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BIOMEDICAL ASPECTS OF MILITARY OPERATIONS AT HIGH ALTITUDE

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Abstract

High terrestrial elevation with its corresponding hypoxia offers one of the most inhospitable and debilitating environments found anywhere on the planet. Warfare in such a setting is a formidibable undertaking. Twice in the last 25 years, major powers in Asia have waged wars at high altitude. Their experiences, as well as limited clinical studies involving soldiers and mountaineers, have outlined how dramatic a factor acute mountain sickness (AMS) will play in any high-altitude military operation. This review outlines the hazards peculiar to high altitude and summarizes the clinical and military studies which are pertinent to developing strategies for acclimatization and prophylaxis of illness in troops committed to high-altitude warfare. Finally, general medical guidelines for planning military operations at high terrestrial elevation are established, and the applications of high altitude as a tactical weapon in such scenarios is discussed.

RUNNING HEAD: High Altitude Military Operations

Introduction

Military operations at high terrestrial elevation entail a significant risk to personnel from morbidity and mortality resulting directly from the diminished pressure of oxygen at high altitude. Furthermore, mountainous terrain at higher elevations comprises a hostile and often fearful environment which seriously compromises the ability of the individual soldier to carry out his duties and of the commander to accomplish his military objectives. In fact, one can simply state: in conducting and planning military operations at high altitude, the greatest single obstacle to their successful completion is more likely to be the effect of the mountains themselves and not the enemy. While the military has acquired considerable expertise in planning and conducting warfare in mountainous terrain, United States forces have never conducted a war or any large scale military operation at high altitude. The purpose of this review is to outline the health hazards peculiar to high terrestrial elevation and to summarize the recent clinical and experimental literature where it is pertinent to high-altitude military manuevers. The last part of this review will establish general medical guidelines for the planning and execution of high-altitude warfare and discuss the use of altitude as a tactical weapon in such scenarios.

Background

High altitude is arbitarily defined as those elevations above which the relative lack of oxygen imposes limitations to physical and mental performance. In practice, high altitude should be divided into two realms: high altitude and extreme altitude. High altitude extends from elevations of 2,500 m to 5,500 m (approximately 8,000 to 18,000 ft, respectively). This constitutes the spectrum of elevations in which hypoxia can curtail physical activity and produce illness but where man can successfully acclimatize given sufficient time. Extreme altitude ranges from 5,500 m to 8,840 m (29,000 ft) and represents those altitudes attainable by acclimatized men without supplemental oxygen but where long-term physiological acclimatization does not take place. While much medical research has been performed among climbers undergoing acclimatizaton during the course of mountaineering expeditions at extreme altitude, warfare and military operations are largely limited to high altitude. More specifically, however, strategists confine most of their planning to operations in which there is a need for rapid deployment of unacclimatized troops to an altitude where hypoxia may significantly jeopardize troop function.

That there is a need for planning for the possibility of conducting high altitude warfare there can be little doubt. The Alpine massif in Europe, the Andes in South American and the Himalayan-Karakoram ranges of Asia are all regions which directly or indirectly hold strategic interest to the United States. Furthermore, several components of the U.S. Armed Forces have been tasked with developing the capability and expertise for high-altitude operations, thus reinforcing the need for a realistic understanding of the formibidable difficulties that would be entailed in actually conducting military activities at high altitude. In the last twenty-five years, several armed conflicts have involved foreign powers at high altitude. For example, in 1962, 2000 unacclimatized Indian soldiers engaged an acclimatized Chinese force at elevations from 3,000 to 5,000 m and suffered 42% casualties from AMS within the first three days[1]. In 1979, a Chilean company of 120 men suffered 25 fatalities from altitude sickness over the course of one year while carrying out military operations on the altiplano (3,000-4,500 m) (Robert Wood, personal communication). Again, in 1985 to the present, the Pakistani and Indian armies have carried out a border war at altitudes from 4,500 to 6500 m in the Karakoram range, once again incurring more casualties and deaths from altitude sickness than enemy action (Galen Rowell, personal communication).

The High Altitude Environment

Several environmental hazards are unique to high terrestrial elevation. These include first and foremost hypoxia. Other factors which impact on military operations but are not wholly specific to high altitude are: terrain, paucity of natural resources, solar radiation, winds and cold.

1. Hypoxia

The amount of oxygen declines in direct proportion to increasing altitude. At sea level, 21% of inspired air is oxygen. Between 2500m and 5500m, the relative percent of sea-level inspired oxygen declines to approximately 15% and 10%, respectively. The lack of oxygen hinders adequate oxygenation of all organ systems. The central nervous system (CNS), cardiovascular and muscuolskeletal systems are all significantly affected by hypoxia (see below). Furthermore, combustion engines operate with reduced efficiency. Motors, compressors and engines all may require specific adjustment to function even at reduced capacity at altitude. *For example,* portable generators at 4400m on Mt. McKinley function at one-half of the output specified by the manufacturer (P. Hackett, personal communication). In addition, combustion is hindered by inadequate oxygen with a greater production of carbon monoxide which leads to even greater risk of hypoxia to soldiers required to operate equipment in confined spaces (such as tents) at altitude.

2. Terrain

Mountainous terrain is usually steep and rugged. Not only does this impose a greater cardiovascular burden and risk of injury for soldiers negotiating such terrain but it significantly compromises transport, supply and communications. By their nature, mountains tend to isolate the units operating within them. This places a greater premium on employing only units and squad leaders prepared to carry out their operations in the setting of substantial functional autonomy and geographic isolation. Furthermore, operations requiring movements of large numbers of men with extensive material support are less likely to succeed at altitude than those which utilize independent, self-supporting units.

Medical support and evacuation may be a distinct impossibility at certain times during high-altitude operations. Terrain often makes evacuation only feasible by air. Mountain weather is notoriously unpredictable and helicopters have diminished carrying capacity due to the less efficient function of their engines at high altitude. In short, every non-ambulatory casualty at altitude seriously jeopardizes the mission of the entire unit and such casualties must be avoided at all costs by careful planning. Units operating under almost any scenario at high altitude will have to be capable of treating their own casualties in the field with the assumption that evacuation is not available for a period of several days. Furthermore, even self-evacuation is severely restrained at high altitude. For example, litter-bearing is typically a four-man operation at sea level. In the mountains due to the terrain and limitations on physical work capacity, it becomes a six-man operation. The significant limitations to medical rescue in a cold, snow-bound terrain have been recently reviewed[2]. All of the same limitations are operational at altitude with the added feature of steep terrain often making the use of small, tracked vehicles impossible or prohibiting ready access to helicopters. Finally, the elevated, exposed ridges and summits of mountains pose a great and very real threat to soldiers from lightning storms. Lightning strikes have killed or injured soldiers during military maneuvers at high altitude in the past[2].

3. Paucity of Natural Ressources

Above timberline there are no useable natural fuels. Still higher, there is no vegetation and even access to a readily available supply of water may be jeopardized. This places a great premium on transporting fuels or reducing a unit's dependence on combustible fuels to a minimum. Meals should be available in a ready-to-eat format, and troops should be fully familiarized and comfortable with susbsisting for extended periods on such rations. Water is, of course, available from melted snow but requires expenditure of precious fuel supplies. Furthermore, evaporative losses are increased at high altitude: an additional loss of one liter of water per man is incurred with every ten hours of climbing at a moderate level of exertion[3,4]. In addition, there is an increased diffusion coefficient for water vapor which varies inversely with ambient atmospheric pressure: at 5,500 m (18,000 ft), respiratory water losses are doubled compared with losses at sea level[5]. Finally, perspiratory water losees must also be kept in mind. Water requirements at high altitude may thus be increased by as much as three to five additional liters per man per day as compared to sea level. In addition, anorexia is a significant problem during the first five to seven days of altitude exposure. This means that it is often necessary to get sufficient caloric stores into soldiers in a liquid rather than a solid form which increases the need for water as vehicle for soluble caloric supplements. Lastly, daily caloric requirements for strenuous exercise at high altitude may range as high as 4,000 to 6500 kcal/day[6,7] which means that rations must be both compact but also energy-rich[8].

The paucity of water also imposes a medical burden. While insect vectors of disease and bacteria are reduced at high altitude[9], personal hygiene is also significantly compromised. Crowded housing in tents contributes to an increased risk of transmission of disease amongst soldiers. In addition, recent human studies also suggest that individual immunological function is compromised by sustained hypoxia at altitude[10]. Due to the low ambient pressure at altitude, water boils at reduced temperature rendering sterilization of water and medical instruments impossible by this method. Alternate methods for ensuring potable water such as chemical treatment or mechanical ultrafiltration must be envisoned.

4. Solar Radiation

Solar radiation is increased severalfold at high altitude due to the thinner atmosphere absorbing less ultraviolet radiation[9]. Furthermore, the better the weather, the greater the amount of ultraviolet exposure. Snow cover can increase reflected radiation by up to 75% so that both sunburn and snow blindness can cause significant discomfort and disability[9]. Prevention in this respect cannot be over-emphasized since one soldier stricken with snow blindness can render several members of his unit inoperable until the victim recovers. Goggles, sunglasses, and sunscreens must be of the highest quality and redundant supplies carried into the field. Soldiers must be carefuly educated to liberally employ sunscreens in all exposed areas and to scrupously avoid risking snow blindness.

5. Wind

The highest winds in the world have been recorded on the summit of Mt. Washington, New Hampshire at 235 mph. While such a situation represents the extreme, it is important to remember that once units are committed to the field at high altitude they can encounter the most ferocious, inhospitable weather found anywhere on the planet. Wind poses several problems. Most military-designed tentage cannot withstand mountain winds above 50-60 knots. Currently, efforts are being made to develop small, lightweight, self-standing tents for the military that ressemble the geodesic dome tents now universally employed for extreme altitude mountaineering. Lightweight mountain tentage must be capable of being carried by troops into the field and struck and then re-established as the units move higher to their assigned locations. Enough tentage must be available to replace any lost or ripped during storms. Finally, troops must be fully prepared to establish and live for several days in self-constructed snow caves in the event that tentage is lost or members of a unit are caught in sudden storms without shelter.

High mountain winds also pose two additional hazards. First, they can bring about sudden changes in the weather. It is commonplace in the mountains for weather to change from ideal conditions to a life-threatening storm condition in less than one hour. This places a great premium on commanders maximizing the use of clear weather and squad leaders being prepared to bivouac or alter travel plans at a moment's notice. Secondly, high winds greatly increase the risk of cold injury from increased convective losses.

6. Cold

In general, ambient temperature decreases by 1-2 degrees Centigrade per 330 m (1000 ft) of altitude gained during ascent. In addition, snow and ice are to be expected in almost any high-altitude operation. Dehydration and hypoxia both tend to increase peripheral vasoconstriction thereby reducing blood flow to digits and toes and increasing the likelihood of frostibite injury. Education of individual soldiers and vigilance on the part of the squad leaders are critical to preventing cold-induced injuries. A recent innovation in the treatment and evacuation of hypothermia victims is the portable charcoal heater[2] which will greatly enhance stabilization and transport of cold-injured soldiers.

The Pathophysiology of Acute Mountain Sickness (AMS)

Breathing a reduced amount of oxygen means there will be reduced delivery of oxygen to all organs. Below 2,500 m, reductions in oxygen availability that occur with increasing ascent produce few problems. Above 2,500 m, increasing altitude will produce progressively greater decrements in physiological function with increased health hazard. From a military perspective, two issues are of paramount importance. The first is that acute hypoxic exposure will produce significant reductions in physical work capacity. The second is the impact of AMS on overall troop mental performance and optimal team function.

A reduced work capacity translates into soldiers traveling at a slower rate with reduced carrying capacity. For example, at an altitude of 4,300 m (14,100 ft), endurance is approximately cut in half during the first week at high altitude and only returns to normal at the end of approximately three weeks[11-13]. In a study by Dusek and Hansen[3], Special Forces troops were found to require roughly twice as much time after arrival at an altitude between 3,300 m and 4,300 m to cover equivalent distances in similar terrain as they did at sea level. In this same study, soldiers were analyzed by umpires to determine how well they accomplished their unit objectives. Ratings were performed in terms of how much the soldiers "tried", i.e actually undertook to perform a task, how much of the task was performed, and whether or not it was actually accomplished. At sea level, soldiers generally accomplished all the tasks assigned. At altitude, however, there was a great discrepancy between what the soldiers attempted and what they succeeded in attaining. One umpire judged the troops to be nearly 75% ineffective during their first days after deployment to high altitude[3]. These findings point out that a reduced work capacity must be taken into account when planning and coordinating objectives in a high-altitude operation. Furthermore, it must be remembered that these were highly fit and motivated troops and represented an elite force. If anything, their experience should underscore the importance of superb fitness in rapid deployment forces (RDF) tasked with high-altitude operations.

The second important medical issue unique to high altitude operations is that of AMS. AMS is essentially a syndrome of malacclimatization. In its mild form it is limited to lassitude, fatigue, headache, insomnia, nausea, vomiting, dizziness, dyspnea, and mental slowness. In its severe form, AMS is characterized by high-altitude pulmonary edema (HAPE) and cerebral edema (HACE). In HAPE, victims usually experience dyspnea at rest , orthopnea and a dry, nonproductive cough. Often HAPE victims will also exhibit cyanosis, rales, occasionally with pink, frothy sputum and even frank hemoptysis. HACE victims usually suffer severe headache, photophobia, vomiting and a wide variety of neurological problems[14]. Their physical examinations may be notable for mental status changes, ataxia, papilledema, as well as motor and sensory abnormalities[14]. Both HACE and HAPE represent true medical emergencies and must be seen as life-threatening extremes of AMS.

The incidence of AMS is linked both to the rate of ascent and the altitude reached. In a study among trekkers arriving at an altitude of 4,200 m (14,000 ft) in Nepal[15], the incidence of mild AMS was 53% (n=278) and that of life-threatening AMS was 4.3%. These were individuals who hiked up to the final altitude before being assessed for AMS and so were able to benefit from a variable but substantial amount of acclimatization. In a situation where troops are rapidly deployed to altitude, the incidence and severity may be worse. In 1969, Singh et al.[1] reported on their experiences with two thousand soldiers deployed to altitudes between 3,350 m and 5,500 m (11,000 - 18,000 ft). Their classic paper remains one of the most important studies on military operations at high altitude in the Western scientific literature. These investigators found that the incidence of severe AMS varied from 1.0 to 83.3 cases per thousand soldiers. Perhaps more telling, however, was the fact that of the two thousand men sent to wage war at these altitudes against their Chinese oppponents, 840 (42%) were judged to be so incapacitated by AMS as to be unable to carry out their duties. Furthermore, one eighth of these soldiers still remained unable to fight even after two weeks of attempted acclimatization. Probably more telling is the fact that more soldiers (including one commanding general) were killed by altitude than by enemy action during the first three days of this high altitude war[1].

AMS has other important implications for troops sent to high altitude. Even if soldiers are ambulatory, they suffer significant decrements in neurological function from AMS. These can include significant deteriorations in fine motor coordination, short and long term memory, language and speech abilities, and personality changes[14]. This obviously can translate into significant problems with respect to such duties as radiotelecommunications, weapons handling, message decoding, planning and cordinating artillery as well as decision-making. Furthermore, mood changes can combine with neurological dysfunction in such a way as to seriously impair group leadership and cohesion. This was found to be the case in the military study carried out by Dusek and Hansen[5]. One umpire commented about the performance of the Special Forces units upon arrival at altitude: "On the first day there was nothing military about the operation. It was every man against the mountain, every man for himself, and may the best man reach the objective first"[5] (p.1503). It is worth reiterating that these were elite units whose team members had had time together in previous maneuvers at sea level.

Preparation for High-Altitude Military Operations

1. General Principles

Given the extensive problems which the high-altitude environment poses for the conduct of military maneuvers, preparation in the planning of such operations is the keystone to ensuring success. Such preparedness begins with intelligence gathering. Strategists must have as much information about environmental and atmospheric conditions, topography, natural and man-made resources, as well as enemy movement and conditioning. In this respect, high altitude operations differ little from any other kind of military mission. Several specific points deserve mention, however. Accurate information about the enemy's prior experience in high-altitude operations and about the location, movements and availability of acclimatized troops is critical for planning operations at high terrestrial elevation. It is a tenet of high-altitude warfare that one should carefully avoid engaging altitude-acclimatized troops whenever possible until one's own troops have had time to fully acclimatize since such hypoxic adaptation is both a strategic and psychological advantage. Conversely, a commander must make every attempt to capitalize on an opportunity to engage a unacclimatized enemy if his own troops have the advantage of adequate acclimatization.

The decision to utilize the element of surprise with the use of RDF without acclimatization versus gradual ascent with its inherent acclimatization is a delicate one. Obviously, the optimal situation is to have acclimatized troops at one's disposal for rapid high-altitude deployment. At present, there are no specific high-altitude installations above 3000m which would permit the long-term training and housing of sufficient numbers of men to provide and maintain such an acclimatized force. Such troops would have an enormous advantage in high-altitude operations since not only could they be immediately inserted at high altitudes below 4300m with few or no casualties but they would presumably have had ample opportunity to develop the fitness, leadership and experience in high-altitude operations to minimize problems of group cohesion.

The availability of large numbers of altitude-trained, acclimatized troops has not been a military realization since the dissolution of Camp Hale, CO in 1948[16]. Secondly, such acclimatized troops would offer commanders the possibility of insertion at even higher altitudes with reduced casualties compared to unacclimatized troops from sea level. For example, a unit deployed from sea level to 4,300 m (14,000 ft) can expect approximately 50% casualties (i.e. incapacitation) from AMS while a unit which has undergone seven to ten days of partial acclimatization above 10,000 ft should have no casualties at that altitude. If the insertion point is raised to 4600m (15,000 ft),a sea-level unit's casulaties would rise to approximately 60-75%. At 4,900 m (16,000 ft), nearly 90% of the unacclimatized soldiers will be incapacitated. It should also be pointed out that these data are approximate and are derived from several years' study of soldiers in a hypobaric chamber facility or at high-altitude research facilities where subjects are often relatively sedentary.

Complicating the entire picture is the role of stress and physical exercise in the etiology of altitude illness. Current thinking is that severe exertion with increased extraction of oxygen from exercising muscles and diminished transport time of blood through the lungs produces further desaturation of red cells and increased hypoxia. The net effect of demanding physical exercise is to effectively increase the degree of oxygen deprivation and thus augment the incidence and severity of AMS at a given elevation. By employing an acclimatized cadre of soldiers, a commander would have the option of deploying his men to intermediate altitudes up to 4,300 m to 4,600 m with few casualties. If pressed, however, such men could even be inserted at 5,500 m (18,000 ft) with some casualties from AMS. On the other hand, such an insertion would be effectively impossible with completely unacclimatized soldiers. It should be pointed out that several countries are currently maintaining relatively large numbers (in the thousands) of soldiers at high altitude. Most notable amongst these is China which may have upwards of several divisions currently acclimatized at altitudes above 3500m in Tibet. Other nations currently known or believed to maintain some troops chronically acclimatized to high altitude are Russia, India and Pakistan. The latter two nations currently have men committed to combat in the highest military engagement in history with encampments located between 5400m and 6000m[17].

Barring the capacity to have troops maintained in continual, acclimatized readiness for high-altitude warfare, the burden then shifts to focusing intelligence-gathering activities in order to have the capacity to notify military planners about the development of events which may require potential involvement of personnel at high altitude. This must be done with sufficient time to allow troops to undergo at least partial acclimatization. Currently, there are no provisions for large high-altitude staging areas in the United States so there is no capacity to acclimatize sizeable numbers of troops. An alternative approach would be to identify all possible sites at high altitudes which would have sufficient road or air access to permit large-scale staging of troops in anticipation for such eventualities. Such areas could be made available to the Armed Forces for acclimatizing staging areas on relatively short notice and several thousand soldiers acclimatized in a little over a month. Still, such plans would require several weeks' advance notice of a requirement for acclimatized troops. Political events seldom offer such a luxury.

Assuming that no acclimatized troops are available, one is then left with planning for two eventualities: a prolonged approach march which would permit gradual ascent with acclimatization or being compelled to commit unacclimatized troops into a high-altitude situation with little or no notice. Both of these alternatives will be discussed in turn.

Employing a planned, sustained gradual ascent to permit individuals to progressively acclimatize as they ascend is a time-honored principle employed by all mountaineering expeditions. It is the safest and most dependable situation in which to acclimatize men up to altitudes of 5,500 m (18,000 ft). The usual rule of thumb for acclimatizing is a moderate rate of ascent of one day for every 300 m (1,000 ft) of vertical elevation gained above 3,000 m

(10,000 ft) and one full day's rest after each 1000 m (approximately 3,000 ft)[18]. One can see (Figure 1) that even with an initial insertion at an elevation of 3,000 m (10,000 ft), a prudent commander would have to allow troops six days to approach an objective at 4,600 m (15,000 ft) using this formula and having clement weather conditions.

Figure 1 - about here

Great attention must also be paid to topographic features so that squad leaders know where to safely establish staging areas for troop acclimatization during ascent. Furthermore, such staged ascents call for larger amounts of supplies since soldiers must be in the field for a more extended period. The old adage "climb high, sleep low" is a wise principle in planning staged ascents as it takes advantage of using heavy exertion during the day to accelerate acclimatization but avoids the problems of hypoventilation during sleep which may impede recovery from such extended bouts of hypoxic exercise and acclerate the onset and severity of AMS.

In essence, maneuvers should then be planned with an eye towards having advance parties ascend to establish and supply higher camps and then fall back to already established lower camps to rest, recover and allow acclimatization to occur. In such a scheme, climbing parties could 'leap-frog' each other during ascent, leaping forward to set up higher camps, then descending to link up with the other components of their units which are resting or climbing at a slower rate to join them (Figure 2). As the first "high" team recovers, a new advance team goes "high" to bring up more supplies or using the newly established camp as a starting point from which to establish still higher advance camps. Such an approach can theoretically permit a more rapid ascent by carefully stretching out advance parties and pre-establishing advance camps for the main body of troops.

Figure 2 - about here

A new theoretical alternative to stage ascent on foot would be a more rapid alternative: helicopter-supported staged ascent (HESSA). HESSA would permit insertion of unacclimatized units at altitudes between 3000m (10,000 ft) and 4600m (15,000 ft) (Figure 3). Soldiers destined to carry out actual high-altitude fighting would be carefully held in reserve and allowed to acclimatize without undue exertion except when deemed necessary to maintain physical fitness. Other units would ascend and prepare advance camps at higher altitudes. Once advance camps and supplies were ready and fighting units had obtained the benefit of a 2-3 days of acclimatization, they would be ferried by rotary-wing aircraft to higher camps. At the higher elevations, they would undergo further acclimatization. The use of HESSA would permit troops to acclimatize to altitudes up to 18,000 feet but would also conserve fighting units until they were actually ferried to the final altitude where they would establish themselves, relatively acclimatized and ready for combat.

Figure 3 - about here

Current thinking has centered on a different alternative: namely, the committment of non-acclimatized troops into a high-altitude engagement. While economically this is the most practical solution, militarily it is the most difficult to effect. The most likely scenario would be the comittment of RDF to a high altitude locale. The incidence of AMS effectively limits of insertion of unacclimatized troops to an altitude of 4,600 m (15,000 ft). In fact, this is quite liberal if the troops are expected to exert themselves. If significant physical work is to expected of the soldiers, then the ceiling should probably be lowered to 3500m. One should attempt as much as possible to prophylax against AMS with pretreatment with acetazolamide.

Acetazolamide (Diamox^{R}) is a carbonic anhydrase inhibitor that has been found to reduce symptoms of AMS (1 gram/day) by as much as 50% in soldiers and cimbers at 4300m [14,19-21]. In combination with staging, acetazolamide produced a 85% (n=35) reduction in AMS symptoms[22]. The exact mechanism of its action in the prophylaxis of AMS is still debated[14], although one important mechanism is thought to be the reduction of cerebrospinal fluid formation to ease intracranial pressures. Another mechanism may be an alteration of respiratory alkalosis so as to permit better oxygenation through hyperventilation. Acetazolamide may also exert a direct stimulatory effect on respiratory centers. Most authorities agree that prophylaxis with acetazolamide should begin at least 24-48 hours before arrival at altitude since it has a long onset of action. It should be continued throughout ascent and then discontinued after several days of acclimatization at a final altitude.

Dexamethasone is a potent glucocorticoid and at doses of 16 mg per day significantly reduces the incidence of and severity of AMS when employed prophylactically[23,24]. Once again, the exact mechanism whereby steroids exert their ameliorative effect on AMS symptoms is unknown. It is hypothesized[14] that steroids exert similar effects in HACE as they do in situations such as tumor-induced cerebral edema where steroids are thought to stabilize cell membranes and diminish tissue permeability so as to reduce brain parenchymal water influx. It is also presumed that steroids may have similar stabilizing effects on pulmonary membranes and may improve oxygenation by reducing transudation into the alveolar spaces and diminishing pulmonary edema.

While acetazolamide is a relatively benign drug, dexamethasone can have significant side effects, most notably the risk of hyperglycemia, gastric irritation, avascular necrosis of the femoral head, immunosuppression and psychosis. Most of these side effects and complications are rare but represent medical problems which can pose significant problems in the field. How dexamethasone should be employed for altitude operations is still controversial. Further research into the use of dexamethasone in conjunction with acetazolamide administration is required. Currently, the use of dexamethasone is reserved for the treatment of AMS. This is especially true for situations where medical evacuation might be delayed or prevented for several days. Once steroid therapy is initiated, the dosage should be slowly tapered off rather than stopping the medication abruptly. The risk of adrenal suppression with sustained steroid administration must be kept in mind.

There are two final points to consider in planning of high-altitude operations. The first is that an individual's first exposure to altitude, especially in the situation of a sudden insertion, is a often a fearful event. Soldiers receiving a medical briefing often ask questions such as "how's altitude going to feel?", or "how will I know when I'm getting sick?". The easiest solution to this problem is to ensure that both the leadership and the enlisted personnel have as much prior personal experience as possible. This should probably be mandatory with respect to squad leaders. Such experience should be gathered preferably in the field but could be obtained during a three- or four-day long exposure in a hypobaric chamber. At the United States Army Research Institute of Environmental Medicine (USARIEM), we have found that prior altitude exposure and experience with AMS reduces the perceived severity of subjective symptoms of AMS during subsequent exposures. It should be pointed out that this conclusion is based on anecdotal reports. Furthermore, it has also been found that certain individuals have a relatively low threshold for developing AMS while others have a high resistance. Studies are currently underway to develop means of objectively identifying such individuals prior to altitude exposure in the hopes that such methods might be employed in screening soldiers with high-altitude missions.

The second point about preparation of soldiers for high-altitude operations concerns the use of a hypoxic breathing apparatus (HBA). There are a number of HBAs available commercially. These devices are lightweight and can be worn easily during daily activities and exercise. A HBA reduces the amount of inspired oxygen. By wearing such a device for extended periods of time and expecially during exercise, the user can become acclimated to hypoxia even though he is physically still at sea level. One study (unpublished data) was undertaken at USARIEM several years ago to determine if the use of HBA prior to ascent to altitude offered any protection from AMS. This first study was flawed because soldiers found the devices cumbersome and constricting and they were therefore not employed during exercise to help induce further hypoxemia and accelerate acclimatization. Further modifications by the manufacturers are being considered and additional trials with HBA should be undertaken in the future as such devices could offer great potential in acclimatizing large numbers of soldiers while they are stationed at sea level. Such devices may help to circumvent many of the economic and logistical problems outlined above with respect to developing substantial numbers of acclimatized soldiers within the RDF tasked with high-altitude missions.

3. Treatment strategies for AMS

Despite prophylaxis and prior altitude exposure, heavily exercising troops at altitude will develop AMS. If acetazolamide and dexamethasone have not been given prophylactically, then these agents should be administered to any soldiers with symptoms of moderate AMS. Given the relatively long onset of action for both of these agents, however, they will not produce much improvement in symptoms for hours. Oxygen therapy where available will produce amelioration of symptoms in many but does suprisingly little alone to reverse AMS[14]. The reason for this lack of efficacy of oxygen may be linked to two problems. First, in the field there is rarely a great surplus of large oxygen cylinders and so oxygen is often given at insufficient flow rates to AMS victims in order to conserve supplies. This may mean that there is an inadequate correction of hypoxemia which delays and diminishes improvement. The second problem concerns hypobaria, the reduced atmospheric pressure per se. There are some researchers who believe that the low atmospheric pressure at high altitude may have direct effect on lung tissues and may produce some of the signs and symptoms of AMS. Administering even abundant amounts of oxygen will not correct the ambient hypobaria. For these reasons, the cornerstone of therapy for AMS to this day is still descent to lower altitude where there is a greater abundance of oxygen and an increase in ambient pressure.

Nonmotorized evacuation to lower altitude usually requires an ambulatory victim. This requires aggressive recognition of AMS symptoms and rapid decision-making on the part of medics and squad leaders as to when a soldier should be evacuated to lower altitude. As a rough guideline, if an individual has symptoms of only mild AMS and the opportunity to remain at a given altitude and sedentary for a day or two, then it is feasible to attempt to stabilize the AMS victim and let him recover if he can. If the individual does not improve or the unit's assignment will not permit the striken soldier to rest without further ascent, then it would be best to evacuate him before he becomes non-ambulatory and a burden on the unit.

Oxygen cylinders are heavy and cumbersome and, although they represent the best means of treating AMS in the field, their use in smaller, platoon-sized groups in the field is quite limited. It is debatable whether they should even be issued at the level of the squad unit. It would be better that units understand their own limitations with respect to treating AMS and favor early evacuation rather than try to temporize in the field. Commanders should plan to have their forward medical aid stations as close to the area of operations as possible. Difficulties with respect to tracked vehicles and helicopters have been outlined above. Where feasible, soldiers should be encouraged to self-evacaute themselves to aid stations under their own power in the company of a companion for safety reasons. If possible, rescue by helicopter or tracked vehicles permits rapid evacuation and allows victims of AMS to be placed on oxygen during transport. Alternatively, caches of oxygen or air-drops can be employed to make oxygen available at forward positions. Presently, the use of small, portable hyperbaric chambers[25] in the field is under consideration as a potential means for treatment of victims with severe AMS but its actual application to forward medical aid stations is still debatable.

The efficacy of diuretics[14], prostaglandin sythetase inhibitors[26], and calcium-channel antagonists[27] in the treatment of AMS is unclear. The examination of the therapeutic efficacy of these agents has not been proven with well-controlled experimental trials and their use cannot be recomended at this time. Another theoretical possibility for the treatment of life-threatening HACE is the use of emergent lumbar puncture to remove cerebrospinal fluid so as to reduce raised intracranial pressure and improve a victim's neurological and functional status. Because this is an invasive procedure that must be carried out by a trained physician, its application to the treatment of life-threatening HACE is still experimental.

In summary, preparation and prevention still play a much greater role in reducing the impact of AMS on high-altitude operations than does therapeutic intervention after illness has occured. It cannot be over-emphasized how dramatic the impact of altitude is on such operations. For example, Dusek and Hansen[3] reported that amongst Special Forces troops there were only 2 casaulties among 120 men during the sea-level phase in mountainous terrain. By contrast, there were 22 casualties and 1 fatality evacuated to aid stations among the same group when operating at altitudes between 3,700 m and 4,100 m (12,000 and 13,500 ft).

4. Preparation for the field

For the purposes of discussion here, we are assuming that an unacclimatized RDF has been mobilized for a high-altitude operation and are limiting our scope to biomedical rather than tactical and logistic considerations. At present, military-issue mountaineering equipment is incorporating many new materials and designs which have emerged in prototype civilian alpine equipment and clothing. There will be increased availability of semi-permeable waterproof materials such as Gore-tex[R] for wind- and waterproof outer layers; synthetic fiber-pile intermediate weight layers; and lightweight, plastic climbing boots. Clothing strategy must be a multi-layered one with soldiers able to easily doff and don layers as they overheat with exertion and cool abruptly with rest stops. All layers must provide suitable camouflage as soldiers may cross steep terrain in little more than a long-sleeved undershirt if conditions are appropriate and then find themselves donning parkas as soon as they slow down or are in wind-exposed areas. Each soldier or pair of soldiers must carry sufficient personal equipment to be able to function and survive for five days as an independent unit.

A concise and complete medical briefing is essential for all personnel. Each soldier must be able to recognize the development of AMS in himself and his companions. Furthermore, each soldier must understand the importance of taking prophylactic medication on schedule, and maintaining dosage schedule. Medics, squad leaders and medical officers must all understand the importance of urgent evacuation to lower altitudes in all cases of severe AMS.

Caches or air-drops of food, tentage and medical supplies should be carefully planned in advance so as to take advantage of favorable atmospheric conditions and topography to enable units to be as mobile as possible. Coordination of such supply efforts require excellent communications which places a premium on functional radio communications.

As explained earlier, higher caloric intakes for soldiers must be kept in mind when issuing rations. In addition, the first 48 to 72 hours of acute altitude is usually accompanied by moderate to severe anorexia, further complicating the problem of how to keep soldiers adequately supplied with calories and nutrients. Recent military nutriition studies on Mauna Kea (4100 m) have demonstrated that while hunger is suppressed at altitude, the thirst response remains largely intact. These studies (28) have demonstrated that increased carbohydrate intake can be achieved by employing glucose polymers in liquid supplements which do not markedly enhance sweeteness or osmolality and offer great potential for helping to supply require calories during this initial anorexic phase.

5. Biomedical Aspects of High Altitude Tactics

Commanders must take full advantage of high altitude as a tactical weapon in defeating their opponents. First and foremost, this translates into permitting their own troops the greatest possible opportunity to acclimatize before engaging the enemy. This means permitting slow ascents and extended travel times with reduced exertion wherever possible during ascent. Furthermore, where feasible, commanders must try to force the enemy to go as high and fast as possible in order to place the enemy's troops at the greatest possible risk for AMS. In addition, the terrain must be made as inhospitable as possible. Wherever avalanche-prone lines of march are available, artillery, airstrikes, and infantry should be employed to force the enemy into using such avenues. Passes which permit the enemy functional lines of supply, evacuation, or retreat should be effectively closed by means of demolition or bombardment.

Committing unacclimatized troops to a rapid ascent to high altitude should only be done with the knowledge that AMS will begin to set in within six hours. Furthermore, to commit men without guaranteed means of evacuation is to ensure that the troops will become 50 to 75% and perhaps 100% ineffective over the next 24 to 48 hours (depending upon the altitude) with recovery beginning in a variable and unpredictable fashion over the next week. Troops should return to 50 to 90% effectiveness within two to three weeks provided they do not ascend higher.

Given that high terrestrial elevation usually offers a uniformly cold environment, a premium must be placed on heat-seeking, infrared reconnaissance and weaponry as it is next to impossible to set up any encampment at high altitude without generating heat in one way or another. The environment offers fewer sources of conflicting signals for such infrared detection. On the other hand, every effort must be made to confuse detection by the enemy by establishing dummy encampments and false infrared signals.

Wherever possible, troops should be permitted to travel as lightly as possible since heavy rucksack loads are poorly tolerated at high altitude. Heavy weaponry and equipment must be avoided and the use of caches and/or air-drops maximized to improve travel times of units. Once forward positions are established, air supply can become more sustained if the weather permits. Once acclimatized troops are available in the field, they should be preferentially assigned to the highest positions or to those operations which will require extended travel or heavy exertion in order to spare less acclimatized soldiers running the increased risk of AMS. Reserves should be prepared with gradual ascent so that they are available to replace or support more acclimatized units. In addition, acclimatized units can be expected to feel renewed vigor and energy as they descend to lower altitudes so any opportunity to engage the enemy at a given altitude must be viewed in terms of how much will acclimatization favor one's own troops and handicap the enemy's.

A final word should be added about extreme altitudes above 5,800 m (19,000 ft). The environment at this elevation is so inhospitable as to render any combat there very short-lived. Acclimatization will permit an individual to carry out even heavy, sustained exertion at such altitudes[29] but there is a well-described[30] deterioration of individual fitness which occurs when individuals remain at such altitudes in a matter of a few weeks. At such altitudes, operations must be brief or provisions made for soldiers to rotate for duty at extreme altitude. Such an approach is currently employed by the Pakistani who rotate their troops for 30 days at their camp located at 6,000 m (20,000 ft) after first acclimatizing them for at least one to two months through a succession of lower camps between 4,900 m and 5,500 m (16,000 and 18,000 ft, respectively) (Galen Rowell, personal communication). If deterioration begins to set in, *acclimatization will only be regained* by descent to lower elevation and a period of nourishment and recovery.

Summary

Warfare at high altitude is a formibidable undertaking. High terrestrial elevation with its corresponding hypoxia offers one of the most inhospitable and debilitating environments found anywhere on the planet. It would be best if high-altitude combat could be prevented entirely as it always entails a great deal of suffering and loss of life on the soldiers who must conduct such wars. Unfortunately, on several occasions in the last twenty-five years, major military powers have had to engage in such costly warfare. Furthermore, *mountains by their very nature* possess great political and military importance and several high-altitude regions of the world hold strategic importance to the United States. The United States has no experience in conducting a major military operation at high altitude. As a general rule, history has shown that engagements at high altitude will go to the better acclimatized and prepared units. The present strategic approach is to undertake prophylaxis for AMS of unacclimatized forces before deploying them to high altitude. This approach has significant drawbacks as outlined above, especially in light of the fact that other nations may have substantial numbers of acclimatized troops at their disposal in the event a high-altitude engagement must be undertaken. This review highlights many of the medical issues which surround and dictate strategy in high-altitude military operations. Several avenues of military strategy, medical research and equipment development deserve further exploration in the hopes of developing a reasonable and effective high-altitude capability within the Armed Forces of this country.

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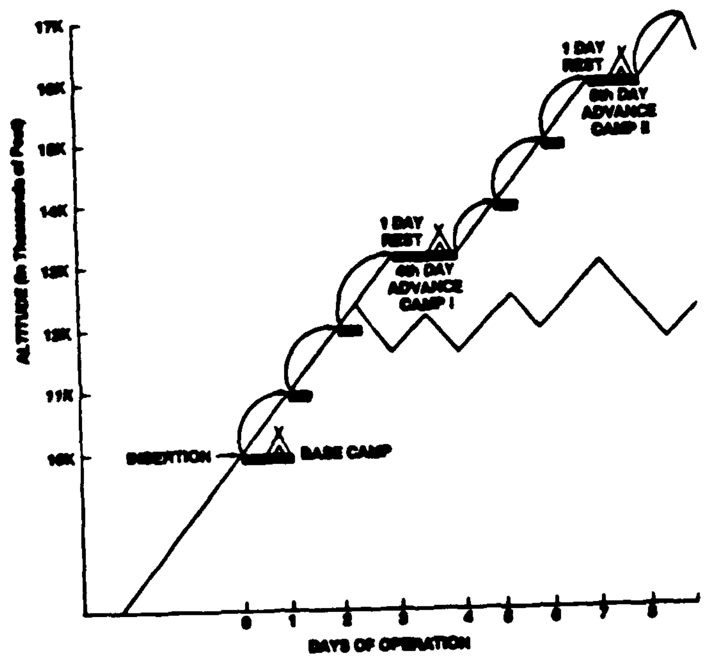
Legends

Figure 1: A schema depicting a traditional staged ascent to 16,000 feet. Cross-hatched areas indicate rest periods to permit acclimatization. Arrows indicate direction of travel. Tent symbols show where staging encampments would be established.

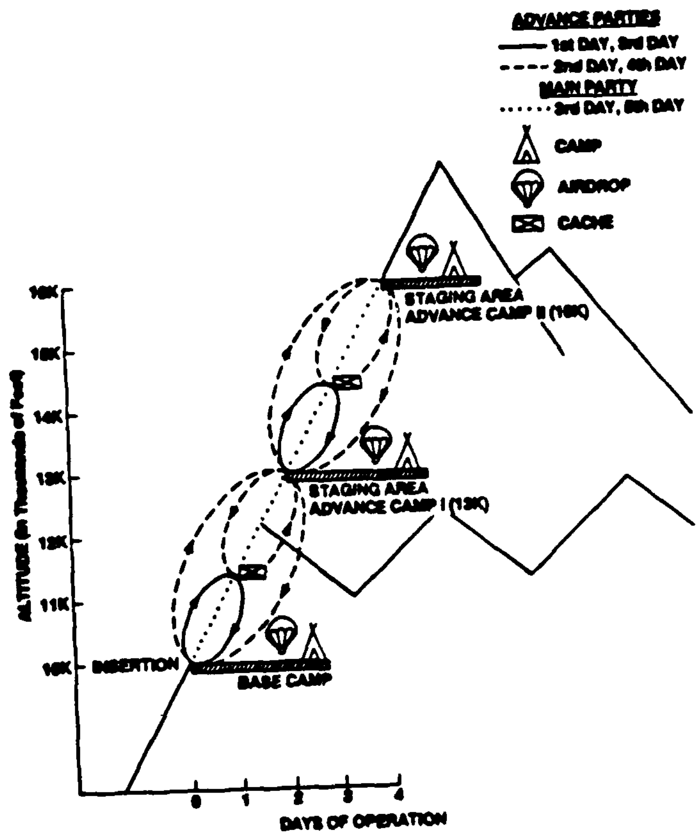
Figure 2: A schema depicting an Alpine-style staged ascent using advance parties to establish advance camps in front of the main body of troops. Cross-hatched areas indicate rest periods to permit acclimatization. Arrows indicate direction of travel. Tent symbols show where staging encampments would be established.

Figure 3: A schema depicting helicopter-supported staged ascent (HESSA) to establish and support advance camps. Cross-hatched areas indicate rest periods to permit acclimatization. Arrows indicate direction of travel. Tent symbols show where staging encampments would be established.



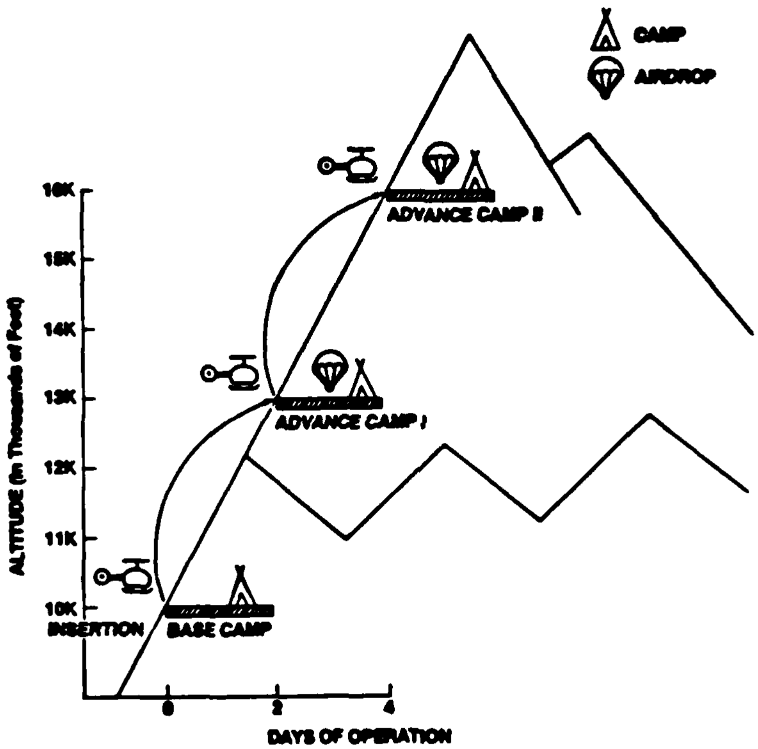
TRADITIONAL STAGED ASCENT

Figure 1



ALPINE-STYLE STAGED ASCENT

Figure 2



HELICOPTER-SUPPORTED STAGED ASCENT (HESSA)

Figure 3