



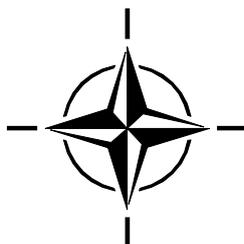
RTO TECHNICAL REPORT

TR-HFM-146

Review of Military Mountain Medicine Technology and Research Barriers

(Point sur les technologies associées à la
médecine militaire de montagne
et les freins à la recherche)

Final Report of Task Group HFM-146.



Published September 2011





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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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HFM-146 Programme Committee

AUSTRIA

Col. Martin Berger
Head of Dept. of Anesthesia
Military Hospital 2
6020 Köldererstrasse 4
Innsbruck
email: m.e.berger@gmx.net

CZECH REPUBLIC

Mr. Libor Soumar
Director, Sports Research Institute of the
Czech Armed Forces (CASRI)
Podbabska 3
160 00 Prague 6
email: libor.soumar@casri.cz

FRANCE

Dr. Andre-Xavier Bigard
Professeur Agrégé du Val de Grâce
Département des Facteurs Humains
Centre de Recherches du Service
de Santé des Armées
BP 87, 38702
La Tronche Cedex
email: xbigard@crssa.net

GEORGIA

Dr. Liza Goderdzishvili
52 Vazha Pshavela Ave, APP 27
0177, Tbilisi
email: liza.genesis@access.sanet.ge

KYRGYZ REPUBLIC

Dr. Valentin Mahnovsky
Director, International Institute of Mountains
22 Manas Prospect
Bishkek 720010
email: irbisv@myway.com

NETHERLANDS

Dr. Bertil J. Veenstra
Royal Netherlands Army
Dept. of Training Medicine & Training Physiology
P.O. Box 90004
3509 AA Utrecht
email: bj.veenstra@mindef.nl

LtCol. Wynand Korterink
Royal Netherlands Army
Dept. of Training Medicine & Training Physiology
P.O. Box 90004
3509 AA Utrecht
email: WE.korterink2@mindef.nl

UKRAINE

Dr. Tatiana Serebrovska
Doctor of Biology
Academician of Int. Acad. Sci.
Principal Researcher
Bogomoletz Institute of Physiology
4 Bogomoletz St.
Kiev 01024
email: sereb@mail.kar.net

UNITED KINGDOM

Dr. Elizabeth Humm
Dstl Human Systems Group
Information Management Department
Room G003, A3 Building, Ively Road
Farnborough, Hants GU14 0LX
email: EHUMM@mail.dstl.gov.uk

UNITED STATES

Dr. Stephen R. Muza
(HFM-146 Task Group Chair)
Mountain Medicine Team Leader
Thermal & Mountain Medicine Division
US Army Research Institute of Environmental
Medicine
Kansas St., Building 42
Natick, MA 01760-5007
email: stephen.muza@us.army.mil

Dr. Barry S. Shender
Senior Scientist, Human Systems Dept
CODE 4656, Bldg. 2187, Suite 2280A
Naval Air Warfare Center Aircraft Division
48110 Shaw Rd, Unit 5
Patuxent River, MD 20670-1906
email: barry.shender@navy.mil



Review of Military Mountain Medicine Technology and Research Barriers

(RTO-TR-HFM-146)

Executive Summary

Mountainous terrain provides sanctuary for hostile forces, particularly terrorist organizations. This harsh environment lessens NATO military technological superiority by limiting use of air support and crew-served combat vehicles. This places the burden of combat on dismounted troops. Many military operations require the rapid deployment of troops to these mountainous regions. However, rapid ascent of unacclimatized troops to high (>1,200 m) mountainous environments causes debilitating effects on fighting capabilities (physical and cognitive work performance) and force health status (altitude sickness). Long-duration (weeks or months) deployments to high mountain areas may increase susceptibility to more severe altitude illness and exacerbate other medical conditions.

NATO RTO HFM-146 reviewed the empirical evidence of the adverse impact of high terrestrial elevations on health and physical and mental performances relevant to military operations. This report summarizes the findings of the Task Group and briefly reviews current capabilities to mitigate these aversive impacts. The report identifies the needed mountain medicine capabilities and current gaps in technology and research barriers which block achievement of these capabilities. The identified technology and research barriers can be used to guide NATO and Partner Nations' research and development programs in mountain medicine.

Recommendations for future work are provided. These include facilitating NATO-sponsored communications to convey new findings, promoting greater data-sharing across NATO and Partner Nations to achieve common solutions to specific military requirements, and developing evidenced-based medicine best practices for prevention and treatment of altitude illness and mitigating performance impairments.

Point sur les technologies associées à la médecine militaire de montagne et les freins à la recherche

(RTO-TR-HFM-146)

Synthèse

Les terrains montagneux fournissent des sanctuaires aux forces hostiles, en particulier aux organisations terroristes. Cet environnement difficile réduit la supériorité technologique militaire de l'OTAN en limitant l'utilisation de l'appui aérien et des véhicules de combat collectifs. Cela transfère le poids des combats sur les troupes à pied. De nombreuses opérations militaires nécessitent un déploiement rapide de troupes vers ces régions montagneuses. Cependant, l'ascension rapide de personnels non acclimatés vers des environnements montagneux élevés (>1200 m) mine les capacités de combat (performances de travail physiques et cognitives) et l'état de santé des forces (mal des montagnes). Les déploiements de longue durée (des semaines ou des mois) dans des zones montagneuses élevées peuvent augmenter la prédisposition à des maladies plus graves liées à l'altitude et exacerber d'autres pathologies.

Le groupe de travail HFM-146 de la RTO de l'OTAN a passé en revue les preuves empiriques de l'impact négatif de la haute montagne sur la santé et les performances physiques et mentales relatives dans le cadre d'opérations militaires. Ce rapport résume les conclusions du groupe de travail et passe brièvement en revue les possibilités actuelles de diminuer ces impacts négatifs. Le rapport identifie les capacités nécessaires à la médecine de montagne, les lacunes technologiques actuelles et les obstacles que rencontre la recherche et qui entravent l'obtention de ces capacités. La technologie et les obstacles à la recherche identifiés peuvent servir à orienter les programmes de développement et de recherche de l'OTAN et des pays partenaires dans le domaine de la médecine de montagne.

Des recommandations ont été faites pour les travaux futurs. Elles comprennent la facilitation des communications sous l'égide de l'OTAN pour transmettre de nouvelles découvertes, la promotion d'un partage des données plus important entre l'OTAN et les pays partenaires, afin d'apporter des solutions communes à des besoins militaires spécifiques, et de développer des meilleures pratiques avérées de médecine pour la prévention et le traitement du mal des montagnes et la diminution de l'altération des performances.

REVIEW OF MILITARY MOUNTAIN MEDICINE TECHNOLOGY AND RESEARCH BARRIERS

1.0 INTRODUCTION

1.1 Problem Statement

1.1.1 Background and Justification

Mountainous terrain provides sanctuary for hostile forces, particularly terrorist organizations. This harsh environment lessens NATO military technological superiority by limiting use of air support and crew-served combat vehicles. This places the burden of combat on dismounted troops. Many military operations require the rapid deployment of troops to these mountainous regions. However, rapid ascent of unacclimatized troops to high mountainous environments causes debilitating effects on fighting capabilities (physical and cognitive work performance) and force health (altitude sickness). Long-duration (weeks or months) deployments to high mountain areas may increase susceptibility to more severe altitude illness and exacerbate other medical conditions.

NATO/RTO/HFM-ET-038 reviewed NATO military mountain operational experiences in Afghanistan to assess issues and problems relevant to NATO medical Research and Development (R&D) programs. That ET concluded that current mountain medicine capabilities were typically not fully utilized by NATO forces and educating military leaders on available capabilities could significantly enhance troop performance and health during operations in high altitude environments. Furthermore, continued research and development of new mountain medicine capabilities was required to keep pace with technological advancements that increase the mobility and rapid deployability of NATO forces to high altitudes. By not addressing these research gaps, troops are placed at high risk for this form of environmental stress. The HFM-ET-038 recommended the formation of a RTG to review NATO members' current and future mountain medicine needs, and identify the technology and research barriers blocking achievement of these capabilities.

1.1.2 Objectives

The goals of HFM-146 were to:

- 1) Review recent advances in the understanding of altitude acclimatization, high altitude sickness pathophysiology, and emerging knowledge and technologies that can enhance soldier performance and health at high altitudes.
- 2) Prepare guidelines for both non-medical unit leaders and medical practitioners to provide state-of-the-art practices for:
 - a) Pre-deployment personnel selection and training;
 - b) Acclimatization procedures;
 - c) Treatments for altitude illness and prophylaxis; and
 - d) Interventions (nutritional, pharmaceutical) to improve troop performance and health during high altitude deployments.
- 3) Prepare a report that:

- a) Identifies gaps in existing mountain medicine knowledge relevant to military operations in altitude environments for potential incorporation into NATO Member Nations' R&D programs; and
- b) Proposes a mechanism by which participating NATO countries can better coordinate their mountain medicine research programs.

During two meetings of the RTG and intervening communications, the RTG achieved several objectives. First, it was determined that the US Army Research Institute of Environmental Medicine and the US Army Center for Health Promotion and Preventative Medicine were jointly writing a new Technical Bulletin Medicine (TBMED) titled, "Altitude Acclimatization and Illness Management" (TBMED 505, September 2010). This new TBMED achieved the RTG's objectives 1 and 2. Thus, HFM-146 focused on completing Objective 3 through exchanging information to identify needed mountain medicine capabilities and the technology and research barriers blocking achievement of these capabilities.

1.2 Topics to be Covered

This technical report is organized in three parts. Section 2.0 summarizes the impact of high terrestrial elevations (>1,200 m) on health and physical and mental performances and briefly reviews current capabilities to mitigate these aversive impacts. Section 3.0 identifies needed mountain medicine capabilities and technology and research barriers (gaps) blocking achievement of these capabilities. Lastly, Section 4.0 recommends future activities the HFM may want to consider on these topics.

2.0 IMPACT OF HIGH TERRESTRIAL ELEVATIONS ON HEALTH AND PERFORMANCE

2.1 Introduction

The focus of this section is hypobaric hypoxia, an environmental stress resulting from ascent to progressively higher terrestrial elevation or altitude. This review defines the threshold altitude at which hypobaric hypoxia becomes functionally and medically significant as 1,200 meters (m) (3,937 feet (ft)) above sea level. Throughout this review the terms altitude, elevation, hypobaric hypoxia, or hypoxia are considered interchangeable. The majority of the information presented here is excerpted from U.S. Army Technical Bulletin Medicine 505, Altitude Acclimatization and Illness Management, 30 September 2010, and other references (see Section 5.0).

Military operations have been successfully conducted at altitudes where personnel were required to endure the effects of hypoxia and push the limits of their physiologic capabilities (for example, Afghanistan). Nevertheless, the altitude environment can degrade many aspects of normal military functioning in the field and, ultimately, the mission. Listed here are the impairments to health and performance directly attributable to hypobaric hypoxia:

- 1) Mission requirements that demand sustained physical activity are most affected by altitude. Soldiers will fatigue sooner or must reduce their pace and/or lighten their load in order to accomplish many activities. As the demand for sustained physical activities increase, so does the risk of developing altitude sickness.
- 2) Altitude induces many adverse symptoms, such as shortness of breath and rapid heart rate, in most soldiers and altitude illness in many. These symptoms can produce unwarranted concerns in soldiers who are unfamiliar with this environment.

- 3) Altitude contributes to impaired neuropsychological function and mood changes that may adversely affect the morale of the troops.
- 4) Continuous exposure to altitude contributes to increased disease and non-battle injury since sick and injured soldiers are susceptible to medical complications produced by hypoxia.

2.2 Adverse Impact of Altitude on Health and Performance

2.2.1 Altitude Classification

The range from sea level up to 1,200 m is considered “low” altitude. In this range, arterial oxyhemoglobin saturation (SaO₂) is generally above 96 percent in healthy people. Also, physiologic changes consistent with altitude acclimatization are absent as is altitude illness and impairments to cognitive performance. Only at the highest range of low altitude is maximal aerobic work performance minimally impaired.

“Moderate” altitude extends from 1,200 to 2,400 m. Generally, resting SaO₂ is normally above 92 percent, and, although the resting arterial oxygen saturation (SaO₂) is well preserved up to ~2,400 m, the drop in alveolar partial pressure of oxygen decreases the diffusion of O₂ from the lungs to the blood and then from the blood to the cells. This decrease in O₂ diffusion rate becomes apparent during physical activities as a decrease in SaO₂. Thus, aerobic work performance (for example, a 2-mile run and a 12-mile road march) is decremented at altitudes above 1,200 m, even though resting SaO₂ is near sea-level values. In the moderate altitude range, cognitive performance decrements are not present and altitude illness is very rare. However, the reduced arterial partial pressure of oxygen (PO₂) is of sufficient magnitude to induce physiological adaptations that are collectively referred to as “altitude acclimatization” (see Section 2.3).

“High” altitude extends from 2,400 to 4,000 m. At these elevations, SaO₂ is on the “knee” of the O₂-hemoglobin saturation curve and ranges from approximately 92 to 80 percent. Aerobic work performance is progressively impaired, and altitude illness and cognitive performance decrements are common in this range of altitude.

The region from 4,000 to 5,500 m is classified as “very high” altitude. At altitudes above 4,000 m, the relationship between PO₂ and SaO₂ is on the “steep” portion of the curve where a small decrease in PO₂ results in a relatively large drop in SaO₂. Without appropriate altitude acclimatization, soldiers rapidly ascending from low altitude to very high altitude are at a very high risk of developing debilitating altitude illness and experience very profound impairments of cognitive and physical work performances.

Altitudes above 5,500 m are classified as “extreme” altitude. Rapid ascent of unacclimatized soldiers from low altitude to extreme altitude will result in rapid incapacitation and a very high probability of developing potentially fatal altitude illness. While the physiologic adaptations discussed below allow humans to function at extreme altitude for short periods of time, permanent human habitation at these elevations is not possible.

2.2.2 Impairments to Health

Medical problems related to sustained hypobaric hypoxia are termed high altitude illnesses. They range in incidence from common to rare and in severity from benign to rapidly fatal. The magnitude of the hypoxic stress is determined by the altitude, the rate of ascent, and the length of exposure (hours, days, months). Factors that contribute to the severity of symptoms include:

- The level of physical exertion;

- Individual susceptibility;
- Body mass index;
- Age; and
- Co-existing medical problems.

The most common high altitude illnesses are Acute Mountain Sickness (AMS), High Altitude Cerebral Edema (HACE), and High Altitude Pulmonary Edema (HAPE).

The signs and symptoms of AMS are headache accompanied by insomnia, unusual fatigue, dizziness, anorexia, and nausea. AMS is not accompanied by abnormal neurological findings, such as ataxia or altered mental status. The onset of AMS symptoms occur 4 to 24 hrs after ascent to high altitude, reaches peak severity in 24 to 48 hrs, and subsides over 3 to 7 days at the same altitude. 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.

HACE is a potentially fatal accumulation of fluid in brain tissue that occurs in soldiers who rapidly ascend to high altitude (> 2,400 m) or from high to higher altitude and stay there for a few days or more. The spectrum of altitude-induced brain edema ranges from subclinical cerebral edema manifested as AMS (least severe) to HACE. HACE can have a significant impact on military units operating at high altitude due to its serious prognosis and the need for rapid evacuation. The incidence of HACE is rare, usually less than 1 to 2 percent of persons going to high altitude. The magnitude of hypoxic stress is a major determinant of its development. While HACE can occur as low as 2,500 m, the vast majority of cases occur above 3,500 m, particularly with rapid ascent. Early signs and symptoms of HACE resemble severe AMS but the rapid development of the cerebral edema causes changes in mental status (e.g., confusion, disorientation, inability to talk coherently) and truncal ataxia (e.g., swaying of the upper body, especially when walking); both are hallmark characteristics of HACE.

HAPE is a non-cardiogenic, potentially fatal accumulation of fluid in the lungs, which occurs in soldiers that rapidly ascend from low (< 1,200 m) to high altitude (> 2,500 m) or from high to higher altitude and stay there for a few days or more. It also occurs in long-term high altitude residents who re-ascend rapidly to high altitude following a stay at low altitude lasting several weeks. Untreated, HAPE can be rapidly fatal (6 to 12 hrs) 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 (2 to 15 percent), its impact on military units can be significant because of the serious prognosis and need for rapid evacuation.

Other medical problems related directly to hypobaric hypoxia impacting personnel above 2,400 m include: altitude-induced peripheral edema, high altitude retinal hemorrhage, high altitude pharyngitis/bronchitis, sleep disordered breathing, blood-clotting disorders, sub-acute mountain sickness, immune system suppression, poor wound healing, and body weight loss. The functional impact on the warfighter of these disorders ranges from negligible to potentially life-threatening.

2.2.3 Impairments to Physical Performance

Hypobaric hypoxia will immediately impair maximal and prolonged whole-body physical performance capabilities in all personnel by amounts generally proportional to elevations above 1,200 m. Impairments will occur for nearly all tasks, but will be most conspicuous for those in which a given distance must be traversed in the shortest time or those that involve sustained or intermittent bouts of arduous physical activities for

prolonged durations. The physical performance impairment for a particular task will vary from one soldier to another at any elevation. Generally, an increase in elevation reduces the amount of time that a task can be performed at the same pace as at sea level. Therefore, to successfully complete the tasks, at least one of the following time-based modifications must be included in operational planning at altitude: reduce task intensity or pace, or allow more frequent or longer rest breaks. Any or all of these modifications will increase the time to complete most tasks during any mountain operation. Thus, the number of planned daily tasks performed by a soldier or unit at altitude will have to be reduced from the number that can be performed at sea level.

Task performance will be most impaired in the first few days after rapid deployment from sea level to altitude. Newly arrived military personnel will have difficulty participating in physically demanding tasks or duties, such as dismounted patrolling operations, entrenchment, and combat. Prolonged physical performance at a given altitude is improved by acclimatization but will remain impaired relative to sea level at elevations above 1,200 m. Maximal physical performance at high altitude is not improved by acclimatization, but may be improved by long-duration (months) residence at moderate altitude.

2.2.4 Impairments to Neurocognitive Performance

Altitude stress can cause a wide range of neuropsychological consequences that affect a soldier's mood, senses, judgment, memory and ability to perform cognitive and psychomotor tasks. Generally, significant changes in neuropsychological function emerge at altitudes higher than 3,000 m. However, soldiers who have low levels of ventilation or impaired pulmonary gas exchange may experience neuropsychological problems at lower altitudes. Changes in neuropsychological function are most evident in unacclimatized soldiers during the first 24 hrs of their ascent above 3,000 m.

Changes in mood states and personality are usually not recognized by the affected soldier. Initially, soldiers can exhibit euphoria that can lead to overconfidence. After several hours at altitude, soldiers may become irritable, quarrelsome, uncooperative, anxious, apathetic, less friendly, and muddled thinking. More adverse changes are noted at altitudes above 4,000 m. Moods of soldiers afflicted with severe AMS are more negative and improve more slowly than individuals with no illness. These behaviors are usually not acknowledged by the affected soldiers and may even be adamantly denied. Unit leaders must anticipate these mood changes and their potential impact on unit cohesion.

Vision is sensitive to the effects of hypoxia. Decrements in light sensitivity can occur at altitudes as low as 1,525 m. Visual acuity and color discrimination are measurably decreased above 3,000 m. Above 4,000 m, dark adaptation is impaired and accommodation and convergence decrease, leading to increased occurrence of heterophorias. From moderate to extreme altitude, night vision (light sensitivity and visual acuity) is more affected than daytime vision. There appears to be little recovery of visual function with development of altitude acclimatization. Visual performance through night vision goggles decreases at altitudes above 3,000 m, although less than unaided night vision.

Altitudes above 3,000 m can produce substantial impairments in a number of cognitive and psychomotor performance measures. Cognitive performance is more affected at altitude than psychomotor performance, and complex tasks are usually affected before simple tasks. Impaired cognitive performance at altitude are manifest as decreased accuracy (that is, increased errors), slowing of performance (that is, decreased speed), or a combination of both. While reduced reaction time rather than decreased accuracy occurs most often at altitude, error rates are likely to rise when tasks are paced by external conditions. Both impact successful execution of many military tasks, which are dependent upon the integration of multiple cognitive functions.

2.3 Altitude Acclimatization and Deacclimatization

Altitude acclimatization allows soldiers to reduce their susceptibility to altitude illness and achieve optimal physical and cognitive performance for a given altitude. Altitude acclimatization can be induced in both natural and simulated altitude environments using continuous exposures, such as a staged ascent or graded ascent, and intermittent exposures, such as daily or frequent ascents and descents. Furthermore, altitude acclimatization has no negative side effects and will not harm health or physical performance upon return to low altitude. There are no pharmaceutical therapies that induce altitude acclimatization, but the drug acetazolamide can aid its development. Altitude acclimatization consists of physiological adaptations that develop in a time-dependent manner during continuous or repeated intermittent exposure to hypoxia. Effective and efficient induction of altitude acclimatization can be accomplished by following two golden rules:

- 1) Ascend to a high enough altitude to create an effective hypoxic stimulus, but not too high that significant altitude illness can develop.
- 2) Reside in the hypoxic environment for a sufficient period of time to allow the adaptations to develop.

Current procedures for induction of altitude acclimatization rely primarily on staged and/or graded ascent profiles to altitudes above 2,400 m. Altitude acclimatization can require several days to possibly several weeks or more of residence at altitude to develop functionally useful acclimatization.

When altitude-acclimatized personnel descend to low altitude (i.e., below 1,200 m) deacclimatization begins. The rate of deacclimatization is not well known. In well-acclimatized personnel (for example, residents for 16 days at 4,050 m), approximately 50 percent of their altitude acclimatization (that is, absence of AMS and increased SaO₂) was still present after 7 days residing near sea level upon re-ascent to 4,300 m. Altitude acclimatization to moderate altitudes may be lost faster than acclimatization to higher altitudes.

2.4 Current Capabilities for Mitigating Altitude Stress

2.4.1 Altitude Risk Assessment

Existing guidance is limited and semi-quantitative. Current guidance is also limited to two acclimatization states, unacclimatized or fully acclimatized. Risk of developing altitude illnesses and incurring performance decrements are greatest in unacclimatized personnel rapidly ascending above 2,400 m. This risk rises with increasing altitude, and is exacerbated in personnel performing sustained physical work tasks at high altitudes. Risk is lower in acclimatized personnel ascending to altitudes no greater than 2,000 m above their staging altitude or in personnel ascending no more than 300 m per day above 2,400 m.

2.4.2 Altitude Illness Detection and Diagnosis

Detection and diagnosis of all altitude illnesses is based on presence of signs and symptoms in the context of recent ascent to high altitude. Because the earliest manifestation of all altitude illness symptoms are subjective (headache, light headedness, nausea, dyspnea, etc.), early detection is completely dependent upon the victim's self-reporting of these symptoms. Differential diagnosis must be considered and because the symptoms and few signs of altitude illness are not specific to these illnesses and are similar to other common conditions (fatigue, dehydration, etc.), early diagnosis is difficult.

2.4.3 Altitude Acclimatization

Current altitude acclimatization procedures are based on **continuous** exposure to altitude. General guidance is to ascend high enough to induce adaptations, but not so high as to develop altitude illness. Unacclimatized

soldiers should not ascend above 2,400 m. Staging reduces AMS incidence for altitudes 1,000 to 2,000 m above the staging altitude. Current staging guidance is: 7 – 14 days between 1,400 – 2,000 m and 4 – 6 days between 2,000 – 2,400 m. Graded ascents above 2,400 m should not exceed 300 m/day. Graded ascents greater than 300 m/day should include a rest day at each higher altitude.

2.4.4 Pharmacological Therapeutics

There are several medications that are used for prophylaxis and/or treatment of altitude illnesses. However, only two medications (acetazolamide and dexamethasone) have undergone the appropriate clinical trials to establish their therapeutic efficacy. Some medications are therapeutic for relieving symptoms of altitude illness, but not treating the illness per se. All currently available medications have possible adverse side effects that may limit their use in military operations.

- Acetazolamide: prophylaxis and treatment of AMS, HACE;
- Dexamethasone: prophylaxis and treatment of AMS, HACE;
- Nifedipine: prophylaxis and treatment of HAPE (not confirmed by clinical trials);
- Sildenafil, Tadalafil: prophylaxis and treatment of HAPE (not confirmed by clinical trials);
- Salmeterol: prophylaxis and treatment of HAPE (not confirmed by clinical trials);
- Aspirin, Acetaminophen, Ibuprofen: prophylaxis and treatment of high altitude headache (not confirmed by clinical trials); and
- Prochlorperazine, Promethazine: treatment of nausea/vomiting associated with AMS, HACE.

2.4.5 Nutritional and Hydration Guidelines

Carbohydrate is the most efficient fuel for optimizing physical performance at altitude. A 6-to-12 percent glucose or maltodextran solution in liquid form ingested just before and periodically during moderate to intense physical activity improves endurance performance by 10-to-25 percent at 4,300 m in unacclimatized individuals. No dietary interventions provide effective prophylaxis or treatment of altitude illness. Hypobaric hypoxia stimulates increased erythropoiesis that draws on the body's iron stores, potentially causing iron deficiency. Individuals exposed to altitude should maintain an iron-rich diet and/or consider taking an iron supplement. For a given temperature and work rate, hydration requirements are greater with increasing altitude. While over-hydration does not prevent development of altitude illnesses, hypohydration can exacerbate AMS symptoms and possibly impair development of ventilatory acclimatization.

3.0 REVIEW OF MILITARILY-RELEVANT MOUNTAIN MEDICINE TECHNOLOGY AND RESEARCH BARRIERS

3.1 Introduction

Through information exchanges at its two business meetings and by email, HFM-146 identified desired mountain medicine capability requirements and the technology and research barriers blocking achievement of these capabilities. During the HFM-146 group discussions, it was noted that among the participating Nations, three general themes emerged based on foreign policy, geographical location, and population. First, larger Nations with more world-wide deployment capabilities expressed the need for predictive models and rapid acclimatization capabilities. Second, Nations with high altitude borders (e.g., Georgia, and the Kyrgyz

Republic) expressed the need for maintaining the health and performance of border forces at high altitudes for long periods of time. Third, to keep costs down, Nations with relatively small military forces expressed the need for better selection criteria of personnel for high altitude duty assignments. From these discussions, eight capability requirements were identified. In this section each capability requirement, the current capability and the medical technology and research barriers to achieving the new capability are summarized. No prioritization is implied by the order of presentation of these capability requirements.

3.2 Capability Requirements, Technology and Research Barriers

3.2.1 Predictive Models of Altitude Illness and Performance

3.2.1.1 Required Capability

Commanders, mission and medical planners need accurate estimates and predictions of altitude illness, and work performance to plan and manage missions effectively. Validated, quantitative predictive models are needed to provide this capability. Predictive models need to be integrated into user-friendly decision aids that do not require special medical training.

3.2.1.2 Current Capability

There are no validated predictive models of mountain sickness, acclimatization and military performance for moderate-to-high altitude operations, and current guidance lacks quantitative metrics. Current guidance is in the form of simple look-up tables with rough estimates of overall incidence of Acute Mountain Sickness (AMS) with no quantitative modifiers for known risk factors and no estimate of the dynamic change in AMS severity and prevalence over time at altitude. Likewise, estimates of work performance at high altitudes are completely qualitative (i.e., slower pace).

3.2.1.3 Technology and Research Barriers

The primary barrier is the lack of an adequately large dataset of relevant variables collected under well-controlled conditions. Study conditions should closely approximate militarily-relevant operations, and control for known and potentially confounding variables (metabolic activity, hydration, medication use, etc.). Data sharing agreements and standardization of data collection methods could accelerate development of the datasets required for model development and validation.

3.2.2 Individual Risk Prediction of Altitude Illness and Performance

3.2.2.1 Required Capability

Accurate identification of individuals with high risk of developing altitude illness and/or work performance impairments at high altitudes would improve medical management of personnel through use of individualized medicine and provide improved metrics for selection of personnel for duty assignments at high altitude locations.

3.2.2.2 Current Capability

Prior history of altitude illness and/or performance against some reference during actual high altitude exposure is current standard of practice. However, the current capability has not been validated using appropriately designed and powered studies. Several Nations use physical performance metrics and/or tests of tolerance to brief, severe

hypoxia in their selection process. In the absence of prior history, there is no current capability to assess individual risk.

3.2.2.3 *Technology and Research Barriers*

Individual tolerance to high altitude is not likely dependent on one or even a few key physiological responses, signalling pathways, etc. Basic research into the molecular mechanisms underlying the physiological adaptations to sustained hypobaric hypoxia is needed to identify potential biomarkers of individual tolerance to high altitude.

3.2.3 **Individual Altitude Acclimatization Status Monitor**

3.2.3.1 *Required Capability*

A real-time, automated altitude acclimatization monitor is required to provide medical personnel and unit leaders with current, accurate acclimatization status for efficient and effective risk management of altitude stress.

3.2.3.2 *Current Capability*

A rough estimate based on semi-quantitative guidance limited to continuous altitude exposure above 1,200 m is the current norm. No capability exists for estimating acclimatization status for personnel intermittently ascending and descending above 1,200 m.

3.2.3.3 *Technology and Research Barriers*

The primary barrier is the lack of an adequately large dataset of relevant variables collected under well-controlled conditions to establish acclimatization models. Technology to provide the hardware components is readily available for integration with the newly developed models and software.

3.2.4 **Rapid Altitude Acclimatization Induction**

3.2.4.1 *Required Capability*

Military personnel can be rapidly deployed to high altitudes. To protect military personnel from altitude illness and performance impairments, innovative approaches are needed to accelerate acquisition of natural altitude acclimatization without the need for long-duration altitude or hypoxic exposure.

3.2.4.2 *Current Capability*

Effective altitude acclimatization requires intermittent or continuous exposures to altitudes above 2,000 m for a minimum of 3 to 7 days. Acetazolamide provides some boost to ventilatory acclimatization.

3.2.4.3 *Technology and Research Barriers*

Recent studies indicate that both hypobaria and hypoxia contribute the development of natural altitude acclimatization. The role of hypobaria is not understood and requires elucidation. Better understanding of the molecular pathways involved in natural altitude acclimatization may identify receptors and or signaling molecules that one or more drugs can act through to exert a “hypoxiamimetic” effect and trigger the normal altitude acclimatization process.

3.2.5 Performance Enhancement at High Altitudes

3.2.5.1 Required Capability

Mission performance and success will improve if military personnel are able to sustain their sea level performance levels at high altitudes.

3.2.5.2 Current Capability

At altitudes above 2,400 m, complete natural altitude acclimatization does not fully restore prolonged aerobic work performance to levels achieved at lower altitude. No capability exists to further improve performance.

3.2.5.3 Technology and Research Barriers

Current knowledge indicates that raising arterial oxygen concentration to sea level values does not restore prolonged aerobic performance at high altitudes. This suggests that other physiological mechanisms are limiting aerobic performance. Identification of these mechanisms is required for development of targeted ergogenic aids to fully restore aerobic function.

3.2.6 Detection and Diagnosis of Altitude Illness

3.2.6.1 Required Capability

Early detection and diagnosis of altitude illness prior to onset of severe symptoms that is independent of the victim reporting their symptoms will reduce altitude illness impact on mission and medical support and evacuation requirements.

3.2.6.2 Current Capability

Early detection is not possible with existing technology. Mild to moderately severe altitude illness is completely dependent upon self-reporting by victim.

3.2.6.3 Technology and Research Barriers

Basic research into the molecular mechanisms underlying the pathophysiology of altitude illness is needed to identify potential biomarkers that can be used for sensitive and specific diagnosis of these illnesses.

3.2.7 Therapeutic Prevention and Treatment of Altitude Illness

3.2.7.1 Required Capability

Therapeutic agents with rapid onset, high efficacy, and minimal adverse side effects are needed for both prophylaxis and treatment of all high altitude illnesses.

3.2.7.2 Current Capability

There are several medications that are used for prophylaxis and/or treatment of altitude illnesses. Acetazolamide and dexamethasone are very effective for prevention and treatment of AMS and have some efficacy for HACE. No clinically established therapeutic agent(s) with high efficacy are available for prevention and treatment of HAPE. All currently available medications have possible adverse side effects that may limit their use in military

operations. Supplemental oxygen is effective, but logistically not feasible for most ground-based military operations.

3.2.7.3 Technology and Research Barriers

Specific cellular and genetic factors that play a role in the development of altitude illnesses are not known. Thus, no select targets are known that are most likely to be useful in the development of new treatments for altitude illness.

3.2.8 Health Sustainment during Long-Duration Deployments to High Altitudes

3.2.8.1 Required Capability

New therapeutic and or nutritional interventions are needed to sustain health and performance during long-duration (>30 days) deployments to high altitudes above 2,400 m.

3.2.8.2 Current Capability

Military rations provide normal amounts of macro and micro nutrients to minimize body weight loss as long as caloric intake equals caloric expenditure. At high altitudes, current nutritional guidelines do not sustain immune function or wound healing at normal levels.

3.2.8.3 Technology and Research Barriers

It is necessary to identify the molecular mechanisms underlying the anorexia and immune dysfunctions caused by chronic hypobaric hypoxia.

4.0 SUGGESTED FUTURE ACTIVITIES

4.1 Short-Term Activities

Many NATO and Partner Nation's civilian scientists and military operational personnel are not fully informed of the current best practices in military mountain medicine, or of current and proposed research and development activities in this subject matter. To correct this deficiency, HFM-146 recommends a HFM-sponsored RTO Lecture Series (RLS). The objective of this RLS would be to communicate state-of-the-art practices to the larger NATO audience, and give visibility to current areas of research within Member Nations. With NATO military activities in Afghanistan currently projected into 2014, organization and presentation of a RLS within the next 1 to 2 years may have a significant operational impact on these military activities.

HFM-146 recommends that the HFM establish a NATO-sponsored electronic forum or bulletin board to post information on proposed mountain medicine research studies to encourage multinational data exchanges and collaborations. Moreover, abstracts or briefs of recently completed research projects and publications posted to this forum would greatly aid the conveyance of these new findings to each NATO and Partner country's military scientists and operational forces.

4.2 Long-Term Activities

World-wide, there are relatively few military and civilian research centers actively conducting mountain medicine research projects. Moreover, given the relatively austere and remote regions where many mountain

medicine projects are conducted, studies are generally limited in both the size of the subject population studied and the scope of physiological and biochemical methods used. Consequently, to increase the utility of these studies, HFM-146 recommends creation of a multinational database repository for these studies. A NATO sponsored data repository would promote greater information sharing across NATO and Partner Nations, facilitate achieving solutions to specific military requirements, provide access to data by Nations with limited mountain medicine R&D activities, and develop evidenced-based medicine best practices for prevention and treatment of altitude illness.

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14. Abstract	<p>The subject matter of this review is hypobaric hypoxia, an environmental stress resulting from ascent to progressively higher terrestrial elevation or altitude above 1,200 meters (m) (3,937 feet (ft)). NATO RTO HFM-146 reviewed the empirical evidence of the adverse impact of high terrestrial elevations on health and physical and mental performances and current capabilities to mitigate these aversive impacts. The report identifies needed mountain medicine capabilities and technology and research barriers (gaps) blocking achievement of these capabilities. Recommendations for future work are provided.</p>												





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