

AD_____

USARIEM TECHNICAL NOTE 94-2

**MEDICAL PROBLEMS IN HIGH MOUNTAIN
ENVIRONMENTS**

A Handbook for Medical Officers

**U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE**

**Natick, Massachusetts
01760-5007**

February 1994

Approved for public release; Distribution unlimited

**UNITED STATES ARMY
MEDICAL RESEARCH AND DEVELOPMENT COMMAND**

The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or as reflecting the views of the Army or the Department of Defense.

DTIC AVAILABILITY NOTICE

Qualified requesters may obtain copies of this report from Commander, Defense Technical Information Center (DTIC) (formerly DDC), Cameron Station, Alexandria, Virginia 22314.

DISPOSITION INSTRUCTIONS

Destroy this report when no longer needed.

Do not return to the originator.

Approved for public release Distribution Unlimited

TECHNICAL NOTE
NO. 94-2

**MEDICAL PROBLEMS IN HIGH MOUNTAIN
ENVIRONMENTS**

A Handbook for Medical Officers

Prepared by

Allen Cymerman, Ph.D. and Paul B. Rock, LTC, MC

February 1994

US Army Research Institute of Environmental Medicine
Natick, Massachusetts 01760-5007

Approved for public release
Distribution Unlimited

TECHNICAL NOTE
NO. 94-2

FOREWORD

Following realignment and reorganization in the 1990's, the U.S. Army will consist of fewer units with the same requisite levels of training, technical skill and motivation. These units will have a broader mission, however. Changes in strategic and geopolitical considerations have increased the contingencies the Army faces worldwide to include conducting operations other than war. To meet those contingencies, units must be able to operate successfully in a wide range of environmental extremes, including high-altitude mountainous terrain.

High mountain environments are inherently dangerous. They can be very unforgiving for those without adequate knowledge, training and equipment. Commanders and medical support personnel must understand that the interaction of environmental conditions with mission responsibilities and individual and unit characteristics can have profound negative impacts on the outcome of the mission. Adequate planning and preparedness can reduce or prevent such impacts. Preparing for and responding to environmental health hazards are critical elements to consider in the intelligence preparation of the battlefield.

The most recent official military guidance concerning medical problems at high terrestrial elevations is Department of the Army Technical Bulletin TB MED 288, "Medical Problems of Man at High Terrestrial Elevations," published in October 1975. While that publication contains information that is still relevant and useful, much of its content is not current. The purpose of this technical report is to provide updated information and guidance on the prevention and treatment of medical problems likely to be encountered by soldiers exposed to high terrestrial elevations. This information is based on research and field studies conducted by the U.S. Army Research Institute of Environmental Medicine as well as relevant material published in the medical literature. It is not intended to contravene or replace established policy and doctrine of the Department of the Army or the Surgeon General. General guidance on aspects of military mountain operations can be found in FM 90-6, Mountain Operations and in TC 90-6-1, Military Mountaineering Training.

Suggestions for changes or additions should be addressed to:

COMMANDER
U.S. Army Research Institute of Environmental Medicine
AUN: SGRD-UE-ZA
Natick, MA 01760-5007

TEL.: DSN 256-4811
COMM 508-651-4811
FAX: DSN 256-5298
COMM 508-651-5298
E-Mail: David.Penetar@na.amedd.army.mil

TABLE OF CONTENTS

SECTION	Page
Foreword.....	i
Table of Contents.....	ii
Acknowledgments.....	iv
Introduction.....	1
Human Physiologic Responses to High Altitude.....	4
Barometric Pressure and Oxygen Availability.....	4
Hypobaric Hypoxia and Altitude Acclimatization.....	5
Acclimatization and Military Operations.....	8
Medical Problems in High-Mountain Areas.....	9
Medical Problems Related to Sustained Hypoxia.....	9
Acute Mountain Sickness.....	9
High Altitude Pulmonary Edema.....	14
High Altitude Cerebral Edema.....	19
High Altitude Peripheral Edema.....	22
High Altitude Retinal Hemorrhage.....	23
Thromboembolic Events.....	24
Subacute Mountain Sickness.....	25
Immune Suppression and Poor Wound Healing.....	25
Medical Problems Unrelated to Hypoxia.....	25
Cold Injuries.....	26
Solar Radiation Injuries.....	26
High Altitude Pharyngitis and Bronchitis.....	28
Lightning Injuries.....	29
Carbon Monoxide Poisoning.....	29

Terrain-Related Trauma and Orthopedic Problems	30
Constipation and Hemorrhoids	31
Infectious Diseases	31
Pre-existing Medical Conditions	32
Soldier-Related Factors in High Mountain Operations	34
Reduced Physical Performance	34
Psychological Effects of Sustained Hypoxia	35
Sleep Disturbances	36
Dehydration	37
Inadequate Nutrition	38
Pharmacologically-Active Substances	39
Health Service Support Problems in High-Mountain Operations	42
Impact of Mountain Environments	42
Countermeasures for Adverse Environmental Factors	43
APPENDIX A: Medications Treatment of Altitude Illnesses	45
APPENDIX B: Related Reading	47

ACKNOWLEDGMENTS

This technical note is the product of the contributions and suggestions of many individuals. The following individuals made noteworthy contributions: COL Gerald Krueger, Ph.D., LTC Frazier Glenn, Ph.D., LTC Gaylord Lindsay, Ph.D., MAJ Eugene Iwanyk, M.D., MAJ Paul Amoroso, M.D., MAJ James Roach, M.D., Reed Hoyt, Ph.D. CPT James Cook, M.D., LTC Mary Mays, Ph.D., Stephen Muza, Ph.D., Louis Banderet, Ph.D., Charles Fulco, M.A.T. and Mr. James Devine

INTRODUCTION

Rapid insertion of a military unit into a high terrestrial altitude environment causes a cascade of physiological responses in unacclimatized personnel. This cascade is triggered by hypobaric hypoxia and often develops into pathologic conditions requiring intervention by medical personnel. The pathology induced is usually manifested in distinct symptom syndromes such as acute mountain sickness (AMS), high altitude pulmonary edema (HAPE) and high altitude cerebral edema (HACE). These syndromes are specific to high terrestrial altitude, in contrast to other environmentally related medical conditions such as sunburn, dehydration and cold injury which are common in high mountains, but also are seen frequently in other environments. The impact of these altitude illness syndromes on individual soldiers is variable, ranging from mild, self-limited discomfort to death. The impact on an operational unit can be equally variable, ranging from degraded efficiency of a minor portion of the unit's manpower to loss of enough personnel to compromise the unit's mission.

To accomplish the primary medical support mission of conserving fighting strength, medical officers and other military medical personnel must have sufficient knowledge of altitude medical problems to 1) advise the commander about the potential tactical impact of altitude exposure on unit personnel and operations, 2) recommend measures to prevent altitude-related problems, and 3) diagnose and treat altitude-related and other medical problems when they occur. Such expertise is not widespread in either the civilian or military medical community. Mountain medicine is seldom taught during formal medical training, and most of the skills and experience in this area have been accumulated by individuals with a personal interest in climbing and mountaineering.

Similarly, much of the research on high-altitude medical problems has also centered around recreational altitude exposure. The civilian experience provides an incomplete model, at best, for medical problems occurring during military operations in high-mountain regions because it does not take into account the obligate nature of factors related to a military unit's specific mission. Civilians who engage in mountain recreation are a self-selected group, with equipment designed specifically for the mountain environment and with wide latitude as to the circumstances of their high altitude exposure. On the other hand, soldiers are deployed to mountain areas on the basis of their unit's military function and the tactical situation, rather than their own interests and desires. Tactical equipment, while necessary for the military mission, may be a burden in terms of coping with environmental conditions. Soldiers also have little control over the circumstances of their deployment in the mountains. Tactical situation and mission goals dictate the timing, duration and location of military operations, often exposing soldiers to terrain and environmental conditions that would not normally be considered for recreational activities.

In the recreational setting, environmental factors such as hypobaric hypoxia and climatic conditions interact with individual characteristics such as fitness and state of hydration to cause medical problems. During military operations, this interaction is further affected by mission requirements such as the size and composition of loads carried, specification of uniforms and

combat protective gear, and maneuver routes for unit movements. The combination of environmental, mission and soldier-related factors can be additive or synergistic in its effect on the incidence and severity of environmentally-related illnesses (Figure 1).

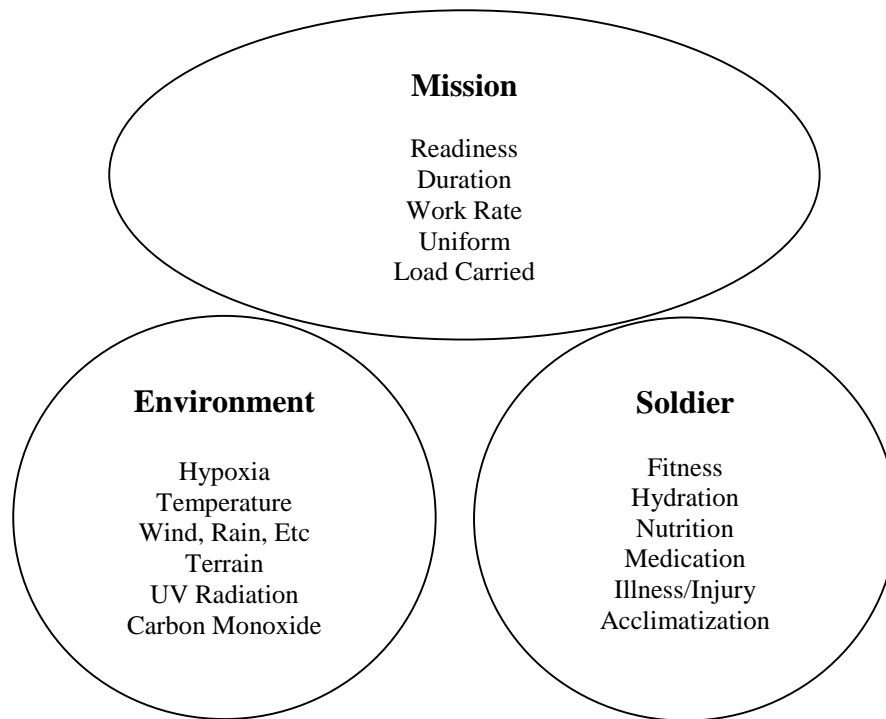


Figure 1. Factors contributing to medical problems of soldiers in high mountain areas.

This handbook is designed to be a resource for use by military medical personnel supporting military operations in the high mountains. It contains information on the specific constellation of environmentally related medical problems that occur at high altitude, but also considers effects of soldier- and mission-related factors that may pose medical and operational concerns. The first section reviews human physiologic responses to hypobaric hypoxia to provide background information for understanding the hypoxia-related medical problems unique to high altitude exposure. The second section discusses the medical problems associated with high mountain military operations. Hypoxia-related medical problems are presented first, emphasizing those which can significantly impact military operations by virtue of their high morbidity and/or mortality. Information is presented on the prevention, diagnosis and treatment of these conditions, as well as the administrative disposition of affected soldiers. Medical problems caused by other environmental factors in high mountain areas are briefly reviewed to alert medical personal to their threat.

Readers should also refer to other readily available resources for more complete description of medical conditions common to many environments in addition to high mountains. A section on soldier-related factors including hypoxia-induced physical and cognitive performance decrements is included to allow medical personnel to advise commanders on the potential impact and measures that can lessen the impact of those phenomena. The last section in the handbook highlights the potential influence of the mountain environment on the field medical support system itself, with general suggestions for modifications in staffing and planning that might reduce that impact.

HUMAN PHYSIOLOGICAL RESPONSES TO HIGH ALTITUDE

Decreased availability of oxygen in the ambient air (hypobaric hypoxia) is the only environmental stress unique to high terrestrial altitude. It lowers the oxygen supply to body tissues which causes altitude-illness and the decline in physical and mental performance often seen in military and civilian personnel operating in high mountain terrain. Hypobaric hypoxia can also interact with other factors in the environment to increase the likelihood of environmentally-related injuries, or it can exacerbate preexisting medical conditions. Given its widespread effects, a basic understanding of hypobaric hypoxia is essential for medical personnel who support military units operating in high mountain regions.

Barometric Pressure and Oxygen Availability

There is a curvilinear reduction in the ambient barometric pressure with increasing altitude (Fig. 2). The exact magnitude of the reduction in any geographic location depends on the combination of elevation, latitude, season and weather. The physiologic significance of decreased barometric pressure is related to the concomitant reduction in partial pressure of oxygen. Although oxygen makes up approximately 21 percent of the atmosphere at all elevations, the

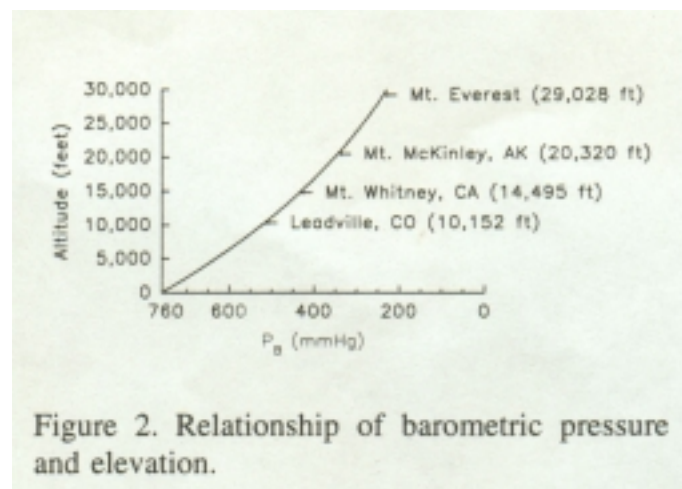


Figure 2. Relationship of barometric pressure and elevation.

progressive decrease in partial pressure of oxygen means there is less *actual* oxygen (i.e., a lower molecular concentration) available for respiration. For example, at sea level the barometric pressure (P_B) is approximately 760 mmHg, and the partial pressure of oxygen (P_{O_2}) in dry air is about 160 mmHg ($760 \text{ mmHg} \times 0.21$). At 18,000 ft (5,500 m), P_B is approximately 380 mmHg and the P_{O_2} is only 80 mmHg (380×0.21).

The reduced partial pressure of atmospheric oxygen at high altitude is the primary factor limiting the amount of oxygen supplied to body tissues through respiration. Although oxygen levels are reduced at each successive level of the respiratory system (i.e., air to lungs, lungs to blood, blood to tissue), the magnitude of these reductions is not greatly affected by altitude and the reduction in tissue oxygen supply is proportional to the partial pressure of oxygen in the rarified ambient air.

The relationship of decreased ambient oxygen to altitude illness and performance decrements provides a classification of altitude exposure based upon arterial oxygen content and its physiologic effects. Sea level to 5,000 ft (0 to 1,525 m) is considered low altitude. Arterial hemoglobin saturations are generally above 96% in healthy people at these altitudes. Moderate

altitude extends from 5,000 to 8,000 ft (1,525 to 2,440 m) where arterial hemoglobin saturation is normally above 92%, and any effects of altitude are mild and temporary. *High altitude* extends from 8,000 to 14,000 ft (2,440 to 4,270m's). At these elevations arterial oxygen saturation is in the "knee" of the oxygen-hemoglobin saturation curve, ranging from approximately 92% down to about 80% saturation. Altitude illness and performance decrements are increasingly common in this range. Altitudes above 14,000 ft produce hemoglobin saturations that are on the "steep" portion of the oxygen-hemoglobin saturation curve where a small decrease in oxygen tension results in a relatively large drop in hemoglobin saturation. The region from 14,000 to 18,000 ft (4,270 to 5,490 m) is classified as *very high altitude*. Altitude illness and performance decrements are the rule at these altitudes. Regions above 18,000 ft to 29,028 ft (8,848 m, the summit of Mt. Everest) are classified as *extreme altitude*. Without physiologic compensation, arterial hemoglobin saturations would drop to the range 50% or below on the summit of Mt. Everest. While the physiologic adaptations discussed below allow humans to function at extreme altitude for short periods of time, it is felt that permanent human habitation is not possible there.

Hypobaric Hypoxia and Altitude Acclimatization

Sustained hypobaric hypoxia at elevations over 5,000 ft (1,524 m) triggers a series of integrated physiologic changes in soldiers who ascend from lower altitudes. These changes function to increase oxygen supply to body tissues and are most noticeable in those body systems that are directly related to oxygen delivery (i.e., cardiovascular and respiratory), but changes probably occur in all organ systems. Over time, the series of changes produce a state of physiologic adaptation termed "acclimatization." Altitude acclimatization allows soldiers to achieve the maximum physical work performance possible for the altitude to which they are acclimatized. More importantly from a medical perspective is that acclimatization is associated with the absence of altitude illness. The time course and success of acclimatization is a function of the interaction between the unique physiologic characteristics of the individual soldier and the magnitude of hypoxic stress as defined by the elevations gained and the speed of ascent. Because it is altitude specific, full acclimatization to a lower altitude confers only partial acclimatization to a higher altitude if a soldier ascends from the lower to the higher elevation. Once acquired, acclimatization is maintained as long as the soldier remains at altitude, but is lost upon return to lower elevations.

The physiologic changes that produce altitude acclimatization affect all phases of oxygen delivery from gas exchange in the lungs to diffusion of oxygen into mitochondria within individual cells. The first consequence of the reduction in alveolar oxygen caused by the reduced partial pressure of oxygen at high altitude is a decrease in arterial oxygen content that stimulates peripheral and central chemoreceptors. This effect occurs when the inspired P_{O_2} is lowered to approximately 122 mmHg or less, a level that is reached at elevations of 5,000 ft (1,524 m) or greater. The sensitivity of peripheral chemoreceptors is probably genetically determined, but can be modified by metabolic stimulants such as caffeine and cocoa, respiratory stimulants such as progesterone, respiratory depressants such as alcohol or sleeping medications, and by miscellaneous other factors.

Chemoreceptor stimulation causes an increase in ventilation, which raises the partial pressure of oxygen in the alveoli by decreasing the partial pressure of carbon dioxide. Above approximately 8,000 ft (2,438 m) the increased ventilation does not entirely compensate for the decreased oxygen content of the inspired air, and there is a sustained decrease in arterial oxygen that is proportional to the specific elevation. The lower arterial oxygen causes continued chemoreceptor stimulation. The resulting hyperventilation causes respiratory alkalosis that tends to limit the increase in ventilation during the early altitude exposure. Within several days at altitude, the compensate for the respiratory alkalosis by increased excretion of bicarbonate. Resting ventilation continues to rise slowly due to the continued chemoreceptor stimulation, reaching a maximum in 7 to 10 days. Upon further ascent, the process is repeated to a smaller degree with further increases in ventilation. **Increased ventilation is the principal mechanism responsible for improving the oxygen availability at the cellular level during acclimatization.**

The next aspect of oxygen delivery affected by sustained hypobaric hypoxia is transport of oxygen from the lungs to the tissues. Changes occur in both the oxygen carrying capacity and distribution of cardiac output. Within hours of ascent there is a 10-20% decrease in plasma volume caused by a movement of fluid out of the vascular compartment into the interstitial and intracellular compartments. In soldiers who acclimatize normally, this fluid is rapidly excreted by the kidneys. The result of the loss of plasma volume is a relative increase in hemoglobin concentration and effective oxygen carrying capacity of the blood without an absolute increase in red cell number. Although erythropoietin stimulation occurs within the hours of the start of sustained altitude exposure, the increase in red cell production it causes is not measurable for several weeks. Plasma volume tends to recover with prolonged (weeks to months) altitude exposure, but the hematocrit and oxygen carrying capacity remain high due to the increased red cell production.

The most notable altitude-induced changes circulatory parameters are associated with cardiac output and the cerebral and pulmonary circulations. Cardiac output is initially increased driven by a hypoxia-stimulation of sympathetic nervous system activity. The increase in cardiac output is a function of increased heart rate, since stroke volume is actually decreased due to the loss of plasma volume discussed above. Sympathetic activity also causes increased systemic blood pressure, peripheral vasoconstriction and increased basal metabolic rate. With sustained altitude exposure lasting for more than three weeks, sympathetic activity decreases and plasma volume tends to recover. As a result, heart rate decreases toward sea level values and stroke volume increases. The balance of these changes result in a decrease in cardiac output over time, although it always remains above sea-level values at rest and during submaximal exercise. On the other hand, maximal heart rate is decreased proportional to elevation and remains so after acclimatization. Consequently maximal work capacity is limited throughout altitude exposure.

Cerebral blood flow at high altitude is a function of the balance between hypoxia-induced vasodilation and hypocapnia-induced vasoconstriction from hypoxia-induced hyperventilation. Cerebral blood flow is always increased above approximately 8,000 ft (2,438m) in spite of hyperventilation, but tends to return toward sea-level values with acclimatization.

Altitude-induced changes in pulmonary circulation are characterized by pulmonary hypertension from increased resistance in the pulmonary arteries. The adaptive function of this change is unclear, but it may improve ventilation/perfusion matching. The magnitude of the increase in pulmonary artery pressure is to some extent proportional to the magnitude of the hypoxia, and any factors that decrease oxygen levels in the blood tend to exaggerate the increase in pulmonary artery pressure. Such factors include exercise, cold exposure and sleep apnea, all of which are common in soldiers at high altitude.

During sustained high altitude exposure, oxygen delivery at the tissue level is facilitated by a hypoxia-stimulated increase in red blood cell 2,3-diphosphoglycerate (2,3-DPG). The increase "shifts" the oxygen-hemoglobin saturation curve to the right, allowing red cells to release oxygen to the tissues more easily. At high to very high altitudes, the effect is counterbalanced by respiratory alkalosis which tends to shift the curve to the left, making it easier to load oxygen into the red cells in the lungs and harder to unload it at the tissues. However, at extreme altitudes the effect of the severe respiratory alkalosis predominates, and the curve is shifted to the left. This left shift allows a significant increase in red cell hemoglobin saturation for a given alveolar oxygen pressure at extreme altitude.

Although not well researched in humans, a number of altitude-induced changes probably occur at the tissue level. These are thought to include an increase in capillary density and number of mitochondria in muscle tissue. These changes function to reduce the distance oxygen has to diffuse from the blood to mitochondria. Additionally, there may be changes in enzymatic pathways themselves to more efficiently use the oxygen delivered.

The sequence of physiologic changes that produces acclimatization to high altitude takes time to complete. As previously noted, the amount of time required for a soldier to become acclimatized is a function of that individual's physiology and the magnitude of the hypoxic challenge as defined by the rate of ascent and the altitude attained. At lower altitudes or during slow ascents, the degree of hypoxia is mild enough that relatively small changes in physiology are effective in minimizing performance decrements. At higher altitudes or during fast ascents, the degree of hypoxia is increased, necessitating a more extensive series of physiologic changes which take more time to complete, and acclimatization takes longer. At extreme altitude the degree of hypobaric hypoxia is so severe that physiologic changes cannot compensate, and soldiers never acclimatize completely to those elevations.

For most soldiers at high to very high altitudes, 70-80% of the respiratory component of acclimatization occurs in a week to ten days and 80-90% of overall acclimatization is accomplished by three weeks to a month. Maximum acclimatization may take months to years, however. Some soldiers acclimatize more rapidly than others. There does not seem to be any way to accelerate the process. A few individuals appear not to acclimatize at all. Soldiers who do not acclimate can affect unit performance by their own degraded performance and/or as causalities to altitude illness. They should be considered for a physical profile to limit their deployment to high altitude. Unfortunately, there is no reliable way to identify these individuals except by their experience during previous altitude exposures.

Acclimatization is altitude specific. Once achieved at any elevation, it will be maintained as long as the altitude exposure continues. Exposure to higher altitudes will induce further acclimatization and descent to lower altitudes will cause a loss of acclimatization, a process often termed “deacclimatization.” Acclimatization is probably lost at approximately the same rate it develops so that soldiers lose 80-90% in the first three to four weeks after returning to low altitude.

Acclimatization and Military Operations

The ideal condition for soldiers operating in high mountain terrain is to be in a high degree of acclimatization because it allows maximum physical and mental performance and minimizes the incidence of altitude illness. However, the time needed to achieve acclimatization may be limited for many operational scenarios, however. Medical officers should be prepared to advise unit commanders regarding the advantages and time requirements necessary to achieve and maintain altitude acclimatization in unit personnel. They also should be prepared to give estimates of performance decrements and casualties due to hypoxia-induced altitude illnesses when operational contingencies preclude adequate acclimatization. Information on altitude illness and performance decrements is presented in later sections.

MEDICAL PROBLEMS IN HIGH-MOUNTAIN AREAS

Medical problems (other than ballistic injuries) that occur in soldiers operating in high mountain environments can be classified into three broad categories: 1) problems caused by sustained hypobaric hypoxia, 2) problems caused by environmental factors other than decreased ambient oxygen and 3) exacerbation of pre-existing medical conditions. The problems caused by sustained hypobaric hypoxia are unique to high mountains, and many medical personnel who have not had previous experience in that environment may be unfamiliar with them. Medical personnel are more familiar with pre-existing medical conditions and environmental injuries such as frostbite or trauma, which can occur in many different environments. However, even problems not directly caused by hypobaric hypoxia can be profoundly affected by it, and medical personnel must be aware of that potential.

Medical Problems Related to Sustained Hypoxia

The medical problems directly related to sustained hypobaric hypoxia are unique to high terrestrial altitude and are often termed “high altitude syndromes.” They range in incidence from common to rare and in severity from benign and self-limited to rapidly fatal. The incidence and severity are a function of the magnitude of the hypoxic stress as determined by the altitude, the rate of ascent and the length of exposure (hours, days, or months). Contributory factors of individual soldiers include their level of exertion, physiological susceptibility, age and coexisting medical problems. The most common high altitude syndromes are all forms of hypoxia-induced edema. These include acute mountain sickness, high altitude pulmonary edema, high altitude cerebral edema and altitude-induced peripheral edema. It is these edema-related syndromes that are usually referred to singularly or in aggregate as “altitude illness.” They are the most likely to impact on military operations and, consequently, are discussed here in the most detail.

An important point to remember about *all* high altitude syndromes is that because they are related to sustained hypoxia, they can usually be treated effectively by raising oxygen levels to the body tissues. Although this can be accomplished using supplemental oxygen, the most efficient means to decrease hypobaric hypoxia is to descend to lower altitude. **The preferred step in treating any high altitude syndrome is to evacuate the patient to a lower altitude whenever possible!**

Acute Mountain Sickness (AMS)

Acute mountain sickness is a self-limited symptom complex which occurs in unacclimatized individuals who ascend rapidly to altitudes 6,000 ft (1,829 m). The cause of this syndrome is thought to be hypoxia-induced subclinical cerebral edema. It is viewed as the benign end of a spectrum of altitude-induced edema in the brain, with clinically apparent high altitude cerebral edema (HACE) being at the opposite, more ominous end. Acute mountain sickness often proceeds both HACE and high altitude pulmonary edema (HAPE). Although benign and self-limited, AMS can have a significant negative impact on military operations by debilitating large

numbers of soldiers, thereby causing their units to be operationally ineffective for some period of time.

Incidence

The incidence and severity of AMS symptoms vary with the initial altitude, the rate of ascent, the level of exertion and individual susceptibility. Ten to twenty percent of soldiers who ascend rapidly (<24 hours) to altitudes between 6-8,000 ft (1,829-2,446 m) experience some mild symptoms. Rapid ascent to 10,000 ft (3,050 m) causes mild symptoms in 75% of personnel. Rapid ascent to elevations of 12-14,000 ft (3,670-4,300 m) will result in moderate symptoms in over 50% of the soldiers and 12-18% may have severe symptoms. Rapid ascent to 17,500 ft (5,333 m) causes severe, incapacitating symptoms in almost all individuals. Vigorous physical activity during ascent or within the first 24 hours after ascent will increase both the incidence and severity of symptoms.

Everyone is susceptible to AMS if they ascend rapidly to a sufficiently high altitude and remain there for several hours or more. Some soldiers are inherently more susceptible than others and experience the same symptoms on repeated exposures. Unfortunately, there is no reliable way to predict susceptibility except by an individual's previous experience. Anecdotally, women and older men appear to be less susceptible, and obese individuals more susceptible. A soldier's level of physical fitness does not appear to influence susceptibility.

The onset of AMS symptoms occurs 3-24 hours after ascent. Symptoms reach their peak severity in 24-72 hours and usually subside over the course of three to seven days. Further ascent without an acclimatization period usually exacerbates symptoms and can result in increased incidence of HAPE or HACE. The majority of AMS cases do not progress to more serious altitude illness without continued ascent.

Symptoms and Diagnosis

Headache is the most common AMS symptom. Usually it is symmetric, global in location and throbbing in character. It can be excruciating enough to effectively incapacitate a soldier. It is often most intense during the night and shortly after arising in the morning, a phenomenon usually attributed to increased hypoxemia caused by altitude-induced periods of sleep apnea which are nearly universal in high mountains. The headache is worsened by strenuous exercise changes in position, or increased intrathoracic pressures (Valsalva maneuvers). It is sometimes helped by very *mild* exercise which increases ventilation and raises the oxygen content of the blood.

Anorexia, nausea and vomiting are the next most common symptoms of AMS. Other symptoms and signs include weakness, lassitude, general malaise, decreased coordination, dizziness or lightheadedness and oliguria. Sleep disturbances and periodic breathing with recurrent apneic periods during sleep are usually present, but are not necessarily a component of AMS. They may persist for weeks even after other symptoms have resolved.

The diagnosis of AMS is based on the occurrence of a headache and at least one other sign or symptom in an individual who ascended from low (<5,000 ft or 1,524

m) to high altitude or from high to higher altitude in the previous 24 to 48 hours. The differential diagnosis includes viral gastroenteritis, hangover, exhaustion, dehydration, carbon monoxide poisoning and high altitude cerebral edema (HACE). In most instances, these conditions can be ruled out by careful history. The presence of neurological symptoms such as uncoordination, ataxia and excessive lethargy or cognitive dysfunction is indicative of progression to HACE. Suspected HACE requires immediate therapeutic intervention including evacuation to low altitude.

Prevention and Treatment

Preventive measures for acute mountain sickness include pharmacologic prophylaxis or non-pharmacologic methods. In general, the non-pharmacologic methods that promote acclimatization are the safest and most effective means for preventing AMS, but they take time to accomplish, and sufficient time may not be available in many operational scenarios.

Non-pharmacologic methods that promote acclimatization are based on altering the ascent rate to allow soldiers to partially acclimatize during ascent. There are two recommended methods for doing this: staging and graded ascent.

A *staged ascent* requires soldiers to ascend to an intermediate altitude and remain there for three days or more to acclimatize before ascending higher. When possible, soldiers should make several stops for staging during the ascent to allow a greater degree of acclimatization.

Graded ascent limits the daily altitude gain to allow partial acclimatization. The altitude at which soldiers sleep is the critical element in this regard. Having soldiers spend two nights at 9,000 ft (2,743 m) and limiting the sleeping altitude to no more than 1,000 ft (305 m) per day above the previous night's sleeping altitude will significantly reduce the incidence of acute mountain sickness.

A combination of graded ascent and staging is the safest and most effective method for prevention of AMS. Acclimatization to one altitude, however, does not prevent AMS from occurring if 'ascent to successively higher altitudes is rapid.

ACUTE MOUNTAIN SICKNESS Some Key Points

- directly related to rate and magnitude of ascent
- *everyone* is susceptible
- predominant symptoms are headache and nausea
- prevent by staging, graded ascent or acetazolamide
- self-limited, if ascent stopped
- can evolve to HACE or HAPE

Consumption of a high carbohydrate diet (>70% of total kcal as carbohydrate) is an additional non-pharmacologic method of reducing AMS symptoms. This effect is probably the result of stimulation of ventilation through increased carbon dioxide produced from metabolism of the carbohydrates. Although such a diet may not prevent AMS entirely, it is a useful adjunct to other preventive measures (see page 38 for additional information on nutrition).

In situations where there is insufficient time for a staged or graded ascent, soldiers may have to use pharmacologic prophylaxis to prevent AMS. The drug of choice for preventing AMS is acetazolamide. At this time (1994), it is the only drug currently approved by the Federal Drug Administration for this indication. When taken appropriately, it will prevent AMS in 50-75% of soldiers ascending rapidly to high altitude and reduce symptoms in most of the others. Acetazolamide is a carbonic anhydrase inhibitor which produces a metabolic acidosis by promoting renal excretion of bicarbonate. Acetazolamide may also stimulate respiratory centers in the brain by altering the pH of cerebrospinal fluid.

For reduction of AMS symptoms during rapid ascents, 1,000 mg a day of acetazolamide orally for 48 hours preceding ascent and for 48 hours after arrival is recommended. It is best administered in divided doses of 250 mg every six hours or 500 mg every twelve hours (a 500 mg sustained release form is available). A lower dose (500 mg per day in divided doses) may be equally effective and reduce side effects, especially in smaller individuals. It may also be effective to begin the regimen only 12 to 24 hours prior to beginning the ascent.

Side effects of acetazolamide include peripheral paresthesias and polyuria. The paresthesias are particularly troublesome in tasks that involve tactile components and are exacerbated by cold exposure. While taking acetazolamide, carbonated beverages have "flat" taste because the drug interferes with carbon dioxide metabolism. It is important to remember that acetazolamide is a sulfa drug and should not be used in sulfa-sensitive individuals.

Other drugs such as methazolamide and benzolamide (both carbonic anhydrase inhibitors), spironolactone, naproxen, ammonium chloride, phenytoin, calcium carbonate and several amphetamines have been examined for effectiveness against acute mountain sickness. None were found to be as effective as acetazolamide. High dose dexamethasone prevents symptoms of AMS in resting soldiers, but not in those engaged in physical work. Additionally, AMS symptoms seem to recur when the drug is stopped. For these reasons and because of its potential serious side effects, dexamethasone is *not* recommended for prevention of AMS.

Because acute mountain sickness is usually self-limited, it does not have to be treated and will normally resolve in three to seven days if the soldier does not continue to ascend. Once the symptoms have resolved, the soldier can resume the ascent. Untreated soldiers must be observed for development of high altitude cerebral or pulmonary edema, however, and immediate intervention should be initiated if evidence of those deadly conditions appear.

The only sure treatment for acute mountain sickness is descent to a lower elevation where the increased barometric pressure provides increased ambient oxygen. A soldier can descend by walking if necessary but should not be allowed to descend alone.

The partial pressure of oxygen can be raised using a hyperbaric chamber, if one is available. Single and two-person, light-weight portable hyperbaric chambers made of impermeable cloth are commercially available (Gamow Bag™ in the U.S.A. and Certec SA in Europe). They can be folded and carried in a backpack. They are operated by either a foot pump or a small electric pump which provides both increased pressure and ventilation to the bag. The chambers are pressurized to 2 psi or approximately 104 mmHg above ambient air pressure. The effect of the increase in pressure on oxygen availability is greater at higher elevations resulting in a greater equivalent descent. When supplemental oxygen is available, it also can be added to the chamber through the pump. These chambers are effective in treating AMS if used for periods of several hours. They may be lifesaving in treating high altitude cerebral and pulmonary edema, but require longer treatment periods (see later sections for more information). As of 1994, portable cloth hyperbaric chambers are not available in the US Army medical inventory.

Continuous supplemental oxygen can be used to treat acute mountain sickness effectively if sufficient quantities are available for prolonged administration. That situation is not common in field operations and tactical situations. Low-flow oxygen is especially effective during sleep when altitude-induced periodic breathing causes greater desaturation than during the day.

Acute mountain sickness can be treated pharmacologically. Acetazolamide in divided doses from 500 mg to 1.5 g per day is often used and may be the best choice for pharmacologic therapy. Dexamethasone in doses of 2 to 4 mg every six hours will treat AMS successfully, but has the same potentially serious side effects as it does when used in a prophylactic role. Furthermore, symptoms of AMS often recur when the dexamethasone is stopped.

Specific symptoms of acute mountain sickness can be treated with various palliative drugs. Care must be taken not to administer medications that could depress respiration or cognitive function, however. Analgesics for treating headache include aspirin (325 to 1000 mg every 4 to 6 hours), acetaminophen (325 mg every 4 hours to 1000 mg every 6 hours) and ibuprofen (200 to 800 mg every 4 to 6 hours) or other non-steroidal anti-inflammatory drugs (NSAIDs) in the usual doses. None of these medications are consistently effective in relieving headache, however. Opioids may be more successful, but they should *not* be used because of respiratory depression and reduction of cognitive function. Prochlorperazine (5 to 10 mg every 6 to 8 hours) can be used to treat nausea and vomiting. It is a good choice because one of its side effects is to stimulate respiration which will increase arterial oxygen saturation.

Prognosis and Administrative Disposition

Acute mountain sickness is a self-limited condition that ordinarily resolves within three to seven days without any adverse consequences. It resolves more rapidly with

descent. Although AMS itself is self-limited, individuals with AMS symptoms may subsequently develop, high altitude pulmonary or cerebral edema, both potentially fatal conditions.

Severity of a soldier's symptoms can be used to determine appropriate duty limitations, if needed, during an episode of AMS. Due to the discomfort caused by AMS symptoms, many individuals may have difficulty performing to their normal standards. Once symptoms resolve, they can return to full duty. Soldiers with persistent symptoms may require a temporary profile and should be considered for redeployment to lower altitude. Soldiers who, in spite of prophylactic measures, have recurrent or incapacitating episodes of AMS on repeat deployment to high altitude should be considered for a permanent physical profile to prevent their future deployment to mountain areas.

High Altitude Pulmonary Edema (HAPE)

High altitude pulmonary edema is a non-cardiogenic pulmonary edema occurring in unacclimatized individuals following a rapid ascent to high altitude. It also occurs in long-term high-altitude residents who reascend rapidly following a several week stay at a low altitude. The edema is thought to be caused by the combination of hypoxia-induced pulmonary hypertension and an increase in permeability of the pulmonary capillary endothelium. It is characterized by elevated pulmonary artery pressure, normal left atrial filling pressure and normal ventricular function. The bronchoalveolar fluid has a high protein content and contains increased numbers of macrophages, leukotrienes and evidence of complement activation. Untreated, HAPE can be rapidly fatal and is the most common cause of death among the altitude illness syndromes. It is often preceded by AMS and is frequently seen in individuals with HACE, but most cases of HAPE occur without concomitant HACE. Although the incidence of HAPE is relatively low, its impact on military units, especially small units, can be significant because of the serious prognosis and need for rapid evacuation.

Incidence

High altitude pulmonary edema in unacclimatized soldiers is a function of both the magnitude of the hypoxic stress and the presence of risk factors, many of which appear to increase pulmonary artery pressure independently of hypoxia. Hypoxic stress is a function of speed of ascent and elevation gained, but also can be worsened by periodic breathing during sleep and medications which depress respiration. Widely accepted risk factors for HAPE include moderate to severe exertion, cold exposure, anxiety, young age, male sex and possibly obesity. Individual characteristics such as a low hypoxic ventilatory drive (as measured by hypoxic ventilatory response, HVR) and congenital absence of one pulmonary artery also play a role, and there is a high rate of recurrence in individuals who have had a prior episode of HAPE.

The incidence of HAPE varies widely with geography, population at risk and the specific circumstances of exposure. In Colorado, for example, with skiing elevations of 6-10,000 ft (1,828 to 3,047 m), the incidence is -1/10,000. On Mt. McKinley (20,320 ft or 6,192 m), the rate in climbers is -1/50. The incidence of HAPE may actually be higher in military units than

in most civilian populations due to increased exposure of soldiers to risk factors resulting from operational requirements. For instance, in some units of the Indian Army at elevations of 11,000 to 18,000 ft (3,352 to 5,485 m) during the Sino-Indian conflict (1962-63), the rate was estimated to have been as high as 15/100.

The incidence of HAPE in long-term high-altitude residents who return to altitude after a short stay (several weeks) at low altitude is high, perhaps up to 20% in some risk groups such as children and adolescent males. While medical officers can expect to see this phenomenon in resident civilian populations, it can also occur in soldiers who may have to descend for administrative purposes, resupply or a "rest and recreation" period after a prolonged deployment to high altitude. This scenario contributed to the death of an Indian Army Brigadier General during the 1962-63 Sino-Indian conflict.

A subclinical form of HAPE occurs frequently. It is manifested primarily by rales, most often heard in the right mid-lung field. Rales are found in one-third to one-half of persons exercising at altitudes higher than 11,500 ft (3,500 m). The clinical significance is unclear, since most individuals with these signs do not progress to frank pulmonary edema.

High altitude pulmonary edema in unacclimatized soldiers usually begins within the first two to four days after rapid ascent to altitudes greater than 8,000 ft (2,438 m), and onset during the second night of sleep at high altitude is a very common occurrence. It can also occur in acclimatized soldiers who ascend rapidly from a high to a higher elevation. Once symptoms become apparent, HAPE can progress very rapidly (<12 hours) to coma and death.

Symptoms and Diagnosis

Symptoms and signs of HAPE are related to the progressive pulmonary edema and the resultant worsening hypoxemia. Early in the course, manifestations are often subtle, nonspecific and are frequently accompanied (and masked) by symptoms of AMS. One useful technique to help distinguish early findings in HAPE from normal responses to hypobaric hypoxia is to compare the findings in the suspected HAPE victim to other unit members who are not suspected of having HAPE.

Early pulmonary edema may be apparent only as a nonproductive cough and a few rales, findings that are also common in individuals without HAPE at high altitude. Early hypoxemia may be manifested by dyspnea on exertion, fatigue and weakness with decreased tolerance for physical activity and increased time needed for recovery after physical exertion. A resting tachycardia and tachypnea greater than that induced by altitude alone may be present. The affected soldier's nail beds and lips may be more cyanotic than other unit members at the same altitude.

As pulmonary edema progresses, the cough may become productive of frothy and sometimes pink or bloodstreaked sputum. Rales become more numerous and widespread, and wheezing may develop. Lung sounds may progress to an audible gurgling in the airway that can

be heard without a stethoscope, especially when the affected soldier is supine. Orthopnea may occur in some individuals (<20%). Progressive hypoxemia causes progressive dyspnea and cyanosis. Arterial blood gas measurements (if available) document significant hypoxemia, hypocapnia and a slight increase in pH. Mental status deteriorates with progressive confusion and sometimes vivid hallucinations. Ultimately obtundation, coma and death will occur without treatment.

A slight fever ($\leq 100^{\circ}\text{F}$, 37.8°C) and a mild increase in white blood cell count may be present with HAPE. Until the 1960's HAPE was often misdiagnosed as pneumonia on the basis of the pulmonary findings, fever and leukocytosis.

When available, chest x-ray shows multiple patchy interstitial or alveolar pulmonary infiltrates. The infiltrates may be predominant in the right middle lobe of the lung. The pulmonary vasculature may be widened, but the heart size is invariably normal. Electrocardiogram often shows a right strain pattern with rightward axis, clockwise rotation, T-wave inversion in the precordial leads and an R-wave in leads V_{1-2} and an S-wave in leads V_{5-6} .

The diagnosis of HAPE is based upon the signs and symptoms of pulmonary edema and increased hyperemia in otherwise healthy individuals following a recent gain in altitude. Because early signs and symptoms can be subtle and nonspecific, medical personnel should maintain a high index of suspicion. Frequent monitoring of suspected cases is necessary due to the potential for rapid progression of HAPE to coma and death. A presumptive diagnosis of HAPE can be made if two of the following symptoms: dyspnea at rest, cough, weakness, chest tightness or congestion, and two of the following signs: rales or wheezing in at least one lung field, central cyanosis or inappropriate tachypnea or tachycardia are present. Treatment should be initiated immediately. **Delay in treatment of progressive pulmonary edema at altitude usually results in death.** The differential diagnosis of HAPE includes pneumonia, congestive heart failure, pulmonary embolus and, in a military setting, possible exposure to chemical warfare agents. As previously noted, for many years HAPE was misdiagnosed as "pneumonia" and inappropriately treated with antibiotics. That error resulted in needless deaths.

Prevention and Treatment

Measures for prevention of HAPE include adequate acclimatization, avoidance of risk factors and pharmacologic prophylaxis. Adequate acclimatization can be achieved by limiting the ascent rate using the same graded ascent or staging schedules used for preventing AMS (see page 11 for acceptable ascent rate). Because arterial desaturation is greatest during sleep, unacclimatized soldiers should sleep at as low an altitude as possible. "Climb high, sleep" is a frequently repeated and useful adage that expresses this principle. Soldiers, especially those with a prior history of HAPE, should also avoid cold exposure and strenuous exertion until adequately acclimatized.

Nifedipine may prevent HAPE from developing in soldiers who have a history of prior episodes. It is administered in a 20 mg dose by mouth every eight hours beginning on the day

of ascent and continuing for three days after reaching the final destination altitude. Because hypotension is a possible side effect of this dose regimen, medical officers should consider administering a test dose or starting the regimen prior to ascent to avoid this effect during ascent. Nifedipine is not indicated for soldiers without a history of HAPE, or for those with no prior altitude experience. For such individuals, acetazolamide may help prevent HAPE, although this suggestion is based upon anecdotal reports. Those soldiers could appropriately take acetazolamide to prevent AMS and thereby gain possible prophylaxis for HAPE.

Because HAPE can have a fulminant course, early recognition and institution of appropriate treatment is necessary to prevent fatalities. Appropriate treatment depends upon its severity, but immediate descent is the definitive treatment for HAPE. Descent should never be voluntarily delayed. Descent of even a few thousand feet (300-1,000 m) can be helpful or even lifesaving in severe cases, but greater descents have better therapeutic effects.

Because physical exertion, cold and anxiety can increase pulmonary artery pressure, descent should be by passive means, if at all possible, and care should be taken to see that the soldier is as warm and comfortable as the situation will allow. When available, supplemental oxygen should be administered during descent, especially in more serious cases. In the absence of a means of passive descent, soldiers with mild HAPE symptoms and who are ambulatory may walk down slowly, but must be accompanied and their physical exertion kept to a minimum. **Soldiers with any altitude illness should not be unaccompanied!**

Although descent is the definitive treatment for HAPE, it may not always be possible. Mission requirements, tactical situation, terrain, weather conditions and evacuation capabilities could delay descent. Mild cases of HAPE can often be successfully treated in place with bed rest and supplemental oxygen, but descent is still mandatory for all but mild cases.

Effective therapy for HAPE is based upon increasing oxygen availability and decreasing pulmonary artery pressure. Supplemental oxygen should always be used when available, but requires a continuous supply to be effective. In mild cases, low-flow oxygen (2 to 4 L per min) by mask or nasal cannula may be appropriate, but moderate to severe cases are best treated with 4 to 6 L per min by mask initially. In the absence of supplemental oxygen, use of a portable

HIGH ALTITUDE PULMONARY EDEMA Some Key Points

- *Non-cardiogenic* pulmonary edema
- Can progress rapidly (<12 hr) to death
- Young age, male sex and strenuous exercise are high risk indicator
- Prevent by adequate acclimatization
- **Immediate descent best treatment!**
- Nifedipine useful for prevention and treatment
- O₂ and/or portable fabric hyperbaric chamber may be lifesaving

cloth hyperbaric chamber may be lifesaving. The chamber provides an ambient pressure equivalent to descent of many thousand feet (see Prevention and Treatment of AMS, page 13), but may require four or more hours of treatment in the chamber to be effective for HAPE. Supplemental oxygen can be added to the fresh air supply of the chamber to further increase its effect. Use of low flow rates of oxygen in this manner will help conserve limited oxygen supplies. Use of an expiratory positive airway pressure mask (EPAP) or pursed-lips breathing can increase the mean alveolar pressure and thereby increase arterial oxygen content somewhat in soldiers with HAPE. These techniques can be tried if other more effective therapeutic modalities are not available. They can also be used in conjunction with other modalities to boost the therapeutic effect. Both EPAP and pursed-lip breathing can easily be accomplished in a cloth hyperbaric chamber or during supplemental oxygen therapy.

Nifedipine can reduce pulmonary pressure as much as 30% in 30 minutes and is efficacious in treating soldiers with HAPE as well as in preventing it. In established cases of HAPE, nifedipine therapy can be initiated by administering 10 mg sublingually and 20 mg orally to be swallowed. A second 10 mg sublingual dose can be administered in 15 to 20 minutes if no improvement in symptoms is apparent. The 20 mg oral dose should be repeated every six hours until the pulmonary edema has resolved and arterial oxygen saturation has returned to normal. Nifedipine should not be used in lieu of descent, supplemental oxygen, or treatment in a hyperbaric bag, but is appropriately used in conjunction with each of these other therapies. Because nifedipine can cause systemic hypotension during initial administration, precautions should be instituted to prevent problems from this side effect should it occur.

Other pharmacologic agents that have been suggested in the past for treating HAPE include furosemide and morphine sulphate. Both agents decrease left ventricular filling pressure through peripheral vasodilatation, but because soldiers with HAPE usually have normal filling pressure and may have a decreased intravascular volume, this effect can be counter-productive. Additionally, morphine sulphate can depress respiration. This effect may be exaggerated in the presence of HACE, which often occurs to varying degrees in soldiers with HAPE. Neither furosemide nor morphine should be used in the treatment of HAPE unless other more effective treatment options are not available.

After a soldier with HAPE has been evacuated to a lower altitude for care in a higher echelon medical facility, treatment should continue to be directed toward ensuring adequate oxygenation and reducing pulmonary artery pressure by the most effective means available. In general, this consists of continuing bed rest, supplemental oxygen and nifedipine. Invasive diagnostic procedures such as bronchoscopy or pulmonary artery catheterization are *not* indicated unless the clinical course deteriorates and the diagnosis is in doubt. Likewise, endotracheal intubation is seldom necessary.

Prognosis and Administrative Disposition

High altitude pulmonary edema can be rapidly fatal. If recognized early and treated appropriately, it usually also resolves rapidly and without permanent adverse consequences.

While many soldiers who have experienced a previous episode of HAPE may subsequently be able to travel to high altitude without difficulty, there is a high rate of recurrence.

Soldiers who have had HAPE can return to duty when their pulmonary edema has resolved, and their arterial oxygen saturation has increased appropriately. Because pulmonary artery pressure increases during exercise, a temporary physical profile (10 days to 2 weeks) limiting strenuous physical activity may be helpful to these individuals. They should also be considered for prophylactic treatment with nifedipine on any subsequent high-altitude deployments. Individuals who experience recurrent HAPE, with or without prophylactic treatment, should be evaluated for a permanent physical profile to limit high altitude exposure.

High Altitude Cerebral Edema (HACE)

High altitude cerebral edema is clinically apparent edema in the brain associated with a rapid ascent to high altitude. The pathophysiology is thought to involve a hypoxia-induced increase in permeability of the blood-brain barrier (vasogenic edema), or a hypoxia-induced alteration of cellular fluid regulation with an intracellular fluid shift (cytotoxic edema), or some combination of the two mechanisms. HACE is the more severe end of the spectrum of altitude-induced edema in the brain with subclinical cerebral edema manifested as AMS at the other end. Individuals with HACE are frequently found to also have HAPE, although most individuals with HAPE do not have concomitant HACE. Like HAPE, HACE can have a significant impact on military units operating at high altitude due to its serious prognosis and the need for rapid evacuation.

Incidence

High altitude cerebral edema, like AMS and HAPE, occurs in unacclimatized individuals who ascend rapidly from low to high altitude, or from high to higher altitude. However, the incidence of HACE is lower than that of either AMS or HAPE, occurring in only about 1% of individuals making rapid ascents. The magnitude of hypoxic stress is a major determinant of occurrence. While HACE can occur as low as 8,000 ft (2,430 m), the vast majority of cases occur above 12,000 ft (3,600 m). Other risk factors include the same risk factors as for AMS. Additionally AMS itself is considered a risk factor. Continued ascent by individuals with AMS is generally thought to carry a very high risk for development of HACE. A previous episode of HACE also seems to confer a high risk for recurrence.

The time for onset of HACE following ascent is highly variable, but it generally occurs later than either AMS or HAPE. For example, in Indian soldiers during the Sino-Indian Conflict of 1962-63, the mean duration of exposure before onset of HACE symptoms was five days with a range of 1 to 13 days. The later onset of HACE is felt to reflect the time for subclinical cerebral edema initially manifested as AMS to progress to clinically apparent HACE. Untreated, HACE can progress to death over one to three days, but the course also can be more fulminant with death occurring in less than 12 hours.

Symptoms and Diagnosis

Most signs and symptoms of HACE are neurologic manifestations of progressive cerebral edema. Early signs and symptoms often resemble AMS and include severe headache, nausea, vomiting and extreme lassitude. These symptoms are not invariably present, however. Truncal ataxia and change in mental status help differentiate early HACE from AMS. Truncal ataxia (i.e., swaying of the upper body, especially when walking) is a fairly sensitive sign of developing HACE. As the cerebral edema progresses, soldiers often develop an ataxic gait in addition to truncal ataxia. Early mental status changes may include confusion, disorientation, drowsiness and impaired mentation. Often the soldier appears withdrawn and the behavior is mistakenly attributed to fatigue or anxiety. Cyanosis and general pallor are commonly present. Symptoms of HAPE may be present also.

If early signs and symptoms of HACE are unrecognized and the soldier is left untreated, a variety of focal and generalized neurologic abnormalities may develop. These include various visual changes, anesthetics, paresthesias, rigidity, hemiparesis, clonus, pathological reflexes, hyperreflexia, bladder and bowel dysfunction, hallucinations, seizures and coma. Papilledema may be present in up to half of soldiers with HACE, but is *not* universal. If a lumbar puncture is performed, the cerebral spinal fluid pressure is usually elevated. Cerebral edema may be apparent on computed tomography (CT) and magnetic resonance images (MR) if these procedures are obtained. As a practical matter, lumbar puncture and sophisticated imaging of the brain are seldom available during military operations at high altitude and are not necessary for diagnosis of HACE.

Diagnosis of HACE is based upon the presence of signs and symptoms of progressive cerebral edema beginning within a few days to weeks of an ascent. Because the early signs and symptoms are similar to AMS, medical personnel need to maintain a high index of suspicion for HACE and monitor potential cases frequently. A presumptive diagnosis of HACE can be made in soldiers with AMS symptoms who additionally have either ataxia, mental status changes or both. If a soldier does not have symptoms of AMS, both ataxia and mental status changes should be present for a presumptive diagnosis of HACE. Given the potential for a fatal outcome, treatment should be started on the basis of the presumptive diagnosis. The differential diagnosis includes altitude-related stroke or transient ischemic attack, infection, migraine cephalgia, trauma, hypothermia, substance abuse, psychosis and severe cerebral hypoxia resulting from HAPE.

Prevention and Treatment

There is no definitive evidence for effective measures to prevent HACE, because its low incidence has precluded adequate studies. However, given the concept that AMS represents a subclinical form of HACE, it has been postulated that the same measures which prevent AMS may also prevent HACE. Consequently, suggested prophylactic measures for HACE include use of staged or graded ascent, high carbohydrate diet and use of acetazolamide (see Prevention and Treatment of AMS, page 11).

Definitive treatment of HACE is immediate descent. In general, the greater the descent, the better the outcome. Descent of more than 1000 ft (300 m) may be required for clinical improvement, and descent to altitudes of less than 8,000 ft (2,500 m) is optimal.

'Affected soldiers can descend by foot if they are ambulatory and are accompanied. In situations where descent is unavoidably delayed by weather, tactical situation or other contingency, treatment with a portable cloth hyperbaric chamber can be lifesaving. Soldiers with HACE may require at least six hours of pressurization in the chamber for adequate treatment.

Supplemental oxygen is also helpful when a soldier with HACE cannot be evacuated to lower altitude immediately. Continuous supplemental oxygen at flow rates of 2 to 6 L per minute by mask or nasal cannula should always be administered if available, but should not be used as a substitute for descent. Supplemental oxygen can be added to the air intake of a cloth portable hyperbaric chamber to increase its efficacy. Oxygen should be used as needed during and after descent to maintain adequate arterial saturation in soldiers with HACE who are able to be evacuated.

Pharmacologic agents that have been suggested as adjunctive therapy for HACE include dexamethasone and various diuretic agents. Their use is based upon theoretical considerations, and none has been tested for clinical efficacy in the treatment of HACE. Their role is strictly adjunctive, and they should never be used as a substitute for descent.

Dexamethasone is the most widely accepted adjunctive therapy for HACE. It can be administered in doses of 4 to 8 mg initially followed by 4 mg every six hours by mouth, vein or intramuscular injection. It should be continued until clinical signs of resolution are apparent and then should be tapered and discontinued. Loop diuretics and osmotic diuretic agents such as mannitol, urea and glycerol also have been suggested for treatment of HACE, but there has been little experience with them in this role. Careful attention must be paid to volume status when using diuretic agents in the treatment of altitude illness syndromes because many soldiers will have altitude-induced decrease in intravascular volume concomitant with their edema.

Following descent, hospital management of HACE consists of supplemental oxygen (if needed to maintain arterial oxygen levels), dexamethasone, supportive care and possibly also diuretic agents. Comatose patients may require intubation and bladder catheterization.

HIGH ALTITUDE CEREBRAL EDEMA Some Key Points

- Less common than HAPE
- Often occurs in soldiers with AMS who continue to ascend
- Prevent by acclimatization
- Truncal ataxia and social withdrawal can be early signs
- **Immediate descent required for treatment!**
- O₂ and/or fabric hyperbaric chamber useful if descent delayed
- Dexamethasone possibly helpful and should be considered

Consideration should be given to intubation with hyperventilation to reduce intracranial pressure in comatose patients.

Because HAPE often accompanies HACE, all soldiers with HACE should be carefully evaluated for possible presence of concomitant HAPE. If present, HAPE should be treated immediately and aggressively (see Prevention and Treatment of HAPE, page 16). The definitive treatment for both conditions is descent.

Prognosis and Administrative Disposition

High altitude cerebral edema, like HAPE, can be rapidly fatal if unrecognized and untreated. If recognized early and adequately treated, HACE usually resolves without permanent adverse effects. Some neurologic deficits, such as ataxia, may last for days to weeks after mental status changes and other manifestations have resolved. Long-term neurologic deficits have been observed in some individuals recovering from severe HACE. Even if individuals fully recover, there is a high rate of recurrence during subsequent reexposure to high altitude. Soldiers who have had a prior episode of HACE should be considered for prophylaxis with acetazolamide if they deploy to high altitude again. As previously noted, this recommendation is based upon the effectiveness of acetazolamide in preventing AMS, which is thought to have similar pathophysiology as HACE. There have been no clinical trials evaluating the prophylactic use of acetazolamide for HACE.

Soldiers recovering from HACE can return to duty when the signs and symptoms of cerebral edema and associated neurologic deficits have resolved. Those with persistent neurologic deficits must be considered for an appropriate physical profile and possible Medical Evaluation Board based upon the extent of their deficit and its impact on their ability to perform their duties. Soldiers who have a repeat episode of HACE, with or without prophylaxis, should be considered for a permanent physical profile to limit high altitude exposure.

High Altitude Peripheral Edema

Altitude-related edema of the hands and face may occur in up to one-third of soldiers who ascend to high mountain areas. The cause of the edema is thought to be hypoxia-induced retention of sodium and water and is not considered to be related to the causes of either the AMS/HACE edema-spectrum or HAPE. The condition is benign, but may cause soldiers enough discomfort to degrade their performance to some degree.

Altitude-induced peripheral edema is most evident in the hands and peripheral areas of the face. It is usually associated with decreased urine output and a weight gain of approximately 6 to 12 pounds (2.7 to 5.4 kg) over several days and is most evident upon awakening.

Diagnosis is based upon the association of the characteristic peripheral edema with ascent to high altitude. The diagnosis can often be made by history alone because it tends to recur consistently with repeat ascents. Peripheral edema is more common in

females, but is not thought to be related to menstrual cycle or oral contraceptives. The differential diagnosis includes cardiogenic edema, allergic reactions and edema of the upper extremities caused by packstraps or binding by tight clothing. This latter condition, often termed “packstrap edema,” is common in both military operations and recreational hiking.

Altitude-induced peripheral edema can be treated successfully with diuretics (one 20-40 mg dose of furosemide, or 250 mg of acetazolamide every eight hours for three doses) and salt restriction. As with most altitude illness syndromes, the definitive treatment is descent to a lower elevation. Prophylaxis with salt restriction and the acetazolamide regimen used to prevent AMS is often successful in preventing altitude-induced peripheral edema. Susceptible soldiers who must participate in high-altitude missions should have a trial of prophylaxis. Because the condition is so benign, affected soldiers seldom need a physical profile for it.

High Altitude Retinal Hemorrhage (HARH)

High altitude retinal hemorrhages are areas of bleeding from retinal vessels during altitude exposure. They are one manifestation of a hypoxia-induced retinopathy that is probably universal in low-altitude residents who travel to high mountain elevations. High altitude retinopathy is caused by increased blood flow to the retina which is one of the most oxygen sensitive tissues in the body. Increased blood flow causes retinal vessels to increase in diameter and appear tortuous. Retinal hemorrhages are thought to result from blood-pressure “surges” within the distended vessels. The pressure surges are caused by Valsalva maneuvers associated with physical activity, coughing or defecation. High altitude retinal hemorrhages can be found in association with other altitude illness syndromes, but are not directly related to them. The hemorrhages are usually asymptomatic and affect military operations only in the rare instance in which they affect an individual soldier’s vision.

The incidence of retinal hemorrhages varies directly with altitude. Although mild altitude retinopathy may be present at altitudes below 10,000 ft (3,000 m), hemorrhages have not been observed at those elevations. Retinal hemorrhages occur in up to 30% of soldiers at 14,000 ft (4,267m), in 50-60% at 18,000 ft (5,486 m) and probably in 100% above 22,000 ft (6,800 m). Strenuous exercise may increase the risk of retinal hemorrhage by increasing systolic blood pressure and decreasing the oxygen in arterial blood. Pressure surges caused by forced Valsalva maneuvers during active climbing or defecating are also risk factors. Unlike other altitude illnesses, HARM appears not to be related to the state of acclimatization, and multiple incidents of retinal hemorrhage are possible throughout any altitude deployment.

High altitude retinal hemorrhages are usually unrecognized because they are asymptomatic; however, hemorrhage into the macular area will cause blurred vision and scotomas. Retinal hemorrhages are easily diagnosed by fundoscopic exam. Fundoscopic exam will show hyperemia and engorgement of the disc and increased tortuosity of retinal vessels that is characteristic of the high altitude retinopathy that occurs in nearly all personnel exposed to high altitude without supplemental oxygen. Typically, retinal hemorrhages appear as “splinter” and “flame” type hemorrhages in the superficial layers of the retina, but hemorrhages in the deeper layers can

occur. Multiple hemorrhages are common. The diagnosis is made by observing the hemorrhages in conjunction with high altitude exposure. The differential diagnosis includes hemorrhage from vascular disease, diabetes mellitus, septic infarcts or from hypoxia caused by cardiac and respiratory disease.

High altitude retinal hemorrhages are self-limited and resolve one to two weeks after descent. There is no treatment other than descent, and there is no known prophylaxis. Because hemorrhages outside of the macula cause few symptoms and usually do not cause a significant permanent visual defect, descent is not necessary when they are discovered. When a macular hemorrhage is diagnosed, descent is imperative to promote healing and prevent further hemorrhage. Soldiers with a previous symptomatic hemorrhage should be considered for possible permanent physical profile to limit their altitude exposure with the intent of preventing further visual deficits from occurring. Physical profiling is not indicated for HARH outside of the macular area.

Thromboembolic Events

Soldiers who ascend to high altitude are at increased risk for thromboembolic events including: thrombophlebitis, deep venous thrombosis, pulmonary embolus, transient ischemic-attacks (TIA) and stroke. Possible causes for these phenomena include hypoxia-induced polycythemia and clotting abnormalities, but also include environmental and mission-related factors such as dehydration, cold and venous stasis caused by prolonged periods of inactivity during inclement weather or by constriction from tight-fitting clothing or equipment (see High Altitude Peripheral Edema, page 22). Although, with the exception of thrombophlebitis, these events are relatively rare, they can have a significant impact on military operations due to the requirement to evacuate the affected soldier. The occurrence of stroke and TIAs in young, healthy soldiers also may have a negative psychological effect on other unit members.

Altitude-related thromboembolic events are unusual below 14,000 ft (4,267 m). At very high and extreme altitudes (>14,000 ft) these events are not uncommon, and thrombophlebitis appears to be relatively common. The clinical manifestations of these conditions at high altitude are similar to their manifestations at low altitude, but their occurrence in young and otherwise healthy soldiers may be unexpected. Medical personnel need to be aware of the possibility of these events occurring during deployment to high-altitude areas.

Prevention of altitude-related thromboembolic events relies on reducing the risk factors by maintaining adequate hydration and warmth and by avoiding conditions that might cause venous stasis. Although aspirin has been suggested for possible use in preventing altitude-related thromboembolic events, it has not been studied. The risk of side effects, including an increase in retinal hemorrhages, makes aspirin unsuitable for prophylaxis at altitude. With the possible exception of mild, superficial thrombophlebitis, the occurrence of an altitude-related thromboembolic event mandates a rapid evacuation to medical facilities at lower altitude. Treatment follows standard clinical guidelines, including appropriate anticoagulation. In afield setting, low-dose subcutaneous heparin (5,000 units every eight to twelve hours) can be used for anticoagulation

prior to and during evacuation. Soldiers with known coagulopathies or a history of prior thromboembolic events should be evaluated for a physical profile to restrict their altitude exposure.

Subacute Mountain Sickness

Subacute Mountain Sickness is a syndrome of persistent symptoms which may occur in some soldiers during prolonged deployment (weeks to months) to elevations above 12,000 ft (3,658 m). Common manifestations include sleep disturbances, anorexia, weight loss, fatigue, daytime somnolence and subnormal mentation. The condition reflects a failure to acclimatize adequately. Some relief from symptoms can be obtained with low-flow oxygen and acetazolamide, but there are no known means to accelerate or insure acclimatization in these soldiers. They should be returned to low altitude as soon as practical. Soldiers who experience subacute mountain sickness may have subtle physiologic abnormalities which will consistently limit their ability to adequately acclimatize. They should be considered for a permanent physical profile to limit their altitude exposure.

Immune Suppression and Poor Wound Healing

Some degree of immune suppression occurs in soldiers at very high and extreme altitudes. T-cell lymphocyte function (but not B-cell function) appears to be primarily affected, which would predict that cell-mediated immunity could be impaired. The clinical significance of the effect of hypobaric hypoxia on T-cell function is not clear, however. The only consistently observed infection pattern at high altitude is an increase in occurrence and persistence of skin and soft tissue bacterial infections. The lack of infections more characteristic of deficits in cell-mediated immunity may be a function of lack of exposure to the infective agents themselves at very high and extreme altitude. Medical officers should be alert to the possibility that soldiers might show higher increased susceptibility to viral, fungal and parasitic infections if they are exposed during a high-altitude deployment. Because immune function recovers at low altitude, descent should be considered in the treatment of persistent infections occurring at high altitude.

Wound healing and recapillarization are directly dependent on the tissue oxygen tension and may be adversely affected by altitude exposure. Consequently, injuries resulting from burns, ballistics and physical trauma should be considered to be more clinically significant at high altitude compared to the same injury at low altitude. These injuries may require oxygen and/or descent for effective treatment and healing.

Medical Problems Unrelated to Hypoxia

In high mountain areas, a number of environmental factors other than hypobaric hypoxia can cause medical problems in military personnel. These factors include climatic conditions, rugged terrain and hazards associated with human activity such as carbon monoxide and poor sanitation. Unlike hypobaric hypoxia, these factors are not unique to the high mountain environment and cause medical problems in other environments as well. Military medical

Personnel are often familiar with these medical problems from having encountered them frequently. Because these problems are familiar to most military medical personnel, they are not presented here in the same detail as hypoxia-related problems were in the previous section. Most are presented in greater detail in other technical bulletins and field manuals (see Appendix B).

Cold Injuries

Cold injuries are common in high-altitude environments. Once a soldier has acclimatized to altitude, the incidence of hypoxia-related illness declines and cold injuries are often the most common environmental injury. The full spectrum of cold injuries from hypothermia to freezing and non-freezing tissue injury can occur. The impact of cold injury on military units is well known. Even relatively benign cold injuries can have a significant impact on unit effectiveness because they are slow to resolve and carry substantial risk of reinjury. In the field setting most cold injuries require evacuation for effective treatment, consequently the injured soldier may be lost to the unit for a prolonged period of time.

At high altitude, cold injuries are caused by a combination of environmental factors and factors related to the individual soldier's physiology. Environmental factors include low ambient temperature and winds. With increasing elevation the mean ambient temperature decreases, averaging 3.6⁰F lower for every 1000-ft increase in elevation (-2⁰C/300 m). Frequent winds in mountain areas cause high wind-chill factors and lower effective biological temperatures. Additionally, cloudless skies and dry, rarefied air causes large daily fluctuations in temperature due to unhampered solar radiant heating during the day and rapid radiative heat loss at night. Physiologic risk factors include hypoxia-related peripheral vasoconstriction, dehydration and heinoconcentration. Because hypoxia-induced psychological effects can result in poor judgment and decision-making, a higher incidence of cold injuries should be anticipated in the combination of altitude and cold than in cold conditions alone.

Prevention, diagnosis, treatment and prognosis of cold injuries, and administrative disposition of soldiers affected by them are discussed in separate military publications listed in Appendix B. Prevention of cold injury is the responsibility of the unit commander and the individual soldier. It is based upon planning, training, adequate hydration and nourishment and protection afforded by protective clothing and shelter. The diagnosis, treatment and prognosis are similar to cold injuries in other environments except that poor wound healing due to hypobaric hypoxia makes evacuation to low altitude helpful and often necessary. Medical officers supporting units deployed to high-altitude areas must be prepared to advise the commander on cold injuries and participate in appropriate planning and training of unit soldiers.

Solar Radiation Injuries

The potential for solar radiation injuries is great at high altitude due to increased ultraviolet radiation (UV) and reflection of light (albedo) from snow and rock surfaces. Ultraviolet radiation is increased as the result of diminished UV filtering capacity of the thinner atmosphere. Ultraviolet light intensity increases approximately 4% for every 300 m gain in

altitude, so that at 14,000 ft (4,300 m) the intensity is about 55% higher than at sea level. Snow and ice reflect as much as 75% of the incident UV light. This effect becomes critical in glacial cirques where UV radiation can be increased several fold. Solar radiation injuries resulting from the increased UV light exposure in high mountain areas include sunburn and snow blindness (photophthalmia).

Sunburn can occur with a much shorter exposure at high altitude and can be severe. Individual soldiers may vary greatly in - sensitivity based upon their skin type and pigment. Sunburn may be more likely to occur on partly cloudy or overcast days because soldiers may not be aware of the threat and do not take appropriate precautions. In addition to sunburn, a number of medications and some cosmetics that soldiers use can cause phototoxic and photoallergic skin reactions which closely resemble sunburn. These substances include antimicrobials, antimalarials, antihistamines, and nonsteroidal anti-inflammatory drugs. Notably, acetazolamide, used to prevent altitude illness, can cause phototoxic reactions. These reactions, although self-limited, also can cause soldiers enough discomfort to affect their performance and impact on unit effectiveness.

Limiting skin exposure with clothes and sunscreens will prevent most sunburn and phototoxicity. Application of sun-blocking lotions with a sun protection factor (SPF) of at least 15 to exposed skin at appropriate intervals is adequate. Application to skin areas that are normally shaded, such as the eyelids and under the chin, is necessary to reduce the likelihood of sunburn from light reflected off snow and rocks. Opaque agents such as zinc oxide, red veterinary petrolatum or titanium dioxide can be used for high risk body areas such as the nose, lips and tops of the ears. These agents should be used carefully in a tactical situation where they could make a soldier more visible to opposing forces. Medications and cosmetics suspected of causing phototoxic reactions should be discontinued if possible.

Treatment for sunburn includes symptomatic relief with cold compresses. Topical anesthetics may cause sensitization and should be avoided. Ointments and creams containing antihistamines, steroids or NSAIDs may be helpful, but have not been adequately studied. Systemic steroids may be useful in treating systemic effects of severe sunburn over large areas of the body and for treating phototoxic reactions. Time for convalescence and any necessary duty restrictions for sunburn depend upon the severity and extent of skin involved.

Snow blindness (photophthalmia) results from UV-light absorption by the external parts of the eye such as the eyelids, cornea and conjunctiva. The resulting sunburn-like damage can occur in a few hours of exposure, and **there is no sensation of abnormality other than brightness as a warning that eye damage is occurring!** Ocular pain and keratoconjunctivitis (keratitis) from the UV-light damage, once it occurs, can lead to temporary visual loss and corneal ulceration. Although self-limiting, the condition can be extremely painful and debilitating for several days. Snow blindness will effectively incapacitate an otherwise healthy soldier, negate his contribution to mission performance and effectively burden the unit with a medical casualty.

Proper eye protection with UV-transmission retardant goggles or sunglasses will prevent snow blindness. Because UV-radiation injury of the eye can occur by light striking the eyes from the sides, sunglasses require side protectors to be effective protection. Neck straps attached to the eye protection are essential to prevent loss, and soldiers should always carry a spare pair of sunglasses or goggles.

Medical management of snowblindness includes application of a patch dressing over the injured eye for at least 24 hours, systemic analgesics, short-acting cycloplegic drops to relieve ciliary spasm and topical antibacterial ointment or drops. Topical anesthetic drops should be used for the initial exam only. Ophthalmic corticosteroid preparations do not offer any significant clinical benefit and should not be used. Snowblindness may take many days to resolve, and the pain and visual decrements will require temporary, but significant duty limitations.

Chapping of lips and nostrils is caused by the combination of desiccating effects of wind and low humidity with damage caused by UV radiation. It can be sufficiently severe to cause cracking and bleeding and will predispose to secondary infection. Reactivation of herpes simplex virus causing "cold sores" (herpes labialis) is also frequent due to sunburn and chapping of the lips at high altitude. Prevention of these conditions is accomplished by appropriate lip balms and ointments containing sunscreen protection (PABA). Prophylactic use of these treatments should be encouraged since these problems are preventable. An adequate supply of lip balms with sun screening capability may not be available for distribution to soldiers without prior planning.

High Altitude Pharyngitis and Bronchitis

Pharyngitis and bronchitis are frequent during prolonged stays (>2 weeks) at high altitude and are very common at altitudes over 18,000 ft (5,486 m). Sore throat, chronic cough and severe cough spasms provoked by exercise are the primary manifestations of these conditions. Cough spasms can be severe enough to cause rib fractures. The coughing is caused by desiccation of the pharyngeal mucosa from breathing dry, cold air. Altitude-induced tachypnea aggravates the problem. Cold-induced vasomotor rhinitis, especially at night, stimulates mouth-breathing and also aggravates the problem. Although desiccation of mucous membranes can lead to an increased number of upper respiratory infections, pharyngitis and bronchitis at high altitude are seldom due to infection. The impact of altitude-related pharyngitis and bronchitis on military operations is related primarily to the discomfort it causes to individual soldiers. Cough spasms could cause soldiers to be easily detected by opposing forces in some tactical situations.

Prevention and treatment of high altitude pharyngitis and bronchitis involves ample hydration, steam inhalation, hard candies or soothing lozenges and a mild cough suppressant. Soldiers can use a mask or a porous, breathable silk balaclava as a mouth covering to reduce respiratory heat and moisture loss. Decongestant nasal sprays may relieve cold-induced vasomotor rhinitis and lessen mouth breathing. Although the symptoms of high altitude pharyngitis and bronchitis may be uncomfortable and irritating, soldiers seldom require duty limitations.

Lightening Injuries

The potential for being struck by lightning is markedly increased at high altitudes, especially those areas above tree line. Lightning injuries differ from electrical injuries caused by high voltage wires because the duration of exposure with lightning is so short that the current tends to “flashover” the body causing superficial burns rather than internal injury. “Fern-like” burns on the skin are characteristic of lightning strikes, but other types of burns often occur. Fatal injuries occur in only about one-third of persons-directly struck by lightning and usually result from prolonged respiratory, cardiac or combined cardiopulmonary arrest. Severe trauma can occur from the explosive force of the strike and victim being thrown through the air. Confusion and various neurologic abnormalities are universal sequelae of lightning strikes. Tympanic membrane rupture is so common as to be almost pathognomonic.

Prevention of lightning strikes depends upon avoiding areas where the risk is increased and taking appropriate protective action when those areas cannot be avoided. Protective measures include taking shelter in solid-roofed structures or vehicles (tents and canvas-topped vehicles are not safe), squatting low if caught in the open, spreading out if in a group in the open and avoiding tall structures and large metal objects. Portable radio-communications equipment with aerials are especially dangerous and should not be operated or carried during storms. Command posts and other areas where several soldiers stand close together around communications equipment are also high risk, and personnel in them should spread out and crouch low to the ground during storm activity just as they would during an artillery attack.

Soldiers struck by lightning should receive *immediate* cardiopulmonary resuscitation if they are in arrest. Because most lightning victims who are not in immediate cardiopulmonary arrest do not progress to arrest, and many who are in arrest will recover spontaneously if supported, the normal triage should be reversed so that immediate care goes to the apparently “dead” victim. Cardiac activity tends to recover much more quickly than spontaneous respiratory function, so care should be taken to insure adequate ventilation. Trauma and burns caused by lightning can be treated using standard clinical guidelines. Most lightning victims will have residual neurologic abnormalities that could significantly interfere with their performance and may need an appropriate physical profile and duty limitations until sufficiently recovered. Those with permanent neurologic damage should be referred to a Medical Evaluation Board.

Carbon Monoxide Poisoning

Carbon monoxide (CO) poisoning is a frequent environmental hazard during military operations in high altitude environments for at least two reasons: 1) inefficient fuel combustion caused by the low oxygen content of the air produces more CO than is produced by combustion at low altitude, and 2) soldiers often run stoves, combustion heaters and engines in enclosed, poorly ventilated spaces to avoid cold conditions outside. Cigarette smoking is another source of CO. Avid binding of carbon monoxide to hemoglobin exaggerates the altitude-induced hypoxemia thereby increasing the pathologic effects of the CO and also the chance for hypoxia-related altitude illness. Symptoms of CO poisoning are very similar to those of the AMS/HACE

continuum, and the two conditions can exist together. Additionally, CO poisoning can cause a non-cardiogenic pulmonary edema similar to HAPE.

Prevention of carbon monoxide poisoning is based upon avoiding sources of combustion in enclosed spaces. Soldiers should be warned against sleeping in vehicles with engines running, cooking inside tents and sleeping in tents with working combustion heaters. Working heaters in tents should be closely monitored to ensure that equipment is operating at maximum efficiency.

The treatment for both CO poisoning and altitude illness is similar with respect to insuring adequate oxygenation. Forced hyperventilation, especially with supplemental oxygen administered by tight-fitting mask, will accelerate elimination of CO from the body and decrease the hypoxemia. Evacuation to a lower altitude is essential in treatment of all but very mild cases of CO poisoning and is helpful in all cases. Use of the portable cloth hyperbaric chamber with supplemental oxygen is helpful when evacuation is prevented by weather or tactical situation.

Soldiers who suffer mild, reversible neurologic damage from a CO exposure can resume their duties when their carboxyhemoglobin levels return to normal. Those with significant sequelae will require physical profile or referral to a Medical Evaluation Board based upon their condition.

Terrain-Related Trauma and Orthopedic Problems

Acute trauma is a prominent hazard in high altitude areas due to the interaction of rugged terrain with other environmental, mission and soldier-related factors. Both hypoxia and cold can impair judgement, cognition and physical performance which can greatly diminish a soldier's ability to safely maneuver in rugged terrain. Heavy clothing worn for protection against the cold and specialized equipment such as climbing ropes and harnesses, crampons, etc. can also restrict movement. Falls are a very common source of acute trauma under these conditions. They are frequently complicated by contusions, lacerations and penetrating injuries from climbing and ski equipment. The diagnosis and treatment of trauma injuries at high altitude follows standard clinical guidelines, but treatment options may be limited by lack of specialized medical equipment. Consequently, injured soldiers may require evacuation to higher echelons for definitive medical care. Prevention of trauma depends upon identifying and avoiding risk factors. Medical officers must remain alert to emerging patterns of injury that may identify specific hazards during military operations in rugged mountain terrain. Once hazards are identified, recommendations can be made to the commander as to how those hazards can be avoided.

Increased frequency of overuse injuries will occur at the beginning of mountain operations due to changes in biomechanics of marching and other activities caused by rugged, sloping terrain. If there is a significant component of technical climbing involved in the mission, upper extremity and especially finger injuries may be prominent. Diagnosis and treatment follows standard clinical guidelines. Rest of the affected extremity is a prominent element of treatment. Most overuse injuries recover with time, but affected soldiers may require a temporary physical profile for minor duty limitations.

Constipation and Hemorrhoids

Constipation and acute exacerbation of hemorrhoids are common during high-altitude deployments due to changes in dietary consumption patterns, reduced water intake and voluntary delay of defecation to avoid cold or unsheltered areas. Both conditions can adversely affect physical performance as well as mood of soldiers. Normal bowel movements can usually be maintained with an adequate fluid intake and the inclusion of fruits or other sources of fiber in the diet. Soldiers with preexisting hemorrhoids should have them medically evaluated and if necessary, treated to prevent exacerbation during deployment to high-altitude areas. Constipation and hemorrhoids occurring during high-altitude deployment can be treated according to standard clinical guidelines including hydration, dietary manipulations, mineral oil (one tablespoon twice a day) for lubrication, mild anesthetics such as dibucaine, hemorrhoidal suppositories, or hydrocortisone ointment. Medical personnel should insure that sufficient supplies of these materials are available during deployment.

Infectious Diseases

Although there is some decrease in T-cell function at high elevations (see Immune Suppression, page 25), the patterns of infectious disease seen in high mountain areas primarily reflect patterns of exposure rather than any degree of immunodeficiency. In general, there are progressively fewer bacteria in the environment and fewer insect vectors at higher altitudes. This results in a narrower spectrum of infectious disease at very high and extreme altitudes. The types of infections found there tend to be from endogenous bacterial flora and agents that are easily transmitted directly from person-to-person. Person-to-person transmission is enhanced by the tendency for soldiers to crowd together in relatively small confined spaces (tents, vehicles, etc.) for relief from the cold. Another factor that strongly influences disease patterns at these altitudes is poor field sanitary conditions. Soldiers may not practice proper field sanitation or personal hygiene in very high mountains due to the cold conditions, water shortage and hypoxia-induced decrements in energy and motivation. Commanders and medical personnel should insist that good personal hygiene and proper sanitation are accomplished (see Appendix B).

The spectrum of infectious disease seen at moderate to high altitude is generally wider than at higher elevations. Insect-borne disease is more common with ticks and flies being significant vectors. In a few specific areas malaria-bearing mosquitos range as high as 6000 ft (1,829 m). Some of the diseases carried by insect vectors may be very regional, and medical officers need to obtain medical intelligence on the specific region to which the unit is deployed. Indigenous populations in mountain regions are another source of infectious disease because they tend to have generally poor economic status with limited or non-existent public health systems. The problem is even more pronounced with refugees. High exposure rates to tuberculosis, hepatitis and diarrheal disease should be expected when soldiers contact either refugees or indigenous populations.

Infection with the parasite *Giardia lamblia* is extremely common in mountain regions world-wide, including the western mountains of North America. Ingestion of *Giardia* cysts in unpurified water contaminated by human or animal feces is the most common route of transmission. Less common, but equally significant, is direct passage of cysts from feces to the hands and finally directly to food or the mouth. Preventive measures are based on avoiding ingestion of cysts in water and food, or on hands and dirty utensils. Symptoms of giardiasis include abdominal pain, nausea abdominal distension, intestinal gas and frequent diarrhea. Acutely, symptoms may also include weakness, loss of appetite and chilly sensations. Chronic effects include nutrient malabsorption, weight loss and “ulcer-like” pain. A ‘presumptive diagnosis can be made in the field since symptoms are fairly typical. A definitive diagnosis is made by identifying cysts in the stool or upper intestinal tract secretions. A definitive diagnosis is not needed to treat giardiasis, and successful response to treatment can be viewed as diagnostic. Therapy consists of metronidazole 750 mg orally three times a day for ten days or quinacrine 100 mg orally three times a day for one week. These regimens provide approximately an 80% cure rate and can be repeated, or a combination of these drugs can be used when the condition persists. Alcohol should be avoided during and 24 hours after ingestion of metronidazole.

Pre-existing Medical Conditions

A number of acute and chronic medical conditions which may be present in soldiers before deployment to high altitude can interact with hypobaric hypoxia and either worsen the underlying condition itself or aggravate the hypoxia making the soldier more susceptible to altitude illness. Medications that soldiers may be taking during deployment to treat preexisting medical conditions may also increase the risk of altitude illness. Chronic conditions or medications that affect the cardiovascular and/or respiratory systems are obvious risks at high altitude. Examples include chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), congenital and acquired valvular heart disease, unrevascularized coronary artery disease, pulmonary hypertension, anemia and medications that depress respiration. Any blood clotting abnormality as evidenced by a history of stroke or abnormal laboratory values carries a greatly increased risk of altitude-related embolic events. Sleep apnea and obesity can both exaggerate hypoxemia. Temporary or acute medical conditions which can increase the health risk of soldiers deployed to high mountain environments include infections (especially upper and lower respiratory tract infections) and high risk pregnancies.

Many chronic medical conditions that can cause problems at high altitude will normally disqualify soldiers from active duty and are listed here only for completeness. Medical officers should be aware of conditions in individual soldiers that might increase their health risks when deployed to high altitude. Predeployment medical screening should be conducted to identify individuals with preexisting acute or chronic medical problems. If a significant condition is discovered on predeployment screening, that soldier should be evaluated for a temporary or permanent physical profile to limit their altitude exposure.

Sickle cell trait is a chronic condition that does not normally disqualify a soldier from active duty. However, altitude may greatly increase the risk of sickle crisis with splenic sequestration and infarction during altitude exposure. Case reports in the literature suggest that the risk for this complication may be higher in non-black soldiers with sickle trait than it is in black soldiers with the trait. All soldiers with sickle trait should be evaluated carefully prior to high-altitude deployment. Those with a high degree of sickling at low oxygen tensions should be considered for a physical profile to limit altitude exposure.

SOLDIER-RELATED FACTORS IN HIGH-MOUNTAIN OPERATIONS

Soldier-related factors can have significant impact on military operations at high altitude through direct effects such as hypoxia-induced performance decrements, or through interaction with environmental factors to increase the risk of medical problems. Soldier-related factors that are important for medical personnel to be cognizant of during high-altitude deployments include; physical and psychological performance decrements, various general health issues including nutrition, hydration, sleep and hygiene and ingested substances with pharmacologic activity such as caffeine, tobacco, alcohol and medications. Implementation of countermeasures to modify soldier-related factors or compensate for their effect will help conserve the effective unit force and enhance the likelihood of successful mission accomplishment.

Reduced Physical Performance

Hypobaric hypoxia causes a reduction in physical performance of soldiers deployed to high-altitude terrain. As might be expected, the greatest effects are on aerobic activity while anaerobic exercise and muscular strength are virtually unaffected.

Soldiers cannot attain the same maximal physical performance at high altitude that they can at low altitude, regardless of their fitness level. On the average, there is a 10% reduction in maximal aerobic exercise (physical work) capacity for each 3000 ft (914 m) gain in elevation above 5000 ft (1,524 m). This decrement does not recover after acclimatization. An example of the operational impact this decrease can have is illustrated by the reduction in "climbing" rate as a function of altitude irrespective of altitude illnesses, grade of ascent, or work-rest cycle) shown in Figure 3. Upon descent to sea level, maximal work capacity returns immediately to pre-exposure levels unless detraining has

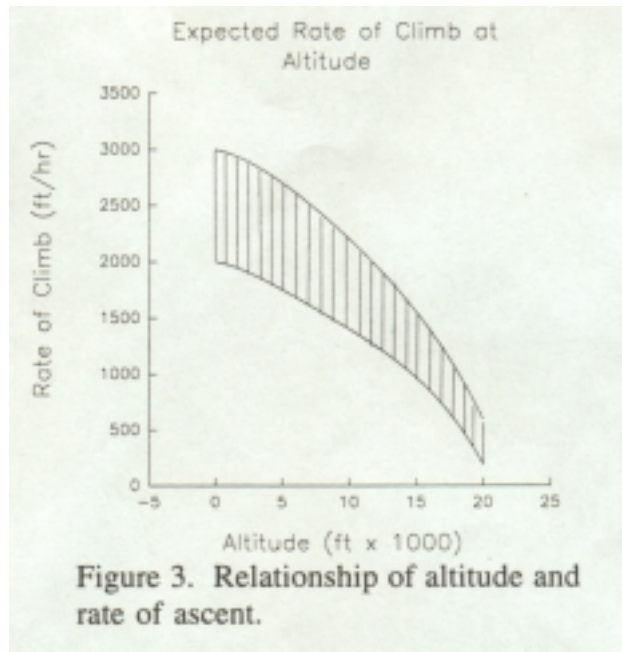


Figure 3. Relationship of altitude and rate of ascent.

occurred. Although submaximal relationship of altitude and physical performance is also reduced with initial rate of ascent, soldiers can achieve the same levels of submaximal performance at high altitude as they do at low altitude by expending more effort. In contrast to maximal physical performance, acclimatization and physical training at high altitude will improve submaximal exercise performance. Endurance performance is also reduced following ascent. Endurance comparable to sea level is possible following one to two weeks of acclimatization and can also be increased with training.

The oxygen content of the blood is an important consideration in physical exercise at high altitude. During exercise at sea level, there is normally no significant change in arterial P_{O_2} because alveolar gas exchange is adequate. However, at high altitude there is a reduction in arterial hemoglobin saturation that is dependent on both the altitude and the intensity of exercise. For example, at 14,900 ft (4,550 m), moderate short-term exercise can cause a reduction in hemoglobin saturation from a resting level of 79% to an exercise level of 69%. This lower saturation is equivalent to the resting level at 18,000 ft (5,500 m).

Two different strategies are necessary to manage altitude-related physical performance decrements. First, because the decrements in maximal performance at high altitude and the submaximal and endurance decrements that occur during initial altitude exposure cannot be avoided, their impact on unit effectiveness must be anticipated and included in operational planning. Work rates and load carriage may have to be adjusted. Frequent short rests during exercise are very useful because they permit the hemoglobin saturation to recover toward resting levels. Use of frequent short rests will lessen the hypoxic insult and any resultant physiological, hormonal and biochemical changes. The second strategy to manage altituderelated physical performance decrements is to insure adequate acclimatization and perform physical training at altitude whenever the mission contingencies permit sufficient time to do so. The influence of training, motivation and previous altitude experience can be a large factor in the improvement of submaximal and endurance performance.

Psychological Effects of Sustained Hypoxia

Altitude exposure can affect a number of psychological parameters in soldiers deployed to high mountain terrain including vision, cognitive function, psychomotor function, mood and personality. The effects are directly related to altitude and are much more common over 10,000 ft (3,048 m). Some effects occur early and are transient, but others persist after acclimatization or even for a period of time after descent. In general, there is a lot of individual variation in psychological effects of altitude.

Vision is the sensory modality most affected by altitude exposure. Many visual effects are acute (onset within minutes of exposure), transient (minutes to hours) and involve aspects of vision that may not be clinically or operationally significant. Some visual effects may contribute to altitude-induced decrements in psychomotor performance, however.

Dark adaptation is significantly degraded by altitude exposure and may be affected as low as 8,000 ft (2,438 m). The effect persists after altitude acclimatization and can only be improved with supplemental oxygen. The decrease in dark adaptation can potentially affect military operations at high altitude.

Both cognitive and psychomotor performance decrements occur at altitudes greater than 10,000 ft (3,048 m). The effects are especially noticeable at very high and extreme altitudes (>18,000 ft, 5,486 m) where there can be decrements in perception, memory, judgement, attention and other mental activity. In general, cognitive function is

more affected than psychomotor function, complex tasks are affected more than simple tasks, and the decision making process is affected before automatic behaviors. Some effects appear to diminish with acclimatization. Some subtle psychomotor and possibly memory deficits may last for at least a year following exposure to altitudes greater than 20,000 ft (6,096 m). These may not be readily apparent or functionally significant. To compensate for functional impairment during altitude exposure, many soldiers devise a strategy of a tradeoff between speed and accuracy. They take longer to accomplish tasks, but are able to limit their error rate. Usually, the more proficiently the soldiers are trained in performing specific tasks at sea level, the less reduction in speed and accuracy will occur at altitude. Some loss of speed should always be anticipated, however. Consequently, important tasks should always be checked for errors. This strategy is also applicable to commanders and medical personal who are subject to the same altitude-related decrements in cognitive and psychomotor function as other unit members.

Alterations in mood and personality traits are common during high-altitude exposure. Within hours of ascent many soldiers may experience euphoria. This euphoria is likely to be accompanied by errors in judgment which may lead to mistakes and accidents. All personnel should be watchful during this early period since the euphoria and bad judgment are not usually noticed by the affected individual. Use of the "buddy system" during this early exposure period helps to identify specific soldiers who may be more severely affected. With continued time at altitude (6-12 hours), the euphoria abates, often changing to varying degrees of depression. Soldiers may become irritable and quarrelsome or may become apathetic. These mood changes depend on factors such as the psychological makeup of the soldier, weather conditions (especially long inclement periods coupled with confinement), isolation and interpersonal relationships. Instilling a high morale and *esprit de corps* before deployment and reinforcing these frequently during deployment will help minimize the impact of negative mood changes.

Sleep Disturbances

High-altitude exposure has significant detrimental effects on sleep. The most prominent effects are induction of periodic breathing with frequent periods of apnea and fragmented sleep with frequent arousals. These altitude-related phenomenon degrade the quality of sleep and impact on soldiers to cause performance decrements when awake.

Periodic or Cheyne-Stokes breathing (alternating cycles of hyperpnea and apnea) during sleep is nearly universal in unacclimatized soldiers when they are exposed to high altitude. The phenomenon is thought to be caused by a sleep-induced decrease in cortical influence on respiration combined with changes in the gain and sensitivity of the peripheral chemoreceptors, so that there is overcompensation for the altitude-induced hypoxemia. Increased ventilation lowers carbon dioxide enough to cause a hypocapnic apnea. The characteristic cyclical respiratory pattern is very distinct and may be noticed by other soldiers. The prolonged periods of apnea (10-20 seconds without a breath are not unusual) can be particularly disturbing to soldiers who observe them in their companions. This type of altered breathing pattern may last for weeks at elevations less than 18,000 ft (5,486 m) and may never resolve

at higher elevations. The periods of apnea can cause profound reductions in hemoglobin oxygen saturation. At an altitude of 17,500 ft (5,350 m), the average reduction can amount to 10% [from 75% (awake) to 65% (asleep)]. This additional reduction in arterial oxygen is associated with larger performance decrements while awake and may contribute to serious altitude illnesses.

Sleep architecture is fragmented at high altitude with frequent short (seconds) arousals and less time spent in stages 3, 4 and rapid eye movement (REM) sleep. Although the arousals are short enough that they may not be noticed by a non-sleeping observer, they are very apparent to the soldier attempting to sleep. Reports of “not being able to sleep” and “awake half the night” are the most common manifestations of frequent arousals, but they may also contribute to mood changes and daytime symptoms of somnolence. These effects have been reported as low as 5,000 ft (1,524 m) and are very common at higher altitudes.

Acetazolamide (250 mg every six or eight hours by mouth) improves sleep quality by increasing the respiratory rate, decreasing periodic breathing and improving arterial oxygen saturation. The increase in oxygen saturation, in turn, lessens sleep fragmentation. Acetazolamide is the pharmacologic treatment of choice for sleep disturbances at high altitude and has the added advantage of being an effective prophylactic against acute mountain sickness. The combination of temazepam 10 mg and acetazolamide 500 mg orally before sleep is also effective in improving sleep and maintaining oxygen saturation. Short-acting sedatives and other soporifics that may cause respiratory depression should be avoided because they tend to compound the sleep hypoxemia. Low-flow (1-2 l/min) oxygen is very effective at eliminating periodic breathing and sleep fragmentation, if it is available. However, the logistics of supplying even low-flow oxygen to individual soldiers in an operational setting will often be prohibitive.

Dehydration

Dehydration is a very common condition in soldiers at high altitude. The causes are many. Low humidity in cold, high-altitude environments results in high rates of insensible water loss from the respiratory tract and evaporative water loss from the skin. Hypoxia-induced increases in ventilation and exercise-induced increases in both ventilation and sweat rate further increase insensible and evaporative water loss. Additional sources of fluid loss include hypoxia-induced diuresis and vomiting associated with acute mountain sickness. Decreased fluid intake due to hypoxia-induced blunting of thirst sensation and the difficulty of obtaining and transporting potable water may also contribute to dehydration.

Dehydration can also interact with many other environmental and soldier-related factors to increase the likelihood of other medical and operationally significant problems. Important examples include increased susceptibility to cold injury and thromboembolism, and increased physical and cognitive performance decrements. Additionally, medical personnel should be aware that many signs and symptoms of dehydration and HACE are similar. Consequently HACE should always be included in the differential diagnosis of dehydration in the mountains.

Three to four quarts of water per day (or more) may be required to maintain adequate hydration in soldiers at high altitude. Hydration status can be monitored in the field by noting urine flow. Soldiers should be trained, or, if necessary, ordered to drink sufficient amounts of fluid to produce a urine flow of greater than one quart per day. Soldiers can monitor the state of their own hydration by observing the color of their urine. Clear or light urine suggests adequate hydration; dark yellow, orange, or brown urine is indicative of significant dehydration. Soldiers should be taught that **thirst is not an adequate warning of dehydration!** They should understand that they can become dehydrated without becoming thirsty.

Obtaining an adequate water supply can be a problem in mountain regions due to limited amounts of surface water in many areas (especially above tree line), frequent contamination of surface water with parasites and other enteric pathogens and the difficulties of transporting large quantities of water over rugged terrain. While snow, streams and lakes may provide sources of water in some areas, there is a high incidence of naturally occurring parasites as well as possible contamination by humans and animals. All water sources should be considered as unsafe unless verified by official US military personnel (preventive medicine teams) or personally purified.

Water can be purified by using portable hand-pump water purifiers, which remove contaminants by passing the water through a micropore filter, or by sterilizing it using heat or halogen (chlorine and iodine) compounds. Hand-pump purifiers remove parasites and enteric bacteria if the pore size on the filter is less than 2 microns in diameter, but they will *not* remove enteric viruses. Heat sterilization will kill all pathogens if water is boiled for a sufficient period of time. At sea level, sterilization by boiling requires 10 minutes at a full boil; at altitude, an additional minute of boiling is needed for each 1000 ft (300 m) gain in elevation, due to the lower boiling point temperature of water caused by the lower atmospheric pressure. Chlorine and iodine will kill viruses, enteric bacteria and most parasites, although some parasite eggs are resistant. The effectiveness of these compounds is a function of the dose and the amount of time they are in the water before it is consumed (contact time). Both organic impurities in the water supply and cold temperature reduce the effectiveness of halogen compounds so that the dose and/or the contact time must be increased. Specific halogen water-treatment regimens and additional information on water treatment can be found in references listed in Appendix B.

Inadequate Nutrition

Poor nutrition, like dehydration, is a very common problem for soldiers operating in high mountain environments. As with dehydration, several physiological and behavioral factors contribute to the problem of poor nutrition. Nutritional deficits, in turn, interact with other environmental, mission and soldier-related factors to cause increased illness and injury, performance decrements, decreased cold tolerance and poor morale.

The most obvious manifestation of inadequate nutrition in the mountains is weight loss. It is common at altitudes over 14,000 ft (4,270 m) and probably universal at elevations greater than 18,000 ft (5,490 m). In mountaineering circles it is often referred to as “climbers’ cachexia.” The weight loss is primarily due to hypohydration and decreased caloric intake combined with increased energy requirements from altitude exposure, cold and physical activity.

Multiple factors contribute to decreased food consumption in the high mountains. Altitude dulls taste sensation enough to make many foods less palatable. There is also some evidence for fat malabsorption at very high altitude, presumably due to the effect of hypoxia on intestinal mucosa. Gastrointestinal symptoms caused by fat malabsorption, and by intestinal parasites such as *Giardia*, or by gas expansion in the intestines due to reduced atmospheric pressure can all function to decrease food intake. Because of altitude-induced lassitude, nausea from altitude illness and anorexia, soldiers also may lack the energy and motivation to prepare hot nutritious meals or even to eat meals provided to them. Limited availability of adequate rations and water supplies due to supply problems in rugged mountain terrain may also limit consumption...

Altitude-induced weight loss and nutritional deficits can be prevented by increasing caloric intake and ensuring adequate hydration. Several US Army field rations can provide adequate calories to meet the increased daily requirement at high altitude if all the components of the ration are eaten. Four - Meals, Ready-to-Eat (MRE); one - Ration, Cold Weather (RCW); or three - Food Packets, Long Range Patrol (LRP) will each provide enough daily calories. Both RCW and LRP require approximately three quarts of water to rehydrate the ration components, which may be a problem in mountain areas with scarce water supplies. All of these rations should be supplemented, and frequent snacking should be encouraged to further increase intake. Items from different rations can be combined or supplemented with non-issue food items to increase variety. Providing hot meals whenever possible and serving meals in a group setting also may help increase food consumption by soldiers at high elevations.

Increased dietary carbohydrates are helpful at high altitude because of their easy digestibility and their stimulatory effect on ventilation (via increased production of carbon dioxide). Diets with greater than 70% of the calories from carbohydrates appear to lessen the incidence and severity of AMS. High carbohydrate snacks are an effective means to increase the carbohydrate content of the diet because they are easily carried by individual soldiers and require no preparation. Many soldiers will prefer high carbohydrate foods due to altitude-induced taste preference changes, but others will not show the same preferences and will need to be encouraged to eat carbohydrates.

Pharmacologically-Active Substances

Substances with pharmacologic activity can interact with effects of environmental factors at high altitude to cause medical problems. There are several possible sources of pharmacologically-active substances for soldiers deployed in high mountain terrain.

Prescription drugs are an obvious source, and medical officers not only must take into account the effects of drugs they themselves may prescribe during altitude deployment, but must also be aware of any drugs, such as blood pressure medication, that a soldier may take chronically. Soldiers often bring non-prescription (“over-the-counter”) medications with them during deployment, and medical personnel may not be aware of these unless they ask individual soldiers. Illicit drugs, while usually not a significant problem in US Army units, are a potential source of pharmacologically active substances that should not be ignored. The most common sources of pharmacologically-active substance that can interact with environmental factors in the mountains are caffeine, tobacco and alcoholic beverages.

Drugs and other substances cause problems at high altitude by interacting with environmentally-induced changes in a soldier’s physiology or by altering the soldier’s mental status, thereby increasing the risk of errors in judgement and accidents. Because hypobaric hypoxia is ubiquitous at high altitude, any substance that interferes with oxygen delivery is a significant threat. Well known examples include sedatives, sleeping aids, tranquilizers and other medications that depress respiration. Tobacco smoke interferes with oxygen delivery by reduction of blood oxygen-carrying capacity through increased carboxyhemoglobin levels. Incomplete combustion of tobacco due to the reduced oxygen content of the air and close, confined spaces in tents or vehicles also increase the amounts of inhaled carbon monoxide. Oxygen-carrying capacity can be reduced by as much as 5-10% by tobacco smoke. Additionally, the irritant effect of tobacco smoke may produce a narrowing of small airways, interfering with optimal air movement. The combination can effectively raise the “physiological altitude” as much as several thousand feet.

Substances with significant diuretic properties such as alcoholic beverages, caffeine and diuretic medications can be a problem at high altitude where soldiers have decreased plasma volume and are often dehydrated to varying degrees due to decreased fluid intake and fluid losses from altitude illness. Acetazolamide, used to prevent AMS, is a fairly weak diuretic and is not usually a problem when used for AMS prophylaxis. Substances which cause significant peripheral vasodilation are also at least a theoretical hazard at high altitude due to the altitude-associated decrease in plasma volume. Additionally, peripheral vasodilation accelerates heat loss and makes soldiers more vulnerable to hypothermia. This is a well known effect of alcohol. Substances which cause peripheral vasoconstriction also increase the risk of cold injury. Peripheral vasoconstriction caused by tobacco products increases the risk for freezing cold injuries such as frostbite.

Medications and other substances that alter mental status interact with hypoxia-induced decrements in cerebral function to greatly increase the chance of errors in judgement and accidents. Alcohol impairs judgment and perception and promotes psychomotor dysfunction. As noted above, alcohol has a number of other undesirable properties at high altitude. It depresses respiration, causes hypoglycemia and induces an undesirable diuresis. Alcohol also adversely affects peripheral temperature regulation and increases heat loss, contributing to the development of hypothermia, frost nip and/or frostbite, even in concentrations well below levels of obvious intoxication. In the civilian population it is an important contributory cause

of death in cold environments. Unlike alcohol, caffeine from coffee and other sources improves physical and mental performance. It also causes diuresis and, therefore, should be consumed in moderation.

The harmful effects of medications and other pharmacologically active substances at high altitude are prevented by limiting the use of those substances during high-altitude deployments or by limiting altitude exposure itself. Medical officers need to be aware of the medications taken by soldiers as well as the tobacco and alcohol consumption habits. Medications that could have a harmful effect at high altitude should be replaced, if possible, prior to deployment. If the medications cannot be replaced, consideration should be given to limiting the soldier's altitude exposure.

HEALTH SERVICE SUPPORT IN HIGH-MOUNTAIN OPERATIONS

The mission of health service support during military operations is to conserve fighting strength through: 1) prevention of injury and illness, 2) effective treatment of casualties to expedite their return to duty and 3) timely evacuation of casualties who cannot be effectively treated in forward echelons. The environment can impact on that mission by adding environment-related medical problems to the spectrum of injury and disease normally associated with military operations and by imposing constraints on performance and operation of medical unit personnel and equipment. To employ field medical support assets effectively, a medical officer needs to be aware of the potential impact of environmental factors on soldiers and medical assets. Information on prevention and treatment of the constellation of injuries and illnesses associated with mountain environments is presented in previous sections of this handbook. This section presents information about the use of field unit medical assets to provide treatment and evacuation in mountain environments.

Impact of Mountain Environments

Environmental factors which impact on health service support in mountain environments include the low barometric pressure and partial pressure of oxygen, cold ambient temperatures, rugged terrain and periods of severe inclement weather. These factors can affect individual patients and medical personnel, but they can also have a profound effect on any field medical unit's ability to accomplish its primary mission. The most significant effects are to cause injury or exacerbate a prior injury or illness, to alter performance of personnel and equipment and to limit mobility. Often several environmental factors act in concert creating additive or synergistic effects.

The wide range of effects that environmental factors can have on aspects of field medical support operations is illustrated by the problems caused by hypobaric hypoxia and temperature extremes at high altitude. Both factors can cause additional injuries to patients with other medical problems (e.g., frostbite or HAPE in a patient with ballistic wounds or hyperthermia in a dehydrated patient). Preexisting medical problems may also be exaggerated (e.g., more profound hypoxemia in patients with respiratory insufficiency). Litter patients may be especially vulnerable to cold due to the lack of physical activity which normally functions to generate additional metabolic heat. Medical personnel are also susceptible to injury from altitude-induced hypoxia and thermal fluctuations.

In addition to causing medical problems, hypobaric hypoxia and temperature extremes can degrade performance of both medical personnel and equipment. As described previously, hypoxia can affect both physical and mental performance, and some performance decrements persist even after successful acclimatization. Decreased physical performance can significantly affect litter evacuation capabilities especially when rugged terrain greatly increases the physical work involved in carrying litters. Hypoxia-related impairment of cognitive performance in

medical personnel can cause errors in judgement that could compromise treatment and cause accidents. Cold can also affect physical and mental performance. Its effect on manual dexterity can be very detrimental in medical care settings.

The lower partial pressure of oxygen at high altitudes causes incomplete fuel combustion in engines of evacuation vehicles which can progressively limit their effectiveness in mountains. Additionally, aircraft, including military helicopters, lose lift capability with the decreased air density at higher altitudes. This can reduce their performance and render them incapable of performing effective medical evacuation or resupply.

Both rugged terrain and inclement weather can severely limit mobility in the mountains. Weather tends to be a more temporary limitation, although deep snow or snow on slopes with danger of an avalanche may hinder travel for variable periods of time. Bad weather and rough terrain also increase the hazard of injury from falls and accidents.

Countermeasures for Adverse Environmental Factors

Although environmental factors can be significant obstacles to the delivery of medical care and evacuation by field medical units in mountain environments, the inherent flexibility of the field health service support organization provides the means to operate effectively. Medical officers may have to alter the “usual” structure and deployment of health service support assets under their control to effectively surmount the impact of the mountain environment. Medical personnel supporting military units in mountain terrain should anticipate the impact of environmental factors and plan for adjustments in the organization and appropriate training of medical personnel well in advance of actual operations. Some general considerations in planning for mountain operations are listed below, but medical officers need to be flexible and alert for other possible ways to increase the effectiveness of health care delivery and casualty evacuation.

Direct injury to patients and medical personnel by environmental factors such as low partial pressure of oxygen and cold can be prevented by appropriate planning and use of protective measures. Planning should include provisions for extra tentage and bedding to protect patients from cold and inclement weather. Provisions for additional supplies of supplemental oxygen should be considered whenever possible. Like patients, medical personnel should also have adequate protective clothing and shelter. To prevent altitude illness and decrease performance decrements, medical personnel should be allowed to acclimatize to altitude whenever possible prior to beginning operations.

The limitation of mobility is a significant impediment to accomplishing field medical unit missions in the mountains. Limited mobility can constrain a medical unit's ability to maintain both proximity to the tactical unit and continuity between echelons. There are two approaches to offsetting the problem of decreased mobility in the mountains, and both require augmentation of medical unit assets. The first approach is to improve mobility. As a general principle, air transport can be emphasized over ground

transport to minimize the effect of rugged terrain, but frequent severe inclement weather and performance limitations of aircraft in the mountains often severely limit this option. Limitations to vehicular ground transportation will require a greater number of vehicles which are more efficient, a careful choice of evacuation routes and/or increased reliance on litter or even pack-animal carriage.

Altitude-induced performance decrements will require augmentation of litter teams, shorter carries and careful choice of litter routes. General guidance is that a four-man litter team should only move one-third the distance in the mountains that it can on level ground. Six-man litter teams should only travel 370 m (1,214 ft) and return in one hour in moderate mountain terrain. Specialized training and equipment (litters, climbing ropes, etc.) may be needed to transport patients in very rugged terrain.

The second method to circumvent the problem of decreased mobility for medical evacuation in the mountains is to increase the ability to hold and treat patients in forward medical echelons. This can be accomplished by decreasing the distances between echelons and by augmenting the forward echelons with equipment and personnel to increase their treatment and holding capabilities. It is essential that these steps be taken to offset the effects of unpredictable, inclement weather.

APPENDIX A

MEDICATIONS TREATMENT OF ALTITUDE OF ILLNESSES

MEDICATION	INDICATIONS	DOSAGE	COMMENTS
oxygen	Severe AMS headache cyanosis HAPE HACE	2-6 L/min 2-6 L/min 2-6 L/min	DO NOT DELAY DESCENT DO NOT DELAY DESCENT
acetazolamide	AMS prevention AMS treatment sleep disorders peripheral edema	250 mg q.i.d or 500 mg b.i.d., p.o., starting 48 h before ascent, continuing for 48 h after ascent 125 mg q.i.d to 500mg, t.i.d., p.o. 250 mg q.i.d. or t.i.d p.o. 250 mg t.i.d., p.o., for 3 doses	Side effects: parasthesias, fatigue, altered taste Contraindicated with sulfa sensitivity
dexamethsone	AMS treatment HACE	2-4 mg, q.i.d., p.o. 4-8 mg followed by 4 mg q.i.d., p.o., i.v., or i.m.	For <u>severe</u> AMS only DO NOT DELAY DESCENT Few side effects if used only 3-4 days
acetaminophen	AMS headache	325 mg q. 4 h to 1000 mg q.i.d., p.o., or t.i.d. p.o.	
ibuprofen	AMS headache	200-800 mg t.i.d. or q.i.d. p.o.	Other non-steroidal anti-inflammatories stomach irritation
aspirin	AMS headache superficial thrombophlebitis	325-1000 mg 4-6h, p.o. 325-1000 mg q. 4-6 h, p.o.	Stomach irritation

MEDICATION	INDICATIONS	DOSAGE	COMMENTS
heparin	thromboembolism deep venous thrombophleptis	PTT adjusted to 2-3 INR; 5000 units s.q. t.i.d. to b.i.d. in the field	REQUIRES EVACUATIOIN
triazolam	insomnia	0.125 mg, q.h.s., p.o.	Short term use only. Possible short-term memory loss
temazepam	insomnia	30 mg, q.h.s, p.o.	
nifedipine	HAPE treatment HAPE prevention	10 mg sublingually, followed by 30 mg q.i.d 20 mg t.i.d., p.o., 24 h before ascent, continuing 72h after ascent	
prochlorperizine	nausea/vomiting	5-10 mg t.i.d.-q.i.d., p.o. or i.m. or 25 mg b.i.d., p.r.n.	Also stimulates respiration
furosemide	peripheral edema	20-40 mg p.o. one dose	

APPENDIX B

RELATED READING

Mountain Medicine

Department of the Army. Technical Bulletin, Medical 288. Medical Problems of Man at High Terrestrial Elevations. 1975.

Dubas, F., and J. Vallotton (Eds). Color Atlas of Mountain Medicine. St. Louis, Mo: Mosby Year Book. 1991.

Hackett, P.H., R.C. Roach and J.R. Sutton. High altitude medicine. In: P.S. Auerbach and E.C. Geehr (Eds). Management of Wilderness and Environmental Emergencies. St. Louis, Mo: C.V. Mosby Company. 1989.

Heath, D. and D.R. Williams. High-Altitude Medicine and Pathology. London: Butterworths. 1989.

Ward, M.P., J.S. Milledge and J.B. West. High Altitude Medicine and Physiology. Philadelphia, Pa: University of Pennsylvania Press. 1989.

Altitude Acclimatization and Physiology

Banderet, L.E., and R.L. Burse. Effects of high terrestrial altitude on military performance. In: R. Gal and A.D. Mangelsdorff (Editors). Handbook of Military Psychology. New York, NY: John Wiley & Sons. 1991. (Available as: U.S. Army Research Institute of Environmental Medicine. Report No T2-92 Effects of High Terrestrial Altitude on Military Performance. 1992, Natick, Mass, DTIC No: AD-A246 695).

Fulco, C.S. and A. Cymerman. Human performance and acute hypoxia. In: K.B. Pandolf, M.N. Sawka and R.R. Gonzalez. Human Performance Physiology and Environmental Medicine at Terrestrial Extremes. Indianapolis, Ind: Benchmark Press, Inc. 1988.

Young, A.J., and P.M. Young. Human acclimatization to high terrestrial altitude. In: K.B. Pandolf, M.N. Sawka and R.R. Gonzalez. Human Performance Physiology and Environmental Medicine at Terrestrial Extremes. Indianapolis, Ind: Benchmark Press, Inc. 1988.

Military Mountain Operations

Department of the Army. Field Manual 90-6. Mountain Operations.

Department of the Army. Field Manual 31-71. Northern Operations

Department of the Army. Training Circular 90-6-1. Military Mountaineering.

Cold Injuries

Department of the Army. Technical Bulletin, Medical 508. Cold Injury.

U.S. Army Research Institute of Environmental Medicine. Technical Note, 93-4. Medical Aspects of Cold Weather Operations: A Handbook for Medical Officers. 1993. Natick, Mass, DTIC No: AD-A263 559.

U.S. Army Research Institute of Environmental Medicine. Technical Note, 92-2. Sustaining Health and Performance in the Cold: Environmental Medicine Guidance for Cold-Weather Operations 1992. Natick, Mass, DTIC No: AD-A254 328.

Cold Weather Operations

Department of the Army. Field Manual 3 1-70. Basic Cold Weather Manual.

Department of the Army. Field Manual 90-11. Winter Operations

Department of the Army. Training Circular 21-3. Soldier's Handbook for Individual Operations and Survival in Cold Weather Areas.

Field Sanitation and Hygiene

Department of the Army. Field Manual, 21-10. Field Hygiene and Sanitation.

Department of the Army, Field Manual. 21-10-1. Unit Field Sanitation Team.

Nutrition

U.S. Army Research Institute of Environmental Medicine. Technical Note, 93-8. Nutritional Guidance for Military Field Operations in Temperate and Field Extreme Environments. 1993. Natick, Mass, DTIC No: AD-A269 969.

US ARMY TRAINING FILMS

- TF 8-4915 Medical Problems of Military Operations in Mountainous Terrain
- TF 8-4916 Medical Problems of Military Operations in High Altitude Terrain
- TF 8-4879 Prevention of Cold Injuries
- MF 3 1-5859 Military Mountaineering Techniques (Summer)