Chapter 27

MILITARY MEDICAL OPERATIONS IN MOUNTAIN ENVIRONMENTS

PAUL B. ROCK, DO, PhD*; AND EUGENE J. IWANYK, MD†

*Colonel, Medical Corps, US Army (Ret); Associate Professor of Medicine, Center for Aerospace and Hyperbaric Medicine, Oklahoma State University Center for the Health Sciences, Tulsa, Oklahoma 74132; formerly, US Army Research Institute of Environmental Medicine, Natick, Massachusetts 01760

†Lieutenant Colonel, Medical Corps, US Army (Ret); Ellis Eye and Laser Medical Center, El Cerrito, California 94530

INTRODUCTION

One of the fundamental challenges faced by medical personnel supporting military units deployed in mountain regions is to deal with the effects of the environment on the health service support mission. Mountain environments have an impact on virtually all aspects of the mission. On one hand, mountains add to the spectrum of disease and injury that normally occurs during military operations. Indeed, in the absence of combat, environmental injuries are the biggest source of casualties that reduce unit fighting strength. On the other hand, they affect the health service support system itself, constraining the options for prevention or treatment of casualties. Factors in the mountain environment degrade the performance of medical personnel and equipment and limit the ways in which medical assets can be deployed. If the effects of mountain environments are not anticipated and successfully avoided or abated, the health support mission, and with it possibly the tactical mission, will be jeopardized.

The purpose of this chapter is to provide information that will help medical personnel successfully manage the impact of mountain environments on the health service support mission. In its simplest form, that mission is to conserve the fighting strength of the tactical unit by

- advising the unit commander about the potential impact of the environment on unit personnel and operations, and recommending means, countermeasures, or both to lessen that impact;
- providing a health maintenance program to (*a*) prevent environmental medical problems and (*b*) treat them effectively when they occur; and
- managing the field medical support assets to allow efficient treatment and return to duty or evacuation of casualties.

In this general formulation, the mission is applicable to most organizational levels of medical support to most tactical units.

The information presented here is organized around the simple formulation of the health service support mission stated above. The first section of this chapter reviews the potential impact of mountain environments on military units and countermeasures that can be recommended to lessen environmental effects. The next section discusses health maintenance in units deployed to high altitude. The final section deals with the effect of the mountain environment on the medical support system itself. The considerations underlying the concepts presented are based on providing support to "traditional" ground combat units such as infantry, light infantry, armor, and cavalry units. Although many of the general concepts are relevant to other types of military units, including special operations units, the unique aspects of medical support of special operations are discussed in Chapter 37, Medical Support of Special Operations, and Chapter 38, Organizational, Psychological, and Training Aspects of Special Operations Forces of this textbook.

ESTIMATING DISEASE AND NONBATTLE INJURY AND PERFORMANCE DECREMENTS

Military leaders need good estimates to plan effectively for their unit's mission. Combat leaders need estimates of the unit's fighting strength (manpower) and performance capabilities in the environment in which the unit will operate. In the mountains, they need estimates of the extent to which the mountain environment itself will degrade unit strength (ie, disease and nonbattle injury [DNBI]) and performance over time. Medical support personnel need estimates of the number of casualties so that they can plan for the care of those casualties. In the mountains, they need estimates of the effects of the mountain environment on manpower and performance to accurately brief the combat commander, guide health maintenance activities, and allocate the medical support resources.

Useful estimates of the effects of mountain environments on unit strength and performance ideally would be based on experience, in the same way as the most useful estimates of battle casualty rates are derived from "experience tables" based on data from previous battles. Unfortunately, there are few useful data about medical problems available from the mountain warfare experience. For instance, although Houston's excellent review of the effects of the environment on past military campaigns in the mountain regions of Europe and Asia (Chapter 20, Selected Military Operations in Mountain Environments: Some Medical Aspects) graphically illustrates the deleterious impact that mountains can have (eg, what commander today would want to suffer the nearly 50% reduction in force that Hannibal experienced while crossing the Alps), much of that historical information is not particularly applicable to current military operations, owing to differences in equipment, transportation, and medical technology. Similarly, the information on combat injuries from previous battles with swords and shields is not especially applicable to the present-day battlefield, with its high-velocity ballistic weapons. Of the conflicts that took place in the mountains during the 20th century and, therefore, might be more applicable, the only readily available data on environmental casualties are from the Sino–Indian border conflict (1962–1963).[1] Additionally, some data are also available from studies of military training activities in the mountains,[2–5] but the information is based on limited numbers of individuals.

Even in the absence of extensive experience-based data, medical personnel can make reasonable estimates of the effects of mountain environments on unit strength and performance by combining some general concepts with extrapolations of the limited data available. Estimates are, after all, *estimates*. Considerations for making reasonable estimates of DNBI and performance decrements for mountain terrain are presented below.

Disease and Nonbattle Injury

The major components of DNBI in high mountain terrain are listed in Exhibit 27-1 and extensively discussed in Chapters 24, 25, and 26, which deal with acute mountain sickness (AMS), high-altitude cerebral edema (HACE), high-altitude pulmonary edema (HAPE), and other edematous and nonedematous illnesses. They include conditions that are caused by the hypobaric hypoxia that is characteristic of high-altitude and conditions related to other environmental factors. That both hypoxia and other environmental factors play a role during military operations in the mountains was strikingly demonstrated during a training exercise at 3,600 to 4,000 m altitude in the Colorado mountains.[3] The number of soldiers evacuated during 5 days of mountain operations was more than 10-fold that for the same unit doing the same maneuvers for the same amount of time in North Carolina. The casualties at altitude were caused by AMS and HAPE, both related to hypobaric hypoxia; traumatic and overuse injuries, related to the rugged topography; and one fatality and five injuries from a lightning strike.

A reasonable method to estimate DNBI for military operations in mountains is to start with estimates for a nonmountainous region, add hypoxia-related conditions, and then make appropriate adjustments for other factors that change in the mountains but are not necessarily related to hypoxia (eg, increased chance of lightning injury, decreased chance of mosquito-borne diseases). Experience tables for DNBI are available for the United States[6] and most other military forces. Estimates of DNBI for temperate climate operations are a reasonable starting point for altitudes from 1,500 to 4,000 m because the climate conditions at those elevations are fairly similar. Estimates for arctic regions may be a better baseline for mountain regions above 4,000 m elevation, where increasingly cold ambient temperatures prevail.

Considerations for estimating the additional effect of altitude on incidence of hypoxia-related and other environmental injuries are drawn from the military and civilian experience in the mountains. Reports from civilian experience are mostly related to recreational activity, however. Because tactical considerations dictate the timing, duration, and location of environmental exposure during military operations, civilian recreational exposure is not

EXHIBIT 27-1

HEALTH THREATS TO MILITARY PERSONNEL FROM MOUNTAIN ENVIRONMENTS

Hypoxia Related
- Acute mountain sickness (AMS)
- High-altitude cerebral edema (HACE)
- High-altitude pulmonary edema (HAPE)
- High-altitude peripheral edema
- High-altitude eye problems
- Sleep problems with sleep deprivation
- Thromboembolism
- Exacerbation of preexisting disease
- High-altitude pharyngitis/bronchitis
- Performance decrements

Not Related to Hypoxia
- Trauma
- Thermal injury (especially cold injury)
- Ultraviolet (UV-A, UV-B) radiation energy
- Lightning strikes
- Carbon monoxide poisoning
- Infections
- Hypohydration
- Inadequate nutrition

entirely equivalent.[7] Estimates can be made from this data, however, by considering activities that might be roughly equivalent to military activities. For example, trekking and backpacking in the mountains (ie, long journeys on foot carrying camping equipment; see Exhibit 19-1 in Chapter 19, Mountains and Military Medicine: An Overview) are roughly equivalent to an approach march, although, owing to tactical contingencies, soldiers often carry more equipment and set a faster pace.

Altitude illness, which includes AMS, HACE, and HAPE, is the only component of DNBI that is unique to the mountains. As detailed in Chapter 24, Acute Mountain Sickness and High-Altitude Cerebral Edema, and Chapter 25, High-Altitude Pulmonary Edema, the incidence of altitude illness is increased with increasing severity of altitude exposure, as determined by the elevation achieved and the speed of ascent. In general, the altitude at which personnel sleep is the most important one in determining the incidence of altitude illness. Additionally, altitude illness decreases over time as individuals acclimatize. Information presented in Chapters 24 and 25 suggests that for ascent rates of 1 to 2 days, the incidence of individuals with AMS symptoms can be as high as 20% at 2,000 m and 67% at 3,000 m; the incidence of HACE may be 0.1% at 2,000 m and as high as 1.8% at 5,500 m; and the incidence of HAPE, 0.1% at 2,500 m and 15% at 5,500 m. Many of those with AMS will not be casualties but will be "medically noneffective" for as long as several days. Dusek and Hansen[3] found that 6% of soldiers in a Special Forces unit were incapacitated with AMS at 3,600 to 4,000 m, while Pigman and Karakla[2] reported that 1.4% of Marines were incapacitated at 2,000 to 2,600 m. For purposes of estimating unit strength decrement, all casualties with HACE and HAPE should be considered as needing evacuation for treatment.

Cases of altitude illness will be clustered in space and time. The units that ascend the highest in the least amount of time will have the most altitude illness, and the prevalence of illness will be greatest during the first several days to a week or more after ascent. An extremely important point is that because exposure to hypobaric hypoxia is ubiquitous at high altitude, all unit members are equally susceptible to altitude illness, including command staff and medical and other support personnel.

Most components of DNBI that are not related to hypoxia also vary with altitude. Cold, ultraviolet (UV) -radiation injury, and trauma are common in many environments other than mountains (interested readers should consult Section II: Cold Environments [Chapters 10–18 and Appendix 1] of *Medical Aspects of Harsh Environments, Volume 1*[8]), and the incidence, prevalence, or both in those situations could provide a baseline reference point for estimating altitude rates. UV radiation exposure is increased with increasing elevation, and consequently the estimated rate of injury should be increased. The potential for cold injury increases with elevation because ambient temperatures drop, and the rugged ("nonlinear") mountain topography will increase the accidental trauma and overuse injury. The magnitude of increase for these factors is not well established but it is substantial. Additionally, environmental causality rates will be higher, because of the interaction of factors. Thus, increasing hypobaric hypoxia may contribute to an increased incidence of cold injury by decreasing plasma volume and impairing cognitive performance and judgment.

Unlike most components of DNBI, the incidence of infectious disease in the mountains is more or less inversely related to altitude (ie, the greater the altitude, the less risk of infectious disease; see Chapter 26, Additional Medical Problems in Mountain Environments). This is largely due to the decrease in arthropod disease vectors and decreased survival of bacteria in the open environment at altitudes above approximately 4,500 m. Diseases that are spread by person-to-person transmission, including fecal–oral transmission of diarrheal diseases, that age-old scourge of military field operations, can occur at virtually any altitude, however. Consequently, rate calculations for the infectious disease component of DNBI can ignore arthropod vector–related diseases at very high altitudes but should retain rate estimates for diseases transmitted person-to-person.

Performance Decrements

Degradation of individual and group military performance during high-altitude exposure has been documented in controlled studies.[3,4,9,10] Most military activity involves behaviors with varying degrees of physical exertion and psychological functioning, combined or in rapid serial sequence. The hypobaric hypoxia of high altitude impairs both physical and psychological performance (see Chapter 22, Physical Performance at Varying Terrestrial Altitudes, and Chapter 23, Cognitive Performance, Mood, and Neurological Status at High Terrestrial Elevation). It is the major cause of decrements in soldier and unit function, although other factors such as cold exposure and hypohydration also contribute.

Because the decrease in oxygen content of ambient air is ubiquitous at high altitude, the effects are universal and they affect all members of a unit deployed to the mountains, including command staff and medical support personnel. Although performance decrements increase with increasing elevation because the degree of hypoxia increases, the effects of hypoxia improve over time as the body acclimatizes to altitude. Medical officers must apprise unit commanders of both the threat from altitude-related performance decrements, which threatens a unit's ability to accomplish its mission, and the means to lessen the impact of those decrements on operations.

Physical Performance

The main effect on physical performance of hypobaric hypoxia at high altitude is decreased maximal aerobic exercise capability and endurance (see Chapter 22, Physical Performance at Varying Terrestrial Altitudes). Muscular strength and anaerobic activity are not much affected. Because the energy required to do a specified amount of work (ie, the metabolic cost) does not change with altitude but the maximum amount of energy that can be expended goes down, individuals have to work at a higher percentage of their maximal aerobic capability to accomplish any physical task. This means that those tasks will either require relatively more effort, take longer to complete, or both, compared with the same tasks done at lower altitudes. The amount of decrement in any specific task is a function of the mix of aerobic and anaerobic activity required to do the job. Tasks that have a greater anaerobic component are less affected.

The threshold for onset of altitude effects on physical performance is low, but meaningful effects do not begin until altitudes higher than 2,400 m are reached. The rate of decline in maximal exercise capacity is dramatic above 6,000 m. Importantly, physically fit individuals suffer a greater decrement in their maximal exercise capacity at high altitude than less fit individuals. They may still be able to do more work than less-fit individuals, however, owing to their higher starting sea-level work capacity.

The effect of physical performance decrements on mission is an interaction of the type of performance entailed by the task and the contribution of the task to the mission. For example, military tasks that require only a small aerobic energy output at sea level will require an increasing percentage of the diminished maximal energy capacity at higher altitudes, but they can still be accomplished. On the other hand, tasks that require a large energy output may not be possible to perform. If the mission depends on tasks that do not require a large energy output, the altitude-induced performance decrement will not create a problem. If it depends on energy-intensive tasks that cannot be done at high altitude, then the mission will be in jeopardy.

Exhibit 22-2 in Chapter 22, Physical Performance at Varying Terrestrial Altitudes, provides specific examples. For a task that entails prolonged standing on a circulation (traffic) control point (see number 1 in Exhibit 22-2, which pertains to Task #3, MOS 95B [Military Police]), the percentage of maximal oxygen uptake increases only from 9% to 13% between sea level and 5,000 m. Consequently it is unlikely that the physical aspects of that task will be significantly degraded by altitude exposure. However, the energy required to carry tube-launched, optically tracked, wire-guided (TOW) missile system equipment up a 20% grade at a rate of 0.89 m/s exceeds the maximal oxygen uptake at 5,000 m and is greater than 95% of the maximal uptake at 4,000 m (see number 32 in Exhibit 22-2; Task #1, MOS 11H [Heavy anti-armor weapons, Infantry]). In theory, the task cannot be accomplished at 5,000 m. If the mission success depends on standing on a traffic control-point at 5,000 m, there will be little problem. But if mission success depends on carrying equipment up a slope at 5,000 m, then the mission is in jeopardy and alternative means to do the task will have to be found.

Once acclimatization has been achieved, maximal exercise capacity improves somewhat with altitude acclimatization and with physical training at high altitude, but it *never* regains sea-level values. It is important that commanders know that maximal performance decrement will *always* occur at high altitude, so they can plan for it. Submaximal physical performance decrements can be negated by expending more effort, but the cost of doing so is increased fatigue. Chapter 21, Human Adaptation to High Terrestrial Altitude, suggests that submaximal physical performance decrements are best approached by (1) increasing the amount of time allowed to complete the task, (2) decreasing the intensity of the work, and/or (3) taking more-frequent rest breaks.

Psychological Performance

High-altitude exposure alters a number of psychological parameters, including cognitive and psychomotor function, visual parameters, and mood and personality adjustments, in ways that can have a negative impact on military performance (see Chapter 23, Cognitive Performance, Mood, and Neurological Status Effects at High Terrestrial Altitude). As with physical performance decrements, the psychological effects are primarily due to hypobaric hypoxia and tend to increase with increasing altitude and improve with acclimatization. Additionally, there is a large individual variability in these effects.

Cognitive function and psychomotor skills are progressively diminished above 3,000 m and are very noticeably affected over 5,500 m. In general, cognitive processes are more affected than psychomotor function. As a result, complex tasks are more affected than simple ones, and tasks requiring decisions or strategy are more affected than more "automatic" ones. There is some improvement in function with acclimatization, but there is always an element of intellectual "dulling" at very high altitudes. This results in an increased number of errors, an increase in the time needed to complete a task, or both.

A common functional strategy for countering the effects of altitude on task performance is to increase the time taken to do the job to decrease the number of errors. Many individuals adopt this strategy on their own volition. As a consequence, more time to complete most tasks should be anticipated at high altitude. Increasing proficiency by training before deployment and maintaining proficiency while deployed at high altitude by frequent practice also help improve performance. Important or critical tasks always should be carefully checked for errors.

The most important sensory decrement from the standpoint of military performance is a persistent decrease in night vision that begins as low as 2,500 m and does not improve with acclimatization. This diminished night vision will increase the possibility for accidents during night travel and may make it more difficult to detect enemy movements at night. Because the decrement is persistent, methods will need to be instituted to lessen its impact (eg, provisions for guidance during night travel, increased reliance on nonvisual means for detecting enemy activity at night).

Mood changes and personality-trait adjustments that occur at high altitude can affect the interpersonal relationships among unit members and disrupt unit cohesion. The euphoric response that many individuals experience during the first few hours after ascent can predispose them to accidents. Once the euphoria subsides, a depressed mood, irritability, or apathy can appear. A number of factors in addition to hypoxia, including the person's underlying psychological makeup, weather, and social bonds will influence mood and personality adjustments in high mountain environments. Symptoms of altitude illness can also influence mood, motivation, and performance. Building high morale and esprit de corps prior to deployment will help lessen the impact of negative mood and personality-trait changes. Prophylaxis to prevent symptoms of altitude illness will also help.

HEALTH MAINTENANCE

Medical support activity to sustain the health and performance of personnel in military units deployed to high mountain areas is directed toward (1) prevention of illness and injury and (2) effective detection and treatment of those illnesses and injuries that occur despite preventive efforts. Effective treatment facilitates rapid return to duty or evacuation of the sick or injured unit member (see Exhibit 27-1 for an array of potential illnesses and injuries found in mountain environments). Specific information on how to prevent, diagnose, and treat those conditions is presented in the previous chapters of the Mountain Environments section of this textbook and in *Medical Aspects of Harsh Environments, Volume 1*,[8] and *Volume 3*.[11] General considerations about ways in which that information can be used to maintain the health of members of a unit deployed in mountain terrain are presented here.

Prevention of Environmental Injury and Illness

Prevention of medical problems caused by the mountain environment can be accomplished by limiting exposure to the mountain environment, by providing ways to counter its adverse effects, or both. High altitude is the major factor conferring risk in the mountains. Increasing altitude not only increases the level of hypoxia and altitude illness but also increases risk of cold injury, UV radiation exposure, lightning, trauma, and most other environment-related conditions. Limiting altitude exposure means controlling the elevation, the rate of ascent, or both. This may not always be possible for military units deploying into mountainous regions because the mission or the tactical situation may be an overriding priority that dictates unit movement. In that instance, increased reliance will have to be placed on protective measures.

Activities by medical personnel to facilitate prevention in a unit deploying to the mountains include (*a*) recommending countermeasures to the unit commander, (*b*) providing medical screening, (*c*) providing training to unit members, and (*d*) facilitating the provision of necessary equipment and supplies to unit personnel.

Recommending Countermeasures

General countermeasures for hypoxia-related illness and performance decrements function either to promote acclimatization or to protect unacclimatized individuals against effects of hypoxia. Different countermeasures have advantages and disadvantages in specific tactical situations. The unit commander must choose the best option based on the mission and tactical constraints.

Options for using altitude acclimatization as a countermeasure are (1) to promote acclimatization through appropriate ascent rates (ie, profiles) or (2) to maintain previously acquired acclimatization until the next ascent (see Chapter 24, Acute Mountain Sickness and High-Altitude Cerebral Edema). Two ascent profiles promote acclimatization and prevent altitude illness: (1) slow or gradual ascent and (2) a staged ascent. The recommended profile for a slow ascent is to sleep 2 or 3 nights at 3,000 m and then spend 2 nights for every 500- to 1,000-m increase in sleeping altitude thereafter. The recommendation for staged ascent is to stop for 3 or more days to acclimatize at one or more intermediate elevations before ascending to the final destination altitude. As previously noted, the altitude at which unit members sleep is the most important factor (ie, the lower the sleeping altitude, the better). The disadvantage of both of these ascent profiles is that they take time, which may not be available to a unit in a rapidly evolving tactical situation.

Maintaining previously acquired altitude acclimatization would allow rapid deployment of a unit without risking altitude illness. The best way to achieve this from a physiological standpoint would be to station soldiers at high altitude so that they would always be in an acclimatized state. This strategy might be appropriate for a unit with a significant ongoing altitude mission. The other way to maintain altitude acclimatization would be to expose unit members to altitude at regular intervals. The schedule for doing that is not known, but could require at least weekly exposures.[12] Like stationing units at high altitude, this strategy might require a significant ongoing mission to justify the effort and expense involved.

When means to acquire or maintain altitude acclimatization are not available, successful rapid deployment to high mountains depends on pharmacological prophylaxis or supplemental oxygen to prevent altitude illness and increase performance. The logistical problems entailed in providing supplemental oxygen to units much larger than a squad probably prohibit this alternative as a realistic option for military deployment. Pharmacological prophylaxis, on the other hand, is a practical means for allowing rapid insertion of unacclimatized military personnel into high mountain environments.

At present, the most suitable pharmacological prophylaxis for military personnel deploying to high mountains is acetazolamide (see Chapter 24, Acute Mountain Sickness and High-Altitude Cerebral Edema). The recommended regimen is 125 to 250 mg twice a day or 500 mg slow-release formulation once a day, beginning 24 hours before ascent and continuing for several days after reaching altitude until soldiers acclimatize. Acetazolamide is both safe and effective in this prophylactic role. It is sanctioned by the US Food and Drug Administration (ie, it is FDA-approved) for prophylaxis against AMS. It also prevents altitude-induced, sleep-disordered breathing, which can cause daytime performance decrements (see Chapter 26, Additional Medical Problems in Mountain Environments). In most individuals, acetazolamide has only minor, easily tolerable side effects. Prophylaxis with acetazolamide should be used in individuals with a history of previous altitude illness. Given its effectiveness and relative safety, it should be strongly considered for all military unit members deploying to altitudes where the incidence of AMS can exceed 25% (ie, > 3,000 m) except for those individuals in whom the drug is explicitly contraindicated. There are currently no other recommended means of pharmacological prophylaxis in a military setting.

Medical Screening

Medical screening identifies individuals at increased risk for medical problems in mountain environments. If the risk to these individuals is high, they can be precluded from deploying. Those with lesser degrees of risk can be deployed with special precautions, surveillance to prevent problems, or both; or they can be identified and treated early before becoming casualties. Screening can identify two general types of problems: (*a*) the potential for environmental injury and (*b*) medical conditions that could be exacerbated by hypobaric hypoxia.

Environmental Injury. Altitude illness and cold injury are the main environmental disorders to which individuals deploying to the mountains might have increased susceptibility. Although several methods to predict susceptibility to altitude illness have been investigated (see Chapter 25, High-Altitude Pulmonary Edema, and Chapter 26, Additional Medical Problems in Mountain Environments), they involve measurements of a person's ventilatory response to hypoxia, and are neither very sensitive nor practical for use on large numbers of people. In the setting of a military deployment, a positive history of a previous episode of altitude illness may be the most practical predictor of susceptibility. Unfortunately, many individuals have not had sufficient prior exposure to high altitude to determine if they are susceptible. For small units with a committed high-altitude mission, measurement of the cardiac and respiratory response to normobaric hypoxia (11.5% inspired oxygen) at rest and during 50% of maximum exercise may allow detection of individuals at high risk of altitude illness.[13]

Exacerbation of Preexisting Medical Conditions. Preexisting medical conditions that can be exacerbated by altitude exposure are primarily those that affect respiration and oxygen transport. These conditions are not common in most military populations because they are not compatible with active service and are either screened out prior to entering the military or at the time the problem develops. Conditions that might be found in military personnel and that should be screened for prior to deployment to high altitude are listed in Table 27-1.

Sickle cell trait may be relatively common in military populations and is thought to confer a risk of splenic infarct during exposure to altitudes over 2,500 m.[14,15] There has been some debate about the risk conferred by sickle trait during altitude exposure, owing, in some reported cases,[16] to possible inaccurate identification of the precise hemoglobinopathy. Because splenic infarct or incapacitation due to sickling at altitude would be a significant problem for the afflicted individual, the unit, and medical resources, screening for the presence of sickle cell trait by history or laboratory testing should be done if deployment to high altitude is a possibility. Those identified as having sickle cell trait can then be further evaluated on an individual basis to determine their specific risk. If they have a mixed hemoglobinopathy, a high percentage of sickling under hypoxic conditions, or both, then the medical officer should give strong consideration to giving those individuals a formal medical profile that limits their exposure to altitudes higher than 2,500 m.

Two general options are possible for individuals who are determined by screening to be at high risk for medical problems during altitude deployment. If the condition for which they are at risk can be prevented by appropriate prophylactic measures, then consideration should be given to allowing that individual to deploy *with prophylaxis*. Examples include use of nifedipine for HAPE or acetazolamide for severe AMS symptoms. Conditions that do not respond to prophylaxis should be evaluated for a medical profile to limit altitude exposure.

Individuals with history of life-threatening HAPE or HACE should be evaluated for a medical profile to limit their altitude exposure. Likewise, those with a history of thromboembolic event at high altitude should also be considered for a medical profile. Individuals with mixed hemoglobinopathies or a high percentage of sickling when their blood is exposed to hypoxic conditions should be considered for a profile to limit their exposure. Pregnant women should receive a temporary medical profile to limit their altitude exposure to lower than 2,500 m while they are pregnant.

TABLE 27-1

MEDICAL SCREENING FOR DEPLOYMENT TO ALTITUDE

Condition or System	Example
History of Environmental Injury	Altitude illness Cold injury
Cardiovascular Disease	Essential hypertension Coronary artery disease
Pulmonary Disease	Chronic obstructive pulmonary disease Asthma Pulmonary hypertension
Neurological Disease	Seizures Migraine headache
Hematological Disease	Anemia Sickle cell trait
Musculoskeletal System	Overuse injury
Pregnancy	—
Medications	Any that cause respiratory depression

In units with an altitude mission, initial medical screening can be done when an individual joins the unit. Prior to any altitude deployment, medical records for all deploying unit members should be screened to identify new conditions that may have developed and that could confer risk. All medical waivers that allow an individual to stay on active duty with an otherwise disqualifying medical condition should be examined to determine whether that condition confers a risk at altitude.

Training

Adequate training is an essential ingredient of an effective health maintenance program for military personnel deployed to a high mountain environment. Three types of training are needed during the predeployment period. First, all unit personnel should be familiarized with the health threats of the mountain environment and the countermeasures for those threats. Second, the military tasks and skills that might be used during deployment should be trained and practiced to the highest degree of proficiency, to lessen the impact of altitude-induced physical and cognitive performance decrements. Specific strategies to decrease errors and increase performance should be briefed (see Chapter 23, Cognitive Performance, Mood, and Neurological Status at High Terrestrial Elevation, and Chapter 24, Acute Mountain Sickness and High-Altitude Cerebral Edema). Third, physical training should be ongoing to maintain a high level of fitness. With regard to physical training, however, it is important that unit leaders understand that fitness will *not* prevent altitude illness, and that the altitude-induced decrement in maximum physical performance will be relatively greater in physically well-conditioned individuals (see Chapter 22, Physical Performance at Varying Terrestrial Altitudes). Training on environmental health threats is the responsibility of medical support personnel. The military task and physical training will be provided through the unit command structure, but it is the responsibility of medical personnel to ensure that the importance of that training to the unit capabilities is understood.

Adequate training on health threats in mountain environments includes recognition of major environmental factors and the injury or illness and performance decrements they cause, the preventive measures that can be taken, and first aid (self care and buddy aid). Environmental factors and the health problems they cause are listed in Exhibit 27-1; they are discussed in detail along with the specific countermeasures in the previous chapters of the Mountain Environments section of this textbook.

In addition to presenting specific environmental health threats and countermeasures, some key concepts should be emphasized. Soldiers should understand that mountains are a complex and inherently dangerous environment. They must realize that hypoxia is ubiquitous, that no one is entirely immune to its effects, and that the physical and cognitive performance decrements it causes can exacerbate risks from other environmental factors. Knowing the usual time course of acclimatization helps people tolerate symptoms of AMS more easily. If pharmacological prophylaxis with acetazolamide is required, then soldiers should understand its purpose, safety, and side effects so that they are comfortable taking the drug.

Factors common to all deployments should also be reviewed in training, not only the factors specific to mountain environments. These include personal hygiene, skin care, and maintenance of hydration and nutrition. Most of this training should take place prior to deployment. Consideration should be given to refresher training during deployment, when specific problems noted by medical surveillance can be emphasized.

Provisions for Protective Equipment and Supplies

Medical support personnel need to facilitate the supply and distribution of items necessary for health maintenance of unit members during deployment to mountain environments. Clothing and shelter suitable for the cold weather conditions are obvious requirements. A consideration with clothing supply is the issue of scarves or balaclavas through which individuals can breathe at very high altitudes to help prevent high-altitude pharyngitis and bronchitis due to drying of the upper respiratory passages. Adequate sun block for the skin and lips is necessary, as are UV-blocking sunglasses with side shields to prevent eye damage from light reflected off snowfields and rocks. Sunglasses, gloves, and other items that can be easily misplaced should have cords to attach them to the person so that they are less easily lost when the individual is hypoxic. Hiking sticks or staffs will help prevent trauma from falls in rugged mountain terrain (Figure 27-1). If prophylaxis with acetazolamide is to be used, then adequate supplies will have to be obtained and issued.

Provisions for adequate water, nutrition, and field sanitation are critical elements of health maintenance in any military deployment—and no less in deployment to mountain regions; medical personnel should be intimately involved in planning

Fig. 27-1. Special equipment may help decrease environmental injuries in mountain environments. Hiking staffs (sticks) can help prevent falls when military personnel move through rugged mountain terrain. Medical personnel should recommend procurement and issue of items that could prevent injury, even if these items are not available in the normal military supply chain. Much useful mountaineering equipment for recreational mountaineering is available in the civilian marketplace. Photograph: Reproduced from *Medical Problems of Military Operations in Mountainous Terrain*. US Army Training Film TF8-4915; 197–.

for them. As discussed in the chapter by Montain in *Medical Aspects of Harsh Environments, Volume 3*,[11] although the fluid requirement at high altitude is increased, assuring an adequate supply is fraught with potential difficulties. Likewise, the caloric requirement is increased in high mountains, but, due to a variety of factors, the tendency is for decreased food consumption. Increasing the carbohydrate content of the diet (to ~70%) will make the rations more palatable and help prevent symptoms of altitude illness.

Poor sanitation, the leading source of noncombat disease and manpower losses for military units from the beginnings of organized warfare through the most recent conflicts, is as least as great a problem—if not a greater one—at high altitude as in any other harsh environment. The combined effects of cold air temperatures, limited water, and hypoxia-related decrements in cognition and mood constrain both the opportunity and the motivation for maintaining good personal hygiene. Rugged terrain and limited water can force personnel to rely on ice and snow within small, confined areas for both their water supply and disposal of waste, creating a high potential for contamination. In addition, reduced ambient air pressure at high altitudes lowers the boiling point of water, making heat sterilization of water progressively inefficient at higher altitudes.

Treatment of Environmental Injury and Illness

When preventive measures are unable to preclude the occurrence of DNBI, the key to maintaining unit fighting strength is either effective treatment with return to duty or timely evacuation. Methods for treating of the constellation of DNBI likely to occur during deployment in mountains (see Exhibit 27-1) are discussed in Chapters 24, 25, and 26. The medical support elements needed to provide adequate treatment include (*a*) a surveillance system to detect illness and injury as early as possible, (*b*) trained medical personnel to provide the treatment, (*c*) appropriate equipment and supplies, and (*d*) treatment and evacuation facilities. Surveillance, training, and equipment and supply needs are discussed here; treatment and evacuation facilities are discussed below in the Deployment of Medical Support Assets section of this chapter.

Medical Surveillance

Medical surveillance is an important tool for medical personnel to use at all echelons of the field medical support system. It serves a dual purpose in that it facilitates early detection of illness and injury and also helps identify developing health threats so that preventive action can be taken. Effective surveillance can be accomplished by (*a*) actively monitoring parameters of health in unit members and (*b*) recording the incidence of injury and illness to facilitate identification of developing problems so that preventive measures can be taken.

To actively monitor a unit deployed in the mountains, medical personnel must see the unit members frequently enough to have some basis for judging their state of health. The signs and symptoms of environmental illness are indicators to which medical personnel obviously should be highly attuned. For instance, the absence of an altitude-induced diuresis in the first day or so following ascent should alert the medical officer to the possible development of serious altitude illness. Likewise, truncal ataxia is a sensitive sign of developing altitude illness. One of the simplest indications of overall health status of individuals at high altitudes is body weight. Weight gain or failure to lose a small amount of weight in the first few days of deployment may signal onset of altitude illness, for it is an indicator that the altitude-induced diuresis necessary for successful acclimatization has not occurred. Over a longer period of time, body weight reflects nutrition and hydration status. Obtaining accurate body weights in the field may not be practical or necessary, however. Most individuals are capable of detecting meaningful weight change in themselves, so that it may be sufficient for medical personnel to merely inquire about weight change rather than actually measure it. Severe weight loss at very high altitudes (climber's cachexia; see Figure 26-7 in Chapter 26, Additional Medical Problems in Mountain Environments) will be apparent from physical appearance. Hydration status can also be monitored fairly simply by noting the color of the urine (as described in Section I: Hot Environments, and Section II: Cold Environments, in *Medical Aspects of Harsh Environments, Volume 1*.[8])

Awareness of the incidence of environmental injury and illness is best achieved by keeping written records and reviewing them regularly to look for increasing incidence, clusters of events, or specific types of illness or injury that indicate a developing threat (ie, sentinel events). This activity is appropriate at all echelons of medical support in mountain environments.

Training

Because the unique constellation of medical problems and the rugged topography associated with mountain terrain present special challenges to providing medical support for military units deployed in the mountains, medical personnel require extra training to function successfully. The training should (*a*) furnish the information necessary to diagnose and treat the injuries and illness associated with high mountain environments and (*b*) teach the specific techniques and skills needed to operate specialized equipment and perform rescue and evacuation from rugged terrain features.

The specific injuries and illnesses that medical personnel are likely to have to treat during deployment to mountain regions are listed earlier in this chapter (see Exhibit 27-1). The techniques for diagnosis and treatment of these are presented in Chapters 24, 25, and 26 of this textbook and are also found in other sources.[7,17–19] In addition to the information on diagnosis and treatment, the key concept, that *hypobaric hypoxia has a pervasive influence in all activity at high altitude,* must be stressed. Medical personnel should know that the first step in treating any altitude-related illness is to either evacuate the victim to a lower elevation or provide supplemental oxygen. Additionally, medical officers should consider the potential for a harmful interaction of hypoxia with any medications they administer. And finally, they need to realize the extent to which hypobaric hypoxia can degrade their own physical and mental performance and take appropriate steps to limit the consequences of those effects.

Techniques for evacuation of casualties during military operations in mountain terrain are found in US Army publications[20,21] and in myriad civilian sources. Some of the subjects that should be covered are techniques for manual carries and litter carries on steep slopes and cliffs (Figure 27-2). Triage and evacuation for a mass casualty situation should be reviewed in the specific context of avalanche and rock slides. In addition to specific tech-

Fig. 27-2. Evacuating casualties and moving medical supplies in mountain terrain can involve techniques that require special training to perform with competence and safety. Training should be accomplished prior to deployment. Refresher training and practice during deployment will help make the skills more automatic and less vulnerable to hypoxia-induced decrements in physical and cognitive performance. Photograph: Courtesy of Murray Hamlet, DVM, Chief, Research Support Division, US Army Research Institute of Environmental Medicine, Natick, Mass.

niques, the trainer should emphasize several important concepts about mountain evacuation. Personnel must realistically assess their own capabilities in the context of hypoxia-induced performance decrements and plan accordingly. Because weather, terrain, and operational conditions can vary greatly in the mountains, personnel involved in evacuations should always have alternative plans and be skilled in the use of field expedients. Finally, to prevent shock or further trauma, they should make the utmost effort to protect the casualty from the harsh environmental conditions.

Ideally, training of medical personnel should take place prior to deployment. The mountains, however, are the best place to train for mountain operations. Consequently, refresher training or practice sessions should be given during deployment whenever feasible. Personnel with an ongoing mission to support units that deploy should train in mountain environments as frequently as possible.

Provision for Equipment and Supplies

The mountain environment affects medical logistical requirements for treatment and evacuation of patients in two ways. First, the characteristic types of medical problems found in the mountains determine the equipment and supplies that will be needed. Second, environmental parameters can alter drug action and the normal operation of some medical equipment. Additionally, environmental factors such as cold temperature and decreased atmospheric pressure can have direct detrimental effects on some supplies and equipment (eg, freezing of liquid medications, volume expansion of air in intravenous bags or bottles of medication). Planning for medical support operations in mountain terrain will have to take these effects into consideration.

The major medical problems caused by the mountain environment are listed previously (see Exhibit 27-1); deployment planning should provide for sufficient medical supplies to treat the projected incidence of these problems. Special consideration should be given to the means for treating altitude illness because those conditions are not found in deployment to other environments. Supplemental oxygen supplies should be made available whenever possible and by whatever means, as oxygen can be used in treating all altitude illnesses and it may be helpful as an adjunctive treatment for other medical conditions at altitude. "Bottled" oxygen (in metal tanks) has the disadvantages of being heavy, cumbersome, and possibly explosive if struck by gunfire or shell fragments. In relatively fixed facilities with adequate power supplies to run the devices, oxygen molecular concentrators are a good alternative to oxygen tanks.[22] In the most forward echelons, the amount of oxygen a patient breathes can be increased through use of lightweight, portable, cloth hyperbaric chambers (PHC; eg, the Gamow bag), and these devices should be made available. Drugs that should be available for treating altitude illness include acetazolamide for treating AMS and altitude-related sleep disorders, dexamethasone for treating severe AMS and HACE, and nifedipine for treating HAPE.

Altitude effects on drug action are primarily a function of hypoxia-induced changes in body physiology. Altitude effects on medical equipment function are largely due to hypobaria. Both effects play a role in general anesthesia for surgery.[23,24] The practical limits for useful general anesthesia are not known precisely, but surgical services should probably not be located higher than 4,000 m, and much lower would be preferable.[25] Ketamine is a reasonable choice for intravenous anesthesia because it has minimal effects on the airway and the respiratory drive.[25]

DEPLOYMENT OF MEDICAL SUPPORT ASSETS

Effective deployment of medical assets is essential to successful support of military units operating in high mountain environments. The assets that are available are a function of organization level, but general principles apply to most levels. The major factors that affect how medical resources are used in the mountains are the tactical mission and the environment. In a sense, the tactical mission determines the support requirements, while the environment sets constraints on how those requirements can be met. Medical assets must be deployed to conform to the tactical plan within the often significant constraints imposed by the mountain environment.

Environmental Effects on Medical Support

Conformity to the tactical plan is a fundamental principle of medical support. The rugged, nonlinear topography of mountain regions shapes tactical plans in a general way, for it severely limits the ability of large units to maneuver. As a result, combat commanders place increased reliance on smaller, separate maneuver units that act more independently within the overall tactical plan. Medical assets must be configured and deployed to support these units.

The mountain environment imposes constraints on virtually all aspects of medical support activities from the ability to establish medical treatment facilities with appropriate proximity to the supported units, to establishing and maintaining effective evacuation and resupply. Environmental factors that have the major impact are (*a*) the rugged terrain, (*b*) the decrease in ambient oxygen, and (*c*) the cold temperature and frequent harsh weather.

Rugged terrain severely limits mobility and lines of communication. The amount of time required for overland transportation or evacuation of casualties can be greatly increased. The routes for movement forward, evacuation, and resupply are often limited by terrain features. Routes that are determined by features of the terrain are susceptible to disruption by enemy action, or by natural events such as rock slides and avalanches. Vertical terrain also limits space for medical facilities.

Low oxygen content in ambient air causes performance decrements in medical personnel and also in any equipment powered by fuel combustion. Personnel suffer decrements in both physical work and cognitive function. Casualties may need supplemental oxygen at high altitude for conditions that would not require it at lower altitude. Internal combustion engines on vehicles, generators, and cooking equipment are progressively less efficient at higher altitudes. In addition to low oxygen content, low ambient air pressure may also degrade performance of equipment. Helicopters and propeller-driven aircraft have progressive difficulty operating at higher altitudes. The problems are especially significant for takeoffs and landings, where both types of aircraft may lack lift, and sufficient runway space may not be available. Low ambient air pressure may alter the operating characteristics of medical equipment. Anesthesia and respiratory support equipment, for example, are progressively inefficient at higher altitudes.

Like low oxygen content, the cold ambient air temperatures at high altitude can effect personnel, equipment, and many medical supplies. Harsh climate conditions affect transportation and may limit options for evacuation and resupply. This means that casualties at forward echelons will be held there longer, and that larger supply stores are needed there also.

General Principles for Deployment of Medical Assets

The major constraints to medical support in the mountains are (*a*) the need to support smaller and disconnected tactical units, (*b*) the facts that transportation may be difficult and mobility limited, and (*c*) significant performance decrements of personnel and equipment. The primary means to counter these constraints are to "fix forward" to maintain proximity to the supported units, to maintain as much flexibility as possible in transportation options, and to augment personnel and equipment.

To provide support to smaller and more isolated maneuver units, the echelons of the medical support within the combat zone may have to be reconfigured and moved far forward. If the maneuver units are widely separated, then forward echelons of medical support may need to be augmented to provide adequate proximity to supported units. Increased reliance may need to be placed on buddy aid training and other multipliers of medical capabilities in small, isolated units. These individuals will need to be trained to care for environmental injuries prior to deployment. Location of assembly points, aid stations, clearing stations, and other elements of support at confluences of natural lines of patient drift and evacuation routes along creeks, streams, and small rivers may allow coverage of units that are dispersed in a wider area, but locating routes at these points also increases the opportunity for disruption by enemy action or by catastrophic environmental events such as flooding or avalanches.

The fundamental principle of flexibility is the key to dealing with transportation problems in mountain terrain. Both alternative routes and alternative methods of transportation must be planned for and maintained. As previously noted, the rugged topography of mountains limits the number of natural transportation routes for evacuation and resupply and makes those routes susceptible to disruption by enemy action or natural catastrophes. To assure continued operations, medical personnel should identify and carefully plan for use of all possible land routes within their area of responsibility.

In addition, all alternative methods of transport should also be considered and planned for. Air transportation circumvents many of the problems inherent in overland travel, but it is severely limited by the landing zone requirements for fixed-wing aircraft and by altitude-ceiling limitations for many military rotary-wing aircraft (ie, helicopters).

Frequent bad weather conditions in the mountains also limit the use of aircraft.

Rugged terrain and the lack of adequate roads may severely limit the use of vehicles in many mountain regions. Many areas will not be accessible by motor vehicles or air transportation. In those areas transportation of patients and supplies will have to be by humans or pack animals (Figure 27-3). Most medical units have contingencies for casualty and supply transport by litter bearers in the forward battle area, but in mountain regions this contingency may have to be used to support areas further to the rear. Many modern military units have not used pack animals, but their use is an option that could be considered in difficult mountain terrain.

In addition to flexibility in routes and in means of transportation in the mountains, flexibility must also be maintained to deal with times when no transportation is possible, owing to weather conditions, blocked routes, or both. Medical support planners must make provisions for the possible extension of normal maximum hold times for casualties at all forward echelons of medical support.

Medical support to military operations will require augmentation of personnel and provisions for specialized equipment and training (Figure 27-4). Augmentation of personnel in forward elements of medical support will be required because of the necessity to support smaller, dispersed combat maneuver units, and because of the decreased reliance on vehicle transport and the hypoxia-induced decreased physical performance. Decrease in physical performance capacity means an increase to 6-man litter teams (from the standard 4-man teams) and shorter distance carries. Litter relay points may be needed. Special training for mountain litter-carrying techniques will be necessary to function in rugged terrain.

Fig. 27-3. *"I calls her Florence Nightingale."* As this Bill Mauldin cartoon from World War II points out, pack animals are an alternative method of transportation of casualties and supplies in rugged mountain terrain. Copyright 1944. By Bill Mauldin. Reprinted with permission by Bill Mauldin.

Fig. 27-4. *"That's our mountain team."* Bill Mauldin's cartoon from World War II uses humor to emphasize the need for augmentation of personnel in medical units supporting military units operating in mountain terrain. For example, this tall–short team of stretcher bearers could carry a casualty up or down a slope and always keep the stretcher level. A more cynical interpretation could be that Mauldin is ridiculing the Army's seeming predeliction to view soldiers as interchangeable parts. Copyright 1944. By Bill Mauldin. Reprinted with permission by Bill Mauldin.

SUMMARY

Medical support in mountain environments requires familiarity with the threat and adequate planning to accomplish the mission. Mountain environments cause a specific constellation of medical problems and performance decrements, in which hypobaric hypoxia plays a significant role. To apprise the tactical commander of possible loss of unit strength and to plan adequate medical support, medical personnel should estimate the DNBI and environmentally induced performance decrements prior to deployment. Health maintenance of military units deployed to high mountain terrain requires preventive measures and effective treatment of injury and illness, with return to duty or evacuation of the casualty being the two best outcomes. Medical screening can identify those at high risk for environmental injury in the mountains. Appropriate ascent profiles or pharmacological prophylaxis for altitude illness will help maintain unit fighting strength. Unit personnel should be trained to recognize environmental threats and be provided with appropriate countermeasures to protect themselves. Medical personnel should be trained to treat the constellation of environmental medical problems in the mountains and provisioned with appropriate equipment and supplies to do so. The mountain environment can severely hamper the function of medical support. To conform to the tactical mission and to operate efficiently under the restrictions imposed by the mountain topography and climate, medical support units will need to be augmented and to maintain flexibility in their configuration and deployment.

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