the bowline on a coil can be used creatively, to attach a person to a belay line if a harness is not available, or create a load-distributing anchor.

Many people prefer to use variations of the figure-8 knot for multiple applications, perhaps because they prefer to learn only one knot. The figure-8 knot may be tied directly onto a bight (Figure 108-12) or may be tied as a retrace (Figure 108-13).

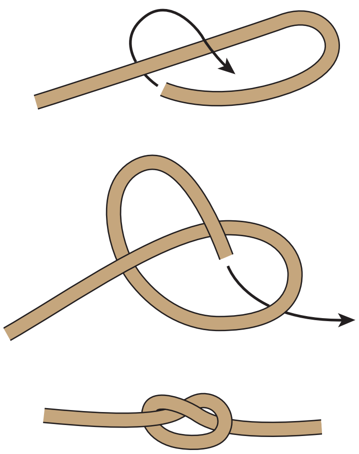

FIGURE 108-6 Overhand knot.

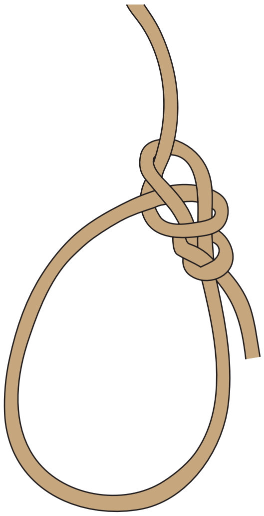

FIGURE 108-8 Bowline with safety.

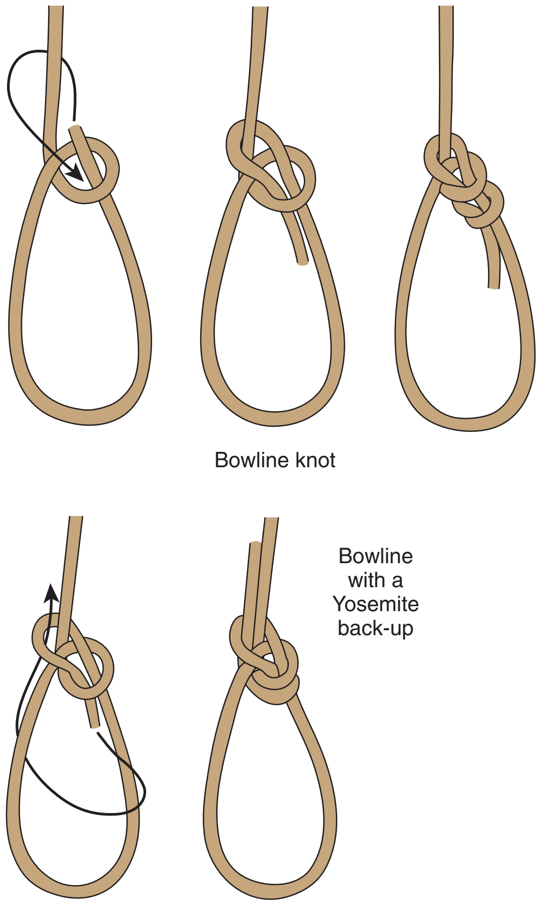

FIGURE 108-9 Bowline with Yosemite safety.

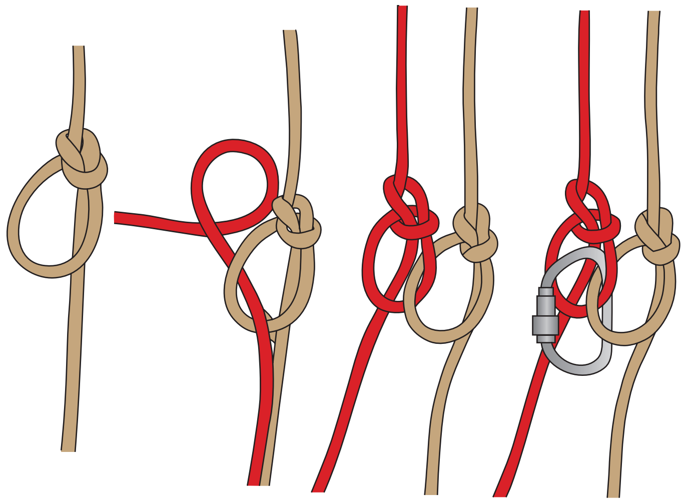

FIGURE 108-10 Interlocking long-tail bowlines.

Although the versatile nature of the figure-8 knot is attractive, it should be noted that learning only one knot is limiting. Some people think that the figure-8 knot is easier to tie and check than other knots. In truth, the redundant nature of the figure-8 retrace can make it deceptive on visual inspection, and this factor has resulted in accidents.

Midline Knots

Knots are often used to form loops in the middle of a rope or for clipping into, grasping, or bypassing a piece of damaged rope. Perhaps the easiest and most common method of making such a loop is with a simple *overhand on a bight* (Figure 108-14). Alternatively, a *figure-8 on a bight* (see Figure 108-12) may be used for this purpose. Either of these options works well as long as the load is attached to the bight. However, both these loops are susceptible to deformation when not loaded. More importantly, if the rope below the knot is loaded, the knots deform, weaken, and can roll down the rope. If nothing is in the loop, it is possible for the knots to roll out of the rope entirely.

More preferable is the *butterfly knot* (Figure 108-15), particularly if the loop and the line beneath it will be placed under significant load. The butterfly can be pulled effectively either from the loop (in any direction) or from below the knot without negative effect. Caution must be exercised with this knot, because if the loop is not big enough and not loaded, it can pull out under tension.

For a quick and versatile solution to creating twin loops in the middle of a rope, a bowline can be tied on a bight of rope. The *bowline on a bight* (Figure 108-16) results in two relatively

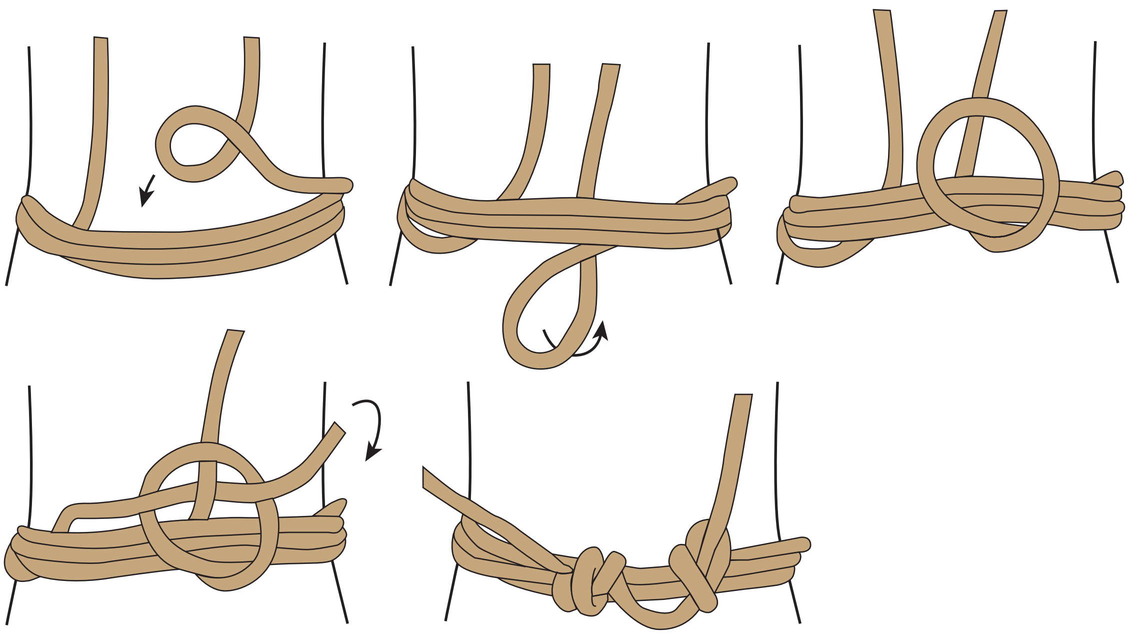

FIGURE 108-11 Bowline on a coil.

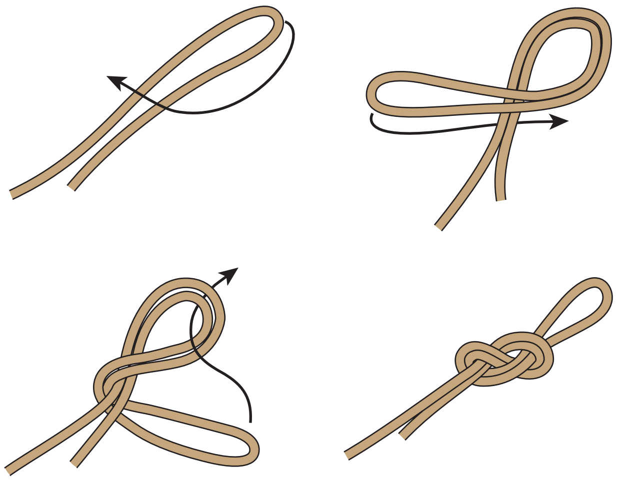

FIGURE 108-12 Figure-8 on a bight.

symmetric loops that can be used to make an emergency boatswains chair, hand loops, or towing bridle.

Another midline knot is the *inline figure-8 knot* (Figure 108-17). It is tied with its loop in line with the direction of pull on the rope. It is possible to make a foot-and-hand loop ladder out of a single piece of rope using this knot, but it should not be used if multidirectional loading of the loop and the rope's ends is anticipated, because it can roll and capsize if pulled in the wrong direction. The butterfly knot is much better suited for multidirectional loading applications.

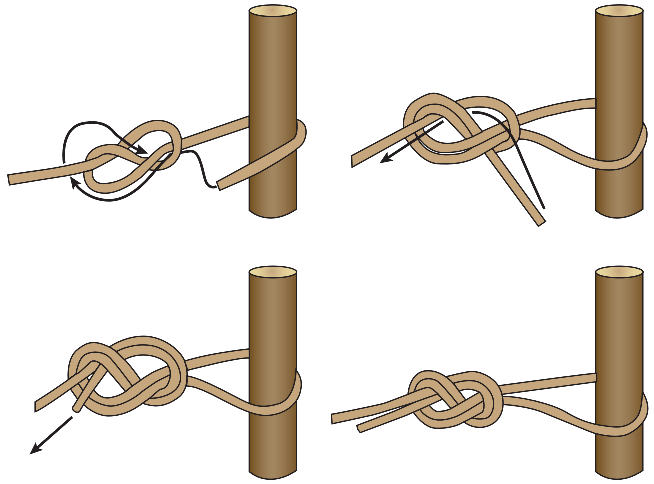

FIGURE 108-13 Retrace figure-8 on a bight.

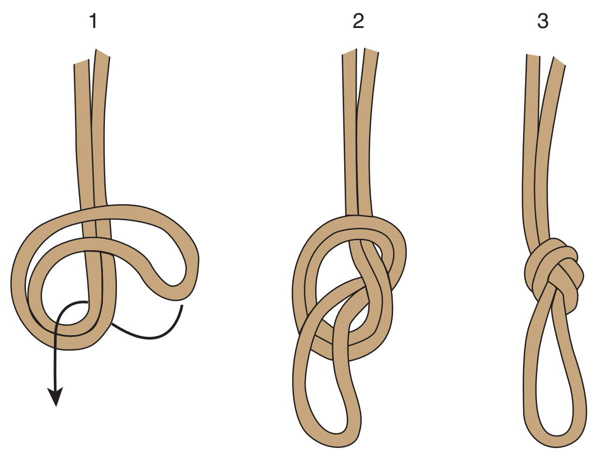

FIGURE 108-14 Overhand on a bight.

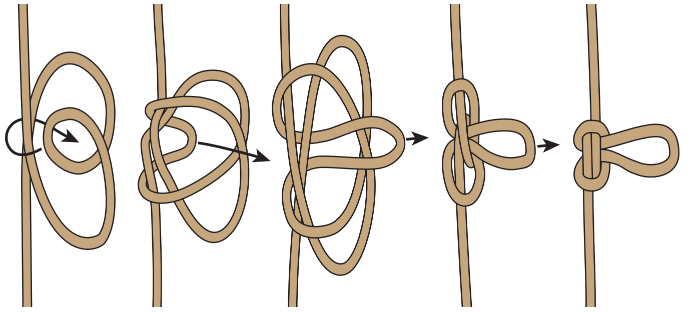

FIGURE 108-15 Butterfly knot.

To create two loops quickly for equalized multiple anchor points to share a load, the *double figure-8* ("bunny ears") *knot* (Figure 108-18) can be tied midline or as an end-of-line knot. The loops or "ears" can be elongated or shortened to equalize the load between two anchor points.

Knots That Join Two Ropes (Bends)

Tying a knot that will not untie is important when joining two ropes, particularly when the ends are in places difficult to monitor.

Most people have learned to tie a *square knot* (Figure 108-19) for the purpose of joining rope ends. Although well known and easy to tie, this knot is far from secure or reliable. It can easily untie itself, either by pulling through when tightened or by shaking apart when loose. In short, the square knot should be avoided for all but decorative purposes, and when used, should be secured with safety knots on both ends.

The *overhand bend* (Figure 108-20) is a preferred choice for joining two ropes in sport climbing and canyoneering, when

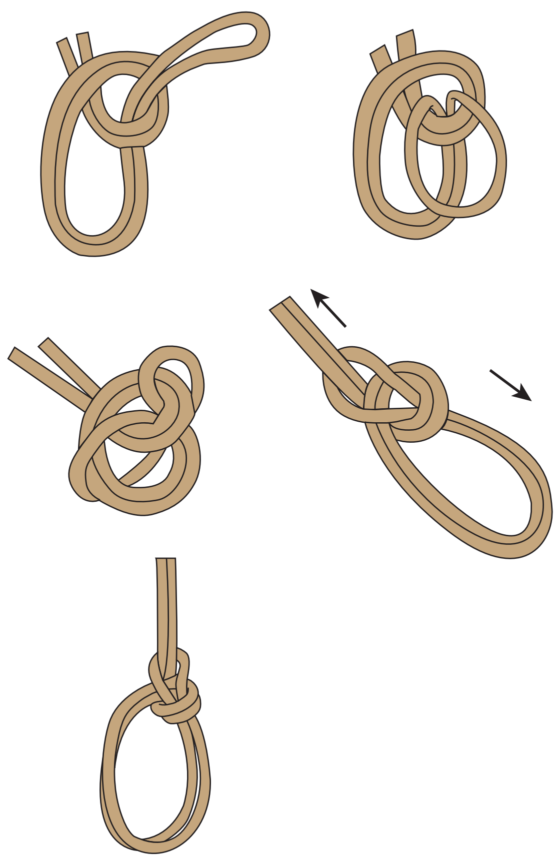

FIGURE 108-16 Bowline on a bight.

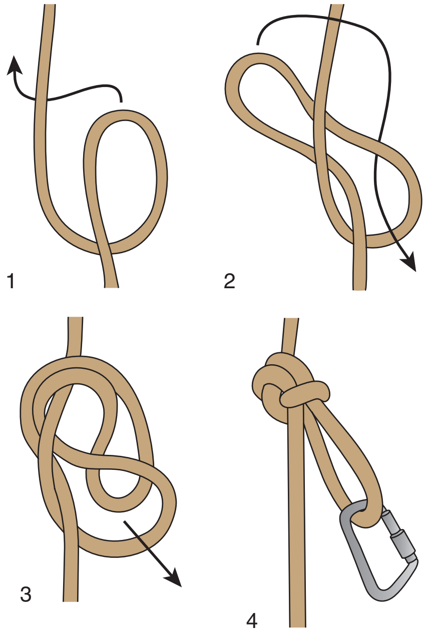

FIGURE 108-17 Inline figure-8 knot.

ropes are to be retrieved and pulled over edges. When used, this knot should be tied with extra-long tails in case the knot rolls when loaded. Because this knot may untie while in use, it is not secure enough for rescue purposes. Instead, the more secure *double fisherman's bend* (Figure 108-21) should be used. This bend is very effective for joining ropes of relatively equal diameter. Care should be taken to ensure that the two halves of the bend nestle against each other, and that there is enough tail protruding from the knot to keep the knot from unraveling. This knot is also used to join two ends of a short length of cordage for use as a Prusik hitch (see Hitches, later).

When ropes of unequal diameter are joined, the *double-sheet bend* (Figure 108-22) is a more effective tie. This is a bulkier alternative that is perhaps not quite as strong, but can be easier to untie. For added security, safety knots can be tied on both sides of the bend.

The versatile figure-8 knot deserves honorable mention here. Retracing a figure-8 knot in the opposing direction, with a second

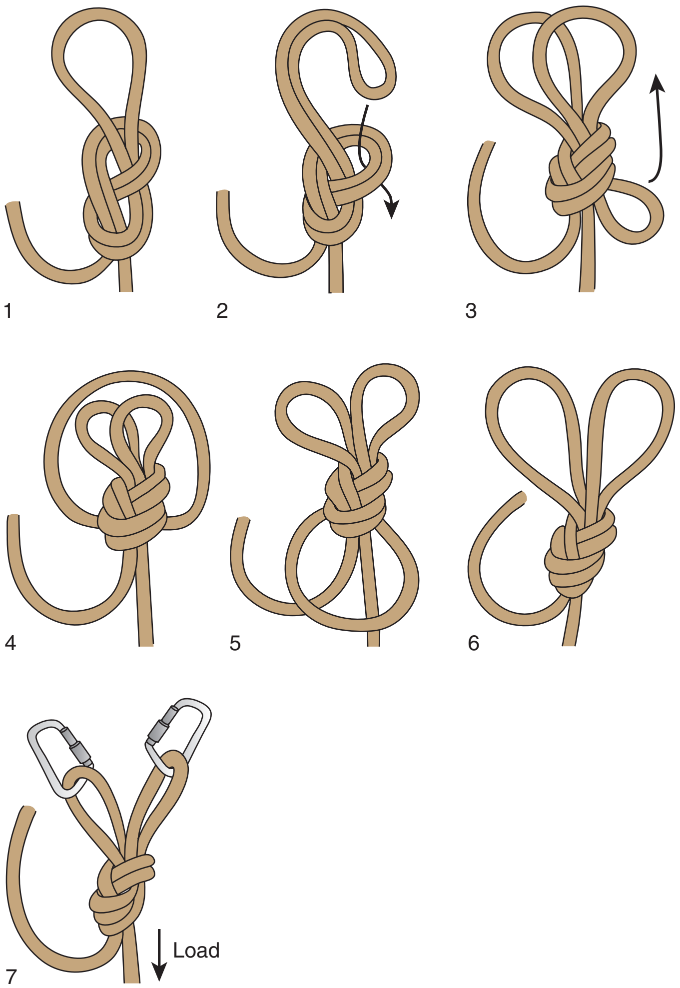

FIGURE 108-18 Double figure-8 loop, or "bunny ears."

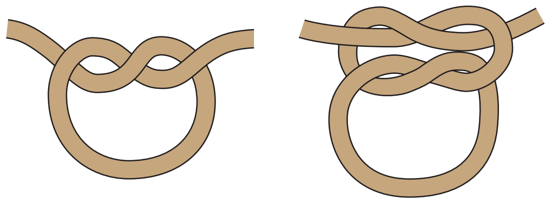

FIGURE 108-19 Square knot.

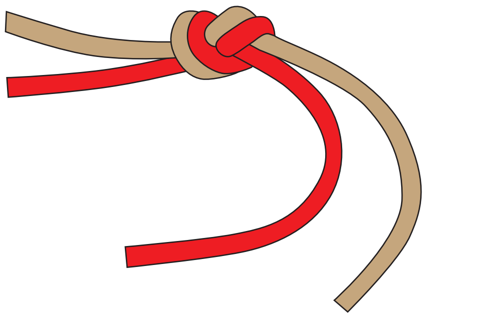

FIGURE 108-20 Overhand bend.

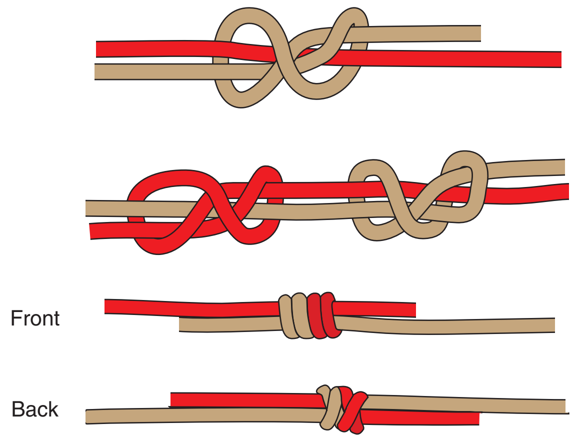

FIGURE 108-21 Double fisherman's bend, grapevine bend, or double-overhand bend.

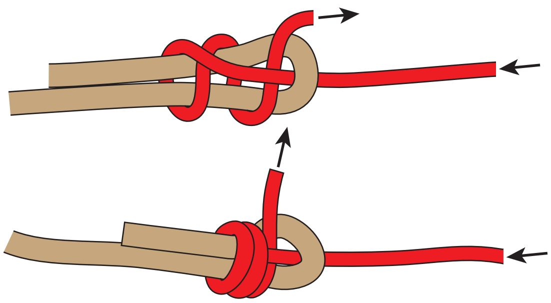

FIGURE 108-22 Double-sheet bend.

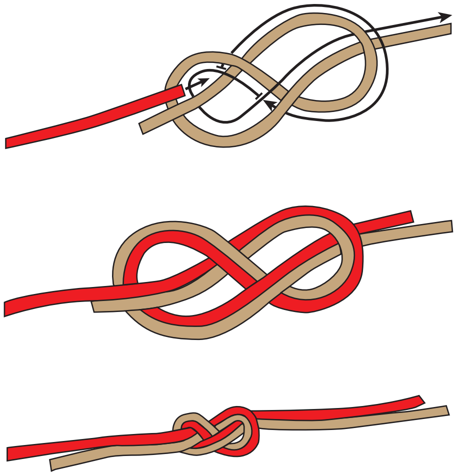

FIGURE 108-23 Figure-8 bend.

rope, results in the *figure-8 bend,* an effective means of joining rope ends (Figure 108-23). Care must be taken with this method to ensure that the rope ends exit from opposite ends of the bend. If tied simply as a figure-8 knot, this bend has a tendency to deform and pull itself apart (Figure 108-24).

Most knots work best in cordage or rope that has a rounded surface. Flat webbing and similar materials perform differently under tension. The preferred bend for joining webbing ends is known as the *ring bend,* sometimes also called the *tape knot* or *water knot* (Figure 108-25). This is most useful for forming webbing slings into a loop, but it can also be used for lashing.

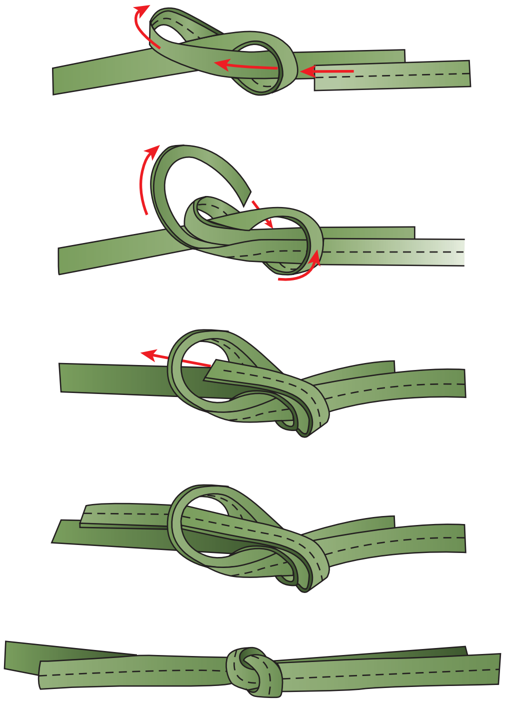

FIGURE 108-25 Ring bend or tape knot.

Hitches

Hitching is a method of tying a rope around itself or an object in such a way that the object is integral to the support of the hitch. Consequently, hitches fall apart when the object around which they are tied is removed. There may be severe consequences when a hitch unties. Specifically, disintegration of a hitch results in immediate release of whatever load it is holding.

One of the most common hitches is the *Prusik hitch* (Figure 108-26). A Prusik hitch is a sliding hitch by which a cord can be attached to a rope and slid up and down the rope for positioning, climbing, or progress capture. However, under tension, the hitch will not slide. A Prusik hitch is created by tying a length of cordage into a loop by means of a double fisherman's bend. Wrapping the loop around the main rope and through its own loop two or three times and then pulling it tight forms the hitch.

Another common hitch used in climbing and rescue applications is the *clove hitch* (Figure 108-27). This hitch is useful when trying to shorten the distance between two objects, such as the climber's belay and the climber or the litter rail and the rescuer. It is also useful in some lashing techniques, but can have a tendency to roll loose, which can be solved by using a stopper knot.

The *Münter hitch* (Figure 108-28), or Italian hitch, can be tied around a carabiner or pole and is used to add friction to a system, or as a belay. This hitch is particularly useful because it effectively adds friction regardless of the direction in which the rope is moving. However, care should be taken when using the hitch around a carabiner, because the moving rope tends to slip through the gate of the carabiner, rendering the hitch useless.

The *trucker's hitch* is handy for pulling cord or webbing tight across something (e.g., a load in the bed of a pickup truck, thus the name) or securing a patient snugly into a litter (Figure 108-29).

The *girth hitch* (Figure 108-30) is useful for quick attachment of a sling or rope to almost anything, although it is not very secure. Girth hitches reduce software strength by about half, so they are more appropriate when strength is not an important feature of the software connection.

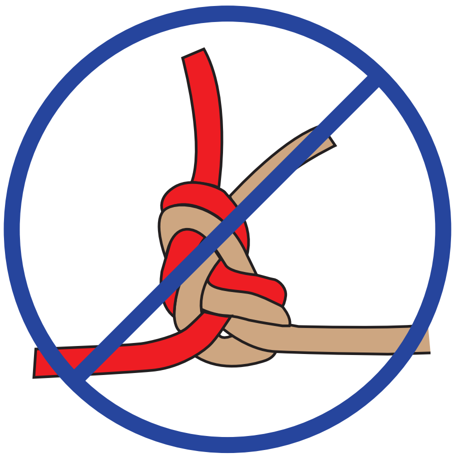

FIGURE 108-24 Incorrectly tied and loaded figure-8 bend.

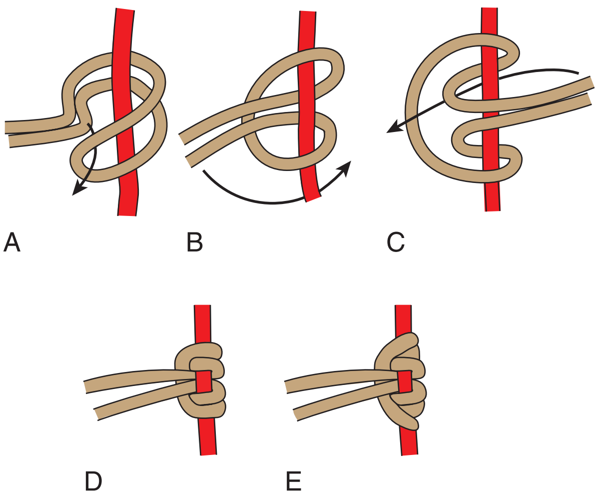

FIGURE 108-26 Prusik hitch. **A** to **C,** Tying sequence for the Prusik hitch. **D,** Two-wrap Prusik hitch. **E,** Three-wrap Prusik hitch.

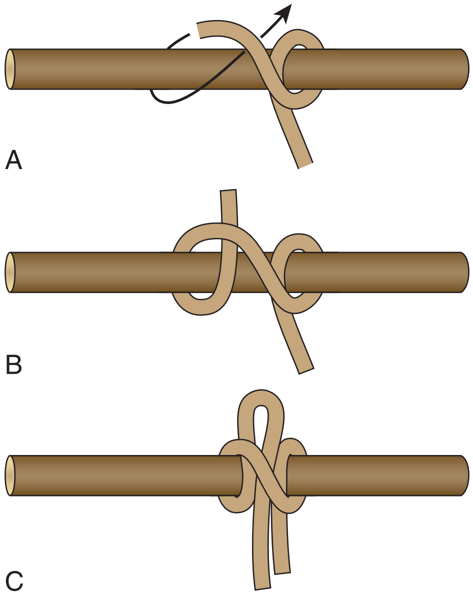

FIGURE 108-27 **A** and **B,** Clove hitch. **C,** Clove hitch with a draw loop for temporary attachment.

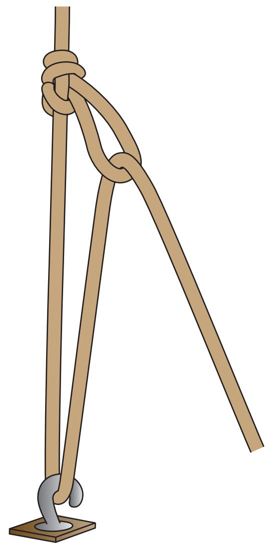

FIGURE 108-29 Trucker's hitch.

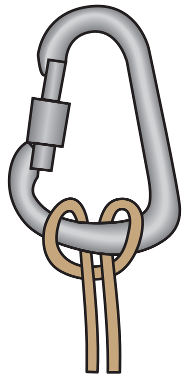

FIGURE 108-30 Girth hitch.

Lashing

Lashing refers to the process of binding items together, such as poles for a shelter or drag. One basic technique used when starting or finishing a lashing involves the *round turn with two half hitches* (Figure 108-31). This is a more secure but bulkier solution for lashing than is the clove hitch. There are several variations on the concept of lashing, including *square lashing* (Figure 108-32) for arranging poles to create a corner, *diagonal lashing* (Figure 108-33) for joining poles to create a triangular shape, and *sheer lashing* (Figure 108-34) for joining poles side by side. Lashings can be extremely useful tools for creating conveniences at camp as well as for emergency use in creating tripods and other mechanical aids.

Emergency Harnesses

The ability to make an emergency harness quickly out of rope or webbing is a key skill for anyone traveling into the wilderness, whether for climbing a damaged mast or belaying someone up or down a cliff. One of the simplest and easiest harnesses to tie is the *hasty diaper harness* (Figure 108-35). A simple loop of webbing is made by tying a ring bend (see Figure 108-25) in the ends of a length of webbing; alternatively, a loop of rope is made by tying a double fisherman's bend in the ends of a length of rope. The loop goes on like a diaper and closes in the front with a carabiner or screw link. There are other ways to use webbing to tie a harness, but this is the easiest way.

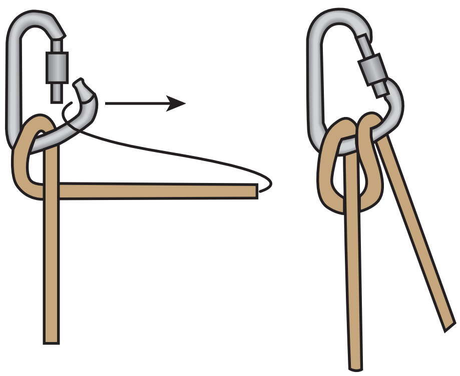

FIGURE 108-28 Münter hitch.

KNOT SAFETY

Knots should be tied, dressed, and tensioned before use. Dressing a knot involves aligning the rope strands parallel to each other so they minimally overlap in the knot. Generally, this results in a "prettier" knot that looks more orderly and can be more effectively tightened. Tensioning a knot keeps it in place and ensures that it does not slip or untie when not under tension. To ensure correct dressing and tension, every knot should be inspected visually and by touch before use, preferably by someone other than the person who tied it. Thereafter, knots should be monitored at intervals. Many knots have a tendency to loosen, and some can even change forms (e.g., into a slipknot).

A safety knot can help prevent mishaps. A safety knot is an overhand knot (see Figure 108-6) or *barrel knot* (Figure 108-36) tied into the tail of the rope after a knot is tied. The safety knot is placed to keep the original knot from deforming or unraveling.

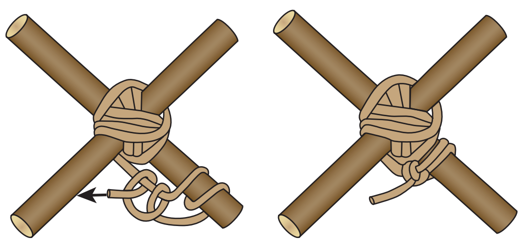

FIGURE 108-31 Round turn and two half hitches.

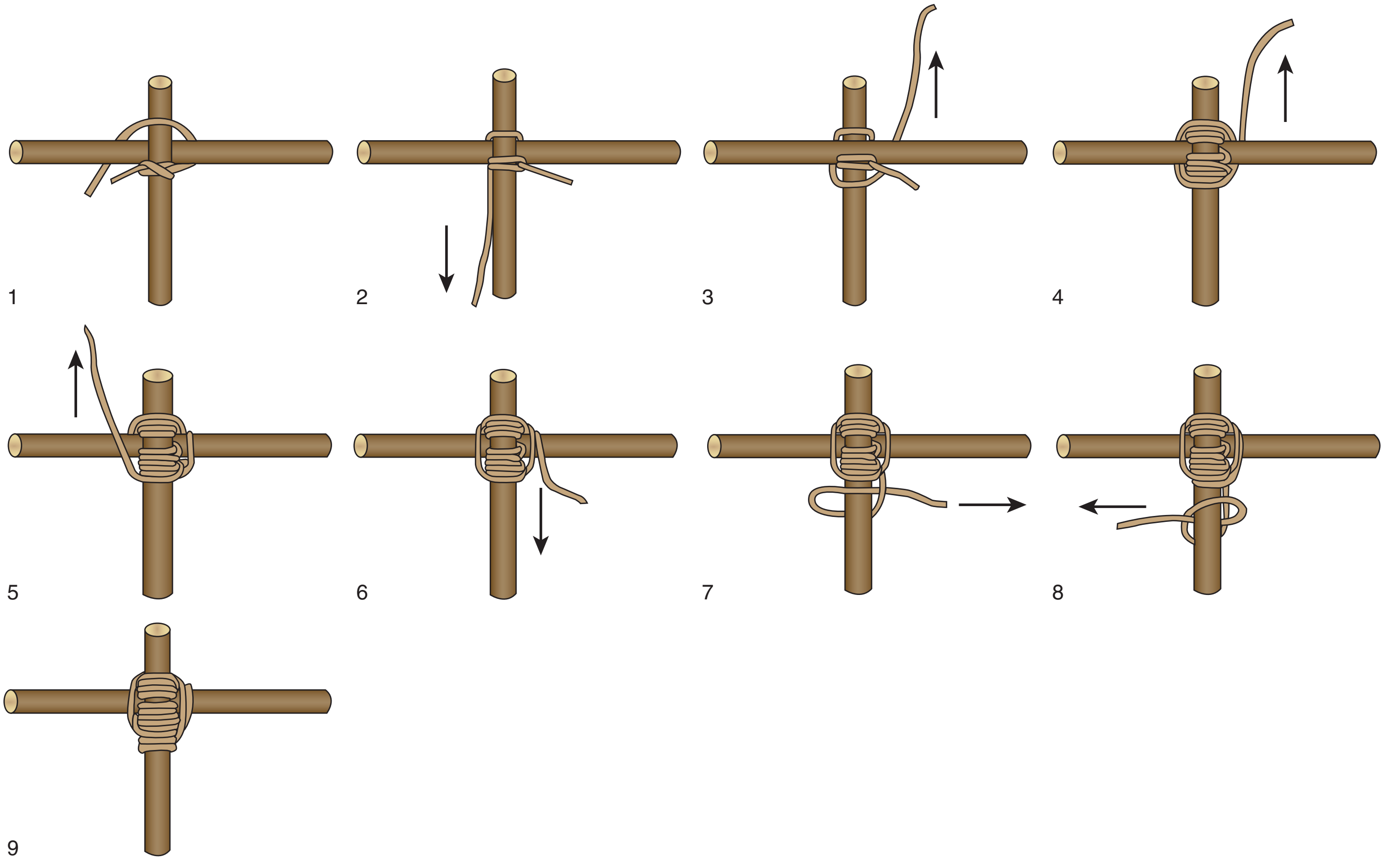

FIGURE 108-32 Square lash.

KNOTS AND SOFTWARE STRENGTH

All knots reduce software strength. The amount of strength loss is affected by tightness of the bends and the "pinching" effect of the knot on itself. The strength of a knot is directly proportional to strength of the material into which it is tied. Knot strengths are usually expressed in terms of *efficiency ratio*. A knot rated at 85% efficiency is said to maintain about 85% of the reported breaking strength of the material in which it is tied.

Some individuals and agencies have reported that any knot reduces the strength of a rope by at least 50%. This information is erroneous, because efficiency of any knot depends on which knot is used, which rope it is tied into, whether it is tied correctly, and how it is maintained. Most knots recommended for use in wilderness rescue reduce the strength of a typical rescue rope to no less than 65% of that rope's minimum breaking strength. Most commonly used knots are even more efficient and have strength in the range of 80%.

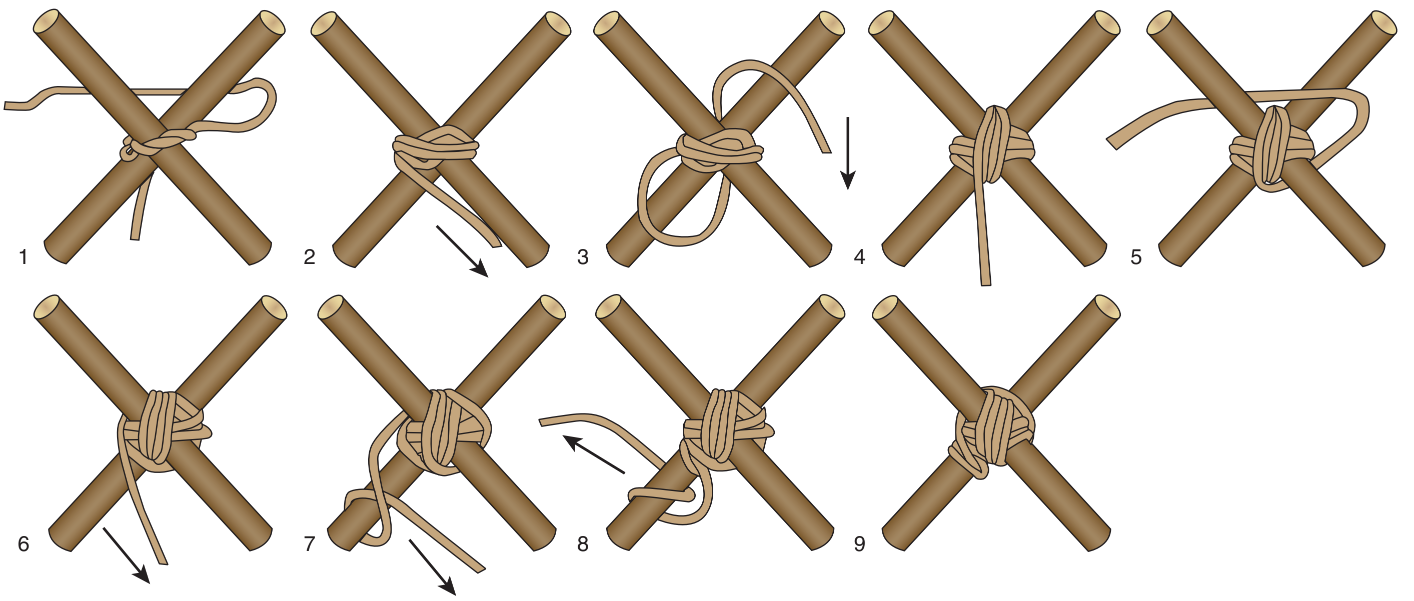

FIGURE 108-33 Diagonal lash.

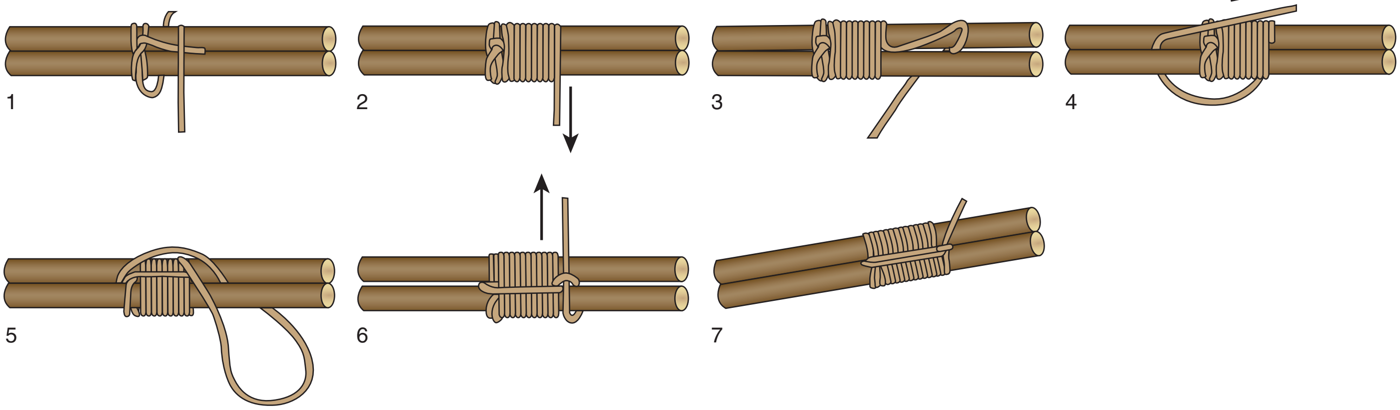

FIGURE 108-34 Sheer lash.

Unfortunately, accurate data about knot efficiencies are difficult to find. Comprehensive testing that includes statistically significant sample sizes, differences among rope fibers, rope construction, rope diameters, rope type (static vs. dynamic), loading rate (dynamic vs. slow), and other variables is nonexistent. However, enough data have been produced to provide a general idea about different knot strengths. The following data, taken from different sources and reflecting limited testing, should be referenced for trend information only.

The relative breaking strength of kernmantle design ropes is listed with the following knots:

- Double fisherman's bend: 65% to 70%
- Bowline: 70% to 75%
- Figure-8 on a bight: 75% to 80%
- Overhand knot: 60% to 65%

The best way to know the strength of a knot on a given rope is to test the knot that is to be used on the rope that is to be used. One should test enough samples to demonstrate the range of variation, which requires using enough samples to provide a reasonable margin of error.

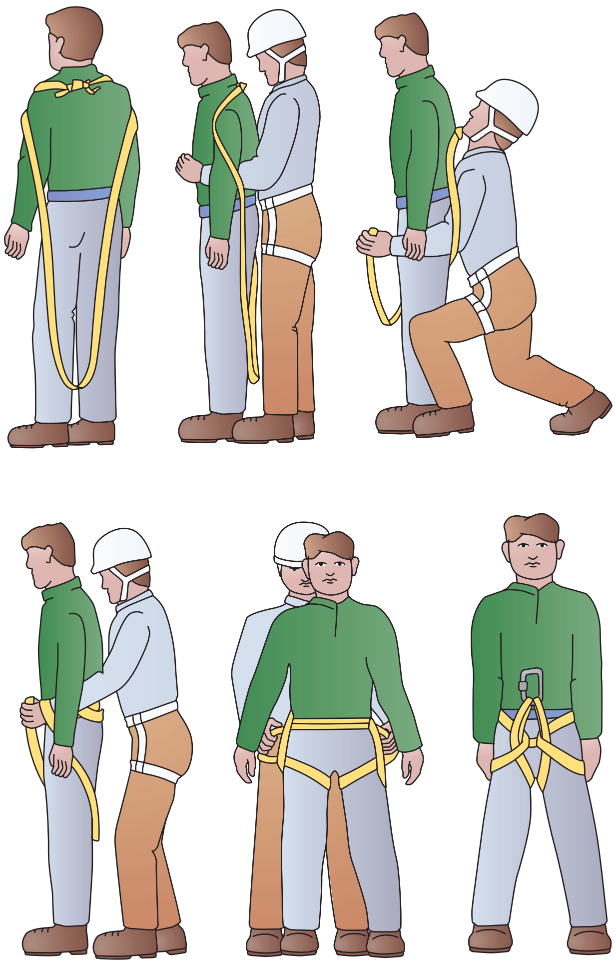

FIGURE 108-35 Hasty diaper harness.

LEARNING MORE ABOUT SOFTWARE AND KNOTS

Learning how to use software for rescue purposes requires training and personal study. A basic vertical class about rappelling and ascending a rope requires a minimum of 2 to 3 days; a rope access certification class generally requires a full week. After a basic rope skills class is completed, regular practice is required to maintain proficiency. Many excellent advanced classes in patient movement by rope or vertical rescue are offered. Anticipate at least 1 week of training for a beginning class about rope rescue. In addition to personal training, there are numerous educational materials to advance this personal study.

For more information about using ropes, webbing, and cordage in rescue-specific situations, see the fourth edition of *High-Angle Rescue Techniques* by Hudson and Vines, which can be supplemented with an education course.

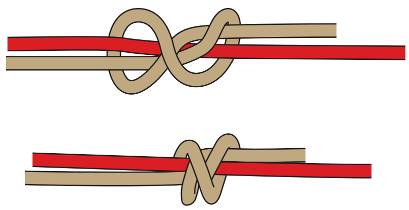

FIGURE 108-36 Barrel knot.

CHAPTER 109

Ultrasound in the Wilderness

VICKI E. NOBLE, ALICE F. MURRAY, AND N. STUART HARRIS

Modern wilderness travelers have ready access to portable medical equipment with advanced imaging and diagnostic abilities.

In this chapter, we explain how current portable ultrasound devices offer an array of powerful diagnostic techniques for medical care in the field. We discuss ultrasound as the one form of human anatomic imaging with obvious, direct application in wilderness clinical care and research. For detailed descriptions of all ultrasound techniques, excellent texts are available dedicated to clinical ultrasound.[45,50] Our goal is to provide sufficient detail so that a provider, even with minimal training in ultrasound, can acquire and begin to apply potentially lifesaving imaging techniques while in the field. Experimental studies and routine clinical practice have established that these skills can rapidly, safely, and effectively be learned for use in austere environments, both by medical experts and nonphysicians.[22] Ultrasound images of diagnostic quality can be acquired by untrained persons under the real-time guidance of ultrasound experts thousands of miles away.[53] We provide simple instructions and representative images for various clinical ultrasound techniques that are likely to prove critical in austere environments. Because of inherent limitations of electrical power sources in austere environments, we discuss systems that can reliably power electrical devices. We discuss multiple promising research techniques using ultrasonographic imaging that are well suited for use in the field.

INTRODUCTION TO ULTRASOUND

Wilderness travelers now have access to machines that are lightweight, compact, and sufficiently robust to be carried in a daypack. Machines provide diagnostic anatomic imaging that can be interpreted in the field at costs within reach of expeditions and individuals (Table 109-1). To best utilize their capabilities, it is necessary to understand the physics of how ultrasound machines acquire and generate images. Many of the "artifacts" generated by these principles are quite useful in wilderness settings.

Sonographic imaging is based on the principle of the piezoelectric effect, defined by Pierre and Jacques Curie in 1880 as a property of quartz crystals that creates an electric potential when stimulated by a mechanical force. These same crystals produce a mechanical potential when an electric force is applied.[19] Using these properties, a modern ultrasound machine functions by applying an electrical charge to a piezoelectric crystal (in the transducer or probe) that then converts the electrical signal to a sound wave. Anatomic structures reflect these sound waves back toward the piezoelectric crystal. The crystal turns this mechanical force into an electric current, which is quantified and interpreted to produce an image.

Sound waves (as a mechanical force) require a medium. Fluid-filled structures provide an excellent medium and conduct sound easily, while air scatters the returning sound so that very little of the mechanical force is returned to the probe. Different tissues (reflecting different densities in the body) have varying abilities to conduct sound waves, known as their intrinsic propagation speeds. These propagation speeds are related to density, and therefore each tissue also has an intrinsic attenuation coefficient that modulates the speed of sound through the tissue (Table 109-2). Differences in wave propagation, refraction, and reflection are the factors that allow internal structures to be imaged. Dense structures tend to reflect sound and thus look bright on ultrasound, whereas less dense structures tend to conduct sound and look darker on ultrasound.

PROBE CONSTRUCTION AND FREQUENCY

Ultrasound machines typically have multiple probes with different frequencies and shapes, optimized for different indications (Table 109-3). High-frequency probes generate a higher number of short-wavelength sound waves per second. This generates more frequent reflections over a shorter distance, yielding a high-resolution image but shallow depth of view. Low-frequency probes generate fewer waves per second of longer wavelength. These waves travel greater distances with fewer reflections and offer more penetration but less resolution. More superficial musculoskeletal structures (e.g., bones, fractures, ligaments, tendons) are best seen with high-frequency imaging. Deeper intra-abdominal organs (e.g., spleen, heart, kidneys) are best seen with low-frequency imaging. In addition, each probe has an inherent limitation to the depth it can image. For a high-frequency probe, a maximal depth of 8 cm (3.2 inches) is typical; for a low-frequency probe, 30 cm (12 inches). In an ideal world, portable ultrasound machines available to wilderness explorers would have both low- and high-frequency options to optimize the ability to image different anatomic structures.

OVERVIEW OF CLINICAL IMAGING

Three buttons on a portable ultrasound machine are important to understand in order to optimize image quality. The first button is depth control. All machines allow adjustment of how long the machine "listens" for reflections. This influences their ability to generate an image from shallow (less time) or deeper (more time) structures. The second important button is gain control. Clinicians may think of gain as analogous to volume on a radio. By turning up gain, the "brightness" of signals displayed on the screen is increased. This can be useful to view an image on a screen under sunny conditions or if the reflected image is very dark. Third, some portable machines allow for different "modes" of ultrasound display. B-mode stands for "brightness" and is the typical gray-scale mode that generates an anatomic image. M-mode stands for "motion" and displays a representation of motion within a single anatomic plane over a linear axis of time. M-mode can be effectively used to highlight and quantify the movement of structures (e.g., physiologic lung sliding, fetal heart rate). Doppler can be used on some machines to show velocity and direction of flow. Doppler ultrasound relies on the principle of Doppler/frequency shift to sense movement of reflected ultrasound waves toward and away from the probe. This is represented either by color changes (color Doppler) or by audible or graphic peaks (spectral Doppler). Power Doppler is a form of color Doppler that uses a slightly different component of returned signal and is more sensitive in low-flow states. Power Doppler sacrifices the ability to demonstrate direction of flow to gain sensitivity in detecting lower levels of flow.

TABLE 109-1 Advantages and Limitations of Ultrasound in the Wilderness

Advantages	Limitations
Portable, lightweight, field-ready Safe, nonionizing (allows multiple assays) Relatively inexpensive Provides immediate data Easy-to-learn techniques, or to be guided from a distance using telemedicine Allows multiple organ systems to be investigated Excellent flexibility for both research and clinical care Allows novel research investigations	Electronic equipment—sensitive to cold, dust, and breakage Power system (or numerous batteries) required for extended backcountry use Requires operator to learn techniques

TABLE 109-2 Attenuation Coefficients in Ultrasound Images

Tissue	Attenuation Coefficient	Appearance
Air	4500	Scattered
Bone	870	Bright; reflected
Muscle	350	Moderately bright
Liver/kidney	90	—
Fat	60	Dark
Blood	9	Very dark
Fluid	0	Anechoic; none reflected

COMMON CLINICAL IMAGING APPLICATIONS

FOCUSED ASSESSMENT WITH SONOGRAPHY FOR TRAUMA

The Focused Assessment with Sonography for Trauma (FAST) examination is a standard component of initial assessment of the trauma patient. It consists of a rapid, focused ultrasound examination of the abdomen, thorax, and heart using a curvilinear 2.5- or 3.5-MHz probe. FAST examination allows prompt assessment for the presence of free fluid in the right upper quadrant (Morison's pouch), left upper quadrant (perisplenic space), suprapubic pelvis (rectovesical pouch in males, pouch of Douglas in females), pericardium, and thoracic cavity.

TABLE 109-3 Types and Ideal Uses of Different Ultrasound Probes

Type (Depth/Resolution)	Ideal Uses
Low-frequency (2-5 MHz) curved array (Excellent depth of imaging)	FAST examination Thoracic evaluation (for pulmonary edema) Cardiac views
High-frequency (8-10 MHz) linear array (Excellent resolution, limited depth)	Foreign body location Thoracic assessment (for pneumothorax) Eye evaluation, optic nerve sheath assays Fractures

FAST, Focused Assessment with Sonography for Trauma.

The FAST examination is indicated for patients who have sustained abdominal trauma. It has the benefit of being easily repeated as a patient's clinical condition changes. The main objective of the FAST exam is to answer whether a patient's hemodynamic instability can be attributed to fluid in the thorax, peritoneum, or around the heart. A negative FAST exam suggests that clinicians should evaluate for other sources of hemodynamic instability (e.g., spinal shock, myocardial infarctions, infection). A positive FAST exam in the hemodynamically stable patient is a warning to anticipate clinical deterioration. Especially for the novice user, FAST examination is an insensitive indicator of solid-organ injury, bowel injury, or retroperitoneal bleeding.

The FAST examination consists of four standard views: right and left upper quadrants, pelvis, and cardiac.

Right Upper Quadrant

Morison's pouch is the most dependent portion of the upper peritoneal cavity and thus is where early evidence of intraperitoneal free fluid may be discovered. To obtain this view, place the probe in the right posterior axillary line at the level of the 11th and 12th ribs (Figure 109-1). Move the probe anteriorly with sweeping, angular adjustments until a clear view of the anterior fascia of the kidney and posterior portion of the liver capsule is obtained. When looking at the right upper quadrant, it is essential that the inferior pole of the right kidney is included in this sweep, because this is the most sensitive location of the right upper quadrant evaluation in which to detect free fluid. Moreover, it is important to image the hyperechoic diaphragm in the right upper quadrant, because seeing anechoic fluid above the diaphragm—or continuation of the spine shadow above the diaphragm—demonstrates fluid in the thorax (Figure 109-2). In a normal study, intrathoracic air prevents transmission of sound waves, so the thoracic spine cannot be seen on this view. Instead, the spine and the diaphragm can be seen coming together at a point (Figure 109-3). Figures 109-4 and 109-5 show negative and positive images, respectively, of the right upper quadrant view.

Left Upper Quadrant

The left upper quadrant examination visualizes the spleen, left kidney, and perisplenic space. To obtain this view, place the probe in the left posterior axillary line between the 10th and 11th ribs (Figure 109-6). In this view, it is more important to see the perisplenic area because blood will collect around the spleen before spilling over the spleno-colic ligament into the splenorenal space. Figures 109-7 and 109-8 show negative and positive views, respectively. Again, ruling out a positive "spine sign" by seeing the spine and diaphragm meet at a point is essential to rule out anechoic fluid in the left thorax.

FIGURE 109-1 Right upper quadrant of FAST examination. Place the probe in the right posterior axillary line at the level of the 11th and 12th ribs. This allows the liver, right kidney (with its inferior pole), and Morison's pouch to be imaged. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

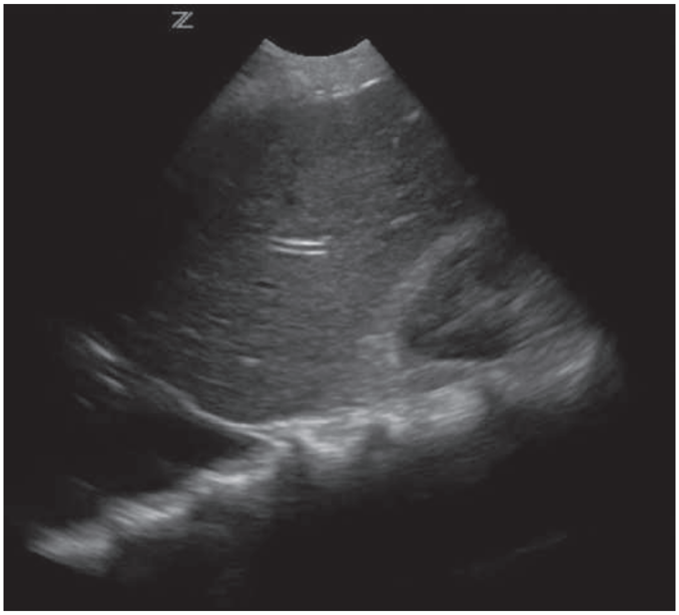

FIGURE 109-2 Presence of a "spine sign" indicates fluid in the thorax. The thoracic spine is visualized extending above the bright, white diaphragm, indicating that sonolucent fluid above the diaphragm is transmitting the sound waves through to the thoracic spine. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

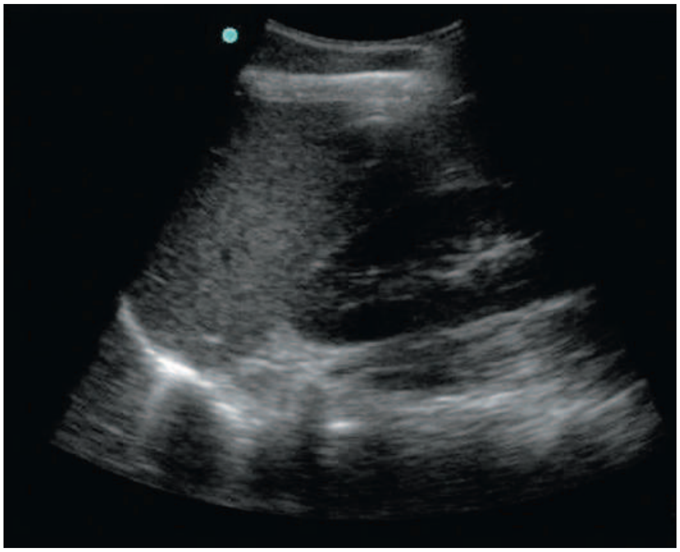

FIGURE 109-4 Right upper quadrant of FAST examination. Normal anatomy reveals the anterior fascia of the kidney *(right midscreen)* and the posterior portion of the liver capsule *(left midscreen)*. A "negative" image shows these two structures clearly and directly apposed. The brightly reflective, curvilinear line of the diaphragm is seen at the far left, lower portion of the screen. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

Pelvis

The suprapubic view visualizes the most dependent section of the lower abdomen and pelvis. In males, the rectovesical pouch is visualized; in females, the pouch of Douglas is seen. These spaces are in the most dependent portion of the lower abdomen and pelvis; hence, they are where fluid is likely to collect. To obtain this view, place the probe in the midline just superior to the symphysis pubis (Figure 109-9). Angle the probe toward the rectum. With the probe held in place, fan up and down and side to side until the pouch of Douglas or rectovesical space is visualized. A negative image shows each gender-specific space without evidence of hypoechoic free fluid (Figure 109-10). A positive image reveals perivesicular free fluid (Figure 109-11).

Cardiac View

Cardiac examination allows rapid assessment for pericardial fluid. It screens for fluid between the pericardium and myocardium, and in the case of traumatic injury can yield lifesaving

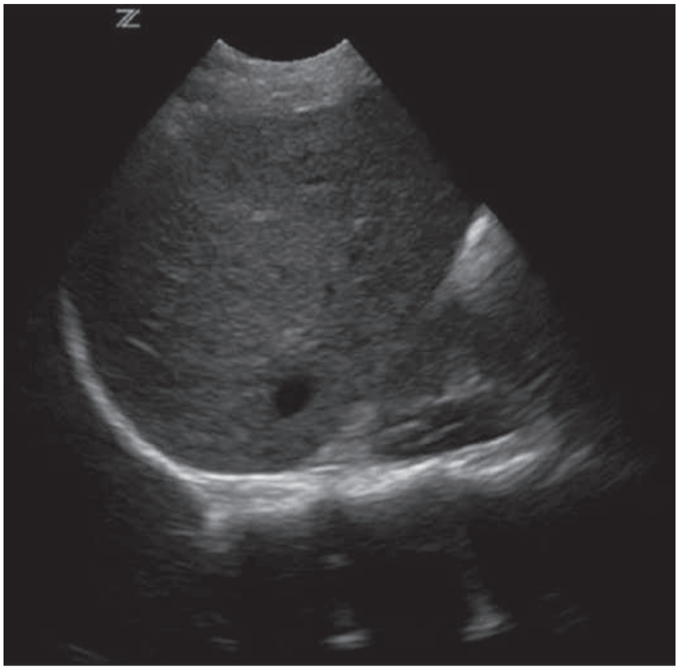

FIGURE 109-3 Lack of a "spine sign" indicates a normal thorax. The abdominal spine stops and meets the diaphragm at a point, indicating that air in the thoracic cavity is blocking the sound waves from reaching the thoracic spine. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-5 Right upper quadrant of FAST examination. A "positive" image for abdominal free fluid reveals a lenticular, hypoechoic, dark stripe between the liver *(midscreen)* and kidney *(top right)*. This image demonstrates why it is important to see the inferior pole of the right kidney for a complete interrogation of this space. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-6 Left upper quadrant of FAST examination. To obtain this view, place the probe in the left posterior axillary line between the 10th and 11th ribs. This allows the spleen, left kidney, and perisplenic space to be imaged. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

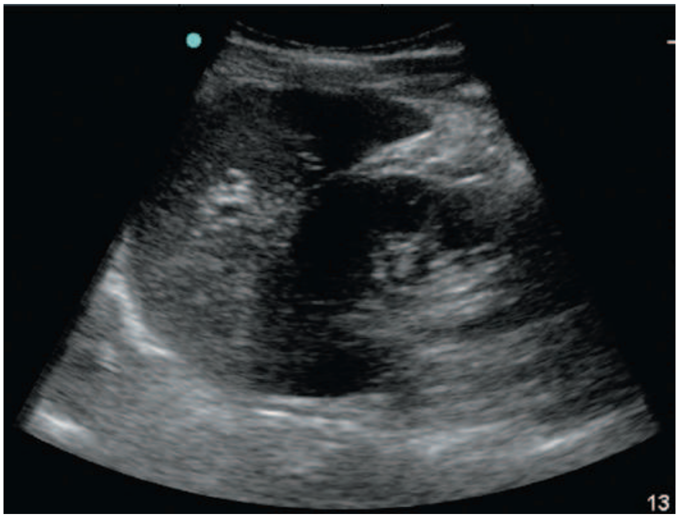

FIGURE 109-7 Left upper quadrant of FAST examination. A "negative" image reveals the spleen *(left side of screen)* and kidney *(right midscreen)* in close apposition. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

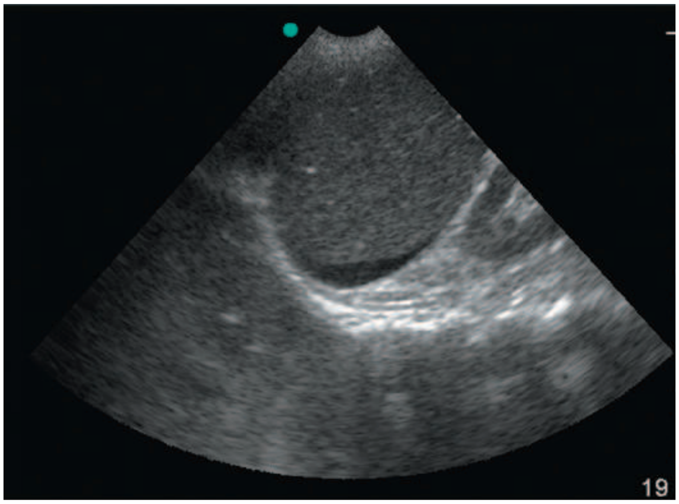

FIGURE 109-8 Left upper quadrant of FAST examination. A "positive" image for abdominal free fluid reveals a hypoechoic, dark stripe, here most notable at the inferior tip of the spleen *(center of screen)*. The kidney is seen on the far right. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-9 Suprapubic view of FAST examination. To obtain this view, place the probe in the midline just superior to the symphysis pubis. Angle the probe toward the rectum, then with probe held in place, rotate up the spine until the pouch of Douglas or rectovesical space is visualized. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

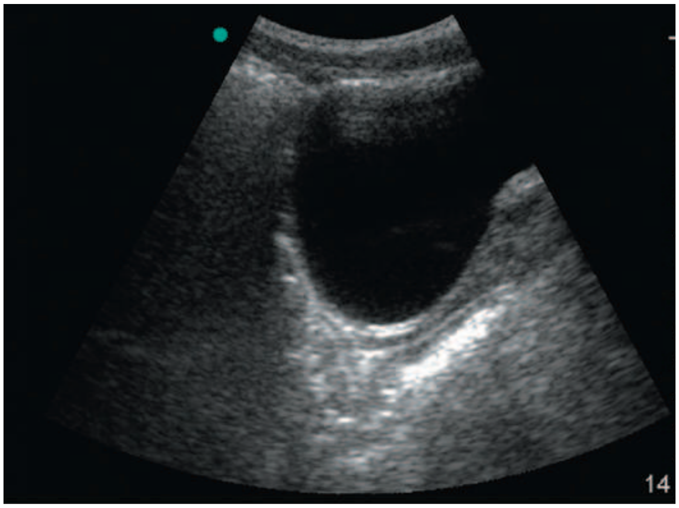

FIGURE 109-10 Suprapubic view of FAST examination. A "negative" image shows each gender-specific space without evidence of hypoechoic free fluid outside of the bladder. Here, the full bladder (globular, dark structure in *midscreen*) is visualized. There is no free fluid outside the bladder. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

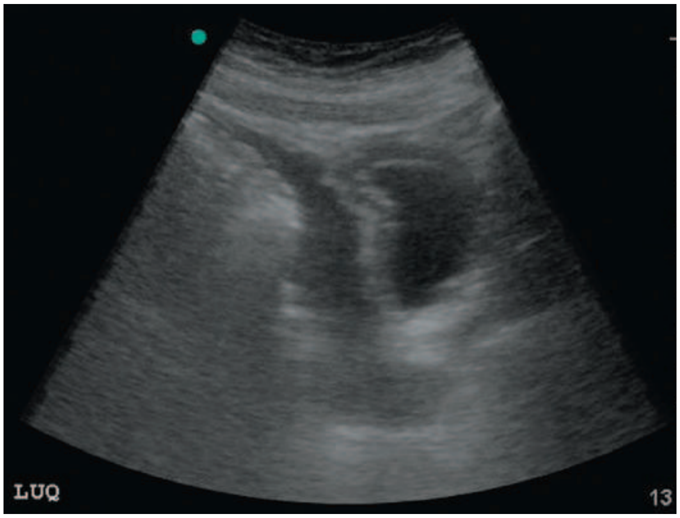

FIGURE 109-11 Suprapubic view of FAST examination. A "positive" image reveals perivesicular abdominal free fluid (irregularly shaped, hypoechoic, dark stripe) in the center of screen. The circle to the right is the partially decompressed bladder. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-12 Subxiphoid view of FAST examination. To obtain this view, place the probe just inferior to the xiphoid process, with the angle upward under the costal margin toward the left shoulder. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

information. To obtain this view, place the probe just inferior to the xiphoid process, with the angle upward under the costal margin toward the left shoulder (Figure 109-12). A "negative" image for free fluid displays the echogenic, bright pericardial sac immediately adjacent to the active cardiac surface (Figure 109-13). A "positive" image for free fluid reveals a hypoechoic, dark stripe between the pericardial sac and the cardiac surface (Figure 109-14). An additional view of the heart may be obtained using the "parasternal long" cardiac view. This view can be helpful in patients who are uncooperative, obese, or in whom the clinician is trying to distinguish between pericardial and left-sided pleural fluid. To achieve this view, position the probe to the left of the sternum in the 4th to 5th intercostal space with the probe indicator pointing toward 4 o'clock (Figure 109-15). Representative negative and positive images are provided in Figures 109-16 and 109-17, respectively.

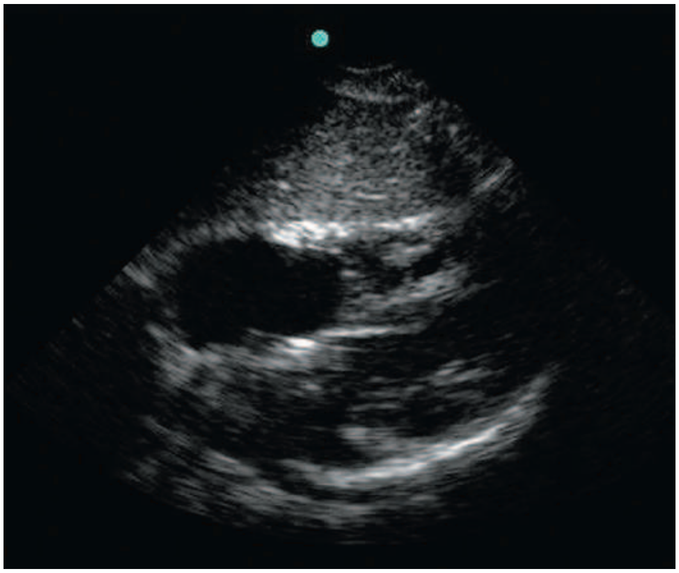

FIGURE 109-13 Subxiphoid view of FAST examination. The pericardial examination screens for fluid between the fibrous pericardium and the heart. In this "normal" study, there is no pericardial effusion. The atria are seen on the left side of the screen, the ventricles to the right. The right atrium and ventricle are at the top of the screen, and the left atrium and ventricle at the bottom. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

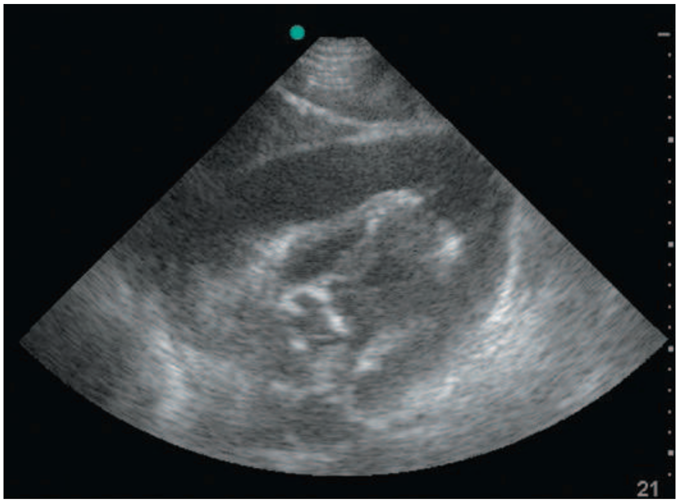

FIGURE 109-14 Subxiphoid view of FAST examination. A large pericardial effusion (dark, anechoic layer) envelops the anterior and posterior heart. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-15 Parasternal long view of FAST examination. To achieve this view, position the probe to the left of the sternum in the 4th to 5th intercostal space with the probe indicator pointing toward 4 o'clock. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

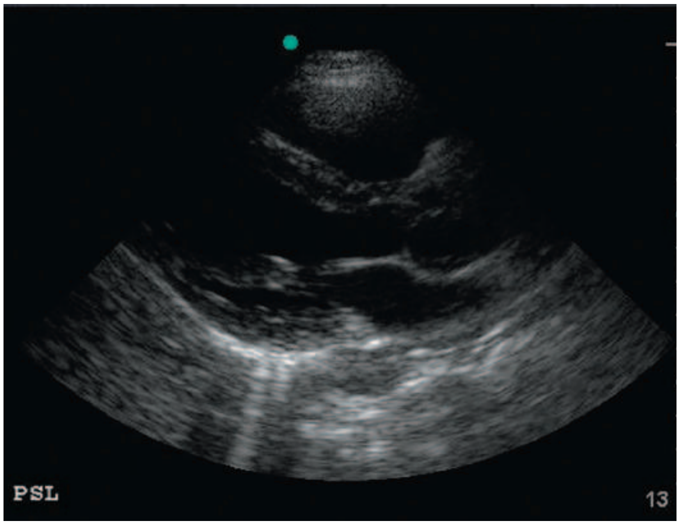

FIGURE 109-16 Parasternal long view of FAST examination. This normal anatomy reveals the left ventricle and outflow track lying horizontally in the middle of the screen. The aortic valve is seen in the right midfield of this image. The bright pericardium is directly adjacent to the myocardium, as there is no pericardial effusion. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

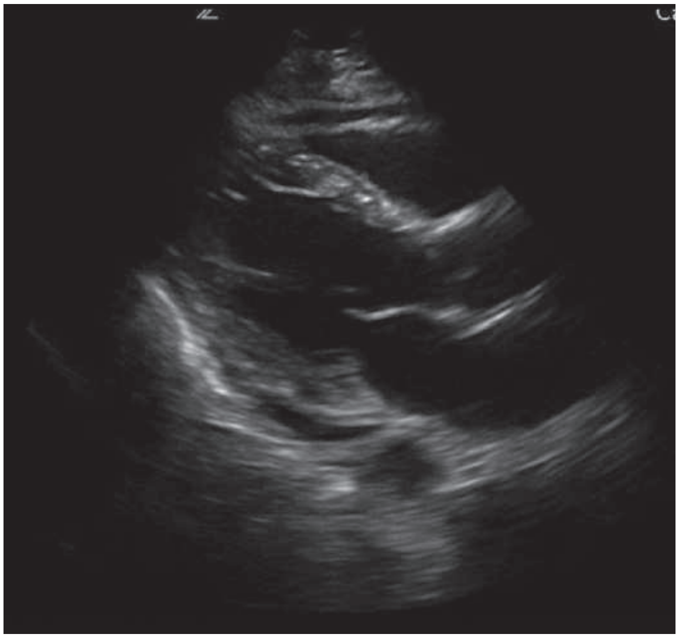

FIGURE 109-17 Parasternal long view of the heart. A large pericardial effusion (darker, hypoechoic layer) envelops the anterior and posterior heart traveling anterior to the descending thoracic aorta, thus distinguishing it from a pleural effusion, which would travel behind the descending thoracic aorta. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

THORACIC ULTRASOUND FOR PNEUMOTHORAX AND PULMONARY EDEMA

Ultrasound of the thorax can be used to screen effectively for pneumothorax, pulmonary edema, pleural effusion, and interstitial disease.

Pneumothorax

Ultrasound for pneumothorax can be done with either the high-frequency or the low-frequency probe. The clinician turns down the gain and decreases the depth when performing this examination so that the bright, echogenic pleural line is centered in the middle of the screen and stands out from the less echoic surrounding structures just below the rib shadow.

The scanning protocol depends on how thorough the clinician wants to be and how small a pneumothorax is suspected. For an initial screen for a hemodynamically significant pneumothorax, the probe is placed on the chest in a sagittal position in the 2nd to 3rd intercostal space in the midclavicular line and slowly moved toward the lateral chest. In real time, normal lung anatomy is revealed through two characteristic findings: presence of "lung sliding" (the sliding motion of the visceral pleura against parietal pleura with inspiration and expiration) and visualization of "comet tails." Comet tails are artifacts that appear as a bright, white line caused by the reverberation of the sound waves between the dense visceral and parietal pleurae (Figure 109-18). If air separated the visceral and parietal pleurae, it would scatter the returning sound waves, and the visceral pleura deep to the pneumothorax would be invisible. In a patient with a pneumothorax, neither lung sliding nor comet tails will be visualized. All that will be seen is the static parietal pleura. It is important to note that only the area of the lung seen under the footprint of the probe can be called "negative." When evaluating for pneumothorax, sensitivity of the ultrasound exam is increased by imaging more of the surface area of the thorax.

An additional technique to screen for the presence of pneumothorax can be accomplished using M-mode scanning. M-mode imaging produces a linear representation of movement in a single plane over a period of time. By aligning that plane through the structure of interest (in this case the pleural line), changes within that plane (e.g., lung sliding) can be readily appreciated.

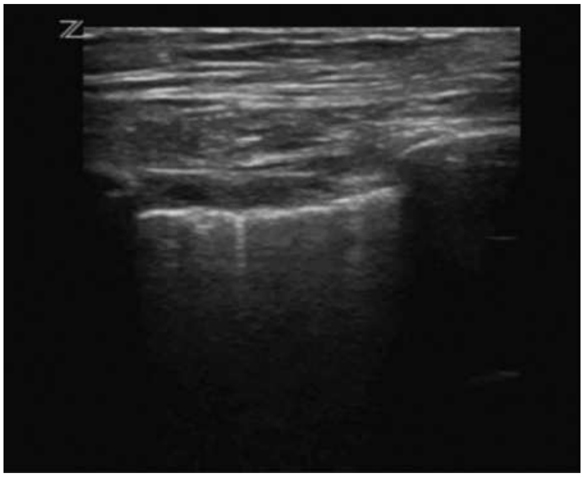

FIGURE 109-18 Normal lung anatomy. The rib shadows and comet-tail reflection are seen well here. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

Normal sliding movement between parietal and visceral pleurae will produce the "seashore" sign (Figure 109-19). Normal skin and intercostal muscles have minimal movement during breathing and appear as flat, stacked lines using M-mode. Below the bright, white line of the pleural surface, normal lung tissue moves, which results in this structure having a granular appearance. This image has been described as reminiscent of waves (the superficial/superior, stacked, linear portion of the image) against a beach (the deeper/lower granular portion of the image). In patients with a pneumothorax, lung tissue appears stationary and thus appears in M-mode as a series of stacked lines, just like the superficial muscle above it. This results in the "bar code" sign (Figure 109-20).

Pulmonary Edema

Ultrasound is very accurate at assessing the water content of lung tissue. However, instead of imaging the tissue directly, this

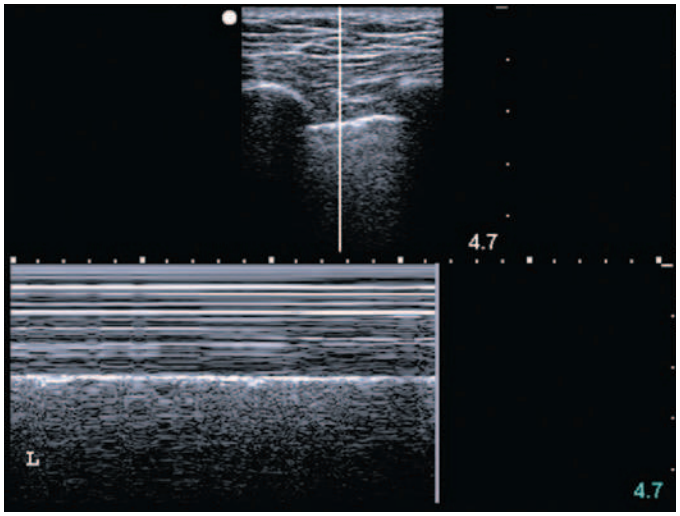

FIGURE 109-19 "Seashore" sign indicates normal anatomy with no pneumothorax. Images obtained of thorax employing B-mode imaging *(top)* and M-mode imaging *(below)*. Normal skin/intracostal muscles *(top of lower image)* have minimal movement during breathing and thus appear as flat, stacked lines using M-mode. Below the bright, white line of the pleural surface, normal lung tissue does move, and this results in this structure having a granular appearance *(bottom of image)*. This image has been described as reminiscent of waves *(superficial/superior, stacked, linear portion of image)* against a beach *(deeper/lower granular portion of image)*. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

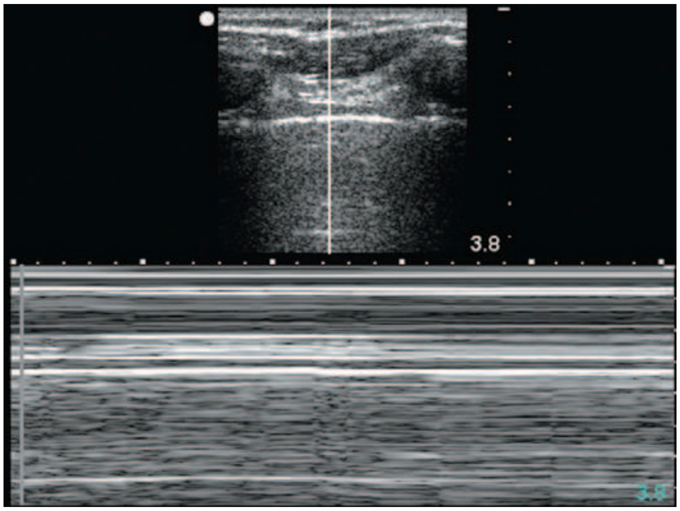

FIGURE 109-20 "Bar code" sign indicates the presence of a pneumothorax. Images obtained of thorax employing B-mode imaging *(top)* and M-mode imaging *(below)*. In a patient with a pneumothorax, the lung tissue appears stationary and thus appears in M-mode as a series of stacked lines no different than the superficial muscle above it. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

assessment is done by evaluating artifacts caused by the impedance difference between air-filled alveoli and fluid-filled interstitium. When the lung is well aerated and without excessive lung water, sound waves generated by a low-frequency probe bounce between the pleural line and skin, causing a horizontal artifact known as *A-lines* (Figure 109-21). If the interstitium and then the alveoli start to fill with fluid, the tissue begins to conduct sound. The reflections generated by this impedance difference (fluid and air) are called *B-lines* (Figure 109-22). B-lines are vertical reflections that originate at the pleura and must travel to at least a depth of 18 cm (7.2 inches; this is why the low-frequency probe is used). B-lines move with the pleural line during respiration.

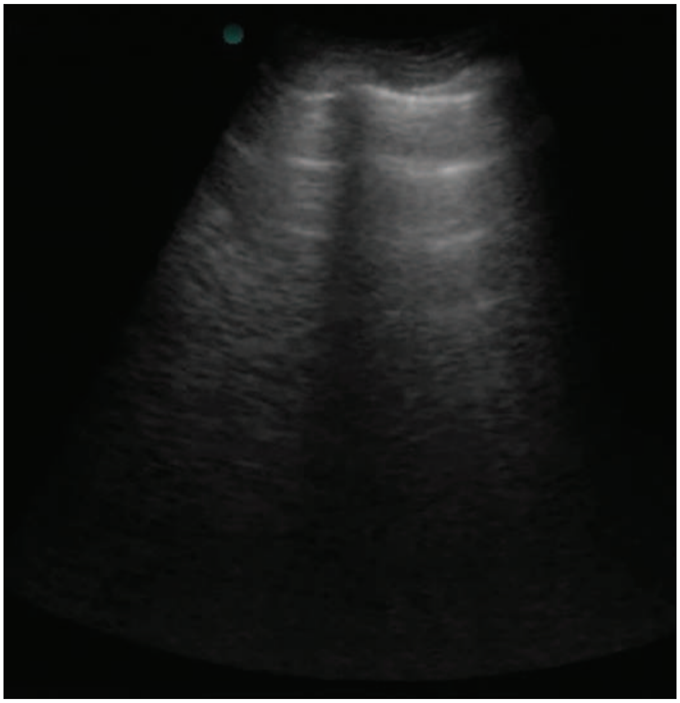

FIGURE 109-21 A-lines are a reverberation artifact between the skin and the pleura indicating an air-filled lung. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

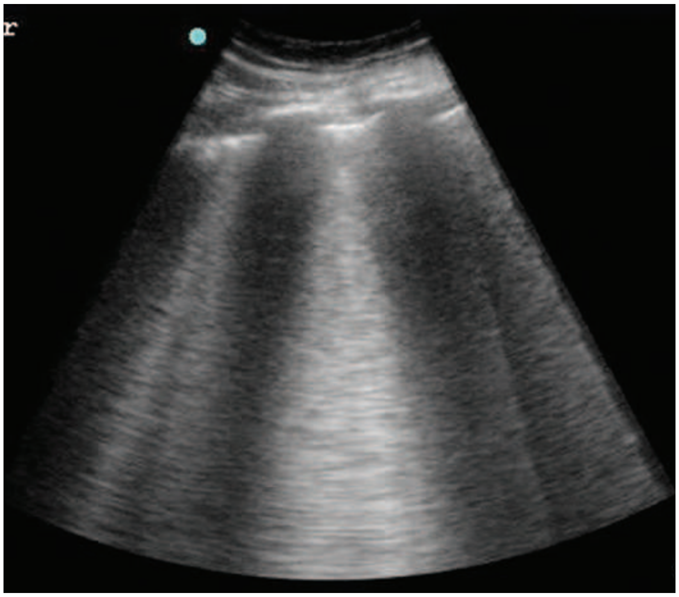

FIGURE 109-22 B-lines are vertical artifacts indicating sound is now being reflected through a fluid-filled lung. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

Numerous papers demonstrate that more B-lines correlate directly with increasing amounts of lung water in the lung tissue.[3,35,70] The scanning protocol usually consists of four zones for each thoracic cavity—superior and inferior midclavicular zones and superior and inferior axillary zones of the right and left thorax—to map out lung tissue and identify whether the B-line artifacts are diffuse or focal. Global assessment of mild, moderate, or severe B-lines and the pattern of interstitial fluid can reveal different clinical scenarios (i.e., diffuse findings are consistent with pulmonary edema, and focal findings with pneumonia).[71]

Presence of B-lines correlates well with natriuretic peptide levels, wedge pressures as determined by pulmonary artery catheterization, and interstitial disease on chest computed tomography (CT).[3,70] B-lines appear and resolve in minutes to hours, so ultrasound for pulmonary edema evolution is particularly useful.[49] Thoracic ultrasound scanning allows diagnosis and monitoring of pulmonary edema in both subclinical and overt high-altitude pulmonary edema (HAPE) that may affect oxygenation at high altitude (Figure 109-23). Multiple papers have described use of ultrasound for diagnosis and monitoring HAPE.[25,56] Conventional radiography is less sensitive to detect subclinical pulmonary edema and early HAPE and does not allow easy tracking of progression or resolution of fluid accumulation.[13,69] Techniques that overcome these shortcomings, such as CT or magnetic resonance imaging (MRI), are not available in the field. Ultrasound is the ideal diagnostic imaging modality for HAPE because it diagnoses subclinical disease and can be used to monitor disease progression or resolution.

MUSCULOSKELETAL ASSESSMENT

Fractures

Ultrasound to diagnose bony fractures in adults and children is well established.[18] Bones of the upper extremities, lower extremities, face and skull, sternum, and ribs have all been studied and are well suited for ultrasound imaging.[14,18,48,64,73] Ultrasound guidance for diagnosis and closed reduction of fractures is useful.[17] Persons employing large animals on backcountry travel now can access a growing body of literature on assessment of veterinary bone and joint integrity using ultrasound techniques.[13]

Technique for ultrasound assessment of bony fracture is simple. A high-frequency (7.5- to 10-MHz) linear-array probe is ideal. The depth of scan should be reduced to that needed to visualize the bony surfaces. Starting with the probe's long surface parallel to the bone, the examiner moves down the bone looking

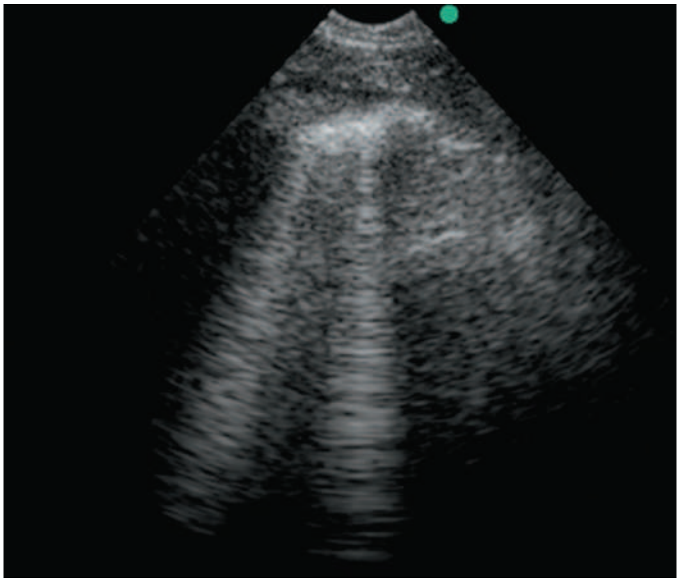

FIGURE 109-23 B-lines can be seen in this patient with high-altitude pulmonary edema diagnosed below Mt Everest Base Camp in Pheriche, Nepal. Views obtained using low-frequency curved probe and B-mode imaging. *(Courtesy Peter J. Fagenholz.)*

at the linear, highly reflective (bright on the screen) bony cortex. A normal study reveals a contiguous, smooth, linear or curvilinear surface along the length of the bone (Figure 109-24). A fracture appears as a sharp, pointed step-off or break in the cortex (Figure 109-25). Clinical correlation is helpful. The site of sonographic step-off is likely to display both sonographic and tactile maximal tenderness to palpation. Skull fracture can be more difficult to discover using ultrasound because of the broad, curved surface to be studied, but excellent diagnostic images may be obtained (Figures 109-26 and 109-27).

Dislocation

Ultrasound has been demonstrated to be quite accurate for diagnosis of shoulder dislocation.[1] There is less literature supporting its use in other joint dislocations, but the principle of use would be the same.

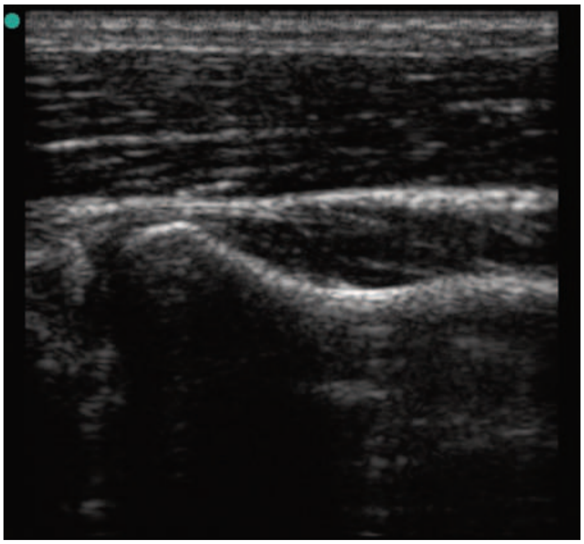

FIGURE 109-24 Ultrasound of normal distal radius. In this "negative" study, the contiguous, smooth, linear, and highly reflective bony cortex is seen running horizontally across the screen at approximately 1 cm (0.4 inch) depth. Normal (darker) muscle tissue is seen superficial to the bone. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

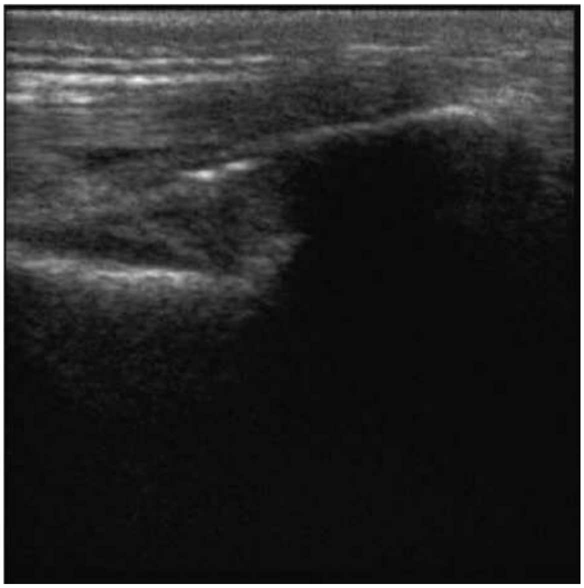

FIGURE 109-25 Ultrasound of fractured distal radius. In this "positive" study, the highly reflective bony cortex is notably irregular and approximately 1 cm (0.4 inch) displaced. In bone studies with a fracture, the site of sonographic step-off is likely to possess tactile maximal tenderness to palpation. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

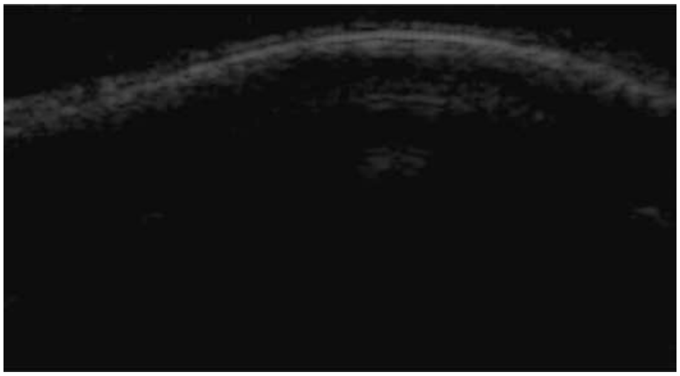

FIGURE 109-26 Ultrasound of normal pediatric skull. In this "negative" study, the contiguous, smooth, curvilinear bony cortex is seen running horizontally across the screen at approximately 0.5 cm (0.2 inch) depth. Bone views were obtained using a high-frequency (7.5 to 10 MHz) linear-array probe. *(Courtesy N. Stuart Harris.)*

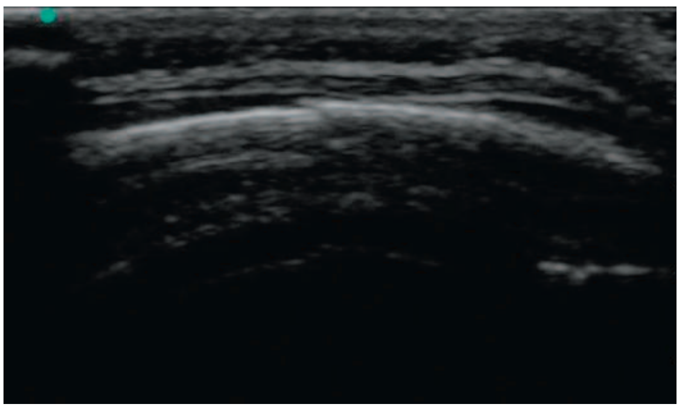

FIGURE 109-27 Ultrasound of a fractured pediatric skull. In this "positive" study, a clear break in the otherwise smooth, curvilinear bony cortex can be appreciated in the middle of the screen. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-28 Normal articulation of the humeral head with the glenoid fossa. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

To assess for shoulder dislocation, use the curved low-frequency probe (2 to 5 MHz) and place it parallel to the top of the scapula, looking at the shoulder joint from posterior to anterior. A normally located humeral head will be seen at the level of the glenoid fossa (Figure 109-28), whereas an anteriorly dislocated shoulder will be seen at a greater depth on the screen, no longer contiguous with the glenoid fossa (Figure 109-29). Ultrasound can be used to demonstrate alignment after relocation of the affected bone.

OPTIC NERVE SHEATH ULTRASONOGRAPHY

Increased intracranial pressure (ICP) plays a role in severe high-altitude cerebral edema (HACE) and thus has long been a parameter of interest in high-altitude research. It is hypothesized that increased ICP is also associated with acute mountain sickness (AMS), but this relationship has not yet been convincingly established.[62] Lack of consistent data on ICP at high altitude largely results from a lack of sensitive, noninvasive techniques for assessing ICP. Where invasive measures have been used, the number of patients has been too small to draw meaningful conclusions.[33] However, published data have correlated symptoms of AMS with ultrasonographic assessment of optic nerve sheath diameter (ONSD). Ultrasound is a promising research tool to explore the pathophysiology of this AMS, especially because other diagnostic imaging modalities are not available in this setting.[26,11]

As measured by ultrasound, ONSD correlates with radiologic measures of increased ICP[30,38] and direct measurement of ICP in intrathecal infusion tests.[32] The physiologic basis of this technique is that increases in ICP are transmitted by cerebrospinal fluid down the perineural subarachnoid space of the optic nerve, causing expansion of the nerve sheath. Ultrasound can be used to follow this change by imaging through the eye and measuring the diameter of the shadow of the optic nerve sheath. This technique has been shown to have some interobserver variability; optimal methods for acquiring and measuring images are still being developed.[6] Nevertheless, a sufficient number of independent studies have documented correlation with radiographic and invasive measures of ICP.[11,66] At present, optic nerve sonography is an important research tool. Its clinical application, which has focused recently on identifying sensitivity and specificity of certain cutoff values for pathologically increased ICP, is still being refined. Given significant individual variability in optic nerve sheath size, using serial examinations to assess for changes within the same person or the same cohort over time may be more important than isolated ONSD values. For research purposes, small numbers of observers can be trained to minimize problems of interobserver variation.[6]

Optic nerve sheath ultrasound is usually performed with the patient supine with eyes closed. There are two acceptable imaging techniques. The first is to place an adhesive plastic dressing over the closed eyelid to keep ultrasound gel off the face and to hold the lid closed. The ultrasound gel is applied on top of the plastic. The second is to put ultrasound gel inside a thin plastic bag, into which the ultrasound probe is placed, after which the external surface of the bag is applied to the closed eyelid (Figure 109-30). A high-frequency (7- to 10-MHz) transducer is used to acquire a longitudinal, cross-sectional image of the optic nerve posterior to the orbit (Figure 109-31). The ONSD is measured 3 mm (0.12 inch) behind the retina; enlarged ONSD measurement is typically considered to be greater than 5 mm (0.2 inch). More important than absolute size are changes noted before and after intervention on the same individual (Figure 109-32).

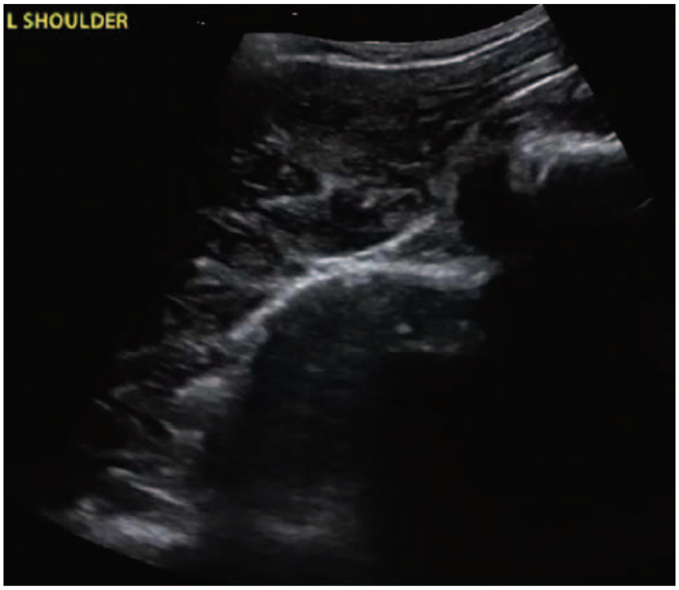

FIGURE 109-29 Anterior dislocation showing inferior displacement of the humeral head. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-30 Optic nerve sheath diameter assay. This study is typically performed with the subject supine and with eyes closed. The probe is placed on the closed lid, typically just lateral to the center of the pupil, and adjusted until a longitudinal, cross-sectional image of the optic nerve (posterior to the orbit) is obtained. To maximize visual clarity, this figure does not show the occlusive dressing (to protect the eye), ultrasound gel, or a high frequency (7- to 10-MHz), linear probe that are typically employed. *(Courtesy N. Stuart Harris.)*

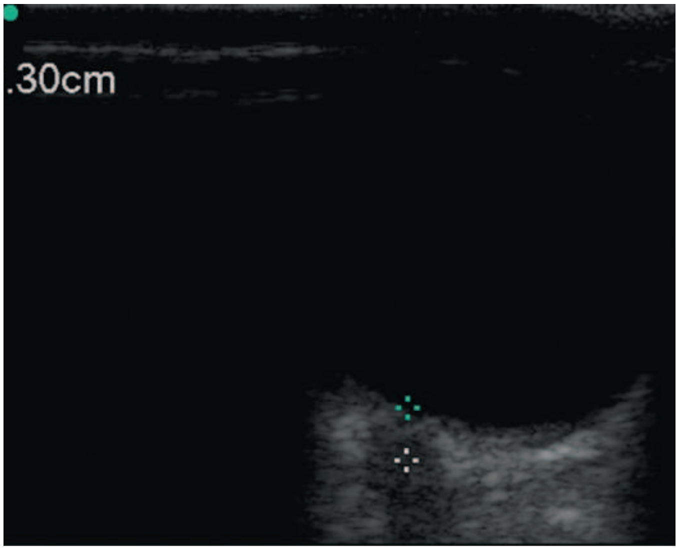

FIGURE 109-31 Normal optic nerve sheath diameter. This "negative" study of a research participant was obtained at low elevation before climbing Mt Kilimanjaro. The patient's optic nerve sheath diameter measures a normal 4.1 mm (0.16 inch). Crosshairs mark the surface of the retina *(upper crosshairs)* and 3 mm (0.1 inch) deep to the retina *(lower crosshairs);* 3 mm (0.1 inch) is the conventional depth at which the optic nerve sheath diameter is measured in cross section. Anechoic, dark, vitreous makes up the majority of this image. *(Courtesy N. Stuart Harris.)*

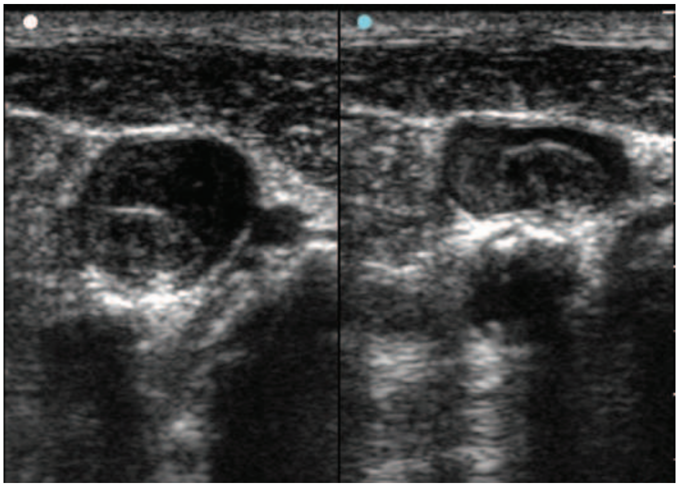

FIGURE 109-33 Vein seen with echogenic, noncompressible clot. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

DOPPLER AND BLOOD FLOW STUDIES

Doppler ultrasound allows determination of blood flow data and associated information (e.g., resistive and pulsatility indices) in any sonographically accessible blood vessel.[66] At high altitude, the effect of hypoxia on coagulation continues to generate interest.[59,67] Doppler and other techniques can be used to identify venous and arterial thromboses. The two-zone scanning protocol for evaluating the lower-extremity venous system has been well studied. A high-frequency probe is used to image the two high-turbulence zones: (1) the common femoral vein from the junction with the greater saphenous vein through the bifurcation of the deep and superficial femoral veins, and (2) the popliteal vein through the trifurcation. Both zones should be compressed in their entirety. Inability to fully compress the vessel indicates the presence of clot[7,36] (Figure 109-33). This technique has greater than 90% sensitivity for proximal deep vein thrombosis (DVT) and approximately 50% sensitivity for distal DVT. Color flow Doppler allows assessment of clot in noncompressible vessels, such as the portal circulation vessels, which are also at risk at high altitude. This scanning protocol is technically more challenging and requires dedicated training.[5] Arterial imaging can be used when arterial thrombosis is suspected clinically. Pulse-wave Doppler is applied to measure velocity amplitude of the affected vessel and can be compared to the maximal velocities on the unaffected side (Figure 109-34).

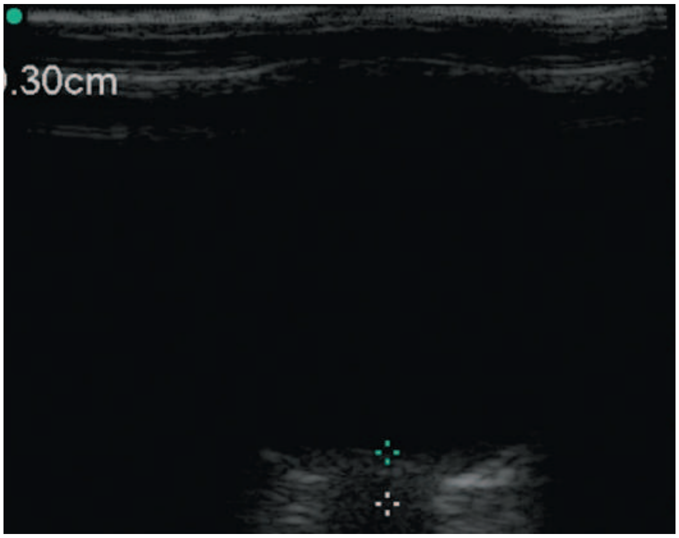

FIGURE 109-32 Enlarged optic nerve sheath diameter. This is the individual seen in Figure 109-31, but now at 5730 m (18,800 feet) in the summit crater of Mt Kilimanjaro and with severe acute mountain sickness. In this "positive" study, this patient's optic nerve sheath diameter now measures a greatly enlarged 6.5 mm (0.26 inch). In many indications, 5.0 mm (0.2 inch) may be considered as potential evidence of increased intracranial pressure. *(Courtesy N. Stuart Harris.)*

INFERIOR VENA CAVA AND VOLUME ASSESSMENT

Techniques exist for estimating volume status by imaging the inferior vena cava (IVC), but this scanning application is most helpful in looking for volume depletion and monitoring the response to oral rehydration. This technique has been used to assess central volume status in the field at high altitude.[58a] The scanning protocol begins by placing the probe in a transverse orientation in the subxiphoid position and then rotating to the long axis, angling the probe under the costal margin, and following the IVC behind the liver into the right atrium (Figure 109-35). A flat, small-diameter IVC indicates low venous pressure (Figure 109-36).[41] A flat, volume-depleted IVC responds in real time to volume challenges by becoming more distended. This imaging technique may be used as a method to monitor a patient's response to rehydration. A distended, noncollapsible IVC indicates elevated venous pressure. This can either be the result of non–fluid-responsive pathology (e.g., heart failure) or fluid-responsive conditions (e.g., cardiac tamponade, pulmonary embolus) (Figure 109-37). Decisions regarding fluid resuscitation of patients with a distended IVC should be made after a careful cardiac evaluation.

ECHOCARDIOGRAPHY FOR PATENT FORAMEN OVALE

Echocardiographic techniques can be of great use to the high-altitude researcher when evaluating physiologic responses to altitude and hypoxia. There is good evidence that basic cardiac ultrasound imaging techniques looking for pericardial effusion, global systolic function, and dilation of the right ventricle can be mastered with focused training.[41] Techniques for detecting a patent foramen ovale (PFO), a condition associated with

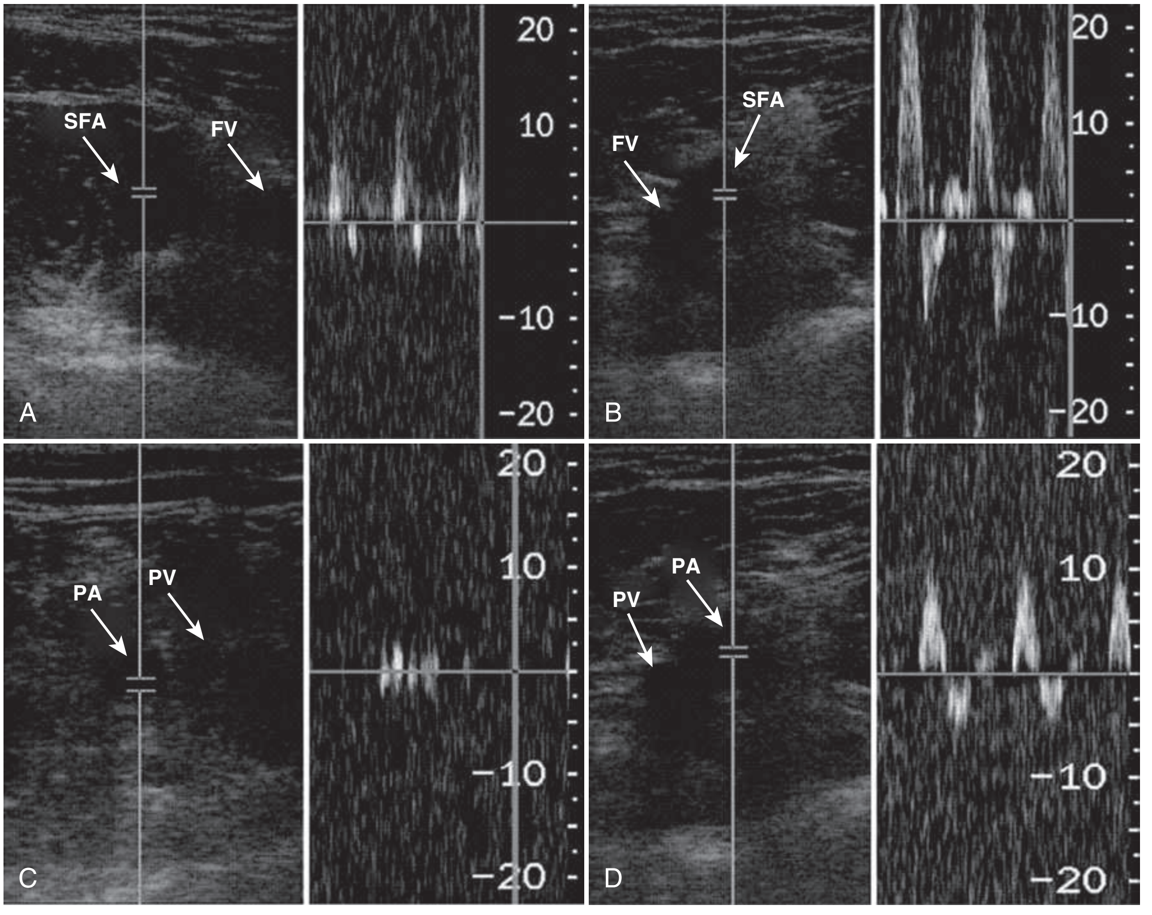

FIGURE 109-34 Two-dimensional and Doppler ultrasound images of the right and left superficial femoral and popliteal arteries. These images are from a trekker stricken with a limb-threatening arterial thrombus a day's walk below Mt Everest Base Camp. **A,** Right SFA and associated Doppler signal showing decreased flow compared with the left SFA. **B,** Left SFA and associated Doppler signal showing normal flow velocity. **C,** Right popliteal artery and associated Doppler signal showing a lack of flow. **D,** Left popliteal artery and associated Doppler signal showing normal flow. The crosshairs indicate the point at which the Doppler signal was measured. Units on the right axis are centimeters per second. *FV*, Femoral vein; *PA*, popliteal artery; *PV*, popliteal vein; *SFA*, superficial femoral artery. *(Courtesy Peter J. Fagenholz, as published in Fagenholz PJ, Gutman JA, Murray AF, et al: Arterial thrombosis at high altitude resulting in loss of limb,* High Alt Med Biol *8:340, 2007.)*

FIGURE 109-35 Probe position for inferior vena cava (IVC) exam. The IVC is usually visualized by initially placing the probe in the transverse orientation in the subxiphoid position. When the central vessels (IVC and aorta) are identified, the probe is rotated in the long axis to follow the IVC behind the liver and into the right atrium. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

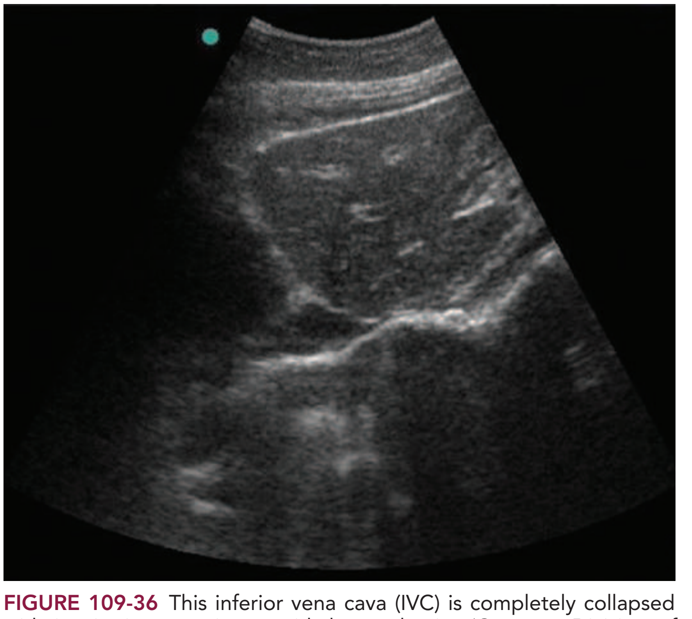

FIGURE 109-36 This inferior vena cava (IVC) is completely collapsed with inspiration, consistent with hypovolemia. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

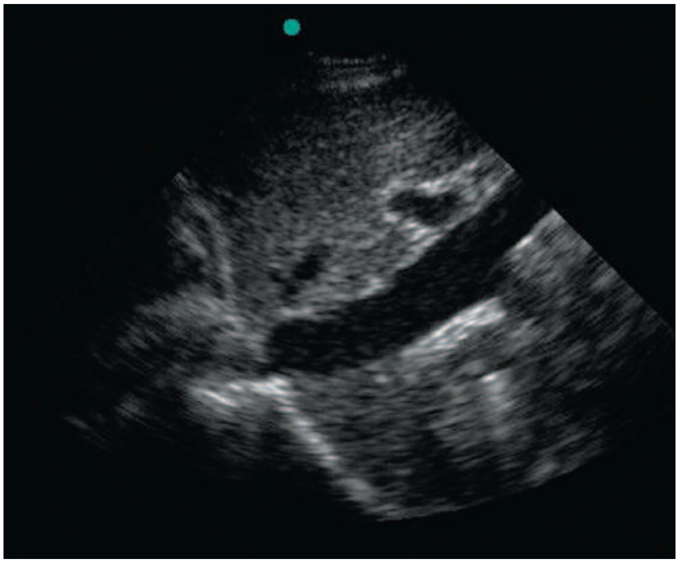

FIGURE 109-37 Inferior vena cava (IVC) image showing a distended, noncollapsible IVC. Before a decision is made about resuscitation strategies, this patient should have a cardiac ultrasound examination. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-38 Probe position to obtain four-chamber apical ("apical-four") cardiac view on transthoracic echocardiography. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

HAPE susceptibility, can be taught with focused methods.[4] More advanced hemodynamic assessments and echocardiology evaluations require more extensive training. The technical demands of the techniques for measuring pulmonary artery pressure, cardiac output, and other aspects of cardiac function are beyond the scope of this chapter.[20,63] Readers are referred to other resources.[15,52]

Because the presence of a PFO has been associated with HAPE susceptibility, researchers will want to monitor for this condition in future HAPE studies. PFO may bear further investigation as a cause of shunting and hypoxemia at high altitude outside the setting of HAPE. Transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) techniques can be used to evaluate for PFO. TTE is less invasive and does not require sedation. Machines with harmonic imaging have made TTE as sensitive (~80%) as TEE for detection of PFO. We discuss TTE technique here.[21] Assessment for PFO is performed with a 2.5- to 5-MHz transducer. An "apical-four" image is obtained with the patient positioned in the left lateral decubitus position and the transducer placed at the point of maximal impulse of the heart apex and pointed toward the right shoulder (Figure 109-38). The atrial (and ventricular) septum should be vertically aligned in a four-chamber apical view (Figure 109-39). After intravenous (IV) injection of 10 mL of agitated saline contrast, the right side of the heart is monitored for opacification with contrast. A first injection is usually performed at rest, with three subsequent injections performed during maneuvers (e.g., cough or Valsalva maneuver) designed to increase right atrial pressure. The presence of a PFO is determined by presence of bubbles in the left side of the heart within five cardiac cycles. PFO size can be characterized as small (0 to 10 bubbles), moderate (10 to 50), or large (>50). The occurrence of bubbles after five cardiac cycles indicates intrapulmonary shunt.

PREGNANCY

Clinical obstetrics has long relied on perinatal ultrasound and a wide array of techniques for assessing the fetus. Many of these have been employed at high altitude, and there is much interest in how the fetus, placental blood flow, and maternal physiology respond to hypoxia and high altitude.[39,40] These ultrasound techniques require more advanced sonographic training and are not described here. We discuss early obstetric ultrasound imaging to assess for the presence of an intrauterine pregnancy. Second- and third-trimester ultrasound techniques are used to assess for number of gestations, fetal lie, placental positioning, and quantity of amniotic fluid. This is only an introduction, and one should seek further guidance elsewhere for more extensive description of these techniques.

First-Trimester Ultrasound

First-trimester ultrasound should be considered in female patients presenting with a positive pregnancy test (or presumed early pregnancy, if testing is unavailable) together with concerns for ectopic pregnancy, such as vaginal bleeding, lower abdominal pain, syncope, and hypotension. The aim of the ultrasound is to demonstrate the presence of an intrauterine pregnancy (IUP) and thus decrease the post-test probability of ectopic pregnancy to near zero. Unless the patient has undergone fertility treatment, the possibility of heterotopic pregnancy is rare if an IUP is identified.

Intrauterine pregnancy is defined as presence of a gestational sac together with a yolk sac and fetal pole (with or without fetal heartbeat). If only a presumed gestational sac is visualized, a number of possibilities exist: the pregnancy is too early for the other pregnancy-related structures to be identified (in which

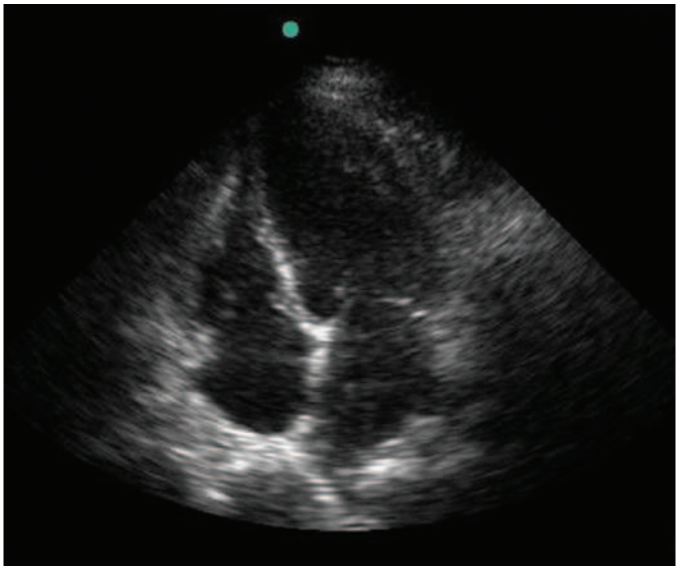

FIGURE 109-39 Image of normal "apical four." Note the vertical alignment of the septum. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-40 Transverse view of the uterus using the transabdominal probe. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

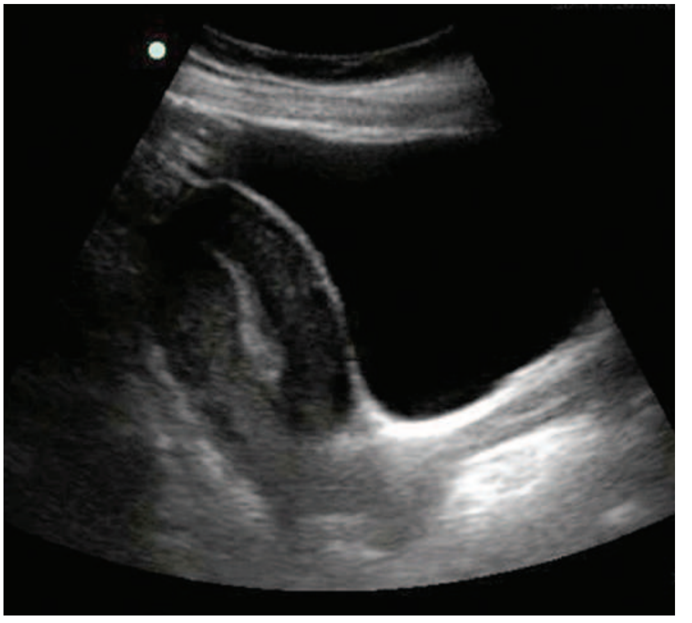

FIGURE 109-41 Longitudinal view of the uterus using the transabdominal probe. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

case either a transvaginal ultrasound should be performed or a repeat transabdominal ultrasound in 1 week), there has been fetal demise, or the patient has an ectopic pregnancy. In austere settings, if a patient has a positive pregnancy test and no identifiable IUP on ultrasound, an ectopic pregnancy is assumed until proved otherwise and appropriate measures taken.

Early-pregnancy ultrasound imaging in the hospital setting often employs both transabdominal and transvaginal scanning. In the wilderness setting, one will likely only have a curvilinear or phased-array probe, and therefore only the transabdominal approach will be possible. Using the curvilinear 2.5-MHz probe, the pelvis should be imaged in both transverse and sagittal planes. The probe is placed in the midline just superior to the symphysis pubis. For the transverse orientation, the probe marker is pointed toward the right side of the patient. The probe should be angled down into the pelvis in order to visualize the uterus in cross section (Figure 109-40). Fan the probe up and down to ensure that the entire uterus is visualized, looking for the presence of an IUP. Note the area posterior to the uterus—the pouch of Douglas/retrovesicular space—where fluid can be seen in the event of a ruptured ectopic pregnancy.

For the sagittal or longitudinal orientation, rotate the probe 90 degrees to have the marker pointing toward the patient's head. Angle the probe into the pelvis. Fan the probe left and right to visualize the entire uterus and cervix (Figure 109-41), looking for evidence of an IUP. Look closely at the pouch of Douglas for the presence of free fluid.

In first-trimester scanning, the gestational sac appears as a black, anechoic circular structure within the body of the uterus (Figure 109-42). The yolk sac is a small, hyperechoic circle located within the gestational sac (Figure 109-43). A fetal pole is an echogenic longitudinal structure that sits between the yolk sac and edge of the gestational sac (Figure 109-44).

If movement or flutterings are seen within the fetal pole, fetal heart rate can be measured. Press the M-mode button on the machine, then place the line over the beating heart. Press the M-mode button a second time to record movement over time across that line. The majority of machines will calculate the fetal heart rate by placing calipers from one beat to the next (Figure 109-45). Normal fetal heart rate ranges from approximately 100 to 180 beats per minute.

A FAST examination should be performed in the hemodynamically unstable patient, looking for free intraperitoneal fluid. In a supine patient, because Morison's pouch is the most dependent area, it may be the first place to visualize free fluid in the setting of a ruptured ectopic pregnancy. If fluid is seen in Morison's pouch in a pregnant, nontrauma patient with hemodynamic instability in the wilderness setting, initiate immediate evacuation.[47]

Second- and Third-Trimester Ultrasound

In resource-limited settings, the point-of-care applications for second- and third-trimester evaluations are usually to (1) look at fetal positioning (transverse, breech, or head first), (2) identify the number of pregnancies, (3) quantify the volume of amniotic fluid, (4) identify placental positioning, and (5) estimate gestational age. In these settings, prenatal evaluation may not occur until late in the second trimester or even at the start of labor.

Fetal Positioning and Number of Pregnancies. The first two applications are to identify patients at greater risk for complications with vaginal delivery and to encourage childbirth in a

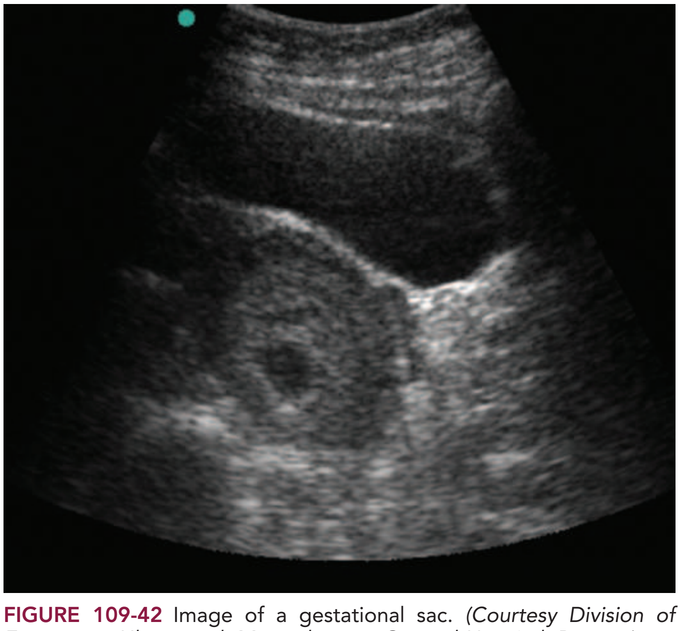

FIGURE 109-42 Image of a gestational sac. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

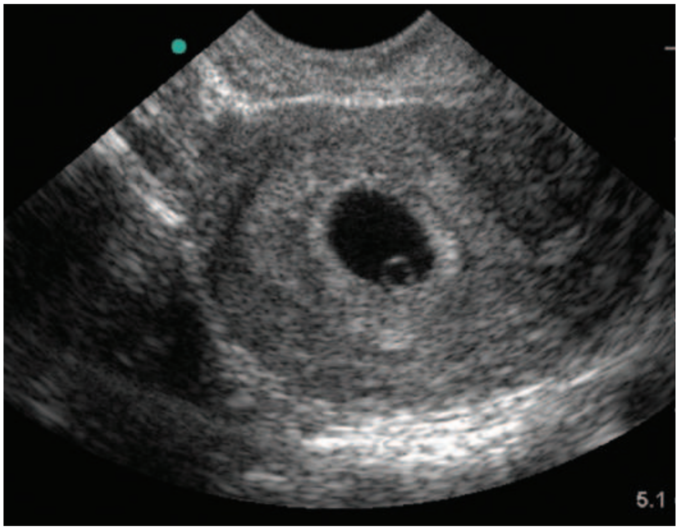

FIGURE 109-43 Image of a yolk sac, the small "sac within the sac." Occasionally, the zoom function on the ultrasound machine will need to be used to see this finding with the transabdominal probe. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

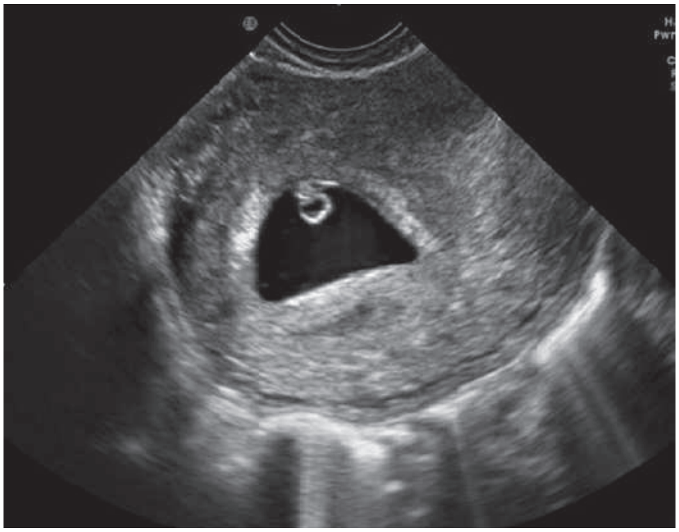

FIGURE 109-44 Image of a fetal pole. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

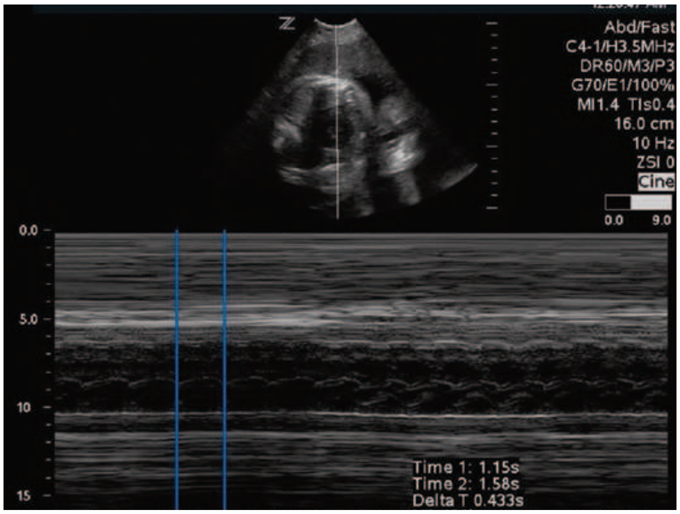

FIGURE 109-45 When calculating the fetal heart rate, M-mode imaging should always be used. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

center that can handle difficult deliveries. The low-frequency probe is used to examine the entire uterus to identify fetal position and number. The head is readily identifiable by the circular bright echotexture of the skull; its location relative to the external probe position identifies the position of the fetus. A common mistake with second- and third-trimester scanning is not increasing the depth of field appropriately. Inadequate depth of field prevents visualization of the entire uterus.

Amniotic Fluid Volume Assessment. Multiple techniques are described to estimate the amount of amniotic fluid. The simplest is the single deepest pocket or maximum vertical pocket technique. Using the transabdominal probe, the entire uterus is interrogated, and the largest anechoic pocket of amniotic fluid is identified. Less than 1 cm (0.2 inch) is a good predictor for oligohydramnios and thus of fetal growth restriction. More than 8 cm (3.2 inches) has been used as a marker for polyhydramnios.[42] This examination is not an emergent procedure, but rather, helps predict a complicated labor and poor fetal outcome because of ongoing issues with the pregnancy. If either of these conditions is seen, the woman should be referred to obstetric care where she can deliver in a supervised environment with surgical capacity. Oligohydramnios can be a marker of severe maternal dehydration, and thus IV hydration is recommended.[51]

Placental Positioning. To identify placental position, use the curvilinear 2.5-MHz probe to perform full interrogation of the uterus. The placenta appears as thickening of the uterine wall with a solid echotexture and should be in the anterior or superior (fundal) positioning. If the placenta is seen in the lower uterine segments, the cervix should be identified to see if the placenta fully or partially covers the cervical opening. Occasionally, this scanning technique can be augmented by performing translabial scan with the curvilinear probe. The probe is placed just external to the labia; in this position, the cervix is more readily identified. It should be stressed, however, that any woman in the second or third trimester with painless, bright-red vaginal bleeding should be assumed to have placenta previa and appropriate care measures (evacuation to a facility with surgical capacity) taken.

Gestational Age/Dating. The most useful function of second- and third-trimester ultrasound is to assist in more accurate dating of the pregnancy to facilitate better labor planning. There are several methods. First-trimester techniques usually involve measuring crown-rump length and using the ultrasound machine's software to translate this distance into gestational age (Figure 109-46). Second-trimester techniques that have shown reliable accuracy are biparietal diameter and femur

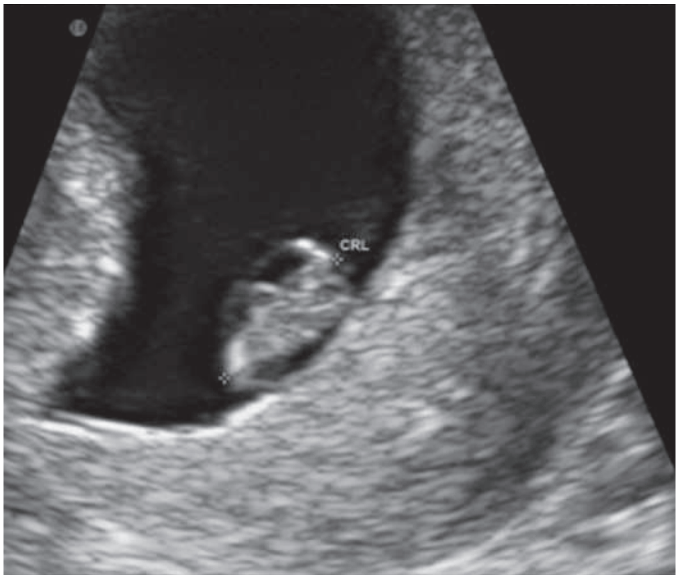

FIGURE 109-46 In this image the crown-rump length (*CRL*) is being measured, and the machine is estimating fetal age based on this measurement. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

FIGURE 109-47 Probe position for right upper quadrant assessment of the gallbladder. To visualize the gallbladder, place a 2- to 5-MHz abdominal probe on the abdomen inferior to the medial edge of the right costal margin. Angle the probe toward the right shoulder, then sweep toward the patient's right flank. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

length measurements.[57] To ensure that correct maximal diameter for both these techniques is obtained, careful fanning through the entire structure is recommended. Machine software translates these dimensions into gestational age.

RIGHT UPPER QUADRANT ULTRASONOGRAPHY

Ultrasonography is the initial imaging test of choice to investigate for acute cholecystitis and gallbladder stones. For these conditions, in trained hands, ultrasonography has sensitivity of 90% to 95% and specificity of approximately 80%.[61]

Place a 2- to 5-MHz probe on the abdomen along the medial edge of the right costal margin (Figure 109-47). Angle the probe toward the right shoulder. Depending on the patient's degree of abdominal obesity, a moderate amount of downward pressure may be required to image under the costal margin. When the large, homogeneous mass of the liver can readily be appreciated, sweep the probe laterally toward the right flank. By using this sweeping motion, the examiner can visualize the gallbladder as an oblong, hypoechoic, cystic structure. In young patients, more anterior positioning of the gallbladder may require the probe to be pressed flat against the abdominal wall while angled toward the right shoulder. In obese patients, an abdominal approach may be difficult and an intracostal approach may be helpful. In these cases, the probe can be positioned perpendicularly to the anterior, inferior left chest wall 5 to 7 cm (2 to 2.8 inches) lateral to the sternum. The probe is pointed between the most inferior ribs and toward the back.

In each of these techniques, the gallbladder should appear in a long-axis view as a pear-shaped organ (Figure 109-48). Small, sweeping motions with the probe should ensure that the entirety of the organ is imaged. Attention should be paid to gallbladder wall thickness, presence of gallbladder stones or sludging, pericholecystic fluid, air within the gallbladder wall, and sonographic Murphy's sign (maximal tenderness when direct pressure is applied to the gallbladder as it is visualized). After completing study of the long axis, rotate the probe 90 degrees to visualize the short axis of the gallbladder. In the short axis, the gallbladder appears as a nearly spherical object. Typically, measurements of gallbladder wall thickness are achieved in the short axis.

A "negative" study for acute cholecystitis reveals an anechoic, cystic structure without stones or sludging. The wall should be crisp and clean without surrounding fluid and should be less than 3 mm (1.2 inches) thick. The gallbladder should not be tender to focal pressure directly applied through the probe (negative sonographic Murphy's sign).

In addition to identification of shadowing gallstones, sonographic findings that suggest a "positive" study for acute cholecystitis include findings of a thickened gallbladder wall (>3 mm), anechoic pericholecystic fluid, intramural gas or bright, white echogenic shadows, and a gallbladder tender to focal pressure directly applied through the probe (positive sonographic Murphy's sign) (Figure 109-49).

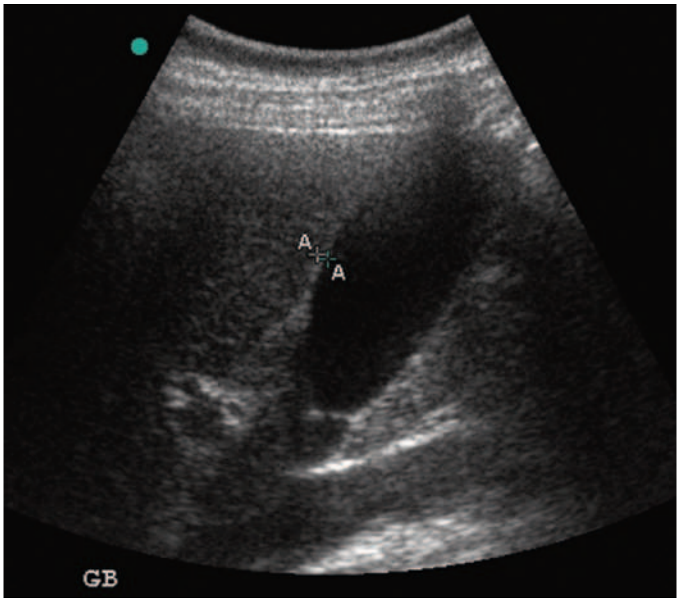

FIGURE 109-48 Normal gallbladder. A "negative" study for acute cholecystitis reveals an anechoic, cystic structure without stones or sludging. It has a nonthickened wall (<3 mm [0.12 inch]), is not surrounded by pericholecystic fluid, has no intramural gas, and is not tender to focal pressure directly applied through the probe (negative sonographic Murphy's sign). *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

In cases of isolated cholecystic stones (without acute infection), the typically rounded intracystic stones are appreciated as bright, white (hyperechoic) structures with resulting dark streaks

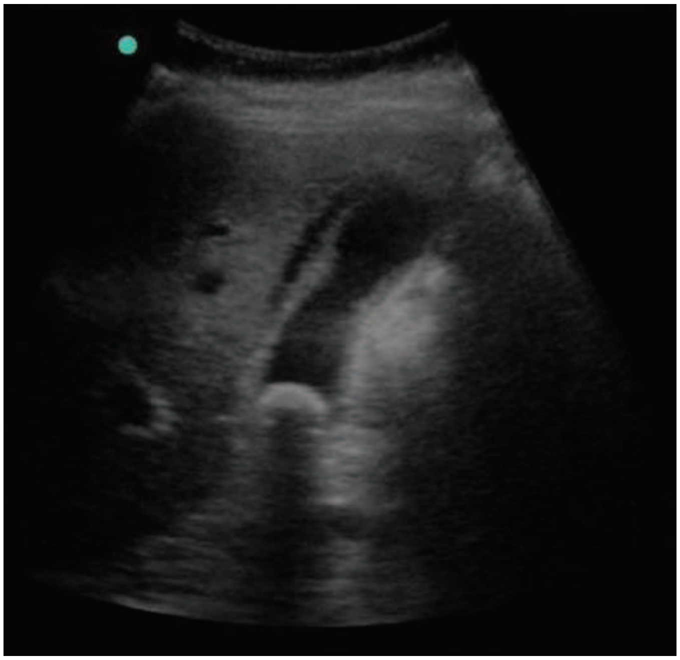

FIGURE 109-49 Acute cholecystitis. Sonographic findings that suggest a "positive" study for acute cholecystitis include findings of a gallbladder that has a thickened wall (>3 mm [0.12 inch]), is surrounded by anechoic pericholecystic fluid, has intramural gas, and is tender to focal pressure directly applied through the probe (positive sonographic Murphy's sign). *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

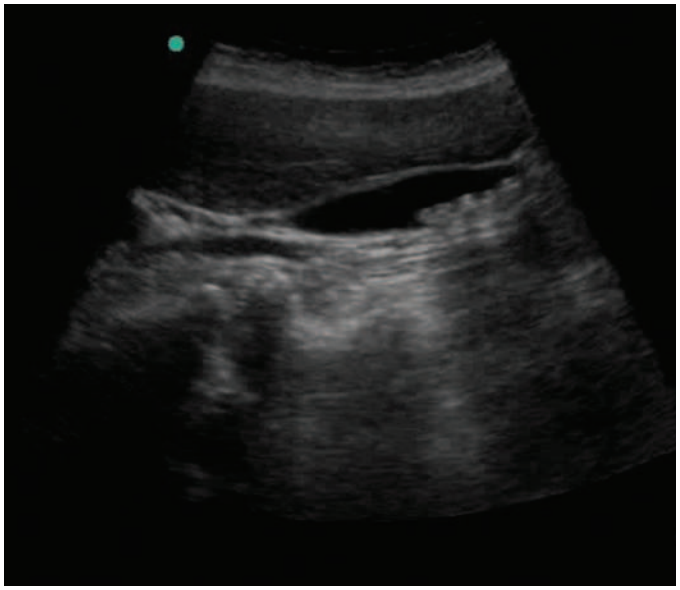

FIGURE 109-50 Isolated cholecystic stones (without acute infection). The typically rounded intracystic stones can be appreciated as bright, white (hyperechoic) structures with resulting dark streaks (anechoic shadowing) behind. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

(anechoic shadowing) behind (Figure 109-50). Isolated stones may be asymptomatic or may cause pain (biliary colic). Asymptomatic biliary stones and acute biliary colic are not surgical emergencies. Presence of stones with secondary signs of infection or inflammation is consistent with cholecystitis and indication for emergent intervention.

RIGHT LOWER QUADRANT ULTRASONOGRAPHY

Ultrasound is an imperfect but potentially valuable tool for imaging of the right lower quadrant. Although abdominal CT scan remains the gold standard to evaluate for acute appendicitis in much of the developed world, this is changing.[58] Benefits of ultrasound include lower cost and lack of radiation exposure. Increased training in right lower quadrant ultrasonography means that the appendix can often be visualized for acute appendicitis.[65] Sensitivity and specificity for ultrasonographic assessment of acute appendicitis are influenced by patient size, abdominal obesity, and appendiceal positioning. Unlike a right upper quadrant study, which can use the liver as a large acoustic window to view the gallbladder, anatomy surrounding the appendix is often air filled and thus may allow only limited image quality. Furthermore, unlike the gallbladder, which has consistent landmarks (immediately inferior to the liver), the position of the appendix can vary significantly within the right lower quadrant, making the study more technically difficult. If located retrocecally, the appendix is even less amenable to ultrasound imaging. For these reasons, most would consider ultrasound for appendicitis a "rule-in" test and not a "rule-out" test.[68] Good evidence suggests using an "ultrasound first" pathway for patients can limit the number of CT scans and expedite treatment.[24] Increasing evidence that uncomplicated appendicitis can often be managed nonsurgically[23,44,46] would be of additional benefit in remote locations. This experience has been described on French nuclear submarines, where ultrasound remains the imaging modality of choice for right lower quadrant assessment.[34]

Technique

Technique for right lower quadrant assessment begins by placing a 2- to 5-MHz probe on McBurney's point (situated about one-third the distance between the right anterior superior iliac spine and umbilicus; this point marks the normal position of the base of the appendix) (Figure 109-51). Sweep the probe along the line between the right anterior superior iliac spine and umbilicus. If the appendix is still not visualized, the operator should sweep superior and then inferior to this line. Puylaert[60] described a graded compression technique for evaluating the appendix. The technique employs gradual application of significant pressure with the probe against the right lower quadrant abdominal wall. This helps to displace gas-filled bowel and to decrease the distance between the transducer and the appendix, thereby enhancing image quality. Findings suggestive of acute appendicitis include an engorged, tubular structure with an outer diameter of greater than 6 mm (0.2 inch), noncompressible lumen, periappendiceal fluid collection, shadowing appendicolith, and lack of peristalsis[60] (Figure 109-52). In patients with high clinical suspicion for disease, a nondiagnostic ultrasound should be followed by further testing.

PERIPHERAL VEINS

Sonographic guidance for placement of peripheral IV lines can prove useful in patients who have difficult vascular access. This imaging is best achieved using a high-frequency (10-MHz) linear probe.

Typical sites for placement of peripheral IV lines are the antecubital and external jugular veins, but any venous structure can be used. It should be remembered that unlike arteries, veins have thin walls, are nonpulsatile, and are readily compressible. Peripheral veins typically travel alone, whereas central veins are accompanied by arterial vessels.

To establish peripheral IV access, standard sterile technique is employed. The probe is sheathed in a sterile cover, and sterile jelly is applied to the antiseptically prepared skin. In a right-hand-dominant operator, the probe is held in the left hand. Place the probe over the vessel, 1 to 2 cm (0.4 to 0.8 inch) proximal to where the needle enters the skin, so that the site where the needle tip will enter the vessel is directly under the probe. As soon as the tip of the needle is seen entering the vessel's lumen, a "flash" of blood should be appreciated within the IV catheter. At this point, if there is only a single operator, put down the probe so that the catheter may be more easily threaded off the needle. The catheter can be appreciated in a cross-sectional view as a bright, punctuate, circular structure within the darker, circular vessel (Figure 109-53).

SPECIAL CONSIDERATIONS FOR ULTRASOUND IN REMOTE LOCATIONS

TELE-ULTRASOUND

Tele-ultrasound, one subset of telemedicine, is the practice of ultrasound whereby the patient, ultrasound machine, and

FIGURE 109-51 Probe position for right lower quadrant assessment for appendicitis. Place a 2- to 5-MHz probe on the abdomen, about one-third the distance between the right anterior superior iliac spine and the umbilicus—McBurney's point—which marks the normal position of the base of the appendix. *(Courtesy N. Stuart Harris.)*

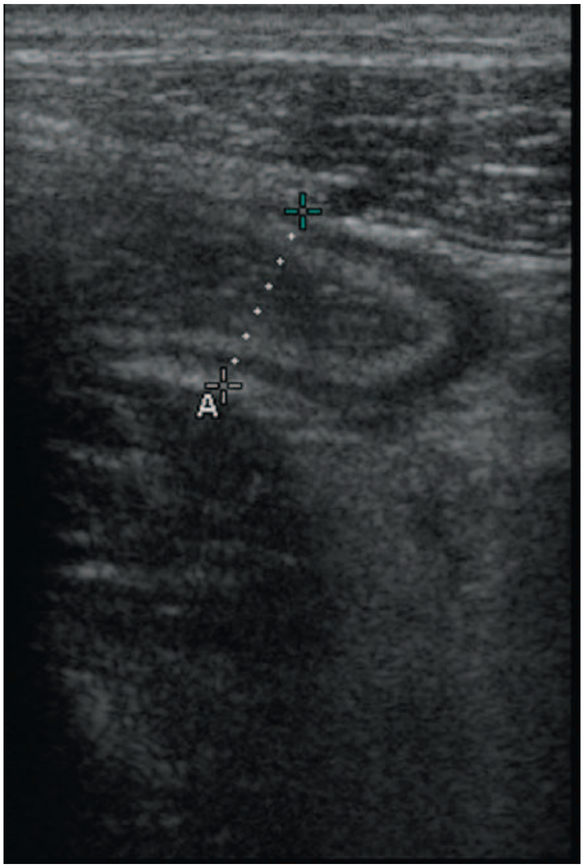

FIGURE 109-52 Acute appendicitis. Findings suggestive of acute appendicitis include an engorged, tubular structure with an outer diameter of greater than 6 mm (0.24 inch) (here seen to be 13 mm [0.51 inch]), noncompressible lumen, periappendiceal fluid collection, and lack of peristalsis. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

nonexpert sonographer are in a location distant from the expert sonographer. Tele-ultrasound has evolved because of decreasing costs of machines and increased expertise in the field, together with exponential increase in the speed, quantity, and quality of data that may be transmitted between the patient and caregiver. Telemedicine is discussed in Chapter 104.

Tele-ultrasound can effectively bring the expert to the bedside. Real-time relay of images allows immediate instruction as well as interpretation by the remote expert. In some cases, environmental or communication conditions require a brief delay, after which the expert can provide feedback and diagnoses. Studies have shown that remote experts can direct nonphysicians to perform examinations and obtain adequate images for the expert to make clinical diagnoses, thereby bringing the physician to the bedside. This is invaluable for patients living in remote rural settings or wilderness locations.

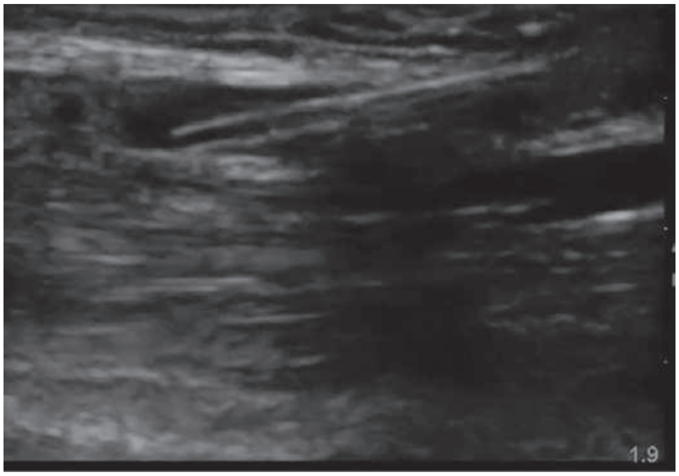

FIGURE 109-53 Peripheral vein. In this longitudinal view, the catheter can be appreciated as a bright, tubular structure within the darker vessel. *(Courtesy Division of Emergency Ultrasound, Massachusetts General Hospital, Boston.)*

Tele-ultrasound requires a machine, means of transmitting acquired images, and a remote site capable of reconstituting images to be interpreted. To create imaging data capable of being transmitted, an ultrasound machine may be connected to a video-streaming device to allow digitization of the images and compression in order for the study to be transmitted to the remote setting. Data can then be transmitted to a distant site. Voice-over Internet protocol (VOIP) systems such as Skype (Skype Technologies S.A., Luxembourg), FaceTime (Apple Inc., United States), and Google Chat (Google Inc., United States) allow voice, together with other multimedia such as video, to be transmitted via the Internet. These programs should be downloaded onto personal computers at both settings before expeditions. By adding video, the remote expert may visualize the nonexpert's probe positioning and give instantaneous feedback and instruction, to allow acquisition of the best images possible. Research supports feasibility of these techniques by novice providers under distant expert guidance in a variety of ultrasound applications.[8,12,43]

Some of the earliest examples of successful utilization of tele-ultrasound came from aboard the International Space Station (ISS). Novice ultrasonographers (crew medical officers) with less than 3 hours of ultrasound training before departure for the ISS have been guided by experts at the Mission Control Center in Texas to successfully perform diagnostic-quality FAST, genitourinary, musculoskeletal, and ocular ultrasound examinations. In a number of these studies, a 2-second time delay was reported in video and audio transmission; however, this did not impair the expert's ability to instruct the novice, and images were always adequate for clinical decision making. Addition of ultrasound aboard the ISS has proved invaluable in management of patients at this location, enabling improved diagnosis to help guide management options, where medical evacuation has very significant consequences.[16,27,28,37]

Otto and colleagues[53] described successful use of ultrasound by nonphysician climbers guided by remote ultrasound experts at Advanced Base Camp (6400 m [20,997 feet]) on Mt Everest. This aided diagnoses of HAPE by visualizing B-lines on thoracic ultrasound. Analog ultrasound images were digitized, compressed, and transmitted via Internet to the computer of the remote expert, who then, by bidirectional radio, guided the examination.

McMurdo Research Station, one of three research stations operated by the United States Antarctic Program (USAP), has proved an ideal setting for tele-ultrasound. In this harsh environment, New Zealand, approximately 3800 km (2361 miles) distant, has the nearest tertiary care center. An ultrasound machine was acquired by USAP in 2000. Tele-ultrasound allowed problems posed by varying degrees of staff training to be overcome. A case report from McMurdo describes cardiac ultrasound performed by a physician with basic ultrasound skills on a 26-year-old patient with pleuritic chest pain suspected as pericarditis. The echocardiogram was transmitted via a DICOM-compatible software program to the radiology department at St Luke's Hospital in Denver. A report was generated and e-mailed back to the Antarctic, confirming a small pericardial effusion. A repeat ultrasound examination 4 days later under expert guidance from cardiologists based at the University of Texas, with the ultrasound machine connected via an S-video input to a PolyCom View Station, enabled live transmission of the images. In addition, a camera recorded the physician scanning the patient. Imaging confirmed a small, resolving effusion with no evidence of cardiac tamponade, enabling the patient to be managed at the research station and avoiding evacuation.[54]

In a retrospective review of all ultrasound examinations performed at two of the USAP research stations over 1 year, 66 ultrasounds were performed on 49 patients.[55] The majority (94%)

were reviewed at a later date by experts, and 6% were interpreted in real time. The majority of studies were abdominal, genitourinary, and gynecologic examinations. Ultrasound prevented intercontinental aeromedical evacuation in 25.8% of cases and had a significant effect on diagnosis and management of illness in patients at the South Pole and McMurdo research stations. The authors concluded that “ultrasound is a valuable addition to remote medical care for isolated populations with limited access to tertiary-healthcare facilities.”[55]

A group in Togo designed a low-cost tele-imaging system to enable novice ultrasonographers (including midwives, nurses, and technicians) based in remote hospitals to have access to real-time tele-ultrasound expertise from hospital centers in Lome, Togo, and Tours, France.[2] Ten radiologists, nine of whom worked in Lome, covered approximately 6 million inhabitants. When high-bandwidth Internet connections were available, they used real-time transmission of ultrasound video sequences via the Internet between providers. If only low-bandwidth connectivity was available, they used a software program called LogMeIn, which enables transmission of video together with audio via the Internet. The group successfully performed real-time tele-ultrasound on 50 patients, with 1.5- to 2-second transmission delays. Image quality was reported as adequate.[2]

Power Supply Considerations

A critical concern for any ultrasound or telemedical device in the field is ensuring an adequate power supply. Limited information is readily available on how best to provide portable, reliable power in the field. To help bridge this critical gap, we briefly discuss different power supply systems that have proved effective in wilderness settings.

A practitioner seeking to use electronic equipment in a wilderness setting faces unique but surmountable problems. When used at field sites with standard current systems (e.g., well-equipped mountain huts or research hypobaric chamber facilities), whether on or off the grid, electronic equipment can be seamlessly incorporated. In foreign countries, appropriate plug and power adapters may be required. For more austere field sites, portable machines are most appropriate. These can usually run on rechargeable batteries for 1 to 5 hours.

Options for portable power supply can be divided into classifications of batteries, solar supply, and other. Light, portable solar arrays that can generate adequate power for charging an ultrasound machine and laptop computer (e.g., Brunton Solaris 26 or CT Solar Expedition Solar Package) are probably the most frequently used power sources for remote field studies. We have successfully conducted sonographic research from the base to the summit of Mt Kilimanjaro (5895 m [19,341 feet]) and Mt Denali (6168 m [20,320 feet]) while depending solely on electric current gathered from solar arrays (Figures 109-54 and 109-55). Our series of solar arrays produced a nominal output of 54 W, controlled by an electronic voltage regulator using a lead-acid battery storage system. This proved adequate for frequent assays using a SonoSite 180 and Mindray M7 ultrasound devices with routine laptop data storage backup.

The total current generated by solar arrays is influenced by many variables, including size of the arrays (“rated” current capacity) and factors that influence intensity and length of exposure to solar radiation, including season of the year; prevalence and density of cloud cover; orientation, latitude, and altitude of arrays; time of day; and ability to position arrays for adequate length of time during each day. A highly mobile expedition, which may not be able to spread out its arrays during peak daylight hours, will be at a disadvantage compared with a fixed team, because the fixed team has the entirety of a day’s available solar radiation to convert to electric current. An obvious limitation of solar power generation is the presence of available solar radiation. An expedition during the dry season under equatorial sun on Mt Kilimanjaro has power-generating advantages over a similarly sized system used at high latitudes and with greater likelihood of cloud cover. Small portable windmills, human-powered crank generators, and small turbines that can take advantage of running water to provide hydroelectric power are options. The power demands of portable ultrasound machines and laptops are small enough that these options may be feasible.

FIGURE 109-54 These rigid solar arrays provide more than 50 W of power under equatorial sun on Mt Kilimanjaro. They weigh less than 4.5 kg (10 lb). This power is controlled by an electronic voltage regulator using a lead-acid battery storage system, housed in the orange, waterproof case in the foreground (6.3 kg [14 lb]). *(Courtesy N. Stuart Harris.)*

Under any but ideal circumstances (e.g., under equatorial sun in a desert climate), solar power may be unreliable, so it is worth bringing multiple sets of batteries to be charged when solar power is plentiful and used to run the machines during less plentiful periods. Choice of batteries for these systems is critical. Variables to consider include decisions about appropriate battery size (measured in ampere-hours) and battery type (lead acid vs. lithium ion). Typical alkaline cells used by consumer electronics are insufficient. By establishing the power draw of all equipment (ultrasound and laptop power requirements are located in the manuals accompanying each machine) and then multiplying current factor (in amperes) by length of time each machine will

FIGURE 109-55 Electronic devices employed in the field on a solar-powered, high-altitude ultrasound research expedition on Mt Kilimanjaro in association with the U.S. Army and Explorers’ Club. *Left to right,* The ultrasound unit (SonoSite 180), laptop data storage (Dell Inspiron 910), DC-to-AC converter (bright-yellow box in foreground, Go Power! 300-W converter), electronic voltage regulator with lead-acid battery storage (orange box, CT Solar.com) with 54-W solar arrays (*at far right,* CT Solar.com). Total weight of all electronic and power storage equipment was less than 18 kg (40 lb). *(Courtesy N. Stuart Harris.)*

TABLE 109-4 Advantages and Limitations of Battery Types to Power Wilderness Electronic Equipment

Battery Type	Advantages	Limitations
Lead acid	Inexpensive Internationally readily available Ease of transport on commercial airlines	Low power density (heavy/current stored) Decreased efficiency in cold temperatures
Lithium ion	High power density (relatively lightweight) Maintains effectiveness even when cold	Expensive Difficult to transport on commercial flights

be employed (in hours), reasonable estimation of battery size (in ampere-hours) can be established. Allowances for any current converters (converters are often less than 50% efficient) must be made.

Standard choices for nonsolar power supplies include "standard" sealed, lead-acid or lithium-ion batteries. Advantages of lead-acid batteries include low price, relative ease of replacement (even in the developing world), and ease of transport on commercial airlines (they can travel as checked baggage without difficulty) (Table 109-4). Disadvantages include relatively low power density (high weight of battery per unit of current compared with lithium-ion battery systems) and marked performance decreases on exposure to colder temperatures. Advantages of lithium-ion batteries include high power density (relatively lighter weight per unit of current stored than with lead-acid batteries) and higher levels of performance at the lower temperatures typically experienced at high altitude. Disadvantages include prohibition on their transport by commercial airlines (without special and expensive packaging and labeling requirements) and relatively greater expense.

Voltage and current regulators may be required to prevent overcharging and potentially destroying batteries or ultrasound machines if using solar panels that provide more that 10 W of power. Commercially available units, some of which come packaged in robust, waterproof cases specifically designed for wilderness expedition use, can contain both battery and current control systems within the armored cases and have proved reliable for high-altitude expeditions.

When a portable power supply is employed, one must account for loss of power from transformer use. Many ultrasound units in North America assume ready availability of 110- to 120-V alternating current (AC). This current is fed through a transformer to produce 10- to 20-V direct current (DC) that powers the unit. Each step of current conversion incurs a (potentially significant) loss of electrical energy, because useful energy is converted to (wasted) heat energy by the transformer. This became especially notable during our Mt Kilimanjaro research, when a series of transformers (with attendant losses in power) were required. For example, our SonoSite 180 employed a 14.4-V DC system, whereas our solar-produced, battery-stored current existed in a standard 12-V DC system (12 V is the standard current employed internationally in automobiles). Ideally, a simple DC-to-DC converter would exist to allow "direct" use of this similar DC current without conversion by DC to AC transformer. Unfortunately, unlike many common consumer electronics (from cell phones to laptops), most currently available ultrasound units do not allow direct use of standard 12-V DC systems. This requires that a wasteful series of step-up (from 12-V DC to 120-V AC) and then step-down (from 120-V AC to 14- to 20-V DC) current transformers be employed. It is hoped that ultrasound and telemedical equipment manufacturers will overcome these inefficiencies in future designs.

Careful troubleshooting before departure for the field will help ensure adequacy of the power supply and compatibility of the power system with the ultrasound machine. All critical components (some as simple as a 10¢ main fuse in some systems, without which the entire power system is unusable) must be backed up with spares.

ADVANTAGES OF ULTRASOUND IN THE WILDERNESS

Portability

Extraordinarily powerful ultrasound equipment can be carried by hand. Compared with other diagnostic imaging devices that might be considered for wilderness use (e.g., conventional radiography, CT, MRI), ultrasound machines are much more compact, lighter, and more portable (see Table 109-3). The revolution in digital and ultrasound technology and manufacturing has allowed small, laptop-sized machines to overtake the capabilities of older, larger machines for virtually every application. Because portable machines have become small, often weighing less than 4 to 6 kg (8.8 to 13.2 lb), their utility has increased for wilderness settings. In austere locations with no power source (e.g., remote alpine environment or disaster area), ultrasound devices can be powered using batteries, including portable photovoltaic arrays. A SonoSite MicroMaxx ultrasound machine used successfully on the 2007 Caudwell Xtreme Everest expedition at Camp Four on the South Col (8016 m [26,299 feet]) of Mt Everest was powered by standard MicroMaxx batteries charged at base camp and Camp Two using a combination of generators or solar power.[9] We conducted research using a SonoSite 180 machine carried to the summit of Mt Kilimanjaro (5895 m [19,341 feet]) and a Mindray M7 to the summit of Denali powered by hand-carried solar arrays. A portable ultrasound setup with batteries, power source, laptop computer for image storage and backup, and enough ultrasound gel for clinical use or research can reasonably be expected to weigh approximately 13.6 kg (30 lb) and to be carried to remote locations by a single physician or investigator. Some machines are essentially modular attachments to laptop computers or even cellphones, further reducing the need for separate pieces of equipment.

Safety and Noninvasiveness

Diagnostic ultrasound has few known risks.[29] To highlight this fact, ultrasound is the clinical imaging modality of choice for many high-risk patient populations, including pregnant women and their fetuses. Ultrasound is routinely used at the bedside for rapid assessment of critically ill trauma and medical patients. A physician with a bedside ultrasound machine can quickly and in real time assay for a range of common, acute life threats, including intraperitoneal free fluid or pericardial effusion, obviating the risks associated with delays caused by patient transport or image processing. No other clinical imaging system allows this combination of speed, safety, portability, and immediacy of result.

In many research applications, such as replacement of invasive pulmonary arterial catheterization by transthoracic echocardiography, ultrasound provides an essentially risk-free, noninvasive option to take the place of a potentially risky, invasive technique.[4] The safe, noninvasive, and painless nature of ultrasound compared with other diagnostic and research techniques encourages patient compliance and aids recruitment for research protocols by making participation more attractive to potential volunteers. For research purposes, the U.S. Department of Health and Human Services Office for Human Research Protections specifically identifies ultrasound, Doppler measurements, and echocardiography as research methodologies eligible for expedited investigational review board review, significantly easing administrative burdens and potentially shortening the time between conception and execution of studies. For research purposes, because ultrasound itself does not significantly impact participants or other experimental manipulations, sonographic monitoring can easily be added to other experimental protocols for purposes of collecting additional relevant data (e.g., monitoring additional parameters of potential interest during a drug trial) or conducting a separate parallel study. For example, we joined research conducted by U.S. Army Research Institute of Environmental Medicine collaborators and were able to assay sonographically measurable parameters (e.g., ONSD, pulmonary artery pressure) during a study originally designed to examine the effects of moderate-altitude prepositioning on combat readiness of military recruits during exposure to high altitude. Ultrasound does not employ ionizing radiation, so there is no known additive risk of repeated ultrasound exposures.

Versatility

Ultrasound machines enable immediate access to advanced diagnostic imaging. Ultrasound provides imaging of soft tissue, abdominal and thoracic organs, bone, muscle, and skin processes that can immediately and directly inform medical decision making.

For both routine clinical and specialized research purposes, a single ultrasound machine and ultrasonographer (with appropriate training) can monitor a wide range of organ systems and potential research parameters. For example, in a research project using ultrasound, multiple parameters (e.g., eyes, chest, heart) can be studied at no more cost to the clinician/researcher or risk to the patient/participant than if a single measurement were taken. Researchers studying ICP and ONSD in trekkers with severe AMS could incorporate chest ultrasound to investigate a separate hypothesis in the same cohort, while all the time having the ultrasound available to help diagnose common clinical conditions.

Cost

Ultrasound machine cost varies widely and is influenced by size, weight, image quality, and special imaging capabilities (e.g., Doppler or color flow imaging). Selecting a machine appropriate for an austere setting requires advance thinking. To ensure reliability, especially under the stresses of harsh conditions, a preference for solid-state, nondynamic systems (e.g., fixed- vs. phased-array probes) is prudent. These systems often offer the additional benefit of being more reasonably priced. It is critical for wilderness practitioners to define exactly what capabilities they will require from the device in their unique work environment so that the correct ultrasound unit can be chosen.

LIMITATIONS OF WILDERNESS ULTRASOUND

There are general drawbacks of ultrasound for wilderness use.[74] Although portable and relatively durable for in-hospital clinical use, ultrasound machines can be fragile and require careful packing and handling during transport and field use. Austere conditions place strains on ultrasound machines far in excess of what the machines ordinarily encounter in routine clinical practice. Mechanical failure has jeopardized or terminated wilderness clinical and research expeditions.[10,72]

Ultrasound machines are not easily serviced in the field. By picking a machine with the fewest movable mechanical parts (i.e., choosing fixed-array rather than phased-array probes and solid-state units rather than spinning hard discs for memory), the risk for mechanical failure can be somewhat mitigated.

Hypobaric cold (high altitude), blowing dust (alpine or desert environments), water damage (riparian or rain forest environments), salt exposure (marine environments), rough handling during transport, and other factors can quickly disable a machine (sometimes permanently), but most difficulties can be anticipated and mitigated. For example, machines should be protected in strong, well-padded rigid cases and ideally carried by a responsible person at all times. Such cases can be readily and inexpensively fashioned from rigid tool cases retrofitted with hand-cut foam padding. Pelican and other strong, waterproof cases can be customized for ultrasound devices and probes. Using such a case, one author has witnessed an ultrasound device survive a 100 foot fall from a helicopter onto a glacial surface—and remain fully functional.

To enhance effectiveness and protect the ultrasound device, it may be necessary to sleep with batteries next to the body, prepare warm water in which to soak a probe to achieve reliable functioning in the cold, or to operate the machine within a plastic bag to protect against dust. Risk of theft is real, particularly in chaotic, urban, or disaster settings. Traditional (spinning) hard drives have been implicated in machine failure at high altitude, probably caused by cold and the influence of decreased barometric pressure on internal air-filled cushioning components. Solid-state memory devices (i.e., flash cards) without moving parts are readily available for primary data storage on laptop computers and USB drives. These solid-state units should prove to be significantly more reliable than their mechanical counterparts. A plan to rapidly service or exchange malfunctioning machines should be made in advance. Bringing a backup machine is an effective hedge against malfunction. Thorough testing before field use, careful machine handling, device security, and thoughtful attention to potential site-specific problems enable a clinician or researcher to increase the likelihood of maintaining the ultrasound unit during a wilderness experience.

Before departure, sufficient ultrasound training must be completed to ensure that diagnostic-quality images and accurate measurements can be reliably obtained. Although some imaging techniques, such as quantitative echocardiography, require more extensive training, other applications, such as thoracic or long-bone applications, are straightforward and have been taught successfully in brief sessions, or even through remote expert guidance at the time of image acquisition. A growing body of evidence, both on Earth and in space, confirms that these techniques can be effectively taught to nonphysicians with minimal prior training, when guided by audiovisual linkage to expert ultrasonographers.[53]

A means to save and review images obtained in the field is typical and prudent practice. When ultrasound images are being used primarily for research purposes, great attention should be paid to the quantity and robustness of data storage options. Data storage needs are influenced by types of images that are saved (e.g., still images vs. video clips), definition of the individual images (e.g., low-definition black-and-white images from an older machine vs. color and velocity data–embedded images from a state-of-the-art echocardiography device), and total number of individual images. It is good practice to routinely back up all data, even if the ultrasound machine is capable of storing all necessary images in its memory. Most machines are accompanied by software packages that allow image downloading and handling on a personal computer. In planning data storage, it is important to be aware of the capabilities of the software. If saved images will be analyzed at a later time by a blinded observer, it is important to be sure that the imaging software is capable of allowing the necessary analysis, and that image labeling at the time of acquisition does not compromise blinding.

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CHAPTER 110

Outdoor Clothing for the Wilderness Professional

JENNIFER DOW

There's no bad weather, just bad clothing. —*SCANDINAVIAN SAYING*

Clothing as an adaptive strategy has evolved a long way from the rough animal hides of prehistoric days. Regardless of its structure, clothing serves two primary purposes: protection from the environment and optimization of thermoregulation. The metabolism of mammals produces heat. The environment demands that heat be retained or released to maintain optimum body temperature. Clothing is one of humanity's behavioral adaptations to changing temperatures that occur as a result of geographic location or environmental shift. Humans adapt modifying clothing systems or changing activity levels to conserve or reduce heat production. To this end, clothing manufacturers take advantage of fiber qualities in the design of fabrics that perform well in all conditions.

The well-designed outdoor clothing available to contemporary wilderness professionals retains or releases heat in response to the environment and individual comfort. When choosing clothing, one must consider personal comfort, weather (both immediate and near future), geographic location, and specifics of the activity. Activity is as much a driver of clothing choice as is the weather. There are vastly different requirements for aerobic or high-exertion activities than for sedentary tasks. Also, when deciding "what to wear," one must consider the duration of the outing. For example, an activity lasting weeks in a remote locale will require different clothing than a short outing close to an urban environment. For the wilderness professional, clothing is not just for personal adornment or comfort—it may also be a lifesaving tool (Box 110-1).

This chapter introduces the wilderness medical provider to the properties of fabrics and fibers used in the manufacture of clothing. The reader should be able to design a personal strategy for choosing the appropriate garment and layering system for the activity and environment to which he or she will be exposed (Figure 110-1).

FIBER AND FABRIC

With the exception of leather and hide construction, clothing is made from fabric woven from fibers. Type of fiber, density of weave, and presence of any treatments or finishes determines the properties of the fabric. The four properties of concern are thickness, reaction to moisture, thermal conductance, and tightness of weave (Table 110-1).

Fibers may be natural, synthetic, or a blend of both. In general, natural fibers are more durable and softer to the touch than are synthetics. Synthetic fibers are typically lighter and quick to dry. Blending is the act of combining different fiber types together to achieve a particular characteristic. For example, blending cotton and polyester produces a fiber with the absorbency of cotton and strength of polyester. Blends influence coloring, strength, absorbency, ease of washing, resistance to wrinkling, and ease of spinning and weaving into fabric.

NATURAL FIBERS

The most common natural fiber is cotton, frequently used in T-shirts and nontechnical clothing. It is highly hydrophilic and has poor moisture regain. Although it wicks moisture away from the skin, the fiber does not redistribute moisture to external surfaces for evaporation. Cotton absorbs and holds moisture, rapidly losing any insulative value. Cotton that is saturated retains only 10% of its original insulative value. These properties make cotton undesirable for use as an insulation layer when heat conservation is the goal. Conversely, in a warm or hot environment, cotton helps to keep a person cool. The moisture absorbed by the fabric aids in cooling by convection and conduction.

Wool and Merino Wool

Cloth woven from traditional wool or merino wool is an excellent insulating fabric. The core of wool fiber absorbs moisture and redistributes it to the fabric surface, from where moisture can evaporate. Wool's moderate affinity for absorbing moisture is balanced by excellent regain, meaning that the fabric retains warmth and does not feel cool or wet when damp. However, when it is saturated with moisture, wool feels wet.

Many people find that wool feels scratchy. Traditional sheep wool has barbs in the outer layer, or epicuticle, of the fiber. In contrast, merino wool is a much finer fiber with far fewer barbs. These ultrafine (17.5 μm in diameter) fibers make for very soft and lightweight fabric with a tight weave. These properties contribute to durability and shape retention. The fabric remains highly elastic and shrinks minimally. The fibers are antibacterial; thus, fewer odor-producing metabolites are present.

Wool, including merino wool, is spun from the fleece of sheep. Other fibers, technically not wool, including alpaca, llama, and cashmere, share many of the properties of merino wool. Alpaca and llama are *camelids*, originally from South America, and cashmere goats produce the fleece from which cashmere is spun (Figure 110-2). These wool-like fibers are frequently blended with true wool to create a soft, durable weave used for direct skin contact.

When considering its purpose for technical clothing, silk is most often used to manufacture base layers. Untreated silk retains moisture, although not to the degree of cotton. The majority of silk used for outdoor clothing is chemically treated and wicks moisture well. Silk can be blended with other fibers to smooth its texture or enhance elasticity.

Down

Down is composed of the very soft, fine feathers that insulate birds. Most birds have some down, but waterfowl have extensive layers of down as an adaptation to their environment. These insulating feathers trap air and the bird's body heat. These same properties are exploited when down is used as insulation in clothing. Natural down forms clusters resembling the head of a dandelion (Figure 110-3). The propensity toward clustering gives down its loft. As an insulating fiber, down traps heat in the air pockets of the cluster. Down's insulative value is quantified as "fill." Fill power is the number of cubic inches displaced by 1 ounce of down. Higher-fill down is composed of larger, more mature clusters. These clusters trap more air, hold more heat, and retain their shape better after compression. In general, the higher the fill value, the warmer is the garment. However, a 600-fill parka may be as warm as an 800-fill parka; it simply requires more down to achieve the insulative value.

BOX 110-1 Considerations for Wilderness Clothing Choice

Consider these questions for any excursion, from a day trip to a multiweek expedition.

- What is the activity? Is it vigorous and heat generating?
- What is your personal metabolic response to activity? How much do you sweat? Are you always hot or cold?
- What is the expected duration of the trip? Have you planned for an unexpected extension or night out?
- What environmental conditions are anticipated?
- What are the probable weather extremes?

FIGURE 110-1 Alaska hiking in Arc'teryx clothing and packs. *(Copyright 2008, Arc'teryx. Courtesy Brian Goldstone.)*

TABLE 110-1 Properties of Fabric

Property	Considerations
Thickness	Positive correlation to insulative value (when dry). Rarely more than 2.5 cm (1 inch).
Moisture	Wicking action: *hydrophilic* fabric moves moisture from the body surface to the material; *hydrophobic* fabric transfers moisture from the body across the fabric to other clothing or the air. Evaporative ability (rate of drying). Moisture *regain*: amount of moisture a fabric can absorb before it feels cold; the higher the regain, the more functional for aerobic activity in wet or cold environments. Amount of insulative value when wet.
Thermal conductance	The less thermal conductance, the better the heat retention and insulation.
Weave	Tighter weaves permit less wind to penetrate and decreases convective cooling; allows perspiration to accumulate between layers (may lead to conductive heat loss).

FIGURE 110-2 Argentinian llama. *(Copyright 2010, J. Dow.)*

Down is an ideal insulator. It is warm, lightweight, and compressible. Its greatest drawback is its hydrophilic nature, making it almost useless when wet. Manufactures have addressed this by treating down clusters with a durable water-repellant coating, preventing down from absorbing moisture. Hydrophobic down is able to retain its loft after being shaken for a minimum of 40 minutes (untreated down can withstand 22 minutes). New brands of hydrophobic down include DriDown, DownTek, and Nikwax Hydrophobic Down.

Fur, Leather, and Hides

Historically, protective clothing was made from animal products. Hides, feathers, and intestines have been used to make garments. Northern indigenous peoples continue to use fur and pelts for outerwear. Pelts and hides are water resistant, warm, and physically protective. They are also heavy and can restrict movement, demonstrating little flexibility or stretch. Traditional fur trim, which traps air around the face and wrists, has largely been replaced with synthetic and wool fleece.

Leather is the finished product of tanned animal hide, with cow, goat, and sheep being the most common. Depending on the refining process, leather can be very soft and supple, or

FIGURE 110-3 Down puff. *(Copyright 2010, Gary Peterson, Western Mountaineering.)*

tough, thick, and abrasion resistant. Leather is frequently used in the manufacture of footwear and gloves, capitalizing on its durability. Leather is not water resistant and saturates rapidly. It must be treated with an oil-based product, such as mink oil or Sno-Seal, in order to have any water resistance. Synthetics have replaced leather in most outdoor clothing, requiring less care while retaining durability. Abrasion-resistant nylon is used to reinforce cuffs, shoulders and elbows, replacing traditional leather patches.

SYNTHETIC FIBERS

Synthetic fibers are manufactured, not found in nature. *Polyester* is a general term for any petroleum-based fiber. Polyester fibers can be manufactured in almost any thickness or configuration. As an insulator, polyester fibers can be molded with a hollow core, trapping air that is then warmed by body heat. Unlike cotton, polyester fibers do not absorb moisture. Moisture wicks along the fiber to the surface of the fabric, from where it is evaporated. Garment manufacturers exploit this combination of insulating and hydrophobic properties. Polyester fleece is soft, washable, and durable. Bulky fleece traps air and is exceptionally warm for its weight. If woven tightly, wind and water resistance improves, but insulative value is lost. This property is showcased by W. L. Gore's Windstopper fabrics.

Polyester is formed into sheets of insulation and sewn into the layers of garments. Polyester insulation has high moisture *regain* and good evaporative qualities; however, it is not as compressible as down. The fibers eventually deteriorate and break down after repeated use and washing. As with down, synthetic insulation should not be stored compressed. Prolonged compression damages both down and synthetic fibers, causing them to lose loft and insulative value (Table 110-2).

Polypropylene was one of the first synthetic fabrics used for base layers. It wicks moisture well, has low thermal conductance, and is durable. Unfortunately, it has high odor retention and stains readily. Other synthetic fabrics, such as Capilene, Polartec, Coolmax, and REI-MTS, have largely replaced polypropylene.

Nylon, like polyester, is another manufactured polymer filament. Nylon absorbs minimal water and is highly abrasion resistant, but melts easily. Nylon can be formed into large-diameter fibers and woven into very durable fabrics, such as Cordura. This tough fabric is used to reinforce wear points, replacing the traditional leather patch. Nylon can be very tightly woven, creating a wind- and water-resistant fabric. Unfortunately, this is at the expense of breathability, so moisture condenses on the inside of the garment (Table 110-3).

TABLE 110-2 Down vs. Synthetic: Comparison of Properties

Property	Down	Synthetic
Compressibility	Excellent	Good
Insulative quality when wet	Traditional down: poor DriDown: good	Good
Weight	Lighter per volume	Heavier than down
Durability	Longer lasting with proper care	Will break down over time even with proper care
Care	Careful laundering	No special products needed
Warmth	Greater warmth-to-weight ratio	
Allergenic properties	Possible	None
Expense	High	Moderate
Drying time	Slow (traditional down) Moderate (DriDown)	Fast

Blends

Fabric manufacturers blend fibers to capitalize on the properties of each type, using natural and synthetic blends. For example, spandex is blended with wool or cotton to improve stretch and retention of shape. Wool is frequently blended with polyester to improve durability and fit.

Waterproof/Breathable Fabrics

Waterproof/breathable fabrics are designed to repel moisture and allow perspiration to escape in the form of water vapor. The combined properties help regulate body heat by keeping clothing dry, preventing perspiration accumulating within clothing and saturation from external moisture. Fabrics are made waterproof/breathable through application of laminates, coatings, and durable water-repellent finishes.

Laminates. Laminate fabrics are designed by bonding a waterproof/breathable membrane to the underside of the garment's exterior. This exterior layer is usually made of nylon fabric. If there are two layers, the fabric is designated "two-ply." The laminate may be sandwiched between two layers, creating three-ply material. This combination is more durable than two-ply

TABLE 110-3 Comparison of Fabric Properties: Synthetic, Wool, and Silk

	Synthetic	Wool	Silk
Moisture management	Excellent Nonabsorptive; transports moisture away from the skin, spreading the moisture over a large surface area to evaporate	Excellent Absorbs up to 36% of weight in moisture before releasing to the surface	Good Treated silk transports moisture; conventional silk absorbs moisture.
Drying time	Excellent Fastest	Good Slower to dry: hydrophobic properties resist moisture, and the fabric feels dry on the skin.	Fair
Temperature regulation	Fair to good	Very good More warmth than synthetics of the same thickness	Very good Performs better in cold than in hot temperatures
Odors	Poor Bacteria flourish	Excellent Naturally bacteriostatic	Fair
Stretch	Very good Retains its shape after stress	Very good	Good
Price	Good: $$$	Expensive: $$$$	Fairly good: $$
Use	For all activities: excels for rain and high heat and humidity. Wear snugly for cold weather, loosely for hot weather.	Most activities: if humidity is too high, the fabric will not dry.	Most cool-weather activities

FIGURE 110-4 Arc'teryx Alpha LT hard-shell jacket. Lightweight and waterproof three-ply shell is ideal for use with a climbing harness.

but is also heavier. W. L. Gore and Associates produced the first waterproof/breathable membrane, called Gore-Tex. This trade name is commonly, and incorrectly, used to refer to the entire category of laminate clothing (Figure 110-4). There are now many manufacturers of laminate products, but the basis of the technology is the membrane. The membrane is formed of stretched (expanded) polytetrafluoroethylene (ePTFE). The stretching process expands the ePTFE and introduces microtears (perforations) in the laminate. These openings are small enough to allow water vapor from perspiration to escape (breathability), while not allowing water droplets to enter from the outside environment (water resistance). The pores of ePTFE are 20,000 times smaller than the smallest raindrop, yet large enough to allow water vapor to pass through. Water can only penetrate ePTFE if it is applied with significant force or if the surface of the ePTFE is contaminated or soiled, leading to leakage. Gore and eVent, two of the predominant manufacturers, use different methods to address soilage. Gore applies a microthin layer of polyurethane to the laminate, designed to be porous and not affect breathability. eVent uses a proprietary method to integrate a substance into the laminate itself. By preventing soilage, the waterproof and breathable properties of the fabric are maintained.

Coated Fabrics. Coatings are liquid solutions, predominantly polyurethane, that are applied to the interior of a garment. *Microporous* coatings are formed of microscopic channels that are too small for water droplets to penetrate but porous enough to allow water vapor to escape. Channels are formed as the coating adheres to the fabric, secondary to a foaming agent or to introduced solids that cause microscopic cracks in the coating. *Monolithic* coating agents form a hydrophilic layer, transporting moisture to the surface of the garment. Microporous and monolithic coating methods are virtually indistinguishable, with some manufacturers using both methods. Coated fabrics are not as breathable as those employing laminates and are generally not as durable. They are, however, more compressible and significantly less expensive than are laminates.

Polyurethane is also used for rubberized nylon garments. These garments are not breathable because of the robust layer of polyurethane. This fabric is ideal for marine environments and sedentary activities, where sweat accumulation is not an issue for maintaining warmth.

Soft-Shell Fabrics. Soft-shell fabric is among the most widely used outerwear fabrics. This fabric excels in breathability and flexibility while demonstrating moderate water resistance. Its tightly woven outer layer and inner lining of varying insulative quality may also employ a windproof or highly water-

FIGURE 110-5 Arc'teryx Gamma AR. Highly breathable, insulated soft-shell jacket with shaping for enhanced mobility.

resistant laminate. Garments of soft-shell fabric combine the properties of an insulating middle layer with a protective outer layer, making them effective tools for both temperature and moisture management. Moderately water resistant because of the tightly woven exterior and DWR finish, soft-shell garments excel when worn for highly aerobic activities when rain is not a concern (Figure 110-5).

Durable Water-Repellent Finish. A durable water-repellent (DWR) finish is applied to all waterproof/breathable fabrics after the garment is completed, enhancing water resistance without compromising breathability. The finish bonds to the fibers, not the pores, causing water to bead up and roll off the exterior. Ideally, the DWR finish forms a dense, chemical buffer, with the molecular structure forming an upright, brush-like texture. Water has a high contact angle with the finish, forming a spherical droplet. A low contact angle causes droplets to flatten into a dome-like shape, increasing the area of contact and allowing water eventually to seep into the pores of the fabric (Figure 110-6).

LAYERING

Dressing in layers enhances the wearer's ability to adapt to a changing environment, with each layer maximizing the properties of the garment's construction. Layering permits addition and subtraction of clothing, adjusting to changes in body temperature

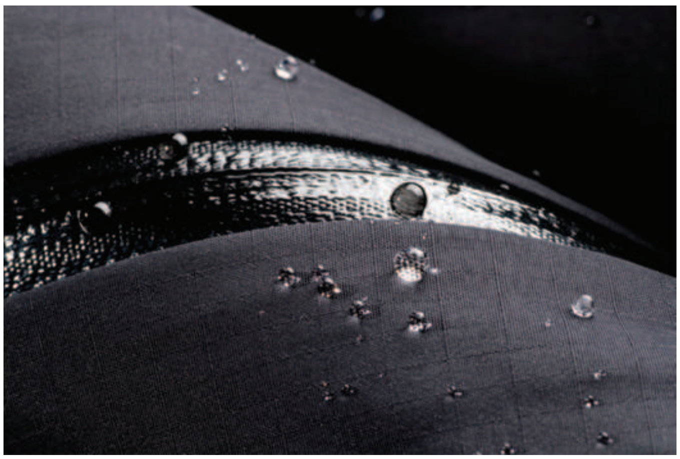

FIGURE 110-6 Watertight zipper and fabric with durable water-repellent finish demonstrates how water beads on the surface. *(Copyright 2010, Arc'teryx.)*

and metabolic output. This optimizes retention (or release) of metabolic heat and energy conservation. By adjusting layers in response to changing conditions, the wearer can either prevent sweating and overheating or prevent undesired heat loss and cooling. In anticipation of increased body heat and sweating when traveling uphill, layers can be preemptively removed and zippers lowered to promote ventilation. This prevents clothing from becoming saturated by sweat, which avoids not only an uncomfortable scenario, but also having saturated fibers lose their insulative properties. This is most important in cold environments, where insulation loss and long drying times lead to hypothermia. Removing layers in response to increased work conserves energy and moisture. In contrast to removing layers to prevent sweating, when workload decreases or the environment cools, adding layers traps metabolic heat in the insulative layers. Simple management of a personal layering system conserves energy. Layering systems permit rapid response to a changing environment, because it is easier to replace a single ruined garment than an entire suit of clothing. By layering, it is possible to pack fewer garments and still be comfortable across a range of environmental conditions and activity levels. When preparing for any excursion, participants must anticipate environmental variations such as unexpected precipitation and temperature change. A versatile layering system accommodates this eventuality.

The fit and physical properties of each layer are important. The base layer should be snug but not confining, with the middle layer fitting comfortably over it. The outer layer need only be large enough to fit over both the base and the middle layer without compressing them. Compressing the middle layer reduces its insulative properties. Seams are ideally flat-sewn. Harness and pack straps should not rub or chafe on seams or folds of fabric. Testing the fit, comfort, and effectiveness of the layering system before the adventure prevents the discomfort of poorly fitting layers and ensures that the purpose of the layering system—warmth and energy conservation—is fulfilled (Figure 110-7).

BASE LAYER

The base layer is next to the skin. It may be as sparse as briefs and a sports bra, or as extensive as full-coverage long underwear. The base layer's primary function is to regulate body temperature by retaining heat and transferring moisture away from the skin. Moisture management is established by the fiber's wicking properties. Moisture is drawn away from the skin surface by the fiber's hydrophobic properties. Moisture, through capillary action, travels the length of the fiber to the outer surface to be evaporated. Base layers must fit without imposing irritating seams or wrinkles. They should allow unrestricted movement. Well-designed insulative base layers are made from polyester, merino wool, silk, or a blend of fibers. Cotton is a poor base layer fabric because it loses its insulative value when wet.

FIGURE 110-7 Although it is sunny, the cold temperatures necessitate layering well with insulating garments. Andy Rich at Camp Muir, Mt Rainier. *(Copyright 2014, J. Dow.)*

TABLE 110-4 Insulating Value of Clothing*

	Approximate *clo* Range	Garment Example
Base	0.15-0.3	Silk weight, cotton t-shirt
Lightweight	0.3-0.5	Polartec 100, Patagonia R1
Midweight	0.75-0.85	Polartec 200, MontBell Thermawrap parka, Icebreaker 150
Heavyweight	0.90-0.11	Polartec 300, Patagonia R3, Icebreaker 260-300
Expedition	≥1.4	Patagonia down pullover and most high-loft insulation

*The insulating value of clothing is measure in *clo*. *Clo* was first defined in 1941 as a descriptive measure of thermal protection. One *clo* is the amount of clothing necessary for a sedentary person to be comfortable at 21° C (69.8° F), relative humidity less than 50%, and with normal ventilation. A lightweight business suit is approximately 1 *clo*. The lowest *clo* value is 0.0 (a naked individual), whereas the highest practical value is 4.0 (Arctic fur clothing). Contemporary manufactures do not use *clo* as a comparative unit. Polartec grades its fleeces as 50, 100, 200, or 300 weight, and other manufacturers grade garments as light-, mid- and heavyweight. This table shows some generalities about different layer types.

Base layers are available in ultralightweight, lightweight, midweight, and expedition weight. The designation of weight varies among manufacturers and is a relative measure (Table 110-4). The choice of layer type depends on the activity and environmental conditions. In mild to moderate conditions, a lightweight or midweight layer is appropriate. In conditions of extreme cold, a heavier base layer, maximizing heat retention, is preferred. Base layers may have zippers for ventilation. If vigorous, heat-producing activity is anticipated, consider a top with a zipped neck. Lowering the zipper allows increased ventilation around the neck to release heat, and it can be quickly closed to restore protection. Bottom layers are available with overlapping flaps or zippers. With a properly fitting system, significantly less skin is exposed to cold, and harnesses do not need to be removed. One-piece base layers cover both top and bottom with a single garment. Most are designed with a long zipper to be used for ventilation and elimination. In general, these garments are suited for extreme cold, where even the chance of exposure through a waistline gap would be dangerous.

The base layer remains a key tool for temperature regulation in hot environments. The choice of a predominantly hydrophilic fabric, such as cotton, enhances evaporative cooling. Cotton's moisture retention and slow drying time are negative qualities in a cool or cold environment but are useful in a hot environment. Base layers employed in hot weather should be loose fitting so as not to retain excess body heat.

MIDDLE LAYER

The purpose of the middle layer is insulation. As with the base layer, it is chosen with consideration of the environment, activities planned, and personal metabolic needs. The middle layer may consist of multiple garments. This is most common when highly variable conditions are expected. A heavy shirt and vest or two midweight garments are significantly more versatile than a single fleece jacket. Wool is a soft and warm material, providing reliable warmth and retaining most of its insulative value when wet. Fleece and other synthetics dry relatively quickly and have a higher warmth-to-weight ratio than wool, but are bulkier. The middle layer retains heat by trapping air next to the body. Fleece garments, down, and synthetic fill jackets operate on this principle. Air is trapped in the space between fibers or feathers and is warmed by body heat. Down performs superbly in a cool, dry environment. Synthetic fiber insulation retains much of its insulative properties when wet and dries quickly. Traditional down is useless when wet, but newer, hydrophobic down garments are performing well in wet environments.

The middle layer must fit appropriately to be functional and comfortable. The design and special features of the garment should be considered. Zippers add weight and may provide entry for cold air or moisture if not protected, but they enhance ventilation and make adding or subtracting a layer easier. For example, full-zip pants can be removed without removing boots or crampons. Pockets are useful for small items but must fasten to prevent loss of items and to keep out snow and water. Zipper placement is important when considering harnesses, packs, and access to inner layers.

OUTER LAYER

The outermost layer provides protection from dirt, dust, wind, rain, and snow. Protection from wind and water does not depend on fabric thickness, but rather on tightness of weave. Unfortunately, the tighter the weave, the less breathable the garment. Therefore, moisture does not wick away from the skin or middle layers. Protective outer-shell fabrics, commonly called “hard-shell,” are tightly woven and abrasion resistant. Most technical outerwear is designed with laminate fabrics. Laminates allow water vapor to pass out through the micropores while not allowing droplets to penetrate. Breathability of any fabric can be overcome by vigorous exercise, because sweat condenses on the inner surface. Similarly, if exposed to very heavy rain or high-pressure water sources, water repellency may be compromised. To combat excess sweat condensation, outer layers are designed to ventilate excess moisture through vents and armpit zippers. A coated nylon rain shell or rubberized nylon shell can be considered if the wearer is sedentary or there is little activity. These garments are essentially waterproof but do not breathe or ventilate through the fabric.

Jacket and parka choices range from light wind-shells to heavy down parkas. The garment needs to fit loosely enough not to compress the middle, insulating layer, but without excess bulk that may bind packs or become caught in gear. Pockets should zip-close, be accessible, and be roomy. Zippers should be sealed or have storm flaps, and the wearer should be able to operate them wearing gloves. Drawstrings and cuffs prevent wind and snow from entering the garment. Hoods should be adjustable, fitting over the head or helmet without restricting vision or movement.

Pants should be loose enough to permit movement and should have no excess fabric to become caught in crampons, foliage, or gear. Full-length zippers, while adding weight, allow pants to be removed without removing footwear. Pockets, as with all garments, should fasten and not be bulky. The waistband should not interfere with hip belts or harnesses. Bibs can be substituted, keeping the core warmer and eliminating the chance of the waistline becoming exposed or the waistband being an encumbrance. As with base and middle layers, pants may have a full fly that zips around to the back of the garment (Figure 110-8).

FIGURE 110-8 Arc’teryx Alpha SV Bib demonstrates protection from the weather and uses a combination of Gore-Tex Pro Shell fabric from the waist down and Schoeller Dynamic GNS stretch-woven fabric for the bib.

MULTILAYERED GARMENTS

Multilayered garments serve as both a middle and an outer layer, with soft-shell garments being the most common. These garments are ideal for vigorous exercise when rain is not expected. Soft-shell design is water resistant because of a dense weave and DWR finish, but prolonged precipitation will overwhelm the water resistance. Once the wearer is no longer exercising, these garments may not provide adequate insulation. Manufacturers have designed insulated waterproof garments that combine a down or synthetic loft layer with a waterproof outer layer. These garments are excellent for inclement weather and nonvigorous exercise.

ACCESSORIES

HEADGEAR

Appropriate headgear is necessary in all climates, whether to protect from the environment or prevent heat loss through the scalp. Hats and caps with brims are necessary in sunny environments and when there are reflective sources, such as water or snow. Hats providing sun protection must have a sufficiently broad brim to shade the face, ears, and neck. Insulating headgear is made of most fabrics. As with all other layers, the anticipated environment, activities, and excursion length should be considered when choosing a hat. Knit hats are made from wool or synthetic yarns, including blends. They vary in thickness from ultralightweight to heavyweight. Hats may be lined with a wind-resistant or insulating layer. The hat should fit snugly enough to keep from shifting or blowing off, but not so tight as to constrict or be uncomfortable. Earflaps, tassels, and ties must not interfere with helmet fit, and the hat should fit comfortably under a helmet or hood of the outer layer (Figure 110-9).

NECKWEAR

Scarves, neck gaiters, and balaclavas are common types of neckwear. Scarves may range from a bandana to a long wrap. Long

FIGURE 110-9 Arc’teryx Firee Hoody demonstrates how a well-fitting hood is adjusted to be snug around the head, protecting the face and neck while not blocking peripheral vision.

FIGURE 110-10 Arc'teryx Rho LTW neck gaiter retains warmth and will not catch in gear.

scarves are useful for full head, neck, and face protection, especially in a hot, sunny environment. They can be cumbersome and can become entangled in hardware. Neck gaiters are tubes of fleece, wool, or other knit fabric designed to pull over the head and encircle the neck (Figure 110-10). They retain heat and protect the neck from sun, wind, and cold. Like hats, neck gaiters need to fit well, should not be too snug, and should allow helmets and other protective gear to be worn comfortably. Balaclavas can be described as long hats with an opening for the face (Figure 110-11). These are quite versatile and can be worn as a hat or can be pulled down around the neck to minimize escape of warmth or entry of cold air. Hats may have integrated skirting or tails to cover the neck while ensuring adequate airflow; these are typically seen in desert environments.

EYEWEAR

See Chapter 48.

HANDWEAR

Gloves and mittens provide protection from environmental heat, cold, ultraviolet radiation, and physical harm (e.g., thorns, abrasions, lacerations, fire, toxic substances). Handwear ranges from thin cotton, wool, or synthetic liner gloves to abrasion-resistant, waterproof, and insulated gloves and mittens for environmental

FIGURE 110-11 Outdoor Research WS Gorilla Balaclava.

FIGURE 110-12 **A,** Arc'teryx Alpha SV glove has an outer waterproof/breathable layer with fingers designed to articulate with maximal dexterity. This is combined with a removable Polartec WindPro liner for insulation and protection. **B,** Arc'teryx Alpha SV mitt is also a layered system with a waterproof/breathable outer shell and insulated liner. Both glove and mitten are reinforced with leather at high-wear zones.

extremes. Gloves separate the fingers, allowing for increased dexterity, but are not as warm as mittens. Mittens separate only the thumb, providing maximal warmth (Figure 110-12).

Thin liner gloves permit maximal dexterity and afford some environmental protection. In extreme cold, this thin layer may protect against frostbite during brief exposures. If the liner snags or tears, it should be repaired or replaced. Following the same principles of layering, liners are frequently worn under heavier gloves or mittens. They also provide a measure of protection if the outer glove must be removed for tasks demanding more dexterity (Figure 110-13).

Gloves vary tremendously, with many hybrids of natural and synthetic materials. A glove may have a soft-shell body and leather palm, or it may be all leather or all fleece. Fleece gloves insulate well, and many are made with Windstopper laminate. Hard-shell, laminate gloves are available as shells to be worn over other glove layers or with integral insulation. Neoprene is used for gloves employed in marine and extremely wet conditions. It is common to have multiple pairs of gloves on any trip; an efficient combination of layers minimizes the number of pairs required.

FIGURE 110-13 Outdoor Research PL Glove is designed to be soft and form fitting without restrictions. It is an ideal base layer or liner glove.

FIGURE 110-14 La Sportiva Imogene. Trail-running shoes are designed to support the foot with strategic cushioning while maintaining flexibility for uneven surfaces.

FOOTWEAR

Proper-fitting and appropriate footwear is essential for any excursion. All footwear must fit snugly enough to prevent slippage and loosely enough to allow adequate circulation. Socks are manufactured from most fibers, including wool, synthetics, and blends. Socks are also usually layered, with a thin wool or polyester sock as a liner or base layer. This provides an initial layer to wick moisture away from the skin, and if fit properly, minimizes friction that can cause blisters. The thicker, insulating sock must also fit well, with no bunching or wrinkles. Improper socks can lead to hot spots or blisters and in extreme cold may sufficiently inhibit circulation to promote frostbite. The chosen sock combination should be tried with each pair of boots and shoes to determine if the fit is correct.

Boots and shoes have become very specialized. Hiking boots are no longer heavy leather "clod-stompers" where fit was accomplished by adding pairs of socks. Professional fitting is ideal when acquiring footwear. A well-fit boot or shoe has no heel rise and adequate room at the toes to move or wiggle them. The foot does not slide forward when walking down an incline, and there are no pressure points. Some people require custom orthotic designs or molded boot liners to achieve proper fit. The sole is constructed of a rubberized polymer with a tread pattern. The tread maximizes traction on uneven surfaces. Trail shoes are designed with a flexible sole (Figure 110-14). Hiking and mountaineering boots may have a metal shank in the sole to increase stability on uneven surfaces. Full-shank boots have no flex and are the most stable (Figure 110-15).

Footwear is constructed from a wide range of materials. Most models are available with a waterproof/breathable membrane. Fabric or mesh construction is the norm for trail shoes and light hiking boots. Leather, or a similar abrasion-resistant synthetic, is frequently sewn over points of stress or common areas of wear. More substantial boots are designed with more leather or synthetic materials (less fabric and mesh), increasing stability and

FIGURE 110-16 **A,** Scarpa Phantom Guide. Single boot with an integrated gaiter, ideal for ice climbing and high-altitude climbing, up to 5000-m (16,404-foot) peaks. Many companies are now producing "all-in-one" boots with integrated gaiter and insulation. **B,** La Sportiva Spantik. Lightweight, extremely warm double boot, ideal for 6000- to 7000-m (19,685- to 22,966-foot) peaks or high, cold mountaineering endeavors.

durability. Mountaineering boots are typically constructed of plastic or a semirigid synthetic. Boots designed for extreme cold and high-altitude conditions have removable and often custom moldable boot liners. These so-called double boots are designed to be maximally insulating while providing for a degree of dexterity while walking and climbing (Figures 110-16 and 110-17).

Gaiters and overboots are designed to protect and insulate footwear. Gaiters, tube-like constructions that cover the lower leg, are constructed of abrasion-resistant nylon with or without a waterproof/breathable laminate (Figure 110-18). Gaiters keep dirt, stones, mud, and snow out of shoes and boots. Supergaiters cover the entire boot, with a rubber rand that covers the boot rand. In addition to the protective qualities of gaiters, many supergaiters have an insulative lining that provides additional

FIGURE 110-15 Two examples of boots: **A,** La Sportiva Thunder II GTX. This midweight boot is designed with Cordura and leather upper, with a Gore-Tex lining for water resistance. **B,** La Sportiva Nepal EVO GTX. This full-shank mountaineering boot is designed with silicone-impregnated leather for water resistance. The leather itself is durable and abrasion resistant.

FIGURE 110-17 La Sportiva Olympus Mon EVO. This boot is designed for the most extreme conditions, with a thermal insulating inner boot and thermoreflective outer boot. The integrated gaiter protects the boot from abrasion and wear, in addition to preventing debris from entering.

FIGURE 110-18 Outdoor Research Verglas Gaiters. Typically used over hiking or mountaineering boots to keep debris from entering the boot. Constructed of a waterproof/breathable Ventia fabric leg section and a Cordura boot section.

thermal protection for the feet. Supergaiters leave the boot sole free, so traction is maintained and crampons do not need to be refit. Overboots cover the entire boot, providing further insulation from the cold ground. Typically, overboots have a fabric sole with no traction. Crampons need to be refit to accommodate overboots (Table 110-5).

CARE AND STORAGE OF CLOTHING

Proper care and storage of outdoor clothing prolongs garment life and maintains properties of insulation, water resistance, and breathability. Technical fabrics do not have universal care guidelines, so manufacturers' care instructions should be followed (Figure 110-19).

Any contaminant on fabric reduces its effectiveness. Soot, grease, sunscreen, dirt, and body oils contribute to garment failure. *N,N*-diethyl-3-methylbenzamide (DEET) may physically damage rayon or spandex fibers. It does not damage wool or cotton. The insect repellent picaridin does not damage synthetic or natural fibers. Soiled fabric is more susceptible to *pilling*, which is fraying of fibers in areas of friction. These abraded fibers attract more soil and enlarge. Contaminants affect the intrinsic fibers of fabric, inhibiting the wicking process and negatively affecting its water resistance and breathability.

LAUNDERING

Before laundering, the garment should be prepared by closing all zippers and sealing all hook-and-loop closures. All pockets should be inspected—a retained stick of lip balm can ruin a garment. All stains should be spot-treated by gently massaging in the proper cleaning solution. Turning the garment inside-out

TABLE 110-5 Shoe Types and Their Uses

Shoe Type	Common Use	Advantages and Disadvantages
Sandals	Water sports	Well ventilated and quick drying Provides protection to sole of foot Does not protect toes or top of foot
Running shoes	Trail running	Good underfoot support and traction Lightweight and ventilated Poor ankle support
Rock shoes	Rock climbing	"Sticky rubber" soles for traction on vertical surfaces Sport-specific shoe and not practical for other uses
Water shoes	Kayaking, boating	Neoprene shoes for insulation in water Rubber soles for traction Little use outside water sports
Approach shoes	Walking, easy hiking, approach to climbing areas	Lightweight with adequate traction Not designed for strenuous hikes or unstable ground
Hiking boots	Hiking, backpacking	Extensive range of design and materials Lightweight synthetic to heavy leather Full and partial shank soles for stability Excellent traction
Mountaineering boots	Mountaineering and ice climbing	Double or single boots Crampon compatible Well insulating Heavy and not ideal for hiking
Pac boots, Sorels	Insulated, water-resistant winter boots	Well insulated and water resistant Good for activities that do not require traction or maximal support

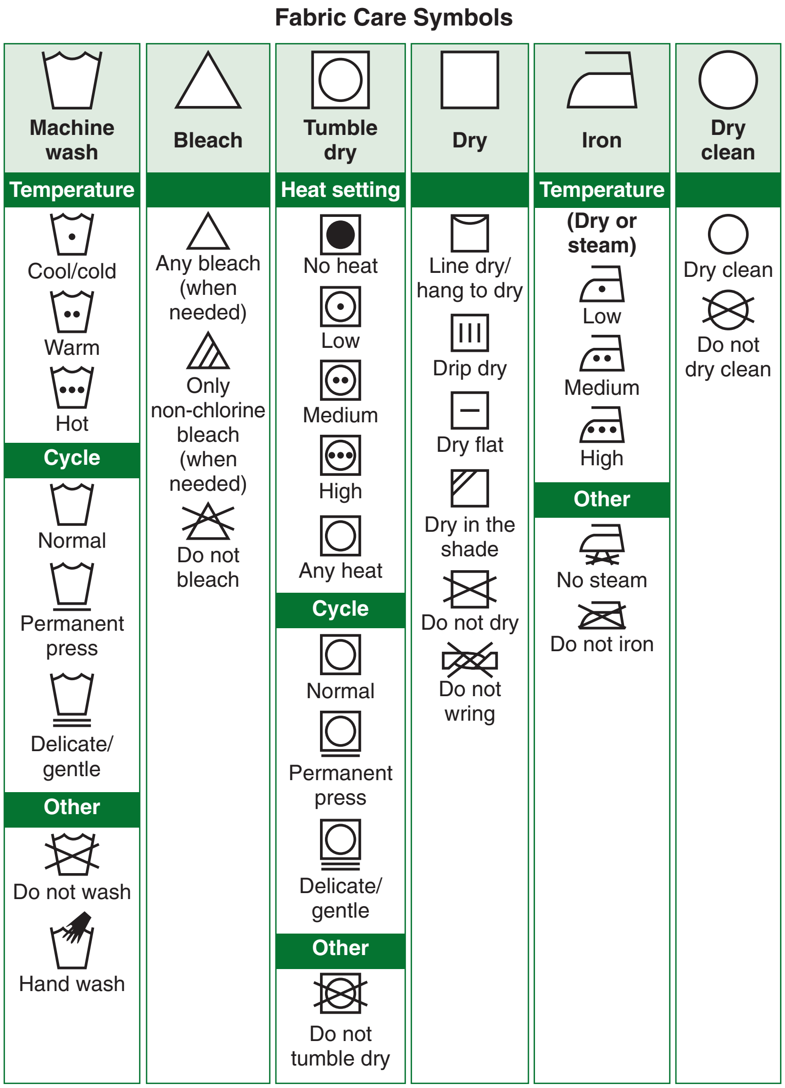

FIGURE 110-19 Laundering symbols. *(From* http://www.cleaninginstitute.org/clean_living/your_guide_to_fabric_care_symbols.asp.*)*

decreases abrasive damage to the outer surface. If available, a front-loading washer is preferred; the central agitator of a top-loading unit may damage clothing. Choose the correct laundry solution. Most mass-market products contain surfactants, designed to bind and lift away grease. This is helpful if the garment is not treated with a DWR finish. The surfactant does not completely rinse away and can leave a residue. This contaminant will decrease effectiveness of the DWR finish and reduce waterproof/breathable properties of the fabric. Specialty detergents formulated for technical fabrics are designed to rinse completely and leave no product bound to the fibers. If specialty detergents are not available, use products labeled "clear," "earth-friendly," or "free," because these tend to leave behind less residue but still require an extra rinse cycle. *Do not* use fabric softener. Fabric softeners are designed to leave behind oils and fragrances, which act as contaminants on fabric. This applies to both liquid softeners and dryer sheets.

DRYING

Adhere to the manufacturer's instructions. If garments are not line-dried, use a low heat setting, and do not allow the garment to sit in the dryer when the cycle is complete. Dryer fins can become extremely hot and may melt synthetic fibers. Be cognizant of the possibility of shrinkage with wool and wool-blend garments. Cotton garments that are not preshrunk will shrink if washed in hot water or placed in a hot dryer. Preshrunk garments may still experience 2% to 3% shrinkage. To mitigate shrinkage, launder in cold water and line-dry.

DURABLE WATER-REPELLENT FINISH

All waterproof/breathable fabrics are treated with a DWR finish. For the finish to continue to be effective, manufacturers recommend washing at least yearly, and more frequently when there is obvious buildup of dirt, oils, or other contaminants. Sunscreens, lotions, and body oil that rub off onto the fabric surface decrease effectiveness of the DWR finish. Smoke specifically decreases water repellency. DWR finishes require maintenance when water no longer beads up on the surface of the garment. If the garment is clean, 10 to 15 minutes in a dryer on the low heat setting will restore the finish. DWR finish, on a microscopic level, resembles upright columns. With soilage, use, and abrasion, the columns no longer stand upright. Heat restores the upright structure of the finish. Reapplication of the DWR finish is possible with after-market products, such as Revive XTM, Sport-Wash, or NikWax. If the garment has a laminate membrane, a spray-on product is more effective. If there is no membrane, use a wash-in product.

FOOTWEAR

Boots and shoes should by well cleaned before storing. It is easy just to kick them into the closet, but dirt and organic material mechanically break down both leather and synthetic materials, decreasing longevity. Never store footwear damp or wet. Newspaper stuffed into a damp boot helps absorb moisture, but be sure to remove it. Do not put footwear in a clothes dryer; air-drying or low heat with commercial boot dryers is best. Do not apply after-market treatments unless suggested by the manufacturer because some may affect the sealants. Boots may require seam sealing and renewal of waterproofing after extended use. Leather boots require conditioners on a periodic basis. Mink oil, Sno-Seal, or similar products can restore water resistance to both leather and seams.

STORAGE

Outdoor clothing and technical fabrics should be stored uncompressed and in a dry environment. A damp basement or garage is not a good location; moisture may lead to formation of mold and mildew, damaging fabrics. Down and synthetic insulating layers lose loft, and thus insulative value, when stored compressed. Insects can damage clothing if an infestation occurs. Moths are especially damaging to wool. Cedar is a natural repellent and is available as blocks or rounds to place with the garments. Cedar-lined chests of drawers are another option. Cedar does not guarantee safety of the garment, because moths may still attack the clothing. In this case, mothballs formed from pesticides may be necessary. Mothballs are made from naphthalene (1,4-dichlorobenzene) or camphor. Camphor may be both naturally occurring, found in the wood of the camphor laurel, or synthesized from oil of turpentine. When placed in an airtight container, mothballs sublimate to vapor, killing both larvae and adult moths. Both are toxic and may be carcinogenic, necessitating that the garment be aired out for at least 1 day before use. If wool is stored in an airtight bag, be certain it is completely dry, or it will mildew.

REPAIR

Even with conscientious care and careful use, clothing becomes damaged. Patch kits available from manufacturers can be applied to maintain fabric integrity. These are far superior to the improvised fix of duct tape. Ideally, repairs are completed professionally, protecting laminates, sealed seams, and specialty zippers. Most manufacturers will repair a garment sent to them. In the field, stopgap measures include tape, fabric glue, and safety pins. Seams and rents in fabric can be temporarily repaired using a needle and polyester thread.

SPECIAL-USE CLOTHING

SUN PROTECTION CLOTHING

Protection from the sun is important both to reduce skin damage from ultraviolet radiation (UVR) and to decrease radiant heat gain in hot environments. With rare exception, clothing protects the skin from UVR by simply covering the surface. Special sun protection or "UV-blocking" garments employ a tight weave to prevent any radiation from penetrating the fabric. Any property that blocks sun, such as a tight weave or thicker fiber, improves sun protection. Stretchy garments create spaces through which UVR can penetrate. Wet garments are not as effective as dry garments at blocking UVR. Sun-protective clothing is characteristically white or pastel colored to maximize reflective qualities.

Clothing manufacturers report an ultraviolet protection factor (UPF), determined by using one of several rating systems. For comparative value, a plain white T-shirt has a UPF value between 5 and 9, whereas sun protection clothing will have UPF of 30 or greater (Table 110-6).

TABLE 110-6 Ultraviolet Protection Factor (UPF) Ratings

General Rating	UPF Rating	UV Light Blocked (%)
Good	15-20	93.3-95.8
Very good	25-35	95.9-97.4
Excellent	40+	>97.5

INSECT-REPELLENT CLOTHING

Mechanical protection offered by clothing is the first barrier to insects. Clothing that is loosely fitted prevents insects from biting or stinging through fabric, and elasticized cuffs and wrists prevent insects from migrating under clothes onto the skin. Insect-repellent chemicals, usually permethrin, are impregnated into garment fibers. Permethrin is an odorless insecticidal compound synthesized to mimic a chemical found in chrysanthemums. It eventually washes out of the garment but is expected to maintain effectiveness for 20 to 25 washings. Products are available that can be sprayed on or used as garment soaks. Any product used should last about five washings. Follow product instructions to maximize effectiveness.

FIRE-RESISTANT CLOTHING

Nomex is the proprietary fabric used to manufacture the majority of fire-resistant clothing. It is a structural variant of Kevlar. Flight suits and some rescue gear are made from this fabric. The fire resistance may be intrinsic to the fabric, as with Nomex, or secondary to an externally applied retardant agent. The base fiber of fire-resistant clothing must not melt, which eliminates nylon as a substrate. Wool is naturally fire resistant; it is still flammable but extinguishes quickly.

VAPOR-BARRIER CLOTHING

The applications for vapor-barrier clothing are limited to extremely cold environments. Most clothing is designed to wick perspiration into the middle layers and away from the skin. In extreme cold, the middle layer may not dry, causing loss of insulative value. The premise of a vapor barrier is to keep the insulating layer dry. Perspiration is wicked into the base layer and remains there, unable to pass the vapor barrier. This leads to damp clothing next to the skin, but the insulative value of the middle layers is preserved because they remain dry. Maintaining effectiveness of the insulating layer outweighs the relative discomfort of a damp layer next to the skin.

SPORT-SPECIFIC CLOTHING

Sport-specific clothing is not necessarily better than general outdoor clothing. The basic principles of construction and fabric utilization are the same, but the clothing has design properties specific to the sport. For example, outer layers for mountaineering and ice climbing have less fabric around the waist or a much shorter torso rise to accommodate a harness. Gloves must both insulate and allow dexterity. Pockets are situated on the chest, and hand-warmer pockets are frequently eliminated. Kayaking jackets have tight-fitting or neoprene cuffs and waistbands to reduce water entry into the garment. Rock-climbing clothing is snug fitting to prevent fabric from catching in gear. Specialty rock-climbing shoes are required (Figure 110-20). Desert environments require increased sun and heat protection. Jungle and snake-infested areas demand protective boots and snug-fitting ankle and wrist cuffs.

CLIMATE-SPECIFIC CLOTHING

When preparing for any excursion, the expected environment is one of the principal factors determining clothing choice. Different clothing systems are needed for each environment, but the basic principles of thermoregulation and moisture management utilizing layering always apply. In addition to anticipating climate and weather extremes, physical features of the environment and activity to be pursued are important considerations. A hike or backpacking trip through an open forest, tundra, or grassland

FIGURE 110-20 La Sportiva Katana Lace. Climbing shoes are the most specialized piece of rock-climbing clothing. The shoe's rubber rand permits the climber to stand on exceptionally thin edges. Climbing shoes must balance fit, comfort, dexterity, and stability.

will not subject clothing to the type of damage made likely by bushwhacking and scrambling over rocks. For all climates, nylon and cotton-polyester blends offer the most abrasion-resistant fabrics. Fleece and any fabric with a loose weave will snag and tear. The need for a garment to tolerate abrasion must be balanced with the considerations for insulation (Table 110-7).

HEAT

Hot and extremely hot environments require clothing that protects from the sun and enhances cooling. Hot climates are those with sustained temperatures above 38° C (100.4° F). Extremely hot climates have temperatures above 46° C (114.8° F); the latter is typically a desert environment.

Fabrics and design of hot-weather clothing must be able to protect from the sun and keep the wearer cool. Air needs to circulate freely across the skin while the clothing shields from UVR. A fabric's ability to protect from the sun is rated as either the ultraviolet protection factor (Australia) or the clothing protection factor (United Kingdom). The fabrics are tested with a spectrometer to measure the ability to block UVR. Not all fabrics receive UV-protective ratings, but they still provide a degree of sun protection. Tightly woven fabrics are more protective than materials with a loose weave. Wet fabrics lose protective value, as do worn or abraided fabrics. Air circulation optimizes both convective and evaporative cooling. Strategically placed vents and mesh panels combined with a loose fit maximize ventilation. Many garments are designed to be "convertible," with zip-off pant legs and easily rolled-up sleeves, offering the wearer maximum versatility for changing conditions (Figure 110-21).

Thermoregulation cannot be managed by clothing alone. Behavior modification is the best strategy for cooling in conditions of extreme heat and humidity. If the environment is dry and hot, moistening the fabric enhances evaporative cooling. Exposing arms and legs promotes more rapid evaporation and convection, but sunscreen must be applied. In extreme heat, seeking shade and avoiding heavy physical activities during the hottest parts of the day are necessary precautions.

FIGURE 110-21 Outdoor Research Venture Pants. These pants offer 30+ ultraviolet protection factor protection and employ a durable water-repellent finish to shed moisture. They are designed for maximum mobility with a gusseted crotch and articulated knees. By rolling up the pant legs, these types of pants are ideal for warmer weather and expected stream crossings.

TEMPERATE

Mild temperatures, ranging between freezing and body temperature, characterize temperate climates. This broad range of environmental conditions requires clothing that accommodates the perspiration of activity during the day and provides warmth during cool nights. Unless it is exceptionally humid or rainy, most clothing dries quickly (Figure 110-22).

Lightweight, quick-drying nylon clothing provides protection from the sun and from abrasion caused by brambles and brush. Polyester-cotton blends are also highly abrasion resistant and dry relatively quickly. Long sleeves and pants may be necessary for cooler evenings or rainy conditions. A lightweight middle layer, such as fleece or a heavy shirt, coupled with gloves and hat, will stave off evening chill. Wind and water protection are accomplished with a lightweight outer layer. A jacket constructed of a waterproof/breathable laminate is most versatile. If extremely wet conditions are expected and the chance of perspiration is low, consider a coated nylon garment.

COLD

Daytime low temperatures that drop below freezing characterize cold climates. Layering systems must accommodate both the relative midday warmth and the potential for precipitation in the form of rain and snow (Figure 110-23). Clothing does not dry readily in these conditions. Efficient moisture management is imperative to maintain warmth as temperature drops. The base layer should accommodate daytime warmth and not contribute

TABLE 110-7 Climates

	Temperature (Daytime)	Moist or Humid Environment	Dry Environment
Extremely hot	High greater than 46° C (114.8° F)	Rare	Desert in summer
Hot	High greater than 37° C (98.6° F)	Rainforest	Desert in summer
Temperate	Between 0° C and 37° C (32° and 98.6° F)	Deciduous forest, coastal forest, maritime mountain	Inland mountain, forest, desert in winter
Cold	Low below 0° C (32° F)	Coastal mountains, high-latitude mountains	Inland mountain, tundra
Extremely cold	Low below –29° C (–20.2° F)	Rare: interior northern climates with inversions (Fairbanks, Alaska)	Alpine winter, high latitude and high altitude

FIGURE 110-22 Stream crossing in Outdoor Research gear. *(Copyright 2010, Outdoor Research.)*

FIGURE 110-23 Anchorage Nordic Ski Patrol members were prepared for the rapid change in weather on this stormy day. Backcountry ski tour/patrol, Chugach Mountains. *(Copyright 2008, J. Dow.)*

to overheating. A lightweight or midweight pair of long underwear is preferable over heavyweight garments. Insulating middle layers that can be easily shed or added are key to maintaining comfort. Careful consideration of the garment's properties, such as the ability to vent through neck and leg zippers and ease of donning the garment over boots, harnesses, or helmets, enhances efficiency of the layering system. The outer, protective layer must be resistant to both wind and water.

Extreme Cold

Extreme cold characterizes the conditions encountered at high altitude, in glaciated terrain, or at extreme latitudes. With few exceptions, these climates are dry with precipitation in the form of snow. High-latitude coastlines and conditions that produce ice fog are the rare times that penetrating moisture is present. Wind is a major factor contributing to heat loss. Garment properties, such as draw cords and waist skirts, keep the wind from entering. All skin must be covered. Gloves, hats, and balaclavas and/or neck gaiters are necessary. Clothing must be easily layered and not constrictive so as not to lose loft. In these conditions, removing an outer layer to add insulation may not be possible. An insulating parka that fits over the outer shell solves this dilemma. This situation is frequently encountered when mountaineering. Heat generated by climbing is rapidly lost, necessitating the added insulation.

Accessories, such as gloves, hats, overboots, and gaiters, maintain warmth. Fit and insulative properties are important considerations. Gloves should have a gauntlet cuff, completely covering the wrist cuff of the outer layer. Overboots must overlap with the cuffs of pants and have no gaps. Headwear should not expose the neck or ears. This may be accomplished by using a balaclava or a combination of neck gaiter and hat. Any exposed areas should be addressed immediately. A pause in activity to maintain clothing may be annoying, but frostbite is a much greater burden.

WATER (OCEAN AND RIVER)

For activities in and around water, hypothermia is the greatest environmental danger. Neoprene garments provide excellent insulation and a degree of wind resistance. Neoprene is a synthetic material impregnated with nitrogen bubbles. This foam-like structure contributes to the insulative quality. Proper-fitting garments are snug but allow a necessary amount of water to be trapped between the wet suit and skin. The water is warmed by the body and acts as an additional insulator. The activity, expected climate, and water temperature determine the necessary body coverage and thickness of the suit. Neoprene accessories extend protection to hands, neck, head, and feet. Dry suits are especially suitable for extremely cold water. Unlike wet suits, dry suits do not let water in and are made of a thicker material, with seals at the neck, wrists, and ankles to prevent water entry. Some suits have integrated booties. Additional insulating layers can be worn under the dry suit.

SELECTED RESOURCES

Selected resources used in this text are available online at www.expertconsult.inkling.com.

SELECTED RESOURCES

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CHAPTER 111

Nonmedical Backcountry Equipment for Wilderness Professionals

JOHN R. HOVEY*

This chapter examines concepts for choosing specialized outdoor equipment. Appropriate gear can enhance speed, safety, comfort, and durability.

GENERAL CONCEPTS FOR CHOOSING EQUIPMENT

Consider these factors when choosing outdoor equipment:

- Activity
- Location of activity
- Transport to and during activity
- Duration of activity
- Budget

Individual and expedition needs guide gear choice. An extended Himalayan high-altitude expedition requires very different gear than a summertime white-water kayak day trip on the Colorado River. In the wilderness, your life might depend on your nonmedical equipment (Figure 111-1).

CHOOSING GEAR

An extensive variety of outdoor gear is available in terms of cost, materials, and quality. More expensive can mean higher-quality equipment, but not invariably. Many activities require sport-specific gear, but basic items (e.g., tents, stoves, sleeping bags) often can be used for many situations.

Weight and bulk are major factors. For car camping, a large two-burner gas stove and bulky sleeping bag are appropriate. Similarly, on trips with support vehicles, boats, or porters (e.g., research or scientific expeditions), having the latest lightweight gear may be less critical. In contrast, travelers carrying their own gear (e.g., backpackers, ski-tourers, cyclists) often want lightweight and compact versions. Alpine mountaineering-style gear perfected by long-distance hikers is lightweight, rugged, and compact. Equipment that is smaller and lighter saves energy and can lead to a safer, more enjoyable experience.

Carbon fiber, titanium, magnesium, aluminum, and plastics can be crafted into lightweight, durable, and high-performing equipment. There are trade-offs to be considered; for example, a standard aluminum avalanche probe is more durable and only minimally heavier than a new carbon-fiber probe. Lightweight gear is often less durable (e.g., a Lexan avalanche shovel is not nearly as durable as a slightly heavier aluminum shovel). Multifunction gear can be an excellent way to shed weight and space, but performance of each function may be compromised (e.g., a dedicated avalanche probe is superior to ski poles that convert to a probe) (Figure 111-2).

Practice using equipment properly is critical, especially with highly technical or complicated equipment. Simple tools are often more reliable and durable. Procure gear that is easy to adjust and repair in the field. Avoid complex gear that requires special tools for setup, repair, or maintenance. For example, choose "tool-free" crampons that adjust without a wrench or screwdriver, and use a compass with an easily adjustable declination correction. When traveling in teams, members should divide equipment to avoid needless redundancy. Teams can split up the weight and bulk of such items as stoves, tents, medical gear, and research equipment. Plan well, but learn to improvise. Never cut corners on emergency kits or survival gear.

ESSENTIAL EMERGENCY EQUIPMENT

When planning wilderness activity, travelers should prepare a basic emergency kit. In 1906, The Mountaineers began creating a series of climbing courses and collaborations that ultimately produced the book *Mountaineering: The Freedom of the Hills*. It included a list of "10 Essentials" that was the gold standard for emergency preparedness in the outdoors.

10 Essentials: Classic list

1. Map
2. Compass
3. Sunglasses and sunscreen
4. Headlamp/flashlight
5. Knife
6. First-aid supplies
7. Fire starter
8. Matches
9. Extra clothing
10. Extra food

The advent of new technologies necessitated revision of the original list; however, the fundamental concept of preparation remains unchanged.

10 Essentials: Updated list

1. Navigation
2. Sun protection
3. Illumination
4. Repair kit and tools/power
5. First-aid supplies
6. Fire starter
7. Nutrition (extra food)
8. Hydration (safe water)
9. Insulation (clothing/sleeping bag)
10. Emergency shelter

Essential equipment may vary according to context. A basic emergency kit should include first-aid, survival, and repair materials. To determine the size and contents of an emergency kit, ask: who, what, where, when, how far, and how long?

WHO?

The number of people and level of expertise are crucial to deciding how much equipment to bring. For example, a sole medical provider on an extended trip with both young and old participants needs a large, comprehensive emergency kit. For a trip with a group of doctors and two guides (carrying kits), one might carry only a small personal kit. Number of people, medical background, medical conditions, and age of participants are factors in the determination of what to carry.

WHAT AND WHERE?

Design the kit based on activity. Although hiking, camping, backpacking, and trekking may yield similar kits, special situations deserve additional consideration. A dive expedition in Hawaii requires much different gear than an international medical

*This chapter is based on work by John Gookin, Christopher Van Tilburg, Marion C. McDevitt, and Nathan K. Friedline in previous editions.

FIGURE 111-1 Hiking in the Bugaboos, Canada. *(Copyright 2010 Arc'teryx, by Brian Goldstone/Angela Percival.)*

relief program to sub-Saharan Africa. Kayakers and rafters need different equipment than cross-country mountain bikers. Persons traveling to developing countries, to high altitude, or on the ocean require specialty equipment related to climate and terrain.

WHEN?

Time of year may be a factor in determining how much gear is carried. During the winter, one may carry more survival gear and equipment for avalanche safety, snow camping, and cold-injury prevention. A summer trip in the desert may focus on sun protection, water storage, and heat mitigation.

HOW FAR? HOW LONG?

Longer trips to remote destinations mandate more advanced equipment for safety and survival. Commercially available emergency kits usually include first-aid, survival, and repair supplies. Alternatively, a wilderness enthusiast can prepare his or her own custom kit. Three basic sizes for emergency kits are generally in use.

FIGURE 111-2 Ski touring in British Columbia, Canada. *(Copyright 2009, Arc'teryx. Courtesy Brian Goldstone.)*

- A basic emergency kit may be used for day outings (see Box 111-1 for an example of a basic compact kit). This includes equipment to cover one unexpected night out in mild weather. A small kit provides only the bare minimum of survival gear for food, shelter, water procurement, navigation, fire building, first aid, and equipment repair. Everyone should carry a personal emergency kit, even if there is a large group emergency kit.
- A large, multiday kit is intended for overnight climbing, backpacking, kayaking, or rafting trips that may last from 1 day to

BOX 111-1 Basic Emergency Kit

A basic emergency kit should include first-aid, survival, and repair materials.

First-Aid Kit
Waterproof-cloth first-aid tape is an essential first-aid item. It has a wide range of uses and is difficult to improvise in the field. A basic kit should include wound care supplies and personal protective equipment (CPR mask, gloves, face mask) at a minimum. Wilderness medicine professionals may carry more advanced supplies, tools, and medicines (see Chapter 102). This kit should also include sunscreen.

Fire-Starting Materials
Carry windproof and waterproof matches in a watertight jar with a striking swatch, lighter, or metal match (flint with steel striking blade). One may also carry fire starter, such as petroleum jelly–impregnated cotton balls or commercial fire-starting tablets.

Navigation
The bare minimum is a compass with declination correction and a topographic map. An altimeter is useful, especially in the mountains or canyons. One may choose to carry a GPS unit but should always have a compass for backup (see Chapter 106). Surveyor's tape can be used to mark dense woods. Wands (1-m [3-foot] bamboo poles with surveyor's tape on the top) are useful for marking crevasses and snow routes on glaciers.

Power
Carry extra batteries for headlamp, camera, avalanche beacon, medical equipment, GPS units, and other electronics.

Sun Protection
Carry sunscreen and sun-protective eyewear, either goggles or glasses. A sun hat and sun protection clothing are important.

Heat
Chemical hand or foot warmers are useful.

Light
Headlamp—include a spare bulb and spare batteries.

Repair Materials
The basic repair supplies can include a multitool. This should include pliers, wire cutters, screwdrivers, small knife blade, and scissors (see Box 111-4). Duct tape, 5 cm × 1.5 m (2 inches × 5 feet), rolled then squeezed flat, is extremely useful and difficult to improvise in the field. Repair materials should include thread and awl, wire or paper clips, plastic cable ties, polyurethane plastic straps, and nylon cord (3 m × 4 mm [9.8 feet × 0.2 inch).

Clothing
Carry at least one layer more than you expect to use on the trip. Consider carrying enough clothing to survive the unexpected night out. See Chapter 110 for detailed information on clothing.

Emergency Shelter
Have the ability to improvise an emergency shelter using materials in the wilderness, or carry an emergency bivouac sack. This can be a simple, compact plastic tube shelter or even a large plastic garbage bag.

Communication
For basic communication in varied terrain or storms, a plastic whistle can be much louder than the human voice. A signal mirror is useful for communicating with rescue aircraft. Cell phones, satellite phones, VHF radios, and FRS radios can aid in emergencies.

CPR, Cardiopulmonary resuscitation; *FRS,* family radio station; *GPS,* global positioning system; *VHF,* very high frequency.

2 weeks. It anticipates advanced needs for water procurement, shelter building, and navigation. Guides, trip leaders, and outdoor professionals often carry these kits.

- Expeditions of 1 week or longer may require specialized equipment and a broad range of supplies for situations that involve large numbers of people encountering problems in extreme environments.

Information about retail emergency kits is found at www.adventuremedicalkits.com. Complete medical supplies are listed in Chapter 102. Equipment for vehicles is listed in Box 111-2.

NAVIGATION

The bare minimum navigation system is a compass with declination correction and a topographic map. Global Positioning System (GPS) technology offers many admirable features; however, it may prove unreliable. A common failure of GPS navigation is when a sufficient number of satellites cannot be acquired in dense foliage or obstructing terrain, such as in a slot canyon. In addition, batteries often do not perform adequately in temperature extremes. One should always carry a compass and appropriate map for backup (see Chapter 106).

An altimeter is useful, especially in the mountains or canyons. Wrist altimeters may use GPS or changes in barometric pressure. GPS devices are more accurate. A sudden change in barometric pressure can indicate an impending storm and allow persons additional time to find shelter. Many wristwatches now feature storm alarms.

GPS devices allow easy and accurate positioning by triangulation with satellites (Figure 111-3). GPS is most useful when used in concert with a topographic map and compass. GPS devices provide information such as velocity, bearing, and distance or deviation to next waypoint. They are available in handheld and wrist-top configurations. Handheld units have a larger screen but are more bulky than the wrist-top devices. Some display topographic maps, although at varying resolutions. Wrist-top devices may offer features such as a heart rate monitor and serve to combine a traditional training wristwatch with a GPS device. Devices are often compatible with software mapping programs (e.g., Google Earth), so users may upload information to a personal computer to track route/performance (Figure 111-3B). Wrist-top GPS units are usually synchronized to a computer, where preplanned checkpoints are established.

BOX 111-2 Suggested Emergency Equipment for Vehicles

Two spare tires
Tire jack and iron
High-lift jack
Sand and snow plate for jack
Jumper cables
Tow strap
Tow rope
Extra gas, at least 20 L (5 gal)
Extra oil, 2 L (2 qt)
Extra food and water for emergency rations
Tire pump
Snow shovel
Sand or dirt shovel
Fire extinguisher
Headlamp/spotlight
Road flares
Tie-down straps
Flat-tire repair kit: awl, rubber cement, patch, or plug material
Flat-tire repair canister: pressurized glue that inflates tire and plugs flat tire
Spare valve stems for tires
Tool kit: screwdrivers, wrench or socket set, pliers, and tongue-and-groove pliers
Repair kit: electrical tape, wire, duct tape
Tarp and spare blanket or sleeping bag
Comprehensive first-aid kit

FIGURE 111-3 Garmin, a leader in GPS navigation, has many models. **A,** Garmin GPSMAP 60CSx. **B,** Garmin eTrex Legend HCx.

SUN PROTECTION

Carry sunscreen and sun-protective eyewear, either goggles or glasses. A sun hat and sun protection clothing are also important (see Chapter 16).

SUNGLASSES AND GOGGLES

Sunglasses and goggles provide visual comfort and clarity while protecting one's vision from the elements and damaging ultraviolet (UV) radiation. Glasses should fit close to the face. Broad temple arms or leather blinders can also be employed to protect against reflected light, which is important in mountain climbing or glacier travel because of higher levels of UV light.

Polarized and mirror lenses can reduce eye fatigue and improve vision. Lens color can provide functional benefit. Red, gray, green, and brown lenses decrease color distortion. Brown, orange, and yellow increase contrast. Orange and yellow increase depth perception but also increase color distortion. No one lens is ideal for any given environment, so interchangeable lenses provide an advantage. An important consideration is the percentage of light transmitted. Most sunglasses fall within a range of 10% to 30%. Dark lenses that allow a low percentage of light transmission can result in loss of vision when moving from a bright environment to one that is dark, such as when driving into a tunnel or shaded turn. Lenses with less than 10% transmission accompanied by tightly fitted side guards are needed in the extreme lighting conditions of glacier travel.

Lenses are constructed of glass or plastic. Glass and plastic are almost transparent to the visible spectrum while opaque to the UV spectrum. Glass lenses maintain superior clarity and scratch resistance but are heavier and more fragile than plastic lenses. Several varieties of plastic lenses (e.g., acrylic, polyurethane, CR-39, polycarbonate) are available. Polycarbonate is the lightest option and offers the greatest impact resistance (50 times greater than that of glass). Polycarbonate is used in aircraft windshields and is preferred for contact sports and outdoor activities.

The UV spectrum is divided into UVA (320 to 400 nm), UVB (280 to 320 nm), and UVC. UVC is entirely blocked by the atmosphere. UVA and UVB are damaging and result in significant morbidity. UV light contributes to a number of ocular disorders (e.g., cataract, pterygium, solar keratitis [snowblindness], macular degeneration). Glasses should absorb 99% to 100% of the UV spectrum at 400 nm. Glasses meeting this requirement are often labeled "UV 400." The U.S. standard is established by the American National Standards Institute (ANSI). According to ANSI Z80.3-2101, lens should have UVB transmittance of no more than 1% and UVA transmittance of no more than 0.3 times the visual light transmittance.

Several ballistic standards exist for military applications (e.g., ballistic International Standards Organization/ISO testing, ANSI test standards, MIL-STD 622 ballistic test). The United States uses ANSI criteria for basic-impact and high-impact protection. In the basic-impact test, a 2.5-cm (1-inch) steel ball is dropped on the lens from a height of 127 cm (50 inches). In the high-velocity test, a 0.6-cm (0.25-inch) steel ball is shot at the lens at 150 ft/sec. To pass both tests, no part of the lens may touch the eye. In the MIL-STD 622 ballistic test, the lens must stop a 0.22-caliber bullet fired from 6.1 m (20 feet). At the time of this writing, Oakley, Revision, Wiley X, Uvex, ESS, Pyramex, and Gargoyles manufacture sunglasses in compliance with this standard.

Consider buoyancy for any water sports activity, and ventilation and antifog coating for cold environments, where perspiration can steam up lenses. Prescription lenses help vision-impaired persons. For contact sports or other activities requiring agility and retention (e.g., kayaking), consider impact-resistant lenses and a strap to secure the frame in place.

Goggles should be judged by the same standards as glasses. Interchangeable lenses may be a convenient option. Goggles should conform to the face using hypoallergenic foam without pressure points. Fogging can impede vision. Proprietary antifog coating and adjustable ventilation can help, as can a double-layered lens. Some goggles incorporate small electric fans to evacuate moisture. Establish compatibility with the intended helmet before buying.

LIGHTS

HEADLAMPS

Headlamps permit hands-free use. Light-emitting diode (LED) technology allows lights to be compact, rugged, and lightweight with long battery life. For these reasons, LEDs have largely replaced traditional lightbulbs.

Lamps have three key properties: brightness (distance), duration (time of usable light), and shape of beam. These depend on type of bulb, shape of housing, and battery type and size. LEDs are small, have a smooth light, and use batteries efficiently. Because they are not nearly as bright as other bulbs, headlamps using LEDs usually have three or more diodes in operation simultaneously. Incandescent bulbs are becoming obsolete in headlamps. They consume moderate amounts of battery power. Halogen and xenon bulbs emit whiter and brighter light but usually consume power at much higher rates. They will also decline in use as LED units predominate in the marketplace.

With two equal AA batteries, most headlamp bulbs perform as follows:

- Xenon halogen: 3 to 4 hours on maximum power; 10 hours on less power
- Standard tungsten: 7 to 10 hours on maximum power
- LED: 30 to 40 hours on maximum power, up to 120 hours on limited power

Some headlamps have two types of bulbs: a bright xenon or halogen for important tasks that require bright light and three or more LEDs for functioning around camp or reading. These lamps can be an excellent choice for professionals. The bright light can be used for night search and rescue or identifying animals. The LED can be used for documenting research or repairing gear. New designs incorporate such features as the ability to change the main LED to a flashing mode, dim or brighten the beam electronically, switch to a red light, and lock the headlamp in a power-off mode to prevent accidental battery drainage when not in use.

A good headlamp is durable, weather resistant, and has smooth light distribution with an adjustable beam. A narrow beam with a longer range, up to 30 m (100 feet), is good for night searches or route finding. Headlamps with a wide but short beam are idea for close work (e.g., within a tent or vehicle). Waterproof lamps have gaskets to resist rain and sweat. Dive headlamps are completely sealed and submersible. Cavers often use long-lasting carbide (also called acetylene) lamps. These lamps produce and burn acetylene (C_2H_2) created by the reaction of calcium carbide (CaC_2) with water (Figure 111-4).

Batteries are disposable or rechargeable. Disposable (alkaline or lithium) batteries have a shelf life of 7 to 10 years and are less expensive. Rechargeable (nickel-cadmium or lithium-ion) batteries have a higher energy density than disposable batteries. They are expensive but cost efficient if used frequently. Large battery packs provide much longer life and may be stored on the back of the helmet or on a waist belt. Remote battery packs can also be stored under clothing and kept warm for more effective operation (e.g., during high-altitude mountaineering). Battery longevity is improved if stored cold.

FLASHLIGHTS

In the wilderness, handheld flashlights are not as useful as headlamps, because the hand occupied by the flashlight is unavailable for other tasks. For special uses (e.g., vehicle-based search and rescue), handheld spotlights can be invaluable. Rechargeable handheld flashlights are available with hand cranks.

LANTERNS

Lanterns are valuable for base camp operations or on trips with large groups when light for cooking, reading, writing, or performing activities is needed. Liquid-fuel lanterns burn white gas, a purified form of gasoline, yielding more light per pound of fuel than do battery-powered lamps. With a gas lantern, one should carry spare mantles and transport the lamp in a protective case. Mantles and glass globes are fragile, and gas must be stored

FIGURE 111-4 Old mining lamp of the carbide type. Carbide lamps are still often used in caving. *(Copyright iStockphoto.com/fergregory.)*

safely. These lanterns become very hot. Hazards associated with liquid fuel are listed in Box 111-3.

Compressed-gas lanterns run on liquefied gas (e.g., butane, propane, or a mixture of both) and are fuel efficient and lightweight. The compressed gas is contained in a cylinder and tends to be less messy than liquid gas. Per ounce, these lanterns are brighter than liquid-gas lamps but have similarly fragile globes and mantles.

BOX 111-3 Stove and Liquid and Gas Lantern Safety

Backpacking stoves often tip over. Burns are common from spilled pots of scalding water, using bare hands near a flame or frying pan, or directly from ignited stove fuel. Lantern globes become very hot. To minimize problems:

- Supervise the stove area so that no one tips a pot over.
- Do not allow people to sit in the impact area around a burning stove.
- Use a ladle instead of pouring from the pot.
- Use a handle when picking up a pot or lid.
- Do not carry a pot of boiling water.
- Do not pour boiling water into a cup that is in someone's hand.
- Place a lantern on secure location.
- Avoid cooking in an enclosed tent or snow cave. Avoid using a fuel lantern in a tent. Carbon monoxide poisoning can result in death.

FIGURE 111-5 Leatherman MUT multitool.

Battery-operated fluorescent-bulb lanterns provide efficient, smooth, and useful light without the risks associated with fuel or the fragility of mantles or glass globes. These lanterns are replacing liquid and compressed-gas lanterns where safety (e.g., on commercial trips with campers inexperienced with the hazards of gas) and ruggedness (e.g., for international travel) are key.

Oil and kerosene lanterns are impractical for wilderness travel and rarely used.

Candle lanterns are used occasionally by campers. These are simple, reliable, and emit only enough light for limited needs (e.g., reading, eating).

Lantern Safety

Liquid-fuel and compressed-gas lanterns emit carbon monoxide (CO) and should never be used in a tent, vehicle, cave, or other enclosed space. Even in extreme-weather and survival situations, adequate ventilation must be ensured, or illness and even death by CO poisoning can occur. Any open flame (even enclosed in a glass globe) can ignite clothing, sleeping bags, or tents and should be used with extreme caution. For these reasons, many professional guides prefer battery-operated lanterns.

TOOLS

MULTIFUNCTION TOOLS

A compact multifunction tool (multitool) or a pocketknife with bottle and can openers may suffice for recreational trips. Professional guides may need a compact folding knife blade and a separate multipurpose tool with many tool components (Figure 111-5 and Box 111-4).

BOX 111-4 Suggested Multitool Options

Awl	Saw
Bottle opener	Scissors
Can opener	Screwdriver, flat head
Corkscrew	Screwdriver, Phillips
File	Tweezers
Knife	Wire cutters
Pliers	

FIGURE 111-6 Leatherman Juice Xe6 multitool.

A pocketknife or a pocket multitool with pliers is sufficient for emergency use or basic camp chores. Although versatile, multifunction tools may not replace specific tools; for example, a real screwdriver may be needed to apply sufficient torque to repair a ski binding. Similarly, to repair a broken bike chain, tongue-and-groove pliers are much easier to use than small, multitool pliers. To cut a rope on the river, a boater's knife is more reliable than the small blade of a multitool.

At a minimum, a multitool should have pliers, wire cutters, knife blade, can opener, and flat and Phillips head screwdrivers. It is useful in many situations to have a saw, awl, tweezers, and scissors (Figure 111-6).

Multitools are available in two configurations. Those incorporating a pair of pliers are preferred. These tend to be heavier, but pliers are useful to repair equipment. The second style is based on a folding pocketknife (e.g., Swiss Army brand). These contain many features but rarely have effective pliers. If one carries a folding-knife style of multitool, a separate pair of pliers should be carried on longer trips.

Choose the multitool that fits your specific needs by comparing different models, as follows:

- Open all accessories. Blades that lock open generally provide more control than nonlocking blades. Blades that are difficult to open when new may be impossible to open after a few trips.
- Discern which tools will really be used.
- Test the pliers on a piece of wood or tent pole by gripping tightly. Some tools have sharper handle corners than do others; the smoother edges may provide more control, better fit, and comfort on gripping. Larger tools or with compound leverage tend to provide more gripping force.

For specific applications, one may need specific tools. Mountain bikers need bike chain repair tools, a tire pump, patch kit, extra tube, and hex wrenches. Skiers and snowboarders need a No. 3 Phillips screwdriver for binding screws. Rafters need tools, as well as a pump and patch kit, to repair a boat or an oar.

KNIVES

Generally, knives exist in two basic forms: fixed blades and folding blades. Many survival experts believe that a nonfolding, fixed-blade knife is best. Folding knives are often more practical because they can be stowed in the handle, making them more compact. Persons who prefer a folding knife usually select one with a locking blade so that more force can be applied without risk for the knife folding accidentally (Figure 111-7). A fixed-blade knife provides greater structural strength for making kindling and other maneuvers requiring force.

Blade Shapes

Knife blades have many shapes, depending on their intended use. For example:

- Hunting knives range from all-purpose utility knives to special skinning or gut hook knives for field dressing game. Large animal knives generally have longer and wider blades compared with those for upland birds and waterfowl.
- Fishing knives, such as fillet knives for field gutting and dressing fish, usually have long, narrow blades.
- Dive knives are usually straight and have symmetric blades and waterproof handles. They usually come with a specialized holster to attach to a diver's leg on the outside of a wet suit.
- Rescue and river knives, such as those used by kayakers, rafters, and canoers, are often serrated to easily cut rope and cord in emergencies. The holsters are designed to attach to a life vest.

Construction

Most blades are made from durable, high-carbon steel. High carbon content (typically 0.5% to 1.5%) makes steel strong, easy to sharpen, and hold an edge during regular use. However, it oxidizes easily and rusts with weather exposure. Many steel alloys use more or less carbon and other alloying elements to optimize performance.

Stainless steel, similar to high-carbon steel, contains enough chromium to resist stains and rust, so it is excellent for use on long trips. Surgical stainless steel is less frequently used. It has more chromium, so it is stain and rust resistant and cleans easily. However, the blade does not hold an edge as well as does high-carbon steel.

Titanium is light, durable, and resists stains well. The main drawback is that titanium is more expensive than steel.

FIGURE 111-7 Leatherman Crater knife.

Ceramic, or zirconium oxide, is extremely hard and thus needs to be sharpened infrequently. However, ceramic knives are brittle and need to be sharpened with a special diamond sharpener.

Handles

The handle should be strong, easy to clean, and fit comfortably in the hand. Wood handles look nice, but plastic handles are more durable and easier to clean and sterilize. Some knives have rubberized grips; if present, these should be well bonded to the blade.

Care

Knife maintenance starts with cleaning. Even the finest stainless steel corrodes if moisture, food, or dirt remain in contact. Dirty knives should be cleaned and dried immediately. Keep knives clean in the field by wiping with a clean cloth, with the sharp side of the blade pointed away from the wiping hand. If used for food or edible game, knives should be disinfected using hot soapy water or alcohol-based cleanser. Locking knives should be lubricated with light oil as recommended by the manufacturer.

If a tool is immersed in saltwater, it should be rinsed in freshwater, dried, and then lubricated. Lubrication not only greases the joints but also displaces water. Joints may be more prone to corrosion because of electrolysis between different metals in the tool.

Keep knives sharp by using a whetstone or ceramic stick. If a knife is used excessively, it may need to be professionally sharpened. Use caution when sharpening with a whetstone to avoid thinning and reshaping the blade.

SHOVELS AND TROWELS

A small, military folding steel shovel is often adequate for emergency use on expeditions using pack animals. For vehicle expeditions or trips, a full garden spade (to shovel dirt or mud) and a large grain scoop (to move snow) may be necessary to extricate a vehicle or clear a road.

For backpacking, a small and lightweight trowel works well to dig cat holes for improvised latrines. A 10- to 15-cm (4- to 6-inch) blade is sufficient. Stainless steel trowels usually have a folding handle. Plastic trowels are not as durable, especially in rocky or hard dirt.

For backcountry snow travel, a compact snow shovel with a removable handle for storage in a backpack is necessary for avalanches, digging snow shelters, and similar uses. Shovel blades for avalanche rescue should be metal and as large as is practical.

SAWS AND AXES

Saws are necessary for vehicle trips to remove downed logs from the road or for large expeditions that need to cut downed timber for fuel. The saw attached to a multitool is sufficient only for dire emergencies. These are too small to cut firewood but may be used to cut tiny limbs for emergency shelters.

Cord saws (e.g., cable or chain saws) are suited for emergencies only. These long strands of cord, cable, or chain are gripped at both ends and pulled back and forth to cut wood.

Folding saws are approximately 20 to 30 cm (8 to 12 inches) long when collapsed. They are small enough to carry in a backpack and can effectively cut tree limbs and small trunks. The blade is stowed in a collapsed, encased position, protecting people and gear from accidental injury.

For vehicle- or pack-animal–supported expeditions, larger folding saws are available that have blades of 30 to 61 cm (12 to 24 inches) in length. A compact ax can be useful for chopping firewood.

GEAR REPAIR

Carry basic materials to repair gear. Anything that can serve as a fastener, patch, or adhesive can potentially return a broken piece of equipment to service. Box 111-5 lists typical contents for a basic backcountry gear repair kit.

BOX 111-5 Basic Backcountry Gear Repair Kit

- Adhesive nylon patches for clothing, backpacks, and tents
- Cable ties
- Duct tape
- Flat 2.5-cm (1-inch) nylon webbing
- Nylon cord, 2 mm × 30 m (0.08 inch × 98.4 feet)
- Safety pins
- Seam adhesive for repairing clothing, backpacks, and tents
- Sewing kit
- Paper clips or similar wire
- Tent pole splint, aluminum tube with hose clamps

FIRST-AID KIT

Medical kits should be designed based on length of trip, number of travelers, and nature of the trip. The kit should be inspected, restocked, and repacked before departure. Commercial kits are often less expensive than individually prepared kits. A custom kit may be more efficient. In the wilderness, the ability to improvise medical supplies is important. Certain components of the medical kit, such as waterproof cloth tape, are difficult to improvise. See Chapter 102 for more information.

FIRE-STARTING MATERIALS

Carry one or more fire starters, including windproof/waterproof matches in a watertight container with a striking swatch, a cigarette lighter, magnesium shaving edge and sparking insert, or a metal match (flint with steel striking blade). Consider carrying fire-starter materials such as dry tinder, candles, priming paste, heat nuggets, dryer lint, cotton balls soaked in petroleum jelly, and commercial fire-starting tablets. A fixed-blade knife without a joint between blade and handle is useful for making kindling. Anticipate how your travel plan will influence the availability of fuel sources. When climbing above tree line, wood may not be available. When traveling in a rain forest, all vegetation may be saturated from heavy rains.

FOOD

Carry extra food or energy sources. Carry extra meals and appropriate snacks (e.g., fruit, energy bars, gels, trail mix) for energy-intensive adventures. See Chapter 87 for more information.

WATER

Safe drinking water and adequate hydration are essential. Water disinfection is discussed in Chapter 88. Use a plastic or metal container for personal water storage. Many bottles (e.g., polycarbonate bottles, epoxy linings in some aluminum bottles) expose people to bisphenol A (BPA), an unhealthy additive. Use bottles that are BPA free. Additives that have not been fully tested may still be present. Because of this concern, metal bottles (e.g., aluminum, stainless steel) have become popular. Aluminum bottles require a thin layer of plastic or resin to prevent the metal from interacting with liquids in the bottle. This lining may constitute a safety issue. Stainless steel bottles do not require a liner but can impart a metallic taste to water. One should seek “food-grade” stainless steel (Figure 111-8). Consider how the bottle will be used (e.g., in a bike cage or side pocket of a backpack), and purchase one that fits. A wide mouth allows for easier filling and cleaning, but it is usually easier to drink from a narrow-mouthed bottle. Sport tops allow one-handed drinking and are popular with cyclists and hikers, but these often leak if inverted or compressed in a pack. The Platy bottle (a bag with a drinking spout) is collapsible and compact when empty.

Vinyl hydration bladders (e.g., Camelbak, Platypus) have an attached drinking tube to allow sipping without having to open a backpack or unscrew a lid. The tube has a mouthpiece that consists of a slit valve, which remains closed when not in use. The user bites the valve, opens the slit, and sucks out water. The

FIGURE 111-8 Drink safely with the all-steel water bottle and filter from Sovereign Earth.

vinyl bags come in 1-, 2-, and 3-L sizes. Many backpacks have an internal sleeve specifically to hold a hydration bag. Drinking tubes freeze in cold conditions but are helpful in hot or moderate conditions. Neoprene sleeves help minimize frozen drinking tubes. In a cold climate, use a neoprene sleeve, and blow all the water from the tube back into the reservoir after each mouth draw (Figure 111-9A). Although not foolproof, this decreases risk of tube freezing. A backup bottle should be carried. In cold weather, put bottles in insulated sleeves (e.g., fashioned from closed-cell foam pad and duct tape). During travel, pack water bottles within a parka to prevent freezing (Figure 111-9B). At night, fill the water bottle with hot water (if approved by the manufacturer), and place the bottle inside the sleeping bag (after ensuring the bottle is securely closed and dry). This contributes heat to the sleeping bag and preserves water to drink. Thawing frozen water bottles is difficult and consumes precious fuel. Frozen water often cracks bottles and renders them useless.

Bottles should not be used for hot liquids unless specifically intended for that purpose, because chemical leaching (e.g., of BPA) may occur. Heat may damage the liners of aluminum bottles. Noninsulated bottles may become hot and cause burns. Most bottles can safely contain juices, sodas, iced tea or coffee, and energy and sports drinks. Some manufacturers claim their bottles are "dishwasher safe," whereas others recommend handwashing with hot water and gentle detergent. A soft brush should be used on aluminum bottles to avoid damage to the liner. Cleaning brushes and cleansing tablets are available (Table 111-1).

TABLE 111-1 Water Bottle Comparison

Bottle Type	Advantages	Disadvantages
Single-use plastic	Convenient	Most not recycled May leach BPA Made of petroleum Not safe to reuse
Polycarbonate	Reduces waste Saves money	Nonrecyclable May leach BPA Made of petroleum May not be dishwasher safe
Aluminum	Reduces waste Saves money 100% recyclable Durable Lightweight	Liner may leach BPA Not dishwasher safe
Stainless steel	Reduces waste Saves money 100% recyclable Most durable BPA-free Dishwasher safe	Most expensive

BPA, Bisphenol A.

Larger containers (e.g., 20-L [5.3-gal] size) are usually carried in vehicles. Collapsible vinyl bottles and bags can be carried empty in a backpack and filled in camp to allow ample water for cooking, bathing, cleaning dishes, and refilling personal water bottles. Accordion-style collapsible bottles tend to crack after repeated use. Nylon-lined water bags are light and collapse when not in use. These are common gear on large expeditions when extra water storage is needed in base camp and when carrying bottles is cumbersome. Water bags are compact when empty (see Figure 111-9A).

Between trips, plastic water containers should be carefully cleaned. Soft-plastic containers and hydration bags need to be scrubbed by hand with hot soapy water and rinsed thoroughly. To disinfect and minimize mold and bacterial growth, rinse with chlorinated water (5 mL [1 tsp] of bleach in 1 L of water) and dry thoroughly. After prolonged storage, eliminate odors by washing with baking soda solution (5 mL [1 tsp] of baking soda in 1 L of water), then rinsing with water. Clean tubes and valves on drinking hoses after each use. Replace worn or excessively soiled parts.

FIGURE 111-9 In cold or hot conditions, use a Platypus Insulator for your water bag **(A)** or an Outdoor Research water bottle parka for your water bottle **(B).**

HEAT PACKS AND HEATERS

Heat packs can prevent hypothermia and frostbite. These are available for feet, hands, and backs. Most disposable heat packs use a chemical reaction to generate heat. When the polypropylene pouch is opened and agitated, iron is exposed to oxygen, oxidizes, and produces iron oxide and heat. This reaction lasts for 4 to 8 hours. Sodium chloride acts as a catalyst, carbon disperses heat, cellulose acts as filler, and vermiculite acts as a heat retainer.

Heat packs can prevent frostbite when used in gloves and boots and can contribute to core warming if placed under the axillae, in the groin, or on the torso. Of note, the heat generated is not independently sufficient to rewarm a moderately hypothermic person. Some heat packs are configured in a belt to be worn on the low back, and some feature adhesive so they can be attached to gloves or socks. Most manufacturers recommend against using them directly on skin, to avoid risk for burns.

Electric boot heaters (e.g., for skiing, biking, hiking, or climbing boots) have small, rechargeable battery packs that fit on the back of the upper boot near the cuff. Cords run into the boot. The heating element is placed just under the ball of the foot on a foot bed. These heaters can provide up to 18 hours of heat production at low power. They are most useful for persons prone to frostbite and for short (e.g., 1- or 2-day) cold-weather outings, because they need to be recharged.

OPTICS

For backpacking, compact binoculars and telescopes are useful because space and weight are priorities. Larger binoculars and telescopes have a wider objective lens, better magnification, and a wider field of view but add bulk and weight, so are best suited for base camps, research stations, and vehicles.

Two numbers identify an optical device's chief properties: the first denotes magnification, the second the objective lens' diameter. The objective lens is that farthest from the eye and is measured in millimeters. A monocular described as "6 × 25" has a magnification of 6 (i.e., the object appears six times closer than with the unaided eye) and a 25-mm (1-inch) objective lens. A larger objective lens allows more light into the binocular or telescope, which is preferred for low-light situations (e.g., dawn or dusk).

Other factors are used to compare optics. *Exit pupil* describes the diameter of light (in millimeters) exiting the near lens when looking through the device at a bright light. It is calculated by dividing object lens diameter by magnification (e.g., $25 \div 6 \approx 4$). The larger the exit pupil, the more light reaches the wearer's eye, and the view is perceived as brighter, especially in low-light conditions. *Field of view* describes the width of view (in feet) at 1000 yards. It is determined by magnification and the focal lengths of the objective and eyepiece lenses. Field of view correlates with magnification. Lower magnification allows a broader field of view; higher magnification (e.g., a telescope) yields a smaller field of view. *Eye relief* is the distance from the eyepiece (in millimeters) at which the full viewing angle is visible. People who wear glasses may require eye relief of 11 mm (0.4 inch) or more to use their glasses while looking through the device.

Other factors to consider when choosing optics include:

- Lens coatings cut glare.
- Waterproof housings protect from rain or snow.
- Plastic housings, sometimes called *armor,* protect the device when stowed during travel, when dropped, and in rugged environments.
- Focus types should include one or two adjustments. One is a central focus found on binoculars and monoculars. Binoculars should have a separate focus on one eyepiece to accommodate different foci for each eye. The user first focuses the eyepiece to equalize eyes, then uses the central focus to bring the object into view.
- Zoom alters magnification and field of view. This adds weight because of additional lenses but can be useful for multipurpose binoculars and telescopes.

PACKS

One ideally should have a professional (e.g., at an outdoor store) assist in fitting any pack for correct size, type, body shape, and specific application.

LUMBAR PACKS

Lumbar packs are small and work well for brief hikes in clear weather or for carrying emergency supplies when skiing within a developed winter resort. They have the capacity to hold food, water, emergency kit, extra windbreaker, hat, and gloves.

DAY PACKS

Day packs, or rucksacks, are small packs that carry gear for a 1-day outing, usually a spare jacket, food, water, and emergency supplies. A day pack's capacity is approximately 16 L (1000 inches^3). Shoulder straps and belt typically have minimum padding. They are light, compact, and often have no frame.

BACKPACKS

There are two types of backpacks: internal- and external-frame packs (Figure 111-10A). Internal-frame packs are an excellent choice for many situations. Aluminum or plastic stays are sewn into pockets inside the pack to add support. Internal-frame packs have more capacity than day packs and have thicker padding on the waist belt and shoulder straps. Compared with external-frame models, internal-frame packs are more flexible and narrower and thus easier to maneuver when hiking in tight spaces (e.g., caves, canyons, thick forests) (Figure 111-10B). Because they stay close against the body, internal-frame packs are warmer and allow better balance and maneuverability when hiking over rough terrain, skiing, or climbing. Compression straps allow the load to be cinched. This keeps the pack tighter and more stable, especially when partially full.

Top-loading packs have one large compartment that opens at the top. These generally have a drawstring closure and a lid covering the top. These packs have great capacity, sit well on the torso, and are easy to unload with the pack upright. Panel-loading packs have a large zipper on the front of the pack. These allow easy access to the entire contents of the pack.

Zippers can be convenient, but overpacking and external forces (e.g., dropping the pack) can cause the zipper to fail. Ensure your pack will still be functional if the zipper fails.

External-frame packs have a stiff aluminum tube frame on the outside of the pack. The frame holds the straps and waist belt. The nylon pack is attached to the frame. External-frame packs are more comfortable when carrying heavy loads, in that they

FIGURE 111-10 **A,** Backpacking with the Mile High Mountaineering Divide pack in the San Juan Mountains. **B,** Backpacking with Mile High Mountaineering Fifty-Two 80 pack. *(Copyright Mile High Mountaineering.)*

distribute weight efficiently between the shoulder straps and waist belt. Some people can carry more than 50% of their body weight using an external-frame pack. External-frame packs can be cooler than internal-frame packs, because the pack sits away from the wearer's back. They can be easier to pack, because they usually have multiple compartments. External-frame packs are bulkier, so are not a good choice for tight spaces, aerobic activity, climbing, airline travel, or off-trail hiking.

Choosing the right size is important. Consider what will be carried (e.g., rescue, research, or work equipment in addition to personal gear). For extended travel, 50 to 100 L, (3000 to 6000 inches^3) may be needed.

Packs are designed to be used substantially full. If a pack is routinely used half full, the pack itself will weigh more than necessary and fit will be suboptimal. If the pack is not large enough, or if one needs to have easier access to certain equipment, pockets can be added. However, pockets can be unstable and are a less efficient way to carry heavy items. Gear (e.g., sleeping pads, tent poles) can be strapped to the outside the pack.

Suspension systems vary from simple webbing belt and shoulder straps to well-padded systems that wrap around the torso, customized for body shape and height. Women should use packs designed for a woman's anatomy. For full loads, choose a system that comfortably rests weight on the hips but snugly pulls the load toward the back. For larger packs, choose thick hip and shoulder padding and a fit that easily adjusts while walking to take pressure off hot spots. A padded hip belt and lumbar pad should fit snugly with ample room to tighten the belt when in the field (Figure 111-11A to C). For small day packs, choose a lightweight and comfortable suspension system that does not have more padding than needed for the relatively light load.

FIGURE 111-11 **A,** Mile High Mountaineering Flatiron 38 internal-frame pack (back). **B,** Mile High Mountaineering Flatiron 38 internal-frame pack (front). **C,** Mile High Mountaineering Fifty-Two 80 Pack. **D,** Backpack suspension system. *(D redrawn from Harvey M:* The National Outdoor Leadership School's Wilderness Guide: The Classic Handbook, *revised and updated, New York, 1999, Touchstone.)*

Ultralight materials are now being used for some packs but rarely are as durable as heavier materials.

Load-adjusting straps are helpful for packs of 50 L (3000 inches^3) or more. A sternum strap brings the shoulder straps into position over the collarbones. Load-lifting straps on top of the shoulder strap bring the top of the pack closer to the shoulders. Belt-stabilizer straps at the waist bring the bottom of the pack closer to the hips. These straps should be adjusted in the field to best stabilize the pack depending on how it is loaded.

Try on a pack before purchase. Load the pack with as much weight as intended for the average trip, hoist the pack up and over obstacles, and climb up and down stairs. A professional fitter can assist with size and selection and adjust the straps and harness system (Figure 111-11D). Certain adjustments, such as shoulder strap height, can be fitted once and then not changed, but other features, such as side-load adjustment straps, should be adjusted at the trailhead and while walking. Make necessary adjustments each time a pack is put on: lean forward, and center the waist belt over the bony iliac crest. Cinch the buckle snugly. While still leaning forward, cinch the shoulder straps snugly under your arms. Stand up. If the pack has more waist belt adjustments toward the back, snug them to pull the weight into the body. Adjust the shoulder top straps to pull the load into the body and take pressure off the shoulders. These tension straps should be approximately 30 to 45 degrees off the horizontal axis and should arise from the top of the shoulder. Backpack accessories may add essential space but also add weight, needless complexity, and bulk. Packs can be made with integral map pockets, hydration bag holders, water bottle pockets, shovel pocket, crampon patch, ice ax straps, removable lids that convert to lumbar packs, and an extension cuff to extend the volume on a top-loading pack. Many packs have lash patches that allow one to strap on additional items (e.g., sleeping pads, tents, climbing gear).

Packs for special use include those in the following situations:

- Climbers and mountaineers require ice ax loops, crampon patches, and wand pockets.
- Backpackers need water bottle pockets or hydration bladder pouch and lash patches for lashing on tents or sleeping bags.
- Mountain bike backpacks are usually compact, about 4 L (250 inches^3), to fit between the shoulders and not impede the rider. They are designed to carry a hydration bladder, food, emergency kit, and bike repair tools.
- Mountain rescuers and ski patrollers may need internal pockets to organize gear such as snow shovels, avalanche probes, and first-aid supplies.
- Backcountry skiers and snowboarders need straps to hold their skis or snowboard on the outside of the pack when hiking.
- Photographers need compartments lined with foam to protect equipment.
- International travelers can use compartments that stow the suspension system when intended as checked airline luggage and can use wheels for easy transport.

Packing a backpack efficiently is an art form. Nylon stuff sacks can be used to compartmentalize gear. Mesh bags or plastic ziplock freezer bags work well for small items. Pack heavy objects low and forward (i.e., close to one's back) to improve balance. Balance the pack so that left and right are equal. Store sleeping bags and bulky clothing in compression stuff sacks to reduce volume (Figure 111-12A). Minimize the amount of gear lashed on the outside, and if tied outside the pack, make sure everything is secured tightly. In wet climates, consider waterproofing the pack by lining it with a tough garbage or trash compactor bag, using a pack rain cover, or packing gear in dry bags (as used by kayakers and rafters).

DUFFELS, STUFF SACKS, AND DRY BAGS

Duffels should be large enough to hold needed equipment but not so large they are cumbersome to transport. Duffels should

FIGURE 111-12 Organize and protect your gear using stuff sacks, compression bags, or dry bags. **A,** Outdoor Research (OR) Ultralight Compression Sack. **B,** OR Durable Stuff Sack. **C,** OR Drycomp Ridge Sack (side). **D,** SealLine Nimbus Sack group.

be constructed with heavy-duty zippers and stitching. Heavy-duty shoulder straps or straps that convert to a backpack can be helpful. Wheels add weight and can fail but are a great benefit for transporting bags in airports. Choose a size that can be reasonably carried and used. This may be as small as 25 L (1500 $inches^3$) or as large as 170 L (10,000 $inches^3$). Duffels larger than 115 L (7000 $inches^3$) are usually too heavy to be carried for more than a short distance. It is often better to use two smaller packs when packing such items as ski, camping, and climbing gear.

For baggage carried in commercial airline cabins (carry-on), duffels must comply with airline restrictions. Most airlines restrict checked bags to 23 kg (50 lb), but restrictions down to 18 kg (40 lb) are not unusual on some flights. Bags should be locked with Transportation Security Administration–approved luggage padlocks.

Stuff sacks are an excellent way to organize gear packed in larger bags or packs. Some have compression straps or are packing cubes with cloth on one side and net on the other with a zipper (Figure 111-12B). Small dry bags can be useful for personal items and electronics and can be clear or opaque; clear bags allow viewing of the contents. Larger dry bags can have straps that convert the bags to backpacks (Figure 111-12C). Dry bags for river or ocean travel help ensure gear remains dry (Figure 111-12D).

ELECTRONICS

Electronics may be ubiquitous in the backcountry. Before purchasing, consider the following:

- Do they enhance the outdoor experience, improve the margin of safety, or increase emergency response capabilities?
- Are they easy to use? Some manuals are difficult to read and are complicated. Does one need the manual to remember how to operate or calibrate the device?
- Does the device still work after a week in the field? Devices can be rendered useless because of exposure to cold weather or water, or from being dropped.
- Are the batteries fresh and fully charged? (See Box 111-6.)

If an electronic device will be used, have contingency plans for emergencies. For example, when using a GPS or wrist-top electronic compass, carry a standard compass and altimeter. Consider the following:

- GPS units and GPS-equipped smartphones are small, lightweight, and easy to use. A map and compass should be carried for backup. GPS may be unreliable, especially when in a deep canyon where it is not possible to receive adequate satellite signal.
- Wrist-top computers are valuable and versatile. They often contain a compass, altimeter, stopwatch, timer, multiple alarms, barometer, and even a heart rate monitor. They can be accurate but more complicated to use than a standard nonelectronic compass.
- Family radio station (FRS) radios are inexpensive and valuable, especially for outdoor families. These small, ultrahigh-frequency (UHF) walkie-talkies are easy to use and excellent for communication within the effective range. Some ski patrols and park rangers monitor FRS channels. However, most FRS radios transmit at 0.5 to 1 W of power and have a range of only 1.6 to 3.2 km (1 to 2 miles) in clear, line-of-sight terrain. (See Chapter 105.)
- Very-high-frequency (VHF) radios are typically used by marine travelers and are also available for backcountry land travelers. In the United States, VHF radios need to be registered with

FIGURE 111-13 **A,** Camp is set. **B,** Cooking dinner with MSR WhisperLite stove and MSR Reactor canister stove. *(**A** copyright 2010, Outdoor Research Marketing; **B** copyright 2008, Arc'teryx, by Brian Goldstone.)*

the Federal Communications Commission. These usually transmit at 5 W and thus have much longer range than FRS radios. Certain channels may be monitored by local law enforcement, park service, or forest service personnel.

- Personal locator beacons (PLBs) are used by mariners and aviators. Now widely available for all backcountry travelers, the unique number is registered with an international satellite locator system. If activated, the PLB broadcasts a signal through a satellite to a ground station rescue center.
- Cell and satellite phones are common in the wilderness. Cell phones have made rescues much easier by allowing quicker and more accurate responses. However, these phones cannot always connect with a cell tower or satellite, and they exhaust batteries quickly.
- Weather radio is broadcast in the United States by the National Weather Service. The continuous broadcast operates on 162.40-, 162.475-, or 162.55-MHz VHF frequency, depending on the area, and gives detailed weather information on a continuous, round-the-clock basis that is updated daily or, in some cases, hourly.

POWER

Carry extra batteries for headlamp, camera, avalanche beacon, medical equipment, GPS units, and other electronics. Power converters may be useful when car camping and can help recharge batteries. See Chapter 109 for a more detailed discussion of how to power electronic devices using solar systems.

BOX 111-6 Important Tips on Battery Selection and Use

- Alkaline batteries are standard and relatively inexpensive. Name brands may provide more useful hours than budget brands. Alkaline batteries are shorter lasting and perform worse in cold environments than lithium batteries. Lithium batteries provide a constant voltage output until they fail. Alkaline batteries slowly decrease voltage output as they are drained.
- Rechargeable batteries are an option for short outings. Disposable alkaline cells yield about double the power/weight of rechargeable batteries. Lithium-ion rechargeable batteries are preferred. They do not have "memory" and thus do not need to be deep-charged; they can be "topped off" without a full discharge. Older nickel–metal hydride rechargeable batteries need to be frequently fully discharged, then recharged.
- Try to choose electronics that all use a single type of battery so that you only need to carry one type for replacement (e.g., carry a headlamp, laryngoscope, otoscope, avalanche beacon, radio, and GPS unit that all take size AA batteries). Newer, lighter electronics may use AAA, rechargeable, or camera-size batteries.
- Make sure to have a backup plan if batteries fail. For example, be prepared to navigate with a compass if a Global Positioning System (GPS) unit stops working. Remove batteries from stored electronics when trip is completed to prevent corrosive damage.

OVERNIGHT GEAR

For overnight wilderness travel, cooking, sleeping, and shelter equipment are necessary (Figure 111-13A). Some backpackers and climbers prefer minimal equipment to enable a faster rate of travel (e.g., by shortening and drilling holes in the handles of their toothbrushes or utensils to reduce weight). Be certain to plan for adverse weather (Figure 111-13B).

STOVES

Camp stoves are valuable to disinfect water, improve nutrition and hydration, and improve morale in foul weather by allowing for hot food and drink. In alpine environments, camp stoves may be needed to melt drinking water from snow. Stoves have varied efficiency (i.e., how much water can be boiled per unit of fuel) and heat output (i.e., how quickly they boil water). There are a variety of stove types from which to choose (Tables 111-2 to 111-4).

TABLE 111-2 Recommended Stove Type per Activity

Activity	Stove Type
Backpacking	Canister stove system
Winter or high-elevation use	Liquid-fuel stove
Large groups	Liquid-fuel stove
To boil water only	Canister stove system
Ultralight backpacking	Canister, alcohol, or solid-fuel stove
International travel	Multifuel stove

TABLE 111-3 Canister Stove: Advantages and Disadvantages

Advantages	Disadvantages
Easy to use	Fuel is expensive.
Compact and lightweight	Poor cold-weather performance
Good flame control	Reduced heat output over time
No spilled fuel	Difficult to judge quantity of fuel remaining
Instant maximum heat output	Canister fuel difficult to find internationally
Burns clean	Can be unstable—small base, high center of gravity
No priming	Not widely recyclable

TABLE 111-4 Fuel Comparison

Fuel	Advantages	Disadvantages
White gas	Cleanest, most efficient fuel Spilled fuel evaporates quickly. Readily available in United States Best for cold weather use	Priming usually required Spilled fuel very flammable
Kerosene	Spilled fuel will not ignite easily. Fuel sold throughout world High heat output	Priming required Spilled fuel evaporates slowly. Noticeable odor
Unleaded auto gas	Most readily available in United States	Priming usually required Spilled fuel very flammable Gas additives can lead to clogging.

The simplest stove is a solid-fuel stove. These stoves burn wood, natural charcoal, or other burnable materials. They are light and compact because fuel is not carried but usually gathered at the site. They are good for emergency or limited use, especially when abundant wood is available. Variations in heat and flame may make cooking unpredictable. They are best for short trips when one is not relying on the stove for survival.

Alcohol-fuel stoves are usually aluminum with brass burners. Liquid alcohol is poured into the burner and lit. Denatured alcohol (sometimes called methylated spirits or solvent alcohol) is a mixture of ethyl and methyl alcohols and is often available in hardware stores. Isopropyl alcohol and grain alcohol (pure ethanol) can also be used. Alcohol stoves are lightweight, compact, quiet, and have no moving parts or complicated valves. They can be difficult to control and can have limited heat output (e.g., the Trangia takes 7 to 10 minutes to boil 0.65 L of water). Given their simplicity, these stoves are sometimes preferred by "ultralight" campers.

Canister stoves burn fuel from a sealed, pressurized canister containing either butane or a butane-propane blend (Figure 111-14). These stoves are easy to ignite and burn hot. They are powerful and typically boil 1 L of water in 3 to 4 minutes. They are clean burning, do not leave soot, and rarely clog. The canisters are not refillable but can be recycled. For single use, Jetboil has an efficient, lightweight, and compact system. The pot also serves as an insulated mug, eliminating the need for additional cook set or bowl/cup (Figure 111-14C). Most canisters feature a Lindal valve with standardized threading so that fuel canisters are interchangeable between brands. Canister stoves have drawbacks. In cold temperatures (<0° C [32° F]), canisters depressurize, leading to a weak or no flame. As the canister warms, it repressurizes, and function returns. Canisters may be kept warm in sleeping bags or inside coats. A windscreen should not be used with a canister stove because it can cause heat to build up around the canister and cause it to explode. Canister stoves are starting to replace white-gas stoves as the standard for backcountry travel. A 226.8-g (8-oz) canister of fuel will boil water for two people for 4 days in summer temperatures. Wind, low temperatures, and longer cooking times increase fuel consumption.

White-gas stoves burn a purified form of gasoline. Fuel-filled bottles are pressurized with a tiny pump before use (Figure 111-14D). In cold temperatures and high altitudes, they may require priming with isopropyl or ethyl alcohol before lighting. They are powerful and reliable but can be messy and smell of gasoline. They may require frequent cleaning using specialized

FIGURE 111-14 **A,** Jetboil Personal Cooking System (PCS) is an ultracompact 1-L (1.1-qt) unit, ideal for dehydrated meals, coffee or tea on the go, remote worksites, and emergency kits. Travel light. The PCS is a complete food and beverage multitool and weighs about a pound. **B,** MSR Reactor canister stove. **C,** Jetboil Ring and Fry Pan used with the Jetboil Group Cooking System (GCS). **D,** MSR WhisperLite International.

tools because of carbon deposits. Some versions have built-in cleaning tools to simplify this task. Gas is found in most camping stores, often sold as Coleman Fuel. These stoves should be used with a windscreen and heat reflector to improve heat transfer. The fuel is stored in refillable aluminum bottles of 0.3-, 0.6-, or 1-L sizes. These stoves may be slightly less powerful than canister stoves and boil 1 L of water in 4 to 5 minutes.

Gas requirements suggested by MSR are 114 mL (3.9 oz) of liquid fuel per person per day for cooking, and double that for melting snow and cooking. For an extremely cold trip, one may require as much as four times the amount of liquid fuel per person per day. Multifuel stoves are variations of the white-gas stove, with a more versatile jet that accepts a variety of petroleum-based fuels, many of which are less pure than white gas. In addition to white gas, these stoves may burn kerosene, unleaded or leaded auto fuel, or jet fuel. They are useful for international travelers who might not have access to white gas or pressurized canisters. Improved versatility may be accompanied by jets frequently clogging with carbon soot, especially with poor-quality fuel. They do not burn as hot when using fuel with impurities. Multifuel stoves should be used primarily with white gas; alternative fuels should be used in emergencies or when standard white gas is unavailable. See http://fuel.papo-art.com/ for a detailed list of international fuel names.

Dual-fitting stoves (e.g., OmniFuel stove by Primus) have fittings for both liquid fuel (similar to multifuel stoves) and pressurized canisters with a butane-propane mix. Although expensive and heavier, this stove burns any available fuel. This may be the best choice for expeditions outside the United States.

Two-burner portable camp stoves usually burn propane or white gas. They work well when camping with vehicle support, pack animals, or boats. A two-burner stove is superb for cooking large meals for groups. Propane canisters are heavier and bulkier than white-gas bottles, but propane burns cleanly and efficiently.

Once stove type has been decided, compare different brands using burn time, boil time, and liters of water boiled per 100 g (3.5 oz) of fuel. *Burn time* describes how long a stove burns using a given amount of fuel. *Boil time* is the period required to bring 1 L of 21.1° C (70° F) water to a boil. "Liters of water boiled (per 100 g of fuel)" measures fuel efficiency at full stove power. Fuel degrades when it contacts air. Fuel should be stored in an airtight container.

Accessories

The following accessories may be available for certain stoves:

- *Flame adjuster.* Many canister and liquid-fuel stoves allow flames to be adjusted from full power to simmer.
- *Auto lighter.* A small, hand-operated piezoelectric sparker ignites the flame. This can be unreliable in wind or rain. Always carry matches or a lighter for backup.
- *Cleaning tool.* Some stoves are maintenance free. However, many liquid-fuel stoves can be clogged with soot. Many models have built-in cleaning devices. Others use a cleaning tool to unclog the valve. In emergencies, a safety pin can suffice if the tool is lost, but the jet may be permanently altered and may impair function.
- *Heat reflector.* Many white-gas stoves include a heat reflector to channel heat from the flame directly to the pot. For most pressurized canister models, this is not recommended because the stove may become too hot, damaging valves and seals and posing a risk of canister rupture. Always follow the manufacturer's recommendations.
- *Windscreens* on white-gas stoves can improve transfer of heat to the pot and minimize wind-related heat loss. Windscreens for pressurized canister stoves are not recommended by the manufacturer in some cases.
- A *stove case* can help protect the stove and reduce soot transfer during transport.

It is important to be able to disconnect fuel from the stove for careful storage. Folding or collapsing the stove makes storage easier, but the stove should be simple to reassemble. Airline regulations prohibit travel with fuel. Box 111-3 includes information on stove safety.

COOK SETS

For most 1- or 2-night trips with one or two campers, a single 1-L pot is usually adequate for boiling water for morning drinks and melting snow for water. For more people, consider carrying two pots or a larger, 2- or 3-L pot. Nesting pots that fit inside each other pack well and offer more versatile sizes (e.g., 0.5, 1, and 2 L). Lids shorten cooking time and protect food from debris. A pot handle or pliers is essential to lift hot pots from burners. Cookware is constructed from aluminum, stainless steel, or titanium. Aluminum is light, inexpensive, and conducts heat well, but it is not as durable as other materials and can dent easily. Titanium is extremely light and strong, but it is expensive and does not conduct heat as well as other materials. Stainless steel is the heaviest and most durable and is scratch resistant.

Nonstick coatings are cleaned easily when adequate water and soap are available. However, sand, dirt, and utensils wear down these coatings quickly.

Specialized pots with a built-in heat exchanger (e.g., Jetboil system previously mentioned) may increase the stove's efficiency.

Cooking utensils include pot grips, serving spoon, ladle, and spatula. For personal utensils, ultralight campers carry only a spoon or spork (a spoon/fork utensil with a spoon on one end and fork on the other; the edge of the fork is serrated for cutting food). Plastic utensils are the norm because they are durable, light, and easy to clean. A small bowl and covered mug usually are adequate for personal dishes.

Dish soap and a small sponge are used to clean cook sets and utensils. Biodegradable camp soap is sold in most outdoor and camp supply stores. Camp soap, hand soap, and shampoo are available in dissolvable sheets that create suds when contacted by water.

PERSONAL TOILETRIES

Personal hygiene is extremely important in wilderness travel for group and individual health. A typical list of toiletries includes:

- Toothbrush, collapsible
- Toothpaste
- Dental floss
- All-purpose camp soap (can be used for dishes, hair, and skin)
- Alcohol-based antiseptic hand gel
- Lotion/sunscreen
- Wet wipes
- Toilet paper
- Feminine hygiene products
- Razor and shaving cream
- Compact hairbrush or comb
- Travel towel (Figure 111-15)

SLEEPING BAGS

Sleep quality is important. A warm sleeping bag can be lifesaving. New products feature higher-fill down, softer synthetics, and lighter constructions. Box 111-7 lists points of comparison for insulation. Determine the purpose of the bag, and then consider comfort, weight, and size.

When choosing a sleeping bag, consider shell material (water resistant vs. untreated nylon), fill materials (down or synthetic

BOX 111-7 Down vs. Synthetic-Filled Sleeping Bags, Comparing Equal-Weight Bags

Down	Synthetic
Warmer	Easy to clean and store
More compressible	Retains significant warmth when wet
Softer	Dries quicker
Longer lasting	Less expensive
	Less likely to be allergenic

FIGURE 111-15 MSR PackTowl UltraLite. Quick-to-dry, lightweight, microfiber travel towels.

[influences weight and warmth]), shape (rectangular or mummy), and zipper options (which side, full length, coupling).

Insulation

Down. Down has no equal for warmth-to-weight ratio and compressibility. Compared with synthetic fill, down is more durable, retaining the ability to rebound to full volume over years of compression cycles. Down settles closely around the body and feels warmer and cozier than do synthetic fillers. Down is best for alpine trips where cold temperatures are encountered and is also a good choice for trips requiring light and compact gear. Down is less well suited for wet environments. Down should not be stored compressed.

Down is expensive and must be used with care. If down becomes wet, it loses its ability to insulate. Wet down takes an enormous amount of time and energy to dry out. Sleeping bag shells can be constructed from water-resistant laminates (e.g., Gore-Tex). Although these may improve weather resistance, they may not breathe well, allowing the down to become wet from perspiration. Uncoated nylon, the typical shell material for sleeping bags, breathes much better but is not waterproof. A tent or bivouac sack can be used to protect the bag from becoming wet.

Fill power provides a valuable measure to quantify the overall insulatory value of down. The volume of a 28-g (1-oz) sample of down being compressed by weighted piston is measured in a Plexiglas cylinder. The test requires controlled temperature, humidity, and preparation of the sample. If other factors are equal, a sleeping bag made with high-fill power will be lighter and more compressible than an equally warm bag filled with lower-quality down. Fill power is expressed as cubic inches per ounce. A lofting power of 400 to 450 is considered medium quality, 500 to 550 good, 550 to 750 very good, and 750+ excellent. Currently, 800+ fill is top quality; for example, 800-fill-power is warmer than 600-fill-power. For the same warmth rating, an 800-fill-power bag is the lightest.

Synthetics. Synthetic insulation does not absorb as much water as does down and continues to provide effective insulation when damp. Synthetic bags are preferred for outings where the bag may become wet (e.g., boating, rafting) or in climates where rain may be anticipated. They work well for people who frequently encounter dirty conditions and for children, because these are easy to launder. Synthetics should not be stored compressed in a stuff sack.

Synthetic insulators include polyester, polypropylene, blends, and proprietary fabrics (e.g., Polarguard, Hollofil, PrimaLoft). Synthetics are extruded petroleum-based polymers formed into *batts* or sheets of fibers to maximize the air-trapping qualities of the fiber. They provide a consistent thickness and durability to allow for use into a sleeping bag. Fiber designs include:

- *Short fiber.* Original polyester fiber fills were made of short fibers loosely arranged in a batt. This offered compressibility, but the fibers tended to shift and settle, allowing thin spots to form in the sleeping bag. Modern versions of short-fiber insulations are now bonded together.
- *Continuous filament.* Designed to prevent the thin spots seen with short-fiber fills, these batts consist of continuous filaments of polyester arranged into uniformly thick layers. They retain their shape and fiber position over time but have decreased compressibility, so tend to be bulky.
- *Microfiber.* In the last decade, development of superfine polyester (and other synthetic) fibers has improved warmth-to-weight ratios. Advanced bonding and fiber stabilization processes create compressible, lightweight synthetic fills with excellent loft, air-trapping ability, and water resistance.

From a pure warmth-to-weight basis, synthetics neither compete with top-quality down, nor are they as durable (tending to lose loft over time). When absolute warmth-to-weight is critical and environmental conditions allow, down is still the preferred choice.

Temperature

Temperature ratings vary between manufacturers, quality of down or synthetic filler, construction, design, and shell material. Choose a lightweight bag rated 30° to 45° F (−1.1° to 7.2° C) for summer fair weather, travel to the tropics, or an emergency bag for search and rescue. For three-season use below timberline, select a sleeping bag rated 20° to 15° F (−6.7° to −9.4° C). Choose a warmer bag, rated 0° F (−17.8° C), if carrying fewer clothes or if you prefer more warmth. For four-season use above timberline, consider a bag rated 5° to −20° F (−15° to −28.9° C). High-altitude expedition bags are usually rated −20° F (−28.9° C) or −40° F/C.

A sleeping bag's temperature rating is only an approximate guide to the lowest temperature at which an average person will remain warm. Although a useful adjunct to consider, in the United States the rating is assigned by the manufacturer, and variability exists across the industry. Factors that influence a rating and one's comfort at low temperatures in a sleeping bag include metabolic rate, type of sleeping pad, type of tent or shelter, amount and type of clothing worn, design and construction of sleeping bag, nutrition, and hydration status. In Europe, a standardized rating system (EN 13537) controls these variables. The European rating assumes use of one synthetic base layer worn (top and bottom), a hat, and a closed-cell foam sleeping pad of standard thickness. The results of this rating system are reported in three numbers: the upper and lower temperature limits at which a man is comfortable, and the lower temperature limit at which a woman is comfortable.

A bag's insulation value is related to the loft material and thickness. Winter and mountain expedition bags usually have 15 to 23 cm (6 to 9 inches) of loft; midweight bags may have 10 to 15 cm (4 to 6 inches) of loft; and those for summer may have 5 cm (2 inches) of loft.

The bag should be fitted to the individual's body size. A bag that is too long or wide results in dead space to be heated. Bags specific to women have greater insulation in the hip and feet areas. Mummy bags provide the most efficient shape (Figure 111-16).

Rectangular bags are bulky, allowing excess material around the legs and feet. Because they allow more space, they can be more comfortable for someone who changes positions frequently during sleep. These bags may be reasonable for car camping or if a mummy bag feels too restrictive (Figure 111-17A and Box 111-8). Consider using a sweater or coat as a "collar" at the top of a rectangular bag to prevent heat loss. Sleeping bags are sized for women (short, 5½ feet [167.6 cm]), men (regular, 6 feet [182.9 cm]), and tall (6½ feet [200.7 cm]). Bags have right- or left-sided zippers. Individual bags may be chosen with compatible

FIGURE 111-16 Standard mummy down sleeping bag.

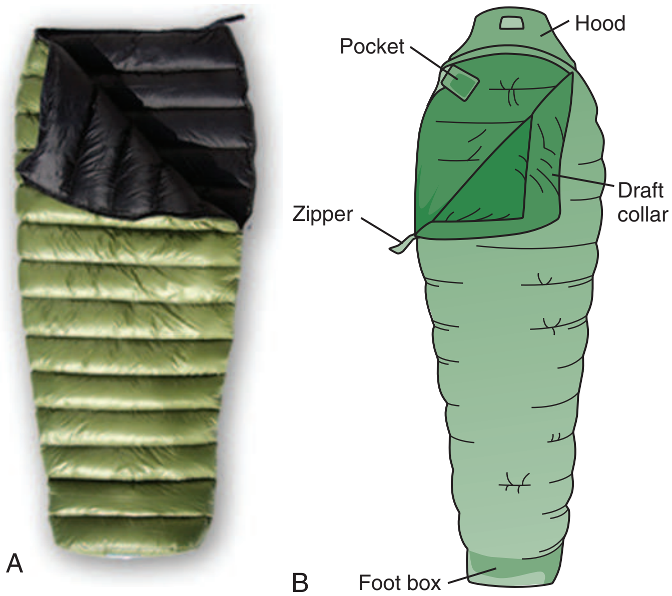

FIGURE 111-17 **A,** Semirectangular down sleeping bag for those who find a mummy bag too restricting. **B,** Anatomy of a sleeping bag.

BOX 111-8 Sleeping Bag Shape Comparison

Mummy	Rectangular
Efficient	High volume
Light	Heavy
Warm	Less warm
Expensive	Less expensive
Restrictive	Comfortable

BOX 111-9 Tips to Stay Warmer at Night

- Wear a hat to bed.
- Wear clothes to bed, especially wool or synthetic long underwear.
- Use a liner of silk or fleece.
- Use a thicker pad or two pads.
- Use a bivouac sack or outer bag.
- Consider buying a warmer tent or bag.
- Eat a high-fat snack or drink a high-calorie beverage before going to bed to provide additional calories for generating heat at night.
- Fill your water bottle with hot water—close securely, and place in sleeping bag.

zippers so that they may be connected. A full-length zipper allows better temperature regulation but adds weight.

Warmth is added to sleeping bags in other ways (Box 111-9). A draft tube is an insulated tube covering the zipper, preventing wind from entering and heat from escaping the bag. A shoulder collar seals in warmth. A hood can insulate the head and most of the face. Both should have drawstrings and should be able to cinch loosely to fully cover the user, except for the nose, mouth, and eyes (Figure 111-17B). A convertible sleeping bag provides an accessory blanket that may be zipped on in winter and off in summer.

SLEEPING PADS

A sleeping pad is critical for warmth and comfort. A thicker pad offers more insulation from the ground and may offer more comfort. A summer camper may be able to stay warm and comfortable with a pad ranging from 1.9 cm (0.75 inch) to 3.8 cm (1.5 inches). A snow camper should use a 5-cm-thick (2-inch-thick) pad for adequate insulation. Thicker pads are likely to be bulkier and heavier.

Closed-cell foam pads are the least expensive and most durable. Dense foam is filled with sealed air cells. If strapped outside a backpack, it can be exposed to the elements and still function well. Closed-cell foam does not soak up water. It provides superior insulation against the cold ground but may provide less cushioning than other pads. Alpinists, climbers, and adventure sports participants favor these pads (Figure 111-18).

Open-cell foam is similar to a sponge with tiny, open air cells. These are comfortable, lightweight, and compressible but not as durable, and they do not insulate as well as closed-cell pads. Open-cell pads can absorb large quantities of water.

A 5-cm-thick (2-inch-thick) dual-density pad provides a blend of warmth, durability, and comfort. These pads usually have thick, abrasion-resistant closed-cell foam on one side and lighter, more compressible open-cell foam for comfort on the other. They are best used in dry or sheltered conditions.

"Self-inflating" pads are preferred by many backpackers for their comfort and compatibility. These are nylon-encased open-cell foam with an air valve. The nylon shell protects the foam from absorbing water and holds air to improve insulation and comfort (Figure 111-19). Although nominally "self-inflating," they usually require a person to blow them up. These pads are often heavier than closed-cell foam pads but can be just as comfortable as open-cell pads. The amount of air in the pad can be adjusted for comfort. A small puncture can render them unusable. Always carry a patch kit, which includes a strip of adhesive-backed shell material or some nonadhesive material and rubber cement. A bike repair patch kit usually works, as may duct tape. In most environments, a ground cloth should be used to prevent punctures.

The newest generation of inflatable pads have no foam inside and use ultralight materials. They are lightweight and comfortable but not as warm as "self-inflating" pads and even more susceptible to punctures.

Pad accessories may improve comfort but add weight. Pads may have built-in pillows, separate air chambers that can be

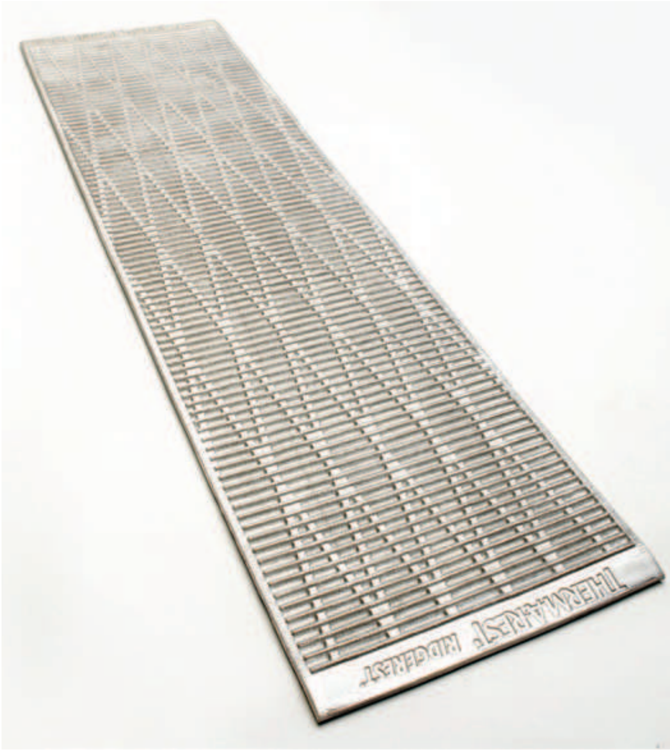

FIGURE 111-18 Therm-a-Rest-RidgeRest SOLite. The unique ridged pattern traps heat and provides more comfort than any flat-foam mattress and is practically indestructible, providing comfort you can take anywhere.

adjusted for comfort, and nonslip surfaces so that the sleeping bag does not slide off the pad during the night. To save weight, consider a mummy-shaped pad that matches the footprint of the sleeping bag. For use in nonwinter conditions, use a three-quarter-length pad in which the feet and forelegs hang off the pad. There are female-specific pads that have more insulation and support in the midsection and foot section.

FIGURE 111-19 Therm-a-Rest sleeping pad. "Self-inflating" air mattresses come in variable thicknesses and lengths.

SHELTERS

Shelters protect travelers from rain, snow, cold, heat, sun, insects, small animals, and dirt. They provide privacy in crowded areas and a place to store and operate equipment (Figure 111-20).

Construction and Design

Most tents used by wilderness professionals are freestanding; they will stand up without guy lines or stakes. The exceptions are tents or tarps used by ultralight backpackers or cyclists, where space and weight are at a premium. Nonfreestanding tents are lighter because they do not require as many poles in the design, but they require stakes and guy lines. They take longer to set up and are typically not as sturdy in wind and rain.

Almost all shelters are constructed of nylon. *Nylon* is a generic term for petroleum-based polyamide fabrics made in numerous weaves and thicknesses. It is light and strong, resists abrasion, is easy to wash, has low absorbency, and is easy to stow. Most tents use thin-strand *ripstop,* an extremely lightweight nylon woven in square grids that resists tears, or *taffeta,* which is a light, soft nylon. Some tents and almost all rain flies are made more waterproof and windproof by using a urethane coating on one side of the nylon.

Poles are usually aluminum, or in some cases, fiberglass or carbon. Aluminum is strong and less expensive.

Most tents are double walled and have a separate rain fly. The double-wall system allows the tent to be used without the rain fly in mild weather. The rain fly, usually waterproof urethane-coated nylon, sheds rain, enhances protection from the wind,

FIGURE 111-20 Bivouac camping under the stars. *(Copyright 2010, Outdoor Research Marketing.)*

and provides warmth because it traps a layer of air. The double-wall system allows the tent to "breathe" moisture through the tent and still accomplish weatherproofing with the second layer.

Certain three- or four-season tents are made with specialized fabrics in a single-wall construction without a separate rain fly. These do not breathe as well and are not as warm but are compact and light. They allow weatherproofing without the bulk and weight of two-layer tents. Ultralight mountaineers, backpackers, mountain bikers, and cyclists favor these when foul weather may be encountered, and when weight and space are at a premium and simplicity of setup is essential.

Shape and Size

Most wilderness tents are dome shaped. Compared with square or triangular tents, dome tents are lower profile, stronger in the wind and rain, easier to set up, lighter, and less bulky when packed. Ultralightweight tents (e.g., those used by ultralight backpackers and cyclists) are sometimes tunnel-shaped or hoop tents. They are set up with one or two hoops with guy lines and are usually not freestanding. A-frame tents are a more traditional style with a rectangular floor and a single center pole at each end. These tents are not freestanding but are very lightweight because they have the fewest poles. Large camping tents, 4 × 4 m (13.1 × 13.1 feet), with external poles are good for car-supported camping and expeditions but are too bulky and heavy for most other applications. Specialty tents, including plastic- and canvas-walled military or research tents, are used in extreme climates.

Tents are measured in square feet or the number of persons who will reasonably fit without backpacks or gear. A typical two- to three-person tent is approximately 2.3 to 4.2 m^2 (25 to 45 $feet^2$). A typical four- to five-person shelter can be around 4.6 to 6.5 m^2 (50 to 70 $feet^2$). Six- to eight-person shelters can be as large as 11.1 m^2 (120 $feet^2$).

Bivouac Sack

A bivouac sack provides basic shelter. This one-person overbag provides protection from the elements in a very small package just large enough to encase a sleeping bag. Some have an aluminum pole that bends to form a hoop to keep the bivouac sac off the face when sleeping. Others are simple nylon bags that slide over the sleeping bag. These provide warmth, and with laminated waterproof coatings, can keep one fairly dry. They are especially useful for brief 1- or 2-day outings, for trips that require minimizing weight and bulk, and for mild-weather adventures. A bivouac sac is also a fairly lightweight option for an emergency shelter (Figures 111-21 to 111-23).

Tarps

Tarps and *wings* are floorless shelters that provide sun and rain protection, but little protection from the wind, insects, or cold, damp ground. These minimum shelters are excellent for ultralight backpacking; cycling in clear, warm weather; and for an emergency shelter. Some wings are freestanding, whereas others need to be tied to trees or vehicles with guy lines. Some can be supported by trekking poles (Figure 111-24). Used with depressions cut into snow, they can provide excellent protection in winter or alpine expeditions for cooking or sleeping (Figure 111-25).

FIGURE 111-21 Outdoor Research Advanced Bivy—closed.

FIGURE 111-22 Outdoor Research Advanced Bivy—open. The Outdoor Research Advanced Bivy has a two-pole design to keep the material off the face and is an excellent lightweight option.

FIGURE 111-23 MSR AC-Bivy. Use a basic bivouac bag for a lightweight shelter in fair weather or as an emergency shelter for an unexpected night out.

FIGURE 111-24 MSR Zing. Tarps can be used for shade and protection from rain and snow.

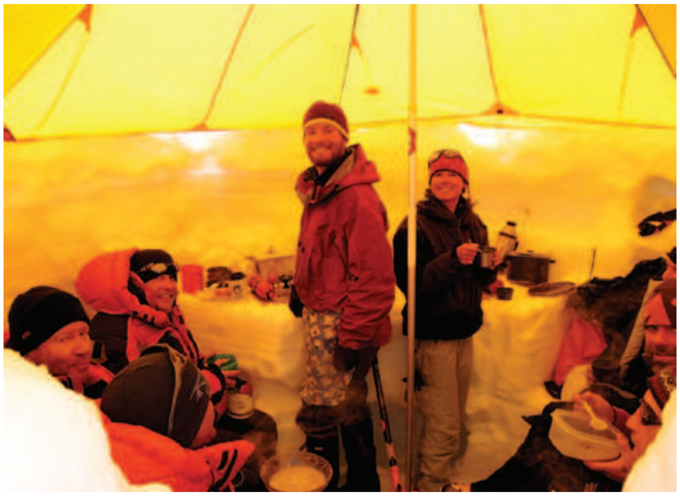

FIGURE 111-25 A snow kitchen. *(Courtesy Alaska Mountaineering School of Talkeetna; AMS Collection.)*

FIGURE 111-26 MSR Carbon Reflex 1 body. Lightweight summer tent with mesh panels.

Tents

Summer tents are usually all-mesh bug shelters or partial-mesh shelters with solid nylon panels at the apex to block the sun and provide shade (Figure 111-26).

Three-season tents are designed to withstand most weather conditions that occur outside of winter. They work well for all applications except mountaineering or severe wind and rain. Rain flies that extend to the ground are the most windproof and waterproof. Some less expensive tents have a rain fly that covers only the top one-third of the tent. Three-season tent sizes may range from one-person shelters to eight-person family tents.

Four-season tents are designed for mountain and winter use. Most have a full rain fly with a vestibule and minimize the use of mesh panels to conserve warmth. They are usually lower profile than are three-season tents, to minimize snow and wind effects, and are also usually constructed with four to six poles to maximize stability and handle loads of snow (Figure 111-27A). A four-season tent's main disadvantage is its bulk and weight. Most have internal guy points to further stabilize the tent in high winds and heavy snow loads. Some have air vents, because these tents do not breathe well.

Accessories

Many tents use accessories to improve function and versatility, as follows:

- Gear lofts and mesh pouches store clothing and equipment off the tent floor.
- Internal lash points can be used to rig clotheslines for drying wet clothing or to hang a flashlight.
- A footprint tarp protects the floor from rocks and dirt on the ground. This thin cloth keeps the tent dry.
- Mesh panels, mesh doors, and skylight panels work well for star gazing and ventilation and keep insects out of the tent.
- Large loops for stakes and guy lines secure the tent in wind and rain. Guy lines should be adjustable.
- Tent stakes help hold the tent on the ground and are sometimes necessary for nonfreestanding tents. These can be thin metal nails or hooks for dry, hard ground. In soft dirt, wide or large-diameter plastic stakes hold better. Long, wide stakes reach down into more compressed sand or snow. A stuff sack filled with snow, sand, or rocks, or "dead men" (stick/ski pole buried in the snow with line leading out) can be used to help secure a guy line (Figure 111-28). Skis are also helpful as "stakes" in snow.
- Many tents have a vestibule on the rain fly; this provides additional dry storage outside the tent (Figure 111-27B).
- Many tents have thicker, more durable material on the floor to protect from dirt and moisture.
- Some tents are "convertible," like the sleeping bags mentioned earlier. Weight and bulk can be adjusted depending on the weather conditions, length of outing, and terrain. For example, a four-season tent can be set up without one or two poles, or a vestibule can be detached. Some tents offer moderate wind and rain protection without the rain fly. Others allow the rain fly to be set up alone, to provide a simple floorless shelter (Figure 111-29).

FIGURE 111-27 **A,** MSR Fury with fly. Standard four-season tent has a low profile with full-coverage fly and vestibule. **B,** MSR Gear Shed fly. Consider a large vestibule for extra space during inclement weather.

FIGURE 111-28 "Dead man" tent stake.

FIGURE 111-29 MSR Carbon Reflex two fly and footprint. To reduce weight during fair-weather camping, use a tent fly and footprint for shelter.

CARE OF OUTDOOR EQUIPMENT

Gear needs to be cleaned and inspected regularly. Replace worn or broken parts before beginning a trip. Carry spare parts and repair material (see Box 111-5). Make sure equipment, especially tents and sleeping bags, are dried thoroughly after use. Soft gear should never be stored in a compressed (stuffed) manner, because materials will break down more quickly. Tents will last longer if stored hung in a cool, dark place. Knives rust and tents mildew when stored damp.

Follow the manufacturer's recommendations on washing and cleaning. Some hardware can be cleaned in warm soapy water. Other equipment should only be rinsed with warm water. Equipment works better when it is clean and well lubricated.

Cooking utensils and pots should be washed with hot soapy water. If hot soapy water is unavailable, an alcohol-based cleanser may be used. Backcountry cooking is not the place to skimp on cleaning or hygiene.

SELECTED RESOURCES

Selected resources used in this text are available online at www.expertconsult.inkling.com.

CHAPTER 112

Native American Healing

KENNETH S. COHEN

***Author's Note*: A Word About Style**
In writing about Native American healing, the third-person voice, common in scientific works, is generally considered neither appropriate nor ethical. It is personal experience and involvement that demonstrate to indigenous readers that the author is legitimate, has considered oral tradition as well as relevant literature, and is accountable to Native people and communities. It is an acknowledgment that the author is a human being rather than an "authority," and that what is known is always a mere raindrop compared to the immense ocean of the unknown. —*KSC*

The very concept of *Native American wilderness medicine* may seem redundant. Until the industrial age, all Native American medicine was learned, developed, and practiced in the wilderness. One might be of the mindset that the wisdom of ancient subsistence cultures has little relevance to the modern world. However, from an indigenous perspective, modern Americans are no less subsistence based (and therefore entirely dependent on the earth's resources) than were precontact (i.e., before 1492) Native Americans. As ecologist Gary Holtaus[33] explains, we are still a subsistence culture, although not a sustainable one. The Native American model of health, in which nature is the source of healing power, is as applicable today as at any time in the past.

Each of the thousands of precontact tribes of "Turtle Island," a common indigenous name for North America, had its strategies and tools for health, adaptation, and survival. Many of these are still used among the approximately 700 Native Nations that remain today. The methods reflect the variety of the North American landscape: The Yoeme of the Sonoran Desert recognize herbs that protect against heat and snakebite, whereas the Inupiaq in Alaska are more concerned with frostbite and mosquito stings. Different remedies are found in the desert, plains, tundra, and mountains and near lakes, rivers, and seas. Similarly, the requirements and seasons for vision seeking, pilgrimage, and ceremony vary by latitude and longitude. In the Northern Plains, it is rare to engage in a fasting and prayer vigil before the first spring thunder. Certain Pacific Northwest peoples may seek spiritual power in the winter, because the rainy season is a good time to commune with the spirit of water.

With so much diversity, it is impossible to explore in depth the specifics of Native American wilderness medicine in a single chapter. These details are better gleaned from many excellent ethnographies, herbal texts,[19,20,27-29,31,38,49,51,53,65,69,80] and biographies of traditional healers,[4,9-11,34,37,41,42,48,79] as well as the few comprehensive surveys of Native healing ways.[5,17,47,74] This chapter introduces widely shared principles among Nations as well as the ethos on which Native American medicine is based, illustrating the applications of this worldview with clinical examples from various tribes and geographic regions. America's original holistic medicine can enhance the modern practice of integrative and wilderness medicine.

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DEFINITIONS

NATIVE AMERICAN

Native Americans or American Indians are the indigenous peoples of North America. In Canada, it is also common to refer to the original peoples as *First Nations, aboriginal,* or *autochthones* (French). Native Hawaiians and indigenous Americans of Central and South America are not discussed, although they share many of the same principles and practices. Ultimately, there is no perfect or correct generalization for North America's original people, because the very concept of "Native American" was a political expediency when indigenous people sought unity in the face of common postcolonial challenges, including military, political, cultural, economic, social, and health. A morally acceptable term was also needed to substitute for the word *savages* and other demeaning labels or stereotypes common in postcontact discourse.

There is no single Native American or First Nations culture. There are more than 4.3 million indigenous Americans in the United States[57] and another 1.3 million in Canada,[66] which are divided into more than 1162 recognized Native governments: approximately 600 in Canada, 562 in the United States, and hundreds more in various stages of the recognition process.[60] Approximately 225 Native languages are spoken in the United States, and another 50 in Canada.[3,60] A far greater number of North American indigenous languages are extinct or are no longer spoken fluently. These languages are divided into 50 language families, many as different from each other as Romance (e.g., Italian) from Sino-Tibetan.

Old Hollywood movies and popular literature characterized as "New Age"[78] promote a particular type of generic Indian: in buckskins and feathered headdresses, speaking Tonto-like broken English, and frozen in popular imagination in western landscapes. Museum exhibits sometimes reinforce the impression that Native Americans are relics from the past rather than a people concerned about their future. Today's Native Americans wear business suits rather than buckskins, prize higher education, and generally identify themselves as Christian (i.e., approximately 85% in the southeastern United States). They are patriots who volunteer in the armed forces in higher percentages than any other ethnic minority. They live in houses and apartments, not in tipis.

Indigenous Americans live in two worlds: the culture of their ancestors and that of the modern United States and Canada. Health care choices are influenced by this duality. Although Native Americans are more likely to seek an allopathic physician than a traditional tribal healer, there remains widespread respect for many traditional remedies, such as prayers, herbal medicines, counseling, and ceremonies. Sometimes, ancient and modern healing methods are combined to create synergistic effects.[23,26] Prescription medicines *smudged* in sage smoke and prepared with prayer are believed to be more effective than other methods of administration. Counseling complements the sweat lodge for treatment of posttraumatic stress disorder.[12] Among diabetes patients, nutrient ratios are managed with a traditional native diet by substituting indigenous grains such as amaranth and wild rice for high-glycemic starches such as potatoes and bread. Native healers have always practiced "holistic" or "integrative" medicine. These terms take on more meaning as Native Americans find creative ways to combine the old and the new.

HEALTH

Like their Western counterparts, Native healers are concerned with relieving suffering, improving quality of life, and managing or curing disease. The World Health Organization's definition of health is congruent with that of many Native American healers: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."[81] Native healers add to this definition two more elements: spiritual and environmental. Health becomes a state of balance characterized by physical, mental, social, spiritual, and environmental well-being. Implicit in this definition is a philosophy summarized by the saying, "All my relations" (or "relatives"). Whether recited in English or in a Native language (e.g., "Mitakuye Oyasin" in Lakota), this phrase means that health is a state of connectedness in which stones, plants, animals, and people are recognized as family. A type of affirmation that may close a prayer, it is sometimes compared with the word *Amen,* but it means much more than that. *Amen,* which is Hebrew for "so be it," implies assent or approval, whereas *Mitakuye Oyasin* may be translated as "We are all children of the Great Spirit. May my words, prayer, song, and ceremonial actions be for the harmony and good of all."

"All my relations" is an expression of the recognition that family and community are essential elements of health. During precontact times, health and survival of a tribe depended on each person doing his or her part to the best of his or her ability. Indulging in shame, self-pity, acting-out behaviors, social withdrawal, or extravagance and excess consumption were not personal matters. What now would be considered "group therapy" might occur during a meeting or council that included one or more wise elders. Confidentiality was not an issue. Today, the value and importance of community remain, but psychological or psychiatric problems and the need for therapy are perceived as social stigma and cause for embarrassment. Confidentiality is an important matter, and patients will sometimes avoid or delay allopathic treatment until they can visit therapists or clinics far away, where office workers or other patients are less likely to recognize them.

TRADITIONAL HEALERS

Many Native healing methods, such as herbal medicine, massage, and music, are similar to complementary and alternative medicine (CAM) therapies. Traditional North American Indian healers are often willing to share these methods with the public and with health care colleagues through lectures, courses, articles, books, and more rarely, in collaborative research.[50] However, it is important to understand that when a technique is removed from its original context of culture, language, and geography, it may not be as effective. In addition, the Native American physician is expected to set an example of Native values by actually believing in the reality of spiritual forces. It is not enough to imitate a method such as blending an herbal tea.

Native American healers may be specialists or have broad expertise. Among some tribes, there are separate terms for herbalists, bonesetters, midwives, diagnosticians, ceremonial experts, and people known for their gifts in massage, counseling, dreaming, or prayer. Some healers are recognized as holy people, whose direct contact with transcendent realms gives them the intuition, knowledge, and power to adapt or create methods that best fit the needs of their patients. These healers are popularly called *medicine men, medicine women,* or *holy people.* Fools Crow[48] (Lakota) and Flora Jones[5,39] (Wintu) are examples of well-respected 20th-century medicine people. None of the English-language terms for indigenous healers is exact; these terms are often used indiscriminately in popular literature. A person described as a "medicine man" may be considered primarily an herbalist in his own tribe. An ethnographer may label a woman an "herbalist" who is in fact a medicine woman. In this chapter, the term "traditional healer" is used as a general category for all the various types of indigenous North American healers. Traditional healers may be male or female and young or old, although most are older than 50 years.

One becomes a traditional healer by any combination of an innate gift or talent; personal training, including ceremonial participation, vision seeking, fasting, or apprenticeship; and a ritual transfer of power from a previous healer. "Personal training," although primarily experiential, may include learning from texts (e.g., healing chants and practices transcribed by the Cherokee in their own language)[9] as well as from historic audio recordings and other media, including representations of healing practices in rock art or herbal remedies drawn on "pharmacopoeia sticks"[52] (Figure 112-1). "Apprenticeship" involves learning from the example, demonstration, mentorship, and wisdom shared by a teacher.

Any of the terms for traditional healers, especially *medicine man/woman,* are conferred by a community or group of Native people in recognition of years of wise and effective service. Although one may call oneself an "herbalist" or "traditional

FIGURE 112-1 Nineteenth-century pharmacopoeia stick from the Museum of the Wisconsin Historical Society. *(Courtesy Daniel Moerman.)*

midwife," it is rare and considered egotistical to call oneself a "medicine person." In his book *Learning Journey on the Red Road,* Lakota medicine man Floyd Looks for Buffalo Hand calls himself a "spiritual interpreter."[45] As he once explained, "The only healer is the Great Spirit. I am only an interpreter" (personal communication, 1992). Most traditional healers have spent at least 7 to 10 years in rigorous training or apprenticeship before assuming their roles.

ELDER

The term *elder* occurs frequently in literature and discussions about Native American culture. Although this word may, at times, refer to a person's age, it more often means a keeper of ancient traditional wisdom. According to the Canadian Council of Elders, in the Algonquin Nation[1]:

> An Elder is defined as someone who possesses spiritual leadership which is given by one's cultural and traditional knowledge. This knowledge is found in the teachings and responsibilities associated with sacred entities such as the Pipe, Wampum [sacred shell beads] belt, Drum and Medicine people. In addition to the spiritual recognition given by the Creator and the Spirit World, an elder is given the title and recognition as elder by other elders of his/her respective community and nation. Also one does not have to be a senior citizen to be an elder.

Various Indian Nations have their own definitions of the term *elder,* but the principles are similar. An elder passes along traditional values; he or she models, guides, and counsels people regarding how to live in a good way.

ETIOLOGY IN A WORLD OF "ALL MY RELATIONS"

In an interconnected and interdependent universe, it is impossible to posit a distinct cause for any disease. An infectious agent requires a vulnerable host, and the degree of vulnerability is affected by many factors, including genetics, environment, emotions, cognitive habits, diet, exercise, timing, and previous health history. Native Americans accept this biomedical model but believe that illness and trauma may also have hidden precipitating causes. For example, was the climbing accident a result of lack of technical skill, simple carelessness, or perhaps not paying attention to warnings from the spirit world in the form of omens or dreams (Figure 112-2)? Ethical and spiritual transgressions (e.g., a breach of taboo), such as disrespectful behavior in or toward nature, may also cause misfortune.

The powerful spirits of nature can be sources of curse or blessing. If one is in harmony with these spirits, even ordinarily dangerous or life-threatening events may cause little adverse effect. For example, a Cherokee medicine man deliberately entered a den of rattlesnakes and lived through 18 snakebites without medical treatment. This was a test issued by his mentor to see if the snake was indeed his helping spirit. If he lived, the answer was obvious. In another example, a young woman swimming near Daytona Beach, Florida, was stung multiple times by a box jellyfish that had wrapped around her leg. She suffered only a little discomfort, which she attributed to her connection with the local Seminole Indian culture and the nature and ocean spirits. Conversely, a person's negative attitude can immediately affect health. While participating in a sweat lodge ritual in Saskatchewan, Canada, a Native man vented anger about one of the other participants. Such a display is considered taboo during a sweat, where there is a strong emphasis on the power of positive words. This man was the only one to suffer burns during the sweat, a phenomenon I had never before or since witnessed. (Although, as discussed later, even relatively safe therapies can become dangerous in the hands of unqualified practitioners.)

Considering common aspects of North American Indian culture, there are four general categories of pathogenesis: biomedical, environmental, psychological/psychosocial, and spiritual. Diseases may be caused by any combination of these factors.

BIOMEDICAL

The biomedical category includes all the etiologic factors recognized by modern medicine. Native American healers are part of the modern world and accept the scientific method as an

FIGURE 112-2 The Oracle Rock, a place for divination and insight, Pipestone National Monument, Minnesota. *(Photo by Ruth Hager–www.ruth-hager.artistwebsites.com.)*

important tool in the human search for truth. I have yet to meet a medicine man who would not go to a physician for diabetes management or for treatment of a bacterial infection. Diseases may certainly result from biochemical, metabolic, and mechanical imbalances; from viruses, bacteria, and parasites; from habits of posture and breathing; and from the influences of heredity and trauma. However, from the traditional healer's perspective, these are causal influences and cofactors rather than final explanations for disease. As one of my Native colleagues astutely commented, "Even germs have spirits." It is admirable that Western science can measure and predict the influence of microorganisms. On a psychological level, this satisfies the human need for certainty. However, for Native American healers, life falls outside the intellectual grid imposed by Western philosophies.

ENVIRONMENTAL

The term *environmental* refers to our connection with nature and nature's cycles as a major influence on health and well-being. In Plains Cree, one of the words for good health is "miyo-pimatisowin," literally "good" (*miyo*) and "alive" (*pimatisowin*). The term could be considered the Cree equivalent of "holistic health" and has a strong environmental component. Miyo-pimatisowin includes the exercise and endurance that are natural to anyone who spends a great deal of time outdoors, whether for subsistence activities or recreation. It connotes reliance on natural, unprocessed, local foods; the freedom to live in a way that honors one's land, people, and culture; and very importantly, a healthy environment for hunting, trapping, fishing, and foraging. Although only a small percentage of indigenous North Americans live by subsistence, there is nevertheless a commonly held philosophy that one cannot be healthy if the trout are unhealthy, the deer diseased, the water polluted, or the trees blighted.

Elders say that only one who spends time in nature will love nature; and only one who loves nature will protect her. Other things being equal, people who enjoy the outdoors are physically and psychologically healthier. "Nature-deficit disorder" has especially devastating effects on childhood development and soundness of adult decision making.[46] Nature, for Native people, is as important a role model as are parents or teachers. Animals remind people of essential values, such as courage, leadership, kinship, and harmony. To see fox or coyote pups frolicking reminds one of the important link between unstructured play and creativity, qualities sadly lacking in the world today. "Where do you like to play?" a third grader from San Diego was asked. "Inside," he replied, "because that's where the electric outlets are."[46] Children who play in nature are more resilient and better at reading and problem solving.

Wilderness, say indigenous people, is healing. The degree of healing power or influence may also vary, with some places having more or less, thus the customs of pilgrimage to and vision seeking at sacred sites (Figure 112-3). To spend more time in healing places is to enhance one's ability to resist and recover from disease. It is also the basis for recognizing healing herbs and connecting with their spirits, a necessity in Native herbal medicine.

FIGURE 112-3 Bear Butte, South Dakota, holy place for the Lakota and many other tribes. Note the colored flags (prayer offerings) hanging from trees in the foreground.

PSYCHOLOGICAL/PSYCHOSOCIAL

The Cherokee traditional healer Rolling Thunder used to admonish, "Pollution begins in the mind" (Figure 112-4). Indeed, the reciprocal influence of mind and body, the core of today's psychoneuroimmunology, is well accepted in Native American medicine. "No evil sorcerer can do as much harm to you as you can do to yourself with negative thinking," the Samish traditional healer Johnny Moses once shared with me. Counseling, dream interpretation, and psychodrama (particularly the acting out of nighttime dreams) were common indigenous treatment modalities.[17,76] A positive attitude goes a long way toward enhancing the efficacy of any therapy or making such therapy unnecessary. Traditional healers are often experts at inducing the placebo effect.

Psychological and psychogenic diseases are of urgent concern to today's Native Americans.[18] Duran and Duran[23] have written insightfully about the prevalence of intergenerational post-traumatic stress disorder, resulting from the tragic history of Native peoples, their marginalization, the continuing challenges of racism, and the lasting effects of boarding school abuses and domestic violence. Some psychological problems are also the consequences of alcohol and drug abuse or birth defects, or associated with diseases such as diabetes and obesity. The breaking up of families and communities means that Native people now face problems on their own that would previously have been addressed by the group. Alienation and loneliness have replaced accountability and security. The programs most successful at treating psychological problems are integrative in nature, combining Western and indigenous therapies.[26,68]

In Native American medicine, major psychological influences on disease include sense of life purpose, degree of self-esteem, cognitive habits, and familial and social harmony.

Of these four, the first merits commentary. Native Americans believe that every person has a life purpose. To live a good life, one must prioritize discovering that purpose. This philosophy explains why dreams, and dream- or vision-quests, are so important in Native American culture. Equally important is to find the courage to live and express this purpose. A purpose not lived or a gift or talent that is kept locked up inside because of fear of failure, worry about disappointing others, and lack of self-esteem, is like stagnant water—a breeding ground for disease. We may become ill from our un-lived dreams just as we may heal by the

FIGURE 112-4 Rolling Thunder and the author, 1982.

dreams we live. To find and live one's purpose is to tell, with one's life, a good story. Many people lose joy in life or make and remake bad choices because they repeat to themselves a bad story. By contrast, good stories create meaning and purpose.

In 2004, I had the honor of presenting a talk about indigenous medicine to the Cree elders advisory council associated with a First Nations health center in Canada. As I was preparing, my adoptive Cree brother, Joseph, reminded me, "The elders will not listen if you give them information. They will pay attention if you present the information in the form of storytelling." One of the goals of the traditional healer is to hear and sense, often through intuition, the stories patients tell themselves, and then to help them "write" a better one. In counseling, raw information rarely heals.

SPIRITUAL

The term *spiritual* refers to the causes of illness that concern or originate in the spirit, soul, or transcendent realms. Unlike with popular Christianity, in Native American philosophy, spirit and soul may be attributes of stones, plants, and animals, not just people. Emotions are also spirits. Traditional Cree healers in Saskatchewan say that the spirits of hatred or shame may cause disease, just as the spirits of love and forgiveness can heal. However, spirit is not opposed to flesh. Aspects of the soul may be linked with the breath of life (*niya* in Lakota) or with the spirit or ghost that exists after the death of the body (*nagi* in Lakota). Spirit is an innate protecting force as well as a sacred power that may be gained by a person through sacrifice and contact with the divine (*sicun* in Lakota).[21] My Cree relatives distinguish between the appearance of the soul as a "ghost" (*tchi-pay*) while it remains on Earth and the soul (*at'-tshak*) that journeys to the spirit world.[24] The latter term, *at'-tshak,* is the root of the word for "star," which is *at'-tshakos*. The stars are the spirits of those who have passed on, and the trail they walk is the Milky Way. We can see that not only are spirit and matter not separate, but that the spiritual realm interpenetrates the ordinary. People can contact this other reality through prayer, ceremony, and waking or sleeping dreams.

Diseases always have a spiritual dimension. We are whole human beings, never divided, no matter how isolated parts look in a scan or under the microscope. In other words, whether the presenting symptoms suggest a predominantly biochemical, environmental, or psychosocial origin, a traditional healer also pays attention to spirit.

A person who is disconnected from his or her own soul or from the Great Spirit is only living a partial life and is more likely to become ill. Dreams are the royal road not only to the unconscious but also to the spirit world, and traffic goes both ways. In dreams, we contact spiritual realms, and these realms reach down to contact us. An effort to remember and interpret one's dreams by looking for clues to health and prevention of illness or misfortune is necessary for optimal health. Sometimes the traditional healer helps an unaware patient by searching for relevant information, both diagnostic and therapeutic, in the patient's dreams, or teaches methods to help the patient have and recall more meaningful dreams.

Contact with spirits may help prevent disease, but it can also cause disease. There is an ancient legend among the Cherokee and other Southeastern tribes that the spirits of animals caused disease as retribution for disrespectful hunting practices that now would be called "trophy hunting."[53] Illness results when people insult or mistreat animals, invade or destroy their habitat, or fail to show respect to animals while hunting or eating them. In *Crossing into Medicine Country*, Choctaw author David Carson[13] associates specific illnesses with various animals. If a person knows this connection, he or she may be able to relieve symptoms or cure disease by honoring the animal (e.g., with a feast among friends that is specifically intended to honor the animal) or by asking forgiveness from the offended animal spirit. As a sign of reconciliation, the animal may heal the illness directly or appear in a dream to offer advice.

Most of these animal-disease associations make good sense. For example, according to Carson's book, the millipede causes aching legs and lack of coordination. The moose may cause self-hatred, manifested as chain smoking, overeating, or destroying relationships without reason. Dog sickness is characterized by fever and delirium. Coyote sickness appears as obsession and addiction, including alcohol, drug, and sex addiction. It is no surprise that beavers may inflict constipation; one feels dammed up. Squirrels eat too much or too little. Turkeys swell with pride and may cause false pride, repressed anger, swollen glands, and cancer.

Spirits may be capricious, mischievous, or malevolent. For this reason, elders advise not contacting the realm of spirits unless one is in need, emotionally mature, or prepared and aided by a traditional healer. Sorcerers, popularly called *witches* by some Native tribes (although they are not to be confused with Western pagan Wicca traditions), can inflict harm by sending disease-causing spirits to their victims. Although many, if not most, of these phenomena are probably examples of the nocebo effect, negative intent may have concrete effects even if the victim does not believe in or is unaware of the "curse." Sorcerers may be hired by people to inflict harm and misfortune on other people, or they may be personally motivated to perform such criminal activities as a result of emotional imbalance (usually jealousy).[22,75]

There is also a traditional and widely held Native philosophy that negative actions eventually return to plague the perpetrator. Rolling Thunder taught that good deeds and bad deeds are both multiplied by seven to help or harm the person who performs them.[10] Tuscarora traditional healer Ted Williams[79] used to say that life is governed by natural and moral laws. To break these laws is the inner meaning of "breaking a taboo." To strike a child, disrespect an elder, pollute the earth, or to act with greed, malice, or egotism is to break the Creator's law. The result is illness in body, mind, or spirit.

ASSESSMENT AND DIAGNOSIS

Most healers base their diagnosis on intuition, sensitivity, and spiritual sight. A healer might sense or see that a patient's mind is clouded, soul fragmented, or body harboring an intrusive force or entity. He or she may dream or feel the spirit of a disease or early spiritual warning signs of cancer, heart disease, diabetes, or other conditions. Tactile clues during indigenous massage or noncontact energy healing (i.e., the hands held near the patient's body) are also important. The healer may feel heat (suggesting inflammation), cold (suggesting depletion), stagnation, pain, or other diagnostic sensations. Some traditional healers use therapeutic tools to refine their diagnoses. For example, a Kiowa colleague gave me what he called "an Indian x-ray machine," with instructions for its proper use: place a black cloth over the patient's body and then look, with the mind's eye, at the underlying tissues. Other healers may use beads to assess the gravity of an illness. For example, Cherokee healers turn black and white beads in the hands. If the black beads move more easily, the problem is serious; if the white beads move more easily, the meaning is good fortune and health. Clouds, patterns on stone or in flowing water, images seen while gazing at a quartz crystal, or the behavior of a campfire may become an indigenous Rorschach test with which the healer or patient reads the diagnosis and cure. The number of such possible tools is without limit.

Extrasensory phenomena are reported in association with traditional Native American diagnosis, reminding one of the out-of-body and clairvoyant skills of Edgar Cayce.[67] I know traditional healers who, when told of a physical trauma, travel psychically to the place of the occurrence to see it for themselves. They may find, at the site of an accident, a lost soul that needs to be retrieved. Other healers have "sympathy pains" starting hours or days before they see an unexpected client for the first time. I once experienced firsthand the work of an Ojibwe healer who specialized in diagnosing and treating from a distance. In 1989, she and I met during a conference in Ontario. Years earlier, septic arthritis had destroyed all the cartilage in both my hips. Noticing my disability, she offered to perform a healing on a specific day and time a few weeks later, after I returned to my home in Colorado. I did not remember the date I had scribbled in a small travel calendar. At the time, I was becoming increasingly skeptical because of the number of generally ineffective alternative healers who had tried to help me. I accepted my inability to climb stairs or to tie my shoelaces as an inconvenience with which I could live. However, one evening while sitting at my kitchen table, I felt a strange sensation, as though an electrically charged cloud surrounded me. I noticed that my hips, legs, and back had suddenly become comfortable. I bent forward and miraculously touched my toes. I then sat on the floor and crossed my legs, an impossible task both before and since. My range of motion was nearly normal. Of course, at this point, I remembered the meeting with the Ojibwe healer and, sure enough, this was the appointed evening. The change lasted for several hours. The next morning, when I woke up, I found that my previous level of disability had returned. For me, this healing remains a shining and encouraging example of the potential to heal and the power of indigenous medicine.

TREATMENT

In Native American healing, diagnosis and treatment are not rigidly divided and are often included in the same therapeutic session. This is true with ceremonial healing (e.g., the sweat lodge), with massage therapy, and especially with counseling. For example, ethnographers have noted the importance of dream interpretation and dream psychodrama among the Haudenosaunee.[76] Tribal members would act out ominous dreams to create more favorable outcomes and thus avoid misfortune. When telling the dream (i.e., diagnosis), the resolution (i.e., treatment) becomes obvious. Similarly, during counseling, the traditional healer listens to the patient and offers meaningful advice or spiritual therapies. My adoptive father, Andrew Naytowhow (Cree), a traditional healer, counseled people in prisons; he sometimes offered advice or "doctored" them with prayer and pipe ceremonies (Figure 112-5). Often, just talking about one's feelings was all the healing needed. He would also host "talking circles" among troubled youth. For a talking circle, after an opening prayer, each person speaks in turn, without interruption or commentary, sometimes followed by group discussion. I use counseling in my own traditional healing practice. After prayer and noncontact energy healing, one of my clients, a Native man in jail for assault, broke down in tears and admitted to me the tragic circumstances in his life that had led to his actions. This was an important step in his return to "the Good Red Road," the Native American path of a spiritual and ethical life.

Native American medicine is North America's original integrative medicine. Guided by a pragmatic philosophy of "use what works," traditional healers apply specific culture-bound methods of therapy, but may also combine or create entirely new treatment methods tailored to the needs of the patient. It is not unusual to bring insulin or an analgesic into a ceremony for blessing and empowerment. Style of treatment may also vary according to the season, the availability of herbs, and spiritual directives received by the healer in the midst of therapy.

FIGURE 112-5 Giant replica of a Native American prayer pipe in Pipestone, Minnesota.

FIGURE 112-6 Griselda A. Sesma (Yoeme-Kumeyaay) offering sage smoke.

Because of these characteristics, Native American healing does not lend itself easily to replicable experiments. Despite the recognition of biochemical individuality, Western medicine promotes standard and uniform methods of therapy. By contrast, Native American medicine is adapted to the perceived or intuited needs of the patient. It is diverse, situational, and individualized.

Native American healing is also a holistic modality because, to borrow what has become a cliché, it seeks to treat the person rather than the disease. I remember a Navajo elder complaining that when he was in the hospital, he could not understand why the doctors seemed more interested in treating a piece of paper than in caring for him. They kept looking at the chart, but not at the patient himself.

The most common categories of Native therapeutics are smudging (i.e., cleansing with the smoke of a sacred plant [Figure 112-6]); prayer and chant; music; counseling; vision seeking, dreaming, and fasting; energy therapies; ceremonies; and herbs. These methods and their purposes are outlined in Table 112-1, an early version of which appeared in *Honoring the Medicine: The Essential Guide to Native American Healing*.[17] However, this is by no means an all-inclusive list.

An additional category not discussed here is Indian Christian healing. For the many Native Americans who identify themselves as Christian, the term *Native American healing* means methods of healing that are acceptable to their pastors and to their churches, such as the Catholic laying on of hands, revival meetings, and charismatic prayer groups. Some churches, such as the Native American Church[64] and the Indian Shaker Church in the Pacific Northwest,[59] integrate Christian symbolism with Native American songs and healing practices. Mexican Americans of Native or mixed background also blend indigenous and Christian elements in *curanderismo*, common throughout Central and South America, as well as in Arizona, Texas, Southern California, and wherever there are large Hispanic populations.[72] Although important culturally and socially, and reported to be effective for the treatment of many illnesses, Indian Christian healing is beyond the scope of this chapter.

CONTRAINDICATIONS

Like their allopathic colleagues, traditional healers are aware of contraindications that would make particular practices inadvisable. Some herbs may be dangerous during pregnancy, when administered with blood thinners, or for cancer patients, being toxic in incorrect dosages or having other negative effects. Similar precautions exist for other therapies, such as sweat lodges or prolonged fasts, which are inadvisable for hypertensive and diabetic patients, respectively. For these reasons, readers are advised

TABLE 112-1 Common Native American Therapeutic Methods

Method	Purpose
Smudging • Artemisia • Sage • Cedar • Sweetgrass • Juniper • Pine needles	Herbs burned to purify the healing space, healer, patient, helpers, and ritual objects; induce spiritual state of mind; increase awareness of both helpful and disease-causing forces; invite and offer respect to helping spirits.
Prayer and chant • Sacred expression • Communion • Invocation • Petition	Focus the mind on healing; engender positive, health-promoting values such as love, peace, acceptance, and trust; induce expanded and receptive state of consciousness in healer, patient, and helpers; commune with, invoke, empower, and express gratitude to sacred healing forces; increase patient self-esteem by helping him or her to feel worthy of divine help; attend gathering and administration of herbs or other medicines.
Music • Voice • Drum • Rattle • Flute • Whistle • Rasp • Clacker • Violin* • Bull-roarer	Same as for Prayer and chant, also: entrain consciousness and induce harmony and unity among healer, patient, and helpers; restore natural rhythms; unify with elements (e.g., flute: wind); accompaniment to any healing intervention, especially dance and ceremony.
Counseling • Talking things out • Advice of an elder or advisor • Storytelling • Dream and vision interpretation • Seeking guidance from nature • Healing imagery • Humor	Explore or clarify disease etiology and pathogenesis, including physical, behavioral, and spiritual components of disease; discover new sources of inner strength, confidence, and self-understanding; encourage positive behavioral changes, including strategies of coping with disease; strengthen family and community relations.
Vision seeking, dreaming, and fasting	Healer, patient, or both retrieve information, guidance, or solutions to problems or illness; attract and commune with helping spirits and spiritual power.
Energy therapies • Massage, sometimes with specific oils or herbal infusions • Laying on of hands • Indigenous acupuncture: thorns puncture therapeutic points • Noncontact treatment, including scooping harmful intrusive objects or forces • Blowing air, water, herbs, or teas on patient • Sucking disease from body • Stones, feathers, plants, earth, or pigments placed or brushed on or near the body	Aid healing of body, mind, and spirit; relieve pain; transmit healing intent, healing energy, and spiritual power.
Ceremony • Sweat lodge • Sacred pipe • Other tribal healing ceremonies (e.g., Diné sand painting, Salish winter spirit dances) • Ceremonies that belong to individual healers	Enact visions or instructions received from Spirit. Empower and provide a formal structure for healing methods; commune with natural and spiritual forces, the Great Spirit, or the spirit of the disease; induce positive and health-enhancing states of mind; affirm shared cultural identity and values.
Plant medicine (including seaweed) • Consumed (chewed, infused, fermented) • Poultices and salves • Rubbed, placed, brushed, or blown on patient • For bathing, smoking, or smudging • Other ritual uses	Enhance physical, mental, and spiritual balance; expand awareness of spiritual realms (e.g., dreaming/vision aid); combat specific physical or spiritual pathogens.

*The Apache violin or *tsii'edo'a'tl* ("wood that sings") is an ancient instrument that is played during some social songs, ceremonial songs, and healing rituals. The body of the instrument is made of the century plant, which is related to agave and common in Arizona.

not to try the formulas or methods described in this chapter without supervision of an expert practitioner.

Unfortunately, there are no statistical data that address the level of adverse effects of Native American medicine. One of the few reported cases is of a healthy 32-year-old Zuni woman who suffered a stroke from a left vertebral artery dissection after manipulation by a Native bonesetter. She was discharged from the hospital with warfarin anticoagulation therapy and improved quickly.[58] A glaring example of the dangers of Native therapies that are attempted by improperly trained individuals was in the widely publicized tragedy that occurred during a sweat lodge ceremony in Sedona, Arizona, on October 9, 2009, leaving three persons dead and 21 hospitalized. A traditional sweat lodge is a small, dome-like sauna covered by "breathable" blankets and hides, with room for 12 to 20 people. Participants have a chance to exit the lodge as needed or at prescribed times. In the Sedona sweat lodge, a monstrous 415-square-foot dome covered in plastic, approximately 60 people were trapped for 2 hours. Their leader, a non-Native motivational speaker, advised that they could survive their ordeal, but he was wrong.[15] There have been other, less dramatic examples of adverse effects, and many probably are not reported.

In all fairness, it seems likely that compared with allopathic interventions, the level of adverse effects in Native American healing is extremely low and certainly not greater than that attributable to Western or other culturally related medical practices.

AFTERCARE

Traditional healers, unless they have dual roles as physicians, psychotherapists, or other health care providers, generally do not follow up with phone calls or recommended appointments. Patients sometimes return to see healers, but it is their responsibility to request the visits. In addition, traditional healers rarely take notes or otherwise record encounters with their patients; there is a general disdain of note taking, photographing, or audio or video recording of healing interventions. Therefore, we know little about long-term results other than those obtained from anecdotal reports.

If recording occurred during diagnosis or treatment, it would be considered a distraction, dividing the mind and spirit of the healer and preventing full attention to the patient. Although few traditional healers today would claim that photographs or recorded words steal the soul or life force, a feeling remains that multimedia recording of sacred, ceremonial, and healing events is disrespectful to the powers that guide the healer. Recording creates a level of separation and abstraction, a step removed from what is happening in the moment; it freezes in time a passing phenomenon and is, in that respect, considered to be a false representation.

Given this caveat, there is nothing inherently wrong with documenting the effects of Native interventions after the therapeutic sessions and using this information to contribute to the literature on healing. As part of the continuing dialogue between indigenous and Western science, this is likely to occur more and more often.

PREVENTION

Native Americans today suffer from disproportionately high rates of diabetes, cancer, alcoholism, suicide, homicide, injuries, and tuberculosis. Conventional preventive medicine is well accepted, including behavioral and lifestyle changes, immunization, and education. Five hundred years ago, Native healers did not recognize prevention as a separate category of medicine: the elders with whom I have discussed this topic say that prevention was a result of living according to traditional values, including "a good heart and good mind" (a common expression), an emphasis on moderation, a caring family and community and feeling of belonging, and natural outdoor living in which organic food and exercise were facts of life. A clean environment, slower pace of life, and relatively low level of stress were also significant positive influences on health.

CLINICAL EXAMPLE: BACK PAIN

As an example of how these theories are applied clinically, consider the various tribal therapies for back pain, whether caused by congenital defect, stenosis, trauma (including strain, sprain, spasm, fracture, and various disk problems), arthritis, or as secondary to another condition such as renal cysts or cancer. Acute and chronic back pain were serious concerns among people whose survival depended on existence in the wilderness. Pain interferes with the ability to walk, run, climb, swim, defend, and practice subsistence activities such as hunting, planting, foraging, and fishing.

Herbal medicine is a common remedy for back pain. Salicin, the well-known analgesic in aspirin, was first listed in the U.S. Pharmacopoeia in 1882. It is found in all species of willow (*Salix*) and was a traditional pain remedy among many tribes. For example, the Blackfeet steeped willow twigs in boiling water for fever and pain. Alaskan Inupiat chewed on green willow bark specifically for back pain.[27] Alabama Indians applied a poultice made of the pulp of saw palmetto roots to a broken or injured back.[74] The Innu of Quebec and Baffin Island drank wintergreen root tea for back troubles of any kind. The Catawba from North and South Carolina crushed fresh horsemint leaves and steeped them in water. The tea was drunk every day to relieve back pain. They also used an arnica root wash for sprains and bruises.[14] The Kashaya Pomo of North Central California used a pepperwood leaf poultice for nerve pain. They also made a poultice from the root of cow parsnip (*Heracleum lanatum*), baking the root, mashing it, and placing it on the painful area under a rag, leaving it overnight.[29] Alaskan Aleut used a compress of heated cow parsnip leaves as a compress for muscle pain.[27] San Carlos Apache from Arizona made a dry poultice of greasewood (*Covillea tridentata*), heating the top of the plant and applying it directly to the painful area.[74] The creosote bush (*Larrea tridentata*), confusingly sometimes also called "greasewood," is used by many Arizona and Southern California tribes as a cure-all. Heated branches, twigs, or leaves are placed on the body to relieve pain. It is also common to treat pain with creosote steam or smoke.[20] Passamoquody herbalist Fredda Paul of Maine admires the healing properties of horsetail (*Equisetum arvense, Equisetum hyemale,* and *Equisetum sylvaticum*), also popularly called "shave grass." It is taken internally as a tea for aching or injured joints and ligaments and to help mend broken bones. Horsetail is rich in silica and may help build collagen.[40] As with other plants, it must be administered with care, because the silica may aggravate hemorrhoids, and the raw shoots contain toxic thiaminase. It is also inadvisable for persons with cardiovascular disease.

Calamus, a member of the sweet flag (*Acoraceae*) family, is an immensely popular herb among Native Americans. It commonly grows in swamps and near water in boreal forests and has a broad range of applications. The Cree of Montana, Alberta, and Saskatchewan call it *wacaskwatapih* ("muskrat root" or, more commonly, "rat root") and believe that muskrat meat is especially nourishing and spiritually potent because muskrats eat this healing root. Cree herbalists recommend chewing on the root to overcome fatigue during long hikes or strenuous activities. It is also applied for treatment of back pain. The fresh, or dried and ground, rhizome is chewed and used as a poultice for painful joints. The root may also be chopped and put in boiling water to make tea, which is then mixed with flour and applied as a hot paste over arthritic joints. The painful area is then wrapped with warm towels and left overnight.[49] The Muskogee Creek, who originally inhabited the region from Georgia to Alabama, use calamus tea in a similar manner, applying it within a hot compress to reduce inflammation and soothe sore joints and back pain. The Creek also use yarrow, another ubiquitous and popular plant, for painful or deep bruises from falls. The smashed leaves or a lukewarm tea made from the leaves are placed in a compress over the bruise. In a modern application, the leaves and flowers may also be soaked in isopropyl alcohol for 7 days to make an antiinflammatory liniment for joint pain and poor circulation.[19]

Cherokee and Hitchiti herbalist Tis Mal Crow[19] recommends a liniment made from Solomon's seal root (*Polygonatum biflorum*) for back pain, sprains, misaligned bones, and ruptured disks. The Tlingit and other Alaskan tribes make ointment or massage oil using skunk cabbage or devil's club (*Oplopanax horridus*) for joint and muscle pain.[32] Devil's club, sometimes called "Indian ginseng," is greatly admired among Northwest and Alaska Native peoples for its broad healing and spiritual qualities, and it is somewhat of a panacea[43] (Figure 112-7).

Massage is a universal remedy for pain. Native healing specialists called "bonesetters" are common among many tribes, from the Yurok of California to the Yoeme of Arizona. In addition to setting broken bones, many of them also practice massage or prescribe herbs that teach the bones how to mend. Traditional healers commonly practice laying on of hands, placing the hands

FIGURE 112-7 Devil's club, Sitka, Alaska.

on or near painful areas. In Washington State, practitioners of the Si.Si.Wiss "sacred breath" healing tradition may work on a patient with a combination of smudging (generally with cedar smoke), song, dance, prayer, candlelight, and healing gestures of the hands.[17,63] I have facilitated several Si.Si.Wiss healing ceremonies for patients with back pain. In one case, a 40-year-old white airline pilot joined a 2-hour healing ceremony without telling anyone about his diagnosis or symptoms. It was his first experience in a Native ceremony. A few years later, I met him by chance in a café, and he recounted an extraordinary story. He had been in a car accident 6 years earlier that had resulted in unremitting pain from three herniated disks: the third cervical and fourth and fifth lumbar vertebrae. The pain was significantly diminished the day after the ceremony; within 1 week, it was completely gone, and had never returned. A 60-year-old Comanche woman who had suffered from years of disk-related back pain asked me to "doctor" her. I smudged her with a mixture of artemisia and sweetgrass (*Hierochloe odorata*), waving the smoke over her body with a turkey feather fan. I then prayed to the Great Spirit for health and help while placing my palms directly on the painful area. I rested my palms there for about 10 minutes. The intervention closed with more prayers. Her pain was gone the next day and never returned.

As do modern massage therapists, Native healers use various oils to ease kneading and manipulation and to make the body more pliable. Oils were historically derived from animal fat, typically bear, bobcat, and raccoon.[74] The spirits of these animals were believed to contribute to the effectiveness of the massage. The power of massage could also be augmented by fanning the body with switches of cedar or other plants or by applying massage in a ceremonial or sanctified space such as a sweat lodge. Some traditional healers are especially efficacious because of the way they prepare themselves for healing. Cherokee healers warm their hands over an outdoor fire and then rub the painful area with circular motions of the palms.[74] Some healers imagine that they are becoming or communing with a dream helper, such as a badger, thunderbird (symbol of thunder, lightning, and life energy), or bear. In the minds of both healer and patient, it is perhaps the bear who "doctors" the patient and whose "paws" massage the painful area. The bear is one of the most common representations of healing among North American Indians. Because of the bear's winter hibernation, the bear is associated with sleeping, dreaming, and the intuitive insights that are considered essential to the practice of indigenous healing. Many tribes consider the bear an especially important teacher of herbal medicine. This may be a result of observing the bear's ability to self-medicate using plants in nature and knowing that humans, like bears, are the only North American mammals with a rotating forearm, giving them the manual dexterity to dig healing roots (Figure 112-8).

Back pain and spasms are often relieved by heat. This fact did not escape traditional healers, who recommended hot compresses, the heat of the sweat lodge, and bathing in hot springs. Rolling Thunder sometimes advised his patients to lie down on a "bed" of warm sand on the beach and consciously, meditatively allow the warmth to heal the back. Like the ancient Chinese, Native American healers for millennia have applied warmth to muscles, joints, or specific therapeutic points to relieve pain. In Chinese medicine, a small ball of moxa (mugwort) is burned at the end of the acupuncture needle to transmit heat and increase the therapeutic effect. Similarly, Cree Indians take a pinch of tinder fungus, found under the bark of birch trees, roll it into a matchstick shape, and burn it on the skin to treat arthritis.[49] Omaha Indians used stems of the shoestring plant in a similar fashion.[28] The Blackfoot sometimes inserted prickly pear or rose thorns into specific areas on the skin to relieve pain. These thorns may also have been heated by burning them. Historian Robert Beverley, Jr (1673-1722), reported that the Indians of Virginia fixed "a pain in any particular Joynt or Limb" by making a cone from soft or rotting wood in the knots in hickory or oak trees and burning it down to the skin over painful areas.[8] Most Native American languages have a word for life force or breath of life (*ni* in Lakota), similar to the Chinese concept of *qi*. It is logical to infer from this that indigenous acupuncture was not merely a counterirritant but rather an example of energy medicine.[35] However, counterirritants were not unknown. Many tribes, such as the Chehalis and Quileute of Washington, applied switches of stinging nettles to painful backs.[31]

Adolf Hungry Wolf[80] recounts a fascinating example of Blackfoot Indian "moxabustion" in his 1975 edition of *Teachings of Nature*. A Blackfoot elder told Hungry Wolf, "… a horse fell on me once. My knee really swelled up. My father told my mother to go get some thorns from a Rose bush, and he told her to bake them. … He checked over my injured leg and he took one of the hot thorns and he pushed it in." His father inserted the thorns directly into the swollen area and then burned them down to the skin. He repeated the treatment later that same day. "This time the swelling went right down and I was able to walk. I guess that was a form of what they call, today, Acupuncture."[80]

Ceremonies may also be deemed effective against back pain, especially if the pain was caused by a negative or evil power, including anger, which may have lodged within the body; by offending an animal or natural phenomenon, such as the aurora borealis or lightning; by contact with the dead or ghosts; by lack of ceremonial preparations for military service or return from service; or by any other etiologic factor generally considered in the realm of spiritual.

There are no set rules regarding the frequency or overall length of Native healing therapies. An intervention lasting only a few hours or a day may bring a lasting cure. Navajo *sings*, which are ceremonies that may include baths, sand painting, and complex chants, may last 2, 5, or 9 nights. Some Native healers give the patient an herbal formula or ritual activity to perform for a set number of days, usually 4 or 7. Other healers may see

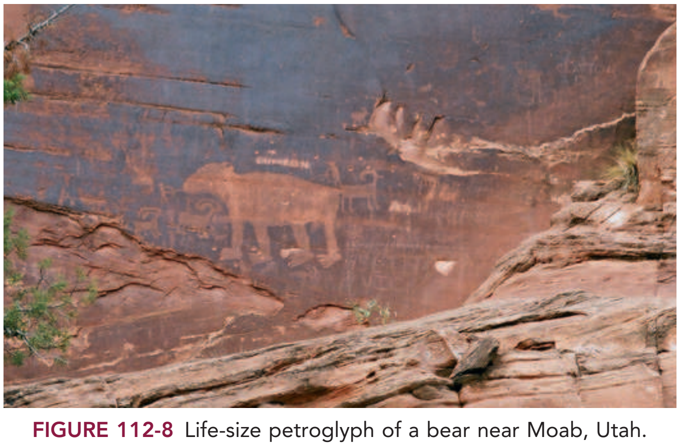

FIGURE 112-8 Life-size petroglyph of a bear near Moab, Utah.

their patients on a daily basis for 1 week or more. If the healer and his or her helpers have traveled a great distance, sometimes at considerable cost to the patient (who is expected to provide transportation costs, lodging, food, and a generous donation for services), the healer will work intensively to complete the treatment in as short a time as possible. A cure may require a commitment on the part of the patient to make lifelong behavioral changes or to perform ritual activities on a seasonal or yearly basis for a certain number of years. In contrast with the "fix-me" attitude that often accompanies allopathic medicine, patients receiving Native American healing treatments are expected to assume considerable responsibility for their own healing. Patients who comply with the healers' directives are much more likely to be cured.

Before leaving this brief survey of healing interventions for back pain, it is important to note that in precontact times, people who could not be cured or who lived with permanent disability were not rejected. Native patients among various tribes ingested datura (*Datura stramonium*) or peyote (*Lophophora williamsii*) to free the mind from pain and disability and to promote visions leading to a new sense of life purpose. I have heard from many elders that disability did not prevent one from living a useful life. On the contrary, a person who is weak in body is often pitied by the Creator and made especially strong in mind and spirit. These individuals find new ways to be of service.

THE CHALLENGES OF RESEARCH

Native American medicine is not found among the categories of CAM on the website of the National Center for Complementary and Alternative Medicine.[54] In various presentations and documents, I have advised officials from the National Institutes of Health that Native American medicine is too closely connected with political, economic, religious, and social issues to be considered a CAM method.[16,62] I was concerned that the benefits of research and control over its applications remain in the hands of the sovereign Native Nations to whom the healing methods belong. It would be a travesty for non-Native licensing or accreditation boards to create standards for or assume control over Native spirituality and culture.

The scientific analysis of Native American healing methods removed from their cultural context poses special challenges for creating standard conditions or replicable experiments. From an indigenous viewpoint, analyzing the chemistry and biologically active agents in plant medicines has limited value. To be effective, plants must be gathered by hand and not bought in a store or pharmacy. Native herbalists also pay attention to the time of day or season to dig roots or pick leaves and are careful to leave enough of a species for regrowth. The way an herbalist handles or prepares an herb (e.g., cutting, drying, mashing, crushing) may increase or decrease a plant's potency. For example, Mohegan herbalist Gladys Tantaquidgeon[69] states that many herbalists prefer to dry their medicines in the sun and crush them with a stone or wood mortar "to avoid contamination by metal."

Interventions vary according to the needs of the patient and intuition of the healer. The location is also considered an influence on treatment outcome. For example, an herbal medicine or massage received in a hogan, kiva, sweat lodge, or beautiful place in nature has a different effect than the same therapy applied in an office or hospital or studied in the laboratory. Songs and prayers may not be repeated, even when treating the same disease, and it is also possible that the powers they invoke are impossible to measure. A traditional healer would not wish to rule out the placebo effect, if it was a possibility. The presence of the healer, quality of relationship between healer and patient, and faith of the patient are powerful influences on treatment outcome. Levin[44] defines faith as "a confluence of belief, trust, and obedience in relation to God or the divine."

This does not mean that scientific research in this field is of no value. On the contrary, research can provide an alternative model for interpreting and appreciating healing phenomena.[50] Some prominent websites, including those of the American Cancer Society[2] and the University of California, San Diego Medical Center claim that the "[f]ormal research of the healing ceremonies and traditions of Native Americans is almost nonexistent even though claims have been made regarding cures of a variety of ailments, including cancer."[73] This is not quite true. We have little data about Native American healing that has been conducted by traditional healers, especially in the context of their own communities or with members of their own tribes. At the same time, the major modalities applied by Native healers have been extensively researched and documented, including herbal medicine, music, touch, massage, and prayer. For example, in "Physical Fields and States of Consciousness," a 12-year research project conducted by the Menninger Clinic in Topeka, Kansas, scientists measured extraordinary surges in body potential, bioelectric fields, and brain-wave amplitude when various well-known healers, including some practitioners of Native American Medicine, attempted to emit healing energy, with or without an actual patient being present (Figures 112-9 and 112-10). At the same time, 600 control experiments with "regular" untrained participants produced no such phenomena.[30,70,71] Given the documented effects of drumming on brain waves and intuition, I believe that even stronger effects would have been evident if Native healers had used drums or other percussive instruments during these experiments.[36,55,56,61,77] However, this would have created movement artifacts, making data interpretation almost impossible. It is also likely that the sensory saturation common during Native rituals—olfactory (sage and cedar smoke), auditory (drumming), kinesthetic (dancing), and visual (masks and regalia)—causes synergistic neurophysiologic effects (e.g., blocking of pain signals).

Daniel Benor[7] has collected and analyzed hundreds of CAM and spiritual healing abstracts previously published in peer-reviewed journals. Many U.S. hospitals, particularly those serving

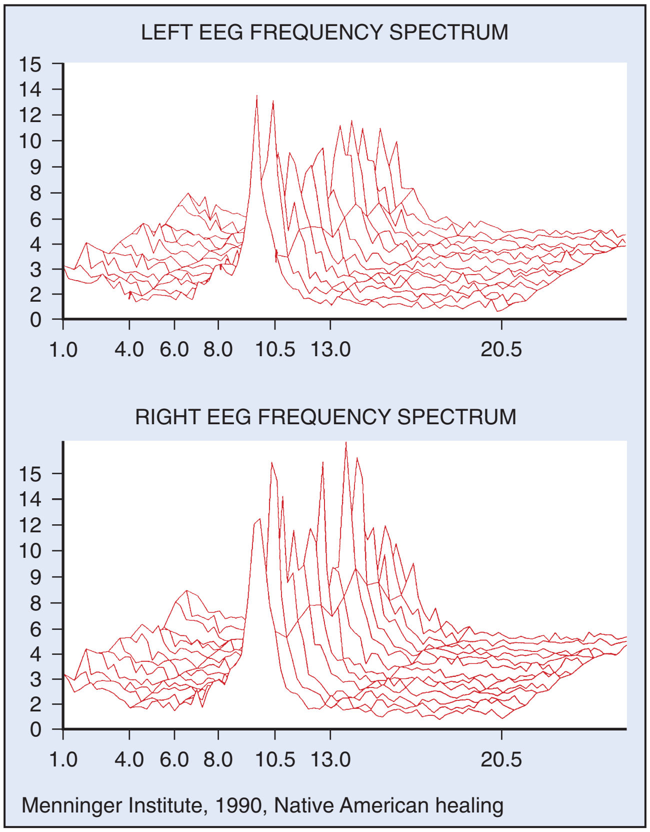

FIGURE 112-9 Left and right hemisphere electroencephalography (EEG) spectra from the Menninger Clinic, 1990. Subject practices Native American healing by mental focus on a distant patient, hidden from him in another office within the Menninger Clinic. Note coherence of upper (left) hemisphere with lower (right), peaking in the alpha range at approximately 10.5 Hz. This amplitude is unusually high, particularly for the right hemisphere.

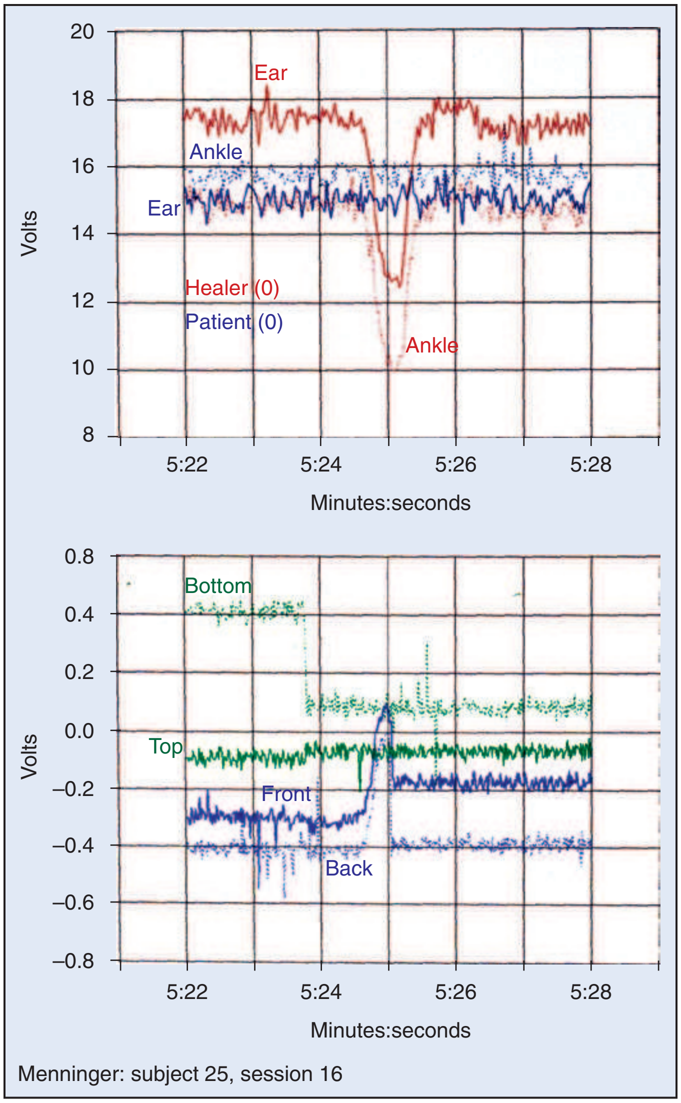

FIGURE 112-10 Anomalous changes in body potential, Menninger Clinic, 1990. Same subject (*healer*) and experimental session as in Figure 112-9. Upper graph shows the healer's baseline ear electrode reading of approximately 17 V, dropping to approximately 13 V before returning to baseline, and ankle electrode at 15 V dropping to 10 V. All this occurred at the moment the healer attempted to "send healing energy" to a patient in another room. No movement was permitted, and video cameras ruled out movement artifacts. The bottom graph displays voltage readings on four copper panels: bottom subflooring, top ceiling, front, and back. A significant spike in the front and back panels occurred in synchrony with the body potential surges.

Native patients or close to reservations, provide integrative health services that allow patients to be treated by traditional healers, often in special Indian treatment rooms reserved for that purpose. I have visited these facilities in New Mexico, Wyoming, and Washington. An administrator at one of these facilities told me that non-Indian physicians joined traditional healers in weekly sweat lodge ceremonies, after which they discussed collaborative treatment strategies. There are also numerous yearly conferences hosted by universities, clinics, and the Indian Health Service that focus on the dialogue between indigenous and Western medicine and the potential benefits of both research and clinical applications.

Returning to a theme from the beginning of this chapter, spending time in nature, whether camping, hiking, or on pilgrimage, has measurable effects on health. Louv[46] cites evidence for "nature-deficit disorder," linked with decreased creativity as well as cognitive and emotional difficulties in both adults and children. Becker and Seldon[6] explain the mechanism by which the earth's electromagnetic field influences healing and may program our biologic clocks and rhythms. Others have shown how rhythmic movement (e.g., healing and ceremonial dances) further encourages homeostasis. According to James R. Evans, Associate Professor of Psychology at the University of South Carolina (Columbia)[25]:

> Some [researchers] perceive the human body as a collection of oscillating subsystems more or less in harmony with each other; the greater the harmony among the systems the less the "dis-ease," while the greater the dissonance the more severe the "dis-ease." According to some such views, internal order can be increased and hence the quality of the human "body symphony" enhanced by exposure to ordered stimuli such as certain music, poetry and rhythms of nature and/or by participation in rhythmic movement activities as diverse as dancing, jogging, and certain martial arts. One might guess that dancing to music under the stars on a beach would be highly conducive to reestablishment of internal order.

It is likely that positive health-enhancing entrainment may also occur between the healer and healed.[70,71] Through a process similar to what electrical engineers call "induction coupling," the information-carrying signals in one neural network produce similar signals in an adjacent biologic system. Of course, the opposite is also possible: an ill-prepared healer may resonate with the patient's disease or transmit his or her own disharmony.

The human race evolved in natural, not man-made, environments. As we become more familiar with these environments, we feel more fully human. The experience of belonging in nature—of being not stewards of the earth but rather, like a stone, a plant, or a fish in the sea, being a *part* of the earth's natural processes—is central to the practice and understanding of traditional healing. The healer draws on this connection to augment spiritual power. The wind, invoked through imagery and song, chases away pain; a healer-turned-wolf hunts for the scent of disease; a stone rubbed on the back strengthens bones. This creates a set of ever-changing variables probably impossible to measure.

In addition, it is important to consider that Native wilderness medicine today is different from that of the past. Modern lifestyles and habits create special challenges for a traditional healer. Many people, including Native Americans, are uncomfortable in the wilderness. Although people try to control it, when we are in nature, we are faced with a reality that is beyond our control and unpredictable. A fall or fracture in the forest may be doubly frightening; first because it happens in nature and second because it happens far from the security of a hospital. Alienation, helplessness, and fear exacerbate pain, impede healing, and may lead to panic. Thus, the very first task of the traditional healer is to communicate to the patient by word, deed, or symbol that the patient is safe and at home. The healer encourages the patient to accept and relax into a reality that, from a deeper perspective, has always been present.

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