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Medical professionals in remote and extreme environments : a mission to Mars

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Medical Professionals in Remote and Extreme Environments: A Mission to Mars

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Abstract:

To give a representative overview of medical professionals working in today's remote and extreme environments, we consider the following teams and organizations:

- Expeditions on 8000m peaks led by accredited guides of the American Mountain Guides Association (AMGA) or International Federation of Mountain Guides Association (IFMGA)
- Everest Base Camp Medical Clinic (Everest ER) in Nepal
- US Antarctic Program (USAP)
- Medical Departments aboard US Navy ships and submarines
- US Special Operations Command (SOCOM) Corpsmen and Medics
- US Navy Diving Medical Officers
- Crew Medical Officers (CMO's) aboard the International Space Station

After reviewing the practice environments and medical training of the various teams, we consider the medical qualifications of a hypothetical future team embarking on a mission to a particularly remote and extreme environment, a human spaceflight mission to the surface of Mars.

Introduction:

This article explores the qualifications and training of current practitioners of medicine operating in remote and extreme environments. Remote environments have limited access to rescue and hospital care. Extreme environments have exposure to temperature and pressure extremes, radiation, as well as exposure to significant mechanical hazards, including from enemy action during military operations. Several environments combine these descriptions. A prospective human spaceflight to Mars would operate within remote and extreme environments through the entirety of the mission.

As observed by Dr. HD Backer, MD, "Wilderness medicine not only overlaps with sports medicine, but also emergency medicine, military, occupational, and travel medicine and international health" and "It shares with military medicine an intense interest in environmental stresses and hazards, field management and mobile response" (Backer, 1995).

Operational medicine is medicine practiced in support of a different mission, such as that of the US military. Operational medicine incorporates three concepts. Practitioners of operational medicine provide advice and planning support to their teams in support of accomplishing the mission. Practitioners are also responsible for the health of team members during deployments, often in extreme environments. Finally, practitioners of operational medicine are responsible for treating team members in the event of injuries sustained in the course of the mission (Llewellyn, 2017).

Exploring remote and extreme environments through the lens of wilderness medicine, military medicine and operational medicine provides a good framework through which to consider the qualifications and training of medical team members.

The qualifications, training and specialized equipment and medications desired for team medical personnel stem from the epidemiological breakdown of ailments they would be expected to treat, best organized in this case by the types of extreme exposure and degree of remoteness of the expedition. This is then combined with the operational constraints upon the medical providers with respect to space and weight restrictions. An investigation of the medical personnel assigned to existing teams and organizations is instructive regarding considerations when developing the medical capability for prospective teams.

Examples abound of teams operating in remote and extreme environments, but further discussion will be devoted to several salient examples. They will include guided expeditions to climb 8000 meter peaks, the Everest Base Camp Medical Clinic (Everest ER), doctors and providers at Antarctic bases (US Antarctic Program), medical departments of US Navy warships, corpsmen and medics from the Special Operations Command (SOCOM), Diving Medical Officers and the Crew Medical Officer aboard the International Space Station.

Given a hypothetical expedition it would then be possible to suggest and bound the number and qualifications of medical professionals desired to provide support for their mission. We will explore the medical qualifications and training of a team in a particularly remote and extreme environment, human spaceflight mission to the surface of Mars.

Expeditions on 8000-meter peaks

To investigate representative levels of medical training, expeditions on 8000-meter peaks led by accredited guides of the American Mountain Guides Association (AMGA) and International Federation of Mountain Guides Association (IFMGA) are considered (Lyon & Wiggins, 2010). As an example of this certification structure, AMGA provides the American Mountain Guide Certification, which is recognized by the twenty member countries of IFMGA. In addition to alpine, rock, and ski certification streams, becoming certified as an American Mountain Guide requires both current CPR training and Wilderness First Responder training (See Appendix 1). Most western companies advertising commercial climbing expeditions on 8000m peaks have at least one guide who is IFMGA certified.

Other medical qualifications particular to the mountain environment exist, such as the Diploma in Mountain Medicine (DiMM), which was set up in 1997 as a joint effort between the International Society of Mountain Medicine (ISMM), International Mountaineering and Climbing Federation (UIAA), and International Commission for Alpine Rescue (ICAR) (Hillebrandt, 2011). The DiMM takes a different approach to qualification in mountain medicine. Existing health care professionals are offered education and training in wilderness medicine, technical rescue, and self-sufficiency in the backcountry (See Appendix 2). Training is separated broadly into alpine and rock sessions. The DiMM is offered to MD's and DO's, nurses and medics. They may be earned through the WMS, DOD, University of New Mexico School of Medicine, and Mountain Medicine Society of Nepal. While the number of medical professionals holding a DiMM is increasing, it is far from the norm for even large expeditions to 8000m peaks to have a DiMM qualified guide or team doctor or medic.

Regardless of the certification status of the guides, there is significant variation in the material preparedness and skills of various teams, and larger teams sometimes provide support to clients of smaller teams through structured or impromptu agreements. For example, smaller teams with a smaller logistical footprint may rely upon tacit or explicit arrangements with larger teams which can afford to bring cross-trained or dedicated medical personnel to their base camps and advance base camps. Larger teams may bring specialized medicines for AMS/HAPE/HACE with them, and specialized equipment such as a Gamow bag. However, any heavy equipment, including the Gamow bag, will be brought only as far as advance base camp.

Occasionally, physicians aspiring to join commercial high-altitude climbing teams are offered a discount on their expeditions. Higher levels of medical training might be helpful at base camp and advanced base camps. Team doctors will generally not move far beyond advance base camp unless they are attempting to summit themselves. Therefore, the team's exposure to the risks of high altitude in the death zone likely occurs without the coverage of a team physician or medic. However, medical emergencies at the high camps or near the summit more likely require recognition of AMS/HAPE/HACE, and physical strength within the team and/or resources such as oxygen to help victims with descent to lower elevation. The Wilderness First Aid (WFA) and Wilderness First Responder qualifications would certainly be helpful to all team members in such scenarios, but are not required by commercial climbing companies.

A physical exam by the climber's primary care provider prior to departure is almost always recommended, but not always required (Hudson, et al., 2013).

Everest Base Camp Medical Clinic (Everest ER)

Doctors at the Everest Base Camp Medical Clinic (Everest ER) in Nepal treat both Sherpas and mountaineers climbing Mount Everest and Lhotse (Nemethy, Pressman, Freer, & McIntosh, 2015). The Everest ER operates at the Everest Base Camp in Nepal with a volunteer staff chosen from previous volunteers with the Himalayan Rescue Association (HRA), at either their Manang or Pheriche posts, also in Nepal (See

Appendix 3). Several of the volunteers listed historically are noted to be Wilderness Medicine fellows. Everest ER doctors are not permitted to participate in rescues or climb with any team.

After noting a general lack of medical preparedness of mountaineering expeditions at Everest during 2002, Dr. Luanne Freer first set up the Everest ER in Spring 2003. (Freer, 2004) In 2012 she noted the top 5 ailments of her patients included high altitude cough ("Khumbu cough"), viral respiratory infections, gastritis, infectious gastroenteritis, and altitude issues (AMS, HAPE, HACE, insomnia, apnea) (Nemethy, Pressman, Freer, & McIntosh, 2015). Some more exotic maladies she saw that season were DVT and a 33yo who suffered from a stroke. The staff of the Everest ER also oversees helicopter rescues, which are becoming more frequent due to introduction of lightweight and powerful helicopters that can operate at the high elevations of the lower camps on Everest (Heil, 2012).

The Everest ER is staffed by at least two physicians each year (Nemethy, Pressman, Freer, & McIntosh, 2015). The most recent business model of the non-profit Everest ER is offering coverage of climbing teams' members for a nominal fee per person. In addition to climbers attempting to summit, approximately 4000 Everest Base Camp (EBC) trekkers briefly visit EBC each month. The limited funds the Everest ER makes from this remuneration arrangement are used to purchase medications for treatment of the Sherpas and locals, who are generally not charged a fee for their care.

United States Antarctic Program (USAP)

Practitioners in Antarctica provide primary care at onsite medical clinics to the 1400 inhabitants of McMurdo station and further afield at other stations on the continent (Pattarini, Scarborough, Sombito, & Parazynski, 2016; Bhatia & Pal, 2012) (Pattarini, Scarborough, Sombito, & Parazynski, 2016; Bhatia & Pal, 2012) (Pattarini, Scarborough, Sombito, & Parazynski, 2016; Bhatia & Pal, 2012). University of Texas Medical Branch (UTMB) Health runs the Center for Polar Medical Operations (CPMO), which in turn hires the medical personnel for the McMurdo, Palmer, and South Pole stations of the United States Antarctic Program (USAP) funded by the National Science Foundation (NSF).

McMurdo has the most advanced medical facility in Antarctica, which is a basic clinic with little critical care or surgical capability. McMurdo also has 4 helicopters, which may be used for rescue operations from smaller outlying bases if necessary. During the summer season, patients may be MEDEVACed from Antarctic by USAF/USANG cargo aircraft flying out via Christchurch, New Zealand. In addition to the challenges posed by the remote location of Antarctica, medical professionals must be prepared to handle problems stemming the low temperatures and high altitude (See Appendix 4).

During the summer season, McMurdo has a roster including 9 personnel in the medical clinic, including a physician, mid-level practitioner, dentist, nurse administrator, and flight nurse. Amundsen-Scott South Pole Station has a physician and a mid-level practitioner, Palmer Station has a physician, and the field camps are assigned a mid-level practitioner (See Table 1).

The physicians are boarded in either emergency medicine or family medicine, with 3 years of practice experience and experience working in remote environments with limited support, while the mid-level practitioners are NP's or PA's required to have 2 years practice experience in either primary care or emergency medicine.

The physician posted at Palmer Station works with diving operations, and expertise in dive medicine is noted to be useful. CPMO also commented the autonomous physicians and mid-level practitioners at sites other than McMurdo would benefit from some knowledge of dentistry and ultrasound.

During the winter, there are approximately 50 people at South Pole and 150-240 people at McMurdo. Those wintering over mostly conduct maintenance work. During the 2013 winter, there was a physician at each of the three USAP sites, with an additional mid-level at the South Pole station. The McMurdo clinic had a physician, a nurse practitioner, and a physical therapist during the 2013 winter.

Extensive use of physical qualification (PQ) screening during the employee selection process is a key tool for ensuring the general health of the population participating in the USAP.

Table 1: USAP Medical Personnel Staffing (Summer):

Station	**Medical Personnel**
McMurdo Station	Physician Mid-Level Practitioner Dentist Nurse Administrator Flight Nurse Physical Therapist Medical Technologist Radiology Technician Pharmacy Technologist
Field Camps	Mid-Level Practitioner
Amundsen-Scott South Pole Station	Physician Mid-Level Practitioner
Palmer Station	Physician

Medical Departments deployed aboard US Navy Ships

Operating in remote and extreme environments is intrinsic to military medicine. Each service in the US Armed Forces has its own very capable and well-integrated medical branch, with the US Marine Corps supported by the US Navy, and all services and medical branches operate in a joint environment providing mutual support for the others. The military makes use of Pre-Deployment Screenings to ensure troops are healthy before making deployments to potentially remote and extreme environments.

There has been a recent proliferation of new types of medical teams and reorganizations. During the conflicts since the beginning of the century in Iraq, Afghanistan and the Horn of Africa, US military medicine has finely-tuned the response to injuries caused by improvised explosive devices (IEDs) and gunshot wounds (GSW), particularly within the "golden hour" following trauma. As American troops have increasingly been subjected to trauma in the line of duty, augmentation of surgical and aeromedical evacuation capabilities has been necessary to quickly stabilize the wounded and bring them to definitive care.

This section focuses on medical departments deployed aboard US Navy ships, ranging in size from submarines and destroyers to aircraft carriers (Fisher & Dunn, 1990; Krentz, Li, & Baker, 1997) and amphibious assault ships. The Department of the Navy also provides medical support to the US Marine Corps, which integrates Navy doctors and Navy corpsmen. This relationship between the US Navy and Marine Corps offers an expanded spectrum of medical team size and function to consider.

Aircraft Carriers and Amphibious Assault Ships have larger medical departments. Destroyers, cruisers and littoral combat ships have smaller medical departments. Surface combatants such as destroyers and cruisers often deploy as escorts within Carrier Strike Groups (CSG's) or Expeditionary Strike Groups (ESG's), but also have the capability to operate autonomously from these larger battle groups. The centerpiece of the CSG is an aircraft carrier, and the centerpiece of the ESG is an amphibious assault ship. Because of this relationship, surface combatants frequently have the resources of an aircraft carrier or amphibious assault ship to rely upon for higher-level medical care or MEDEVAC. Sea mobility and aeromedical evacuation via helicopter or Carrier On-board Delivery airplanes (COD) allow evacuation of casualties within days or weeks to hospitals on land, dependent on time of peace or war and the nature of the ship's mission. Due to their special mission, hospital ships such as the USNS Mercy and USNS Comfort have extensive surgical capability and beds.

Brief mention will be made about the very large medical departments aboard Navy amphibious ships as well as hospital ships. Particular consideration will be given to the medical departments aboard destroyers, submarines and aircraft carriers, as those units may be considered similar in capability, patient population, and injury profiles to other teams discussed in this article.

<u>The Medical Department of an Amphibious Assault Ship</u>

Navy amphibious assault ships carry large numbers of Marine combat troops who may incur trauma as participants in a Landing Force. LHDs and LHAs are amphibious assault ships which carry a crew of 66 Navy officers and 1004 enlisted, and a Marine Detachment of 1687 troops, plus 184 additional troops in surge operations (United States Navy, 2018). Therefore, a Fleet Surgical Team (FST) is typically assigned to each Amphibious Squadron (PHIBRON). Its baseline manning is 8 officers and 10 enlisted. For wartime manning (M+1), the FST will be augmented by 84 additional personnel assigned to the Casualty Receiving and Treatment Ship (CRTS). M+1 platforms are amphibious assault ships such as LHD 1-8 ("Wasp" class) and LHA 6 (USS America). (Surface Warfare Medical Institute, 2016)

The CRTS has a required operational capability (ROC) and projected operational environment (POE) of an amphibious assault ship (LHD or LHA) providing 4 Operating Rooms, 15 ICU/Recovery beds, and 45 ward beds and blood bank capability of 500+ units, FFP, and a walking blood bank. These assets may also be used for Humanitarian Assistance and Disaster Relief (HA/DR) missions. For example, following the Indian Ocean tsunami in late 2004, the USS Essex (LHD-2) and USS Bonhomme Richard (LHD-6) as well as the USS Abraham Lincoln and CSG-9 and USNS Mercy all conducted HA/DR operations off the coast of Sumatra, Indonesia (Leavitt, Vorce, & Hsu, 2005). Most recently, the USNS Comfort and USS Kearsarge (LHD-3) Amphibious Ready Group (ARG) provided support to Puerto Rico following Hurricane Maria.(CNN Wire, 2017; Dyer, 2017)

The Expeditionary Resuscitative Surgical System (ERSS) is an evolution of the FST allowing responsive and flexible positioning of FST components ashore or afloat to allow forward resuscitative surgery in support of split-ARG and special operations. Drawing from the personnel of the FST, a forward-deployed Expeditionary Surgical Team (EST), Expeditionary Trauma Team (ETT) and En-Route Care Team (ERCT) may be formed to provide a chain of emergency life-saving (ETT), damage-control trauma surgery (EST), and then transport of patients (ERCT) back to the amphibious assault ship (Table 2).

Table 2: The Expeditionary Resuscitative Surgical System Components

Expeditionary Surgical Team (EST)
• Team Members
  o 1 General Surgeon
  o 1 Anesthesia provider
  o 1 Critical Care Nurse
  o 2 OR Techs
• Concept of Operations: Set up within 45 minutes, perform 5 damage control cases, and hold patients up to 2-4 hours.

Expeditionary Trauma Team (ETT)
• Team Members
  o 1 Emergency Room Physician
  o 1 Independent Duty Corpsman
• Concept of Operations: Operate from small afloat and ashore platform to provide initial emergency life and limb saving actions.

En-Route Care Team (ERCT) • 1 Flight Corpsman • Concept of Operations: medically managing 2 stabilized casualties for 2-hr transits.

(Surface Warfare Medical Institute, 2016)

The Medical Department of an Aircraft Carrier

In the US Navy a nuclear-powered Aircraft Carrier (CVN) has 3 physicians assigned and 7 additional officers including a PA, nurse, and CRNA, as well as 31 enlisted personnel (Table 3). The assigned air wing brings additional medical personnel: 2 flight surgeons trained in aerospace medicine and 8-9 squadron hospital corpsmen. As the crew of an aircraft carrier plus its embarked air wing can reach more than 5500 sailors, there is a typical ratio of 1 doctor per 1200 personnel and one corpsmen per 150 personnel (Commander Naval Air Forces, 2005).

Table 3: Personnel Roster of the Medical Department of an Aircraft Carrier

- Senior Medical Officer (PREVMED AERO)
- Ship's Surgeon (GENERAL SURGEON)
- CRNA (NRS ANESTH)
- General Medical Officer
- Medical Administrative Officer (HEALTH CARE ADMIN)
- Ship's Nurse (CRITIAL CARE NURSE)
- Physician Assistant
- Clinical Psychologist
- Physical Therapist
- Radiation Health Officer
- Air Wing Flight Surgeons
- Leading Chief Hospital Corpsman (LCPO), Division Leading Petty Officer (LPO)
- 29 Hospital Corpsmen

(Commander Naval Air Forces, 2005)

The Medical Department of a Surface Combatant

Arleigh Burke class destroyers (DDG) and Ticonderoga class cruisers (CG) are surface combatants, which carry a crew of 329 to 330 (United States Navy, 2018; United States navy, 2017). Medical care aboard DDGs and CGs is provided by an Independent Duty Hospital Corpsman (See Appendix 5) and 2 general duty junior Hospital Corpsmen. They could be considered to have a mix of medic and first responder capability. (Surface Warfare Medical Institute, 2016)

The Medical Department of a Submarine

Nuclear-powered ballistic missile submarines (SSBN) have a very particular mission and requirement for stealth. They typically deploy with 15 officers and 140 enlisted personnel for 70-day patrols; the longest patrol to date by a single crew was 140 days.

A submarine independent duty corpsman (IDC) provides the medical care for the crew of an SSBN. A submarine IDC receives an additional year of training (see Appendix 6), with the addition of instruction in radiation health and atmosphere control. Nuclear-powered guided missile submarines (SSGN's) sometimes deploy with a contingent of special operations troops aboard, and during these periods deploy with a physician trained as an Undersea Medical Officer aboard.

One incident aboard the USS San Francisco (SSN 711), a nuclear powered attack submarine, is instructive regarding the medical personnel aboard a US Navy submarine, and their performance during a mass casualty incident (MCI). In 2005 the USS San Francisco had an Independent Duty Corpsman (IDC) assisted by an emergency medical assistance team (EMAT), who were in turn trained by the IDC to perform duties such as patient transport and placing IV lines.

On January 8, 2005, the USS San Francisco collided with an undersea mountain in the Pacific Ocean. Of the 138 sailors aboard, 90% were injured and there was one fatality. The IDC, fortunately uninjured, stabilized the injured crew with the assistance of the EMAT and two additional crewmembers who by chance had had previous EMT training. Most of the injuries were fractures, concussions, and lacerations. The IDC received some medical advice from the Command Center at Pearl Harbor. This communication was roughly analogous to online medical direction given to EMS personnel from land-based hospitals. (Jankowsky, 2008)

The USS San Francisco was met by a helicopter 24 hours after the collision, and additional medical personnel were transferred aboard the submarine, who continued treatment until the submarine docked in Guam another day later, and 29 patients were transferred to the ER at U.S. Naval Hospital Guam.

As a result of this accident, EMT training was provided to ensure at least one additional EMT-trained sailor aboard each submarine, in addition to the IDC and EMAT members. Additional training was conducted to refine use of satellite communications to provide online medical advice to the IDC (and UMO's if aboard). Additional training and drills were also provided to EMAT members in patient transport.

US Special Operations Command (SOCOM) Corpsmen and Medics

Operational medicine is certainly practiced in the setting of medical departments aboard US Navy ships. However, the most classic examples of operational medicine can be seen in the role of combat medics operating with special operations forces, whose responsibilities encompass all three operational medicine concepts in a smaller team footprint. (Llewellyn, 2017)

Corpsmen and medics from SOCOM work under fire as special forces or special operations troops of the United States. They complete the Special Operations Combat Medic Course at Fort Bragg, North Carolina (Dorogi, 2007; Wilson, 2006; Wallace, 2009). Within SOCOM, there are also certain troops who are trained specifically to rescue downed pilots or evacuate wounded troops. Examples include USAF Pararescue Jumpers (PJs) and US Army Special Operations Flight Medics (Faudree, 2010). Special Forces units (Green Berets) are often partnered with large contingents of up to 1500 host country troops; these medics often provide care for those foreign troops as well (Pueschel, 2010).

This section will cover the training offered within the Special Operations Combat Medic course, and the evolution and implementation of the Tactical Combat Casualty Care (TCCC) program for all members of the special operations community.

Special Operations Combat Medic training

Anecdotally, medics completing SOCM are considered to have a scope of practice similar to a mid-level. In 2013, the SOCM course included six 6-week blocks: EMT-Basic, Anatomy & Physiology, Clinical Medicine, Trauma 1, Trauma 2, and Trauma 3, followed by 4 weeks on clinical rotation at a civilian hospital (See Table 4 and Appendix 7). Dental care was also covered in one of the blocks. The most recent SOCM course schedule shown on the Navy Medicine Operational Training Center website shows the Trauma blocks may have been consolidated into one 7-week block, for a total course length of 26 weeks (NMOTC, 2018).

Table 4: Course Outline for Special Operations Combat Medic training

- EMT-Basic
- A&P
- Clinical Medicine
- Trauma 1
  - IV's and splints
  - Advanced Cardiac Life Support (ACLS)
  - Pediatric Education for Pre-Hospital Providers (PEPP)
- Trauma 2
  - Trauma Patient Assessment
  - Combat Trauma Management
- Trauma 3
  - TCCC
  - Advanced Trauma Management
  - Field Training Exercise

Tactical Combat Casualty Care

Finally, all special operations troops in the US today are trained in Tactical Combat Casualty Care (TCCC), which has developed and evolved during the extensive ground combat the US military has seen during the past two decades. TCCC was envisioned in 1992, but was implemented starting in 1996. Progress in the treatment of trauma casualties from ground combat had stagnated, and dogma from civilian trauma treatment and training, such as eschewing use of tourniquets, hampered the life-saving efforts of combat medics (Davis, Martin, & Schreiber, 2017). TCCC was also instructed to troops without extensive medical training (Butler, Leadership Lessons Learned in Tactical Combat Casualty Care, 2017).

TCCC quickly gained acceptance among special operations troops and was embraced by special operations leadership. Today, all special operations troopers are trained in TCCC, allowing them to stabilize their comrades during battle, sometimes even before the combat medic arrives (See Appendix 8). TCCC and swift medical evacuation (MEDEVAC), combined with pre-hospital surgical stabilization of casualties during the golden hour have all contributed to dramatic increases in survival over the past decades of combat.

US Navy Diving Medical Officers (DMO)

Diving Medical Officers complete the Undersea Medical Officer Candidate (UMOC) Course. Dive Medical Technicians work together with DMO's and troops involved in diving operations, and are specially trained in rescue and medical care in the event of a diving mishap (Martin, 2002). For that reason they are trained extensively in the physiology of hyperbaric operations, and the recognition and treatment of decompression illnesses, including completion of Dive School.

NASA Crew Medical Officers aboard the International Space Station (ISS)

Medical emergencies in space are currently handled by Crew Medical Officers (CMO's) of expeditions aboard the International Space Station, from NASA's astronaut corps and partner countries (Summers, Johnson, Marshburn, & Williams, 2005; Papali, 2016). CMO's may or may not be doctors, demonstrating a mission model with more distribution of skills and expertise, consistent with the possibility of evacuation in as short a time as 6 to 24 hours (Kuypers, 2013).

An astronaut assigned as the CMO of an ISS expedition receives 40-70 hours of medical training, including specialized AHA-style CPR training using specialized equipment and skills for performing chest compressions in space (Hurst, Whittam, & Branson, 2011). The CMO will receive this medical training within the 18-month training period before their mission, generally from 4-6 months in duration. Limited equipment for minor surgical procedures is available aboard ISS (Campbell, A review of surgical care in space, 2002; Campbell, Dawson, Melton, Hooker, & Cantu, 2001; Campbell, Williams, Buckey, & Kirkpatrick, 2005).

Current national space programs conduct extensive pre-selection and pre-flight medical screenings on astronaut candidates and astronauts. Selection as an Astronaut Candidate requires at least one week of medical examinations, psychological testing, and interviews by selection committees of astronauts.

As US astronauts are nearly continuously in contact with Mission Control during their mission, extensive use is made of telemedicine consultations with physicians in Houston (Papali, 2016).

Due to weight constraints, ultrasound is currently the only medical imaging modality used aboard ISS. Crew, who may or may not have a medical background, receive 2 hours of hands-on instruction during their training period, and on-orbit complete 1 hour refresher training before use of ultrasound. Their ultrasound scans, mostly for experimental purposes to this point, are assisted remotely by physicians and trained ultrasound operators in mission control who have near-real time access to the images obtained. The astronauts and mission control have a 2-second latency in their communications. Ultrasound scans provided using this operational telemedicine technique have been described as satisfactory, useable, and comparable to scans achieved on earth by trained ultrasound operators (Marshburn, Hadfield, Sargsyan, Garcia, Ebert, & Dulchavsky, 2014; Foale, et al., 2005; Chiao & al., 2005; Sargsyan & al., 2005; Hamilton, et al., 2011).

Although evacuation from ISS via the Soyuz is possible in a relatively short period of time ranging from hours to days, an important consideration is the condition of the patient to be evacuated. Donning a spacesuit and boarding the cramped Soyuz vehicle is challenging at baseline, and high G-forces upon reentry could be lethal to an unstable patient (Hinkelbein, Russomano, Hinkelbein, & Komorowski, 2018). Thus, relatively rapid evacuation from ISS is possible, but only for stable patients.

Summary chart of remote and extreme organizations and teams

The following chart summarizes the different organizations and teams discussed, including information about their operational environment, number of personnel, medical professionals and their training, mission duration, evacuation options, and particular environmental extremes (See Table 5).

Table 5: Medical Professionals in Remote and Extreme Environments

Team/Base/Unit /Expedition	**Location/ Environment**	**Total Patient Population**	**Medical Professionals**	**Mission Duration**	**Evacuation Options and (distance/duration)**	**Environmental extremes leading to Common/Unique Medical Emergencies**
8000m peak summit team	Mountain	4-12	1-3 first responder	4-6 days	Helicopter from high camps (Days)	High altitude Cold exposure Trauma
Everest ER	Mountain	1000+ (itinerant and variable population)	2 physicians	2 months	Helicopter (Days)	High Altitude Cold exposure Trauma
Antarctic base (McMurdo, summer)	Antarctic	1400	1 Physician 1 Mid-Level 2 Nurses Dentist Physical Therapist 3 Techs	6 months	Fixed-wing (Days to weeks)	High Altitude Cold exposure Trauma
Antarctic base (McMurdo, winter)	Antarctic	150-240	1 Physician 1 Mid-Level Physical Therapist	6 months	Fixed-wing (Weeks to months)	High Altitude Cold exposure Trauma
USN amphibious assault ship (LHD)	Marine	2941	Wartime (M+1): 3+12 Physicians 3 +22 Nurses 0+24 Corpsmen 7 +21 Techs	4-9 months	Helicopter (Hours to Days)	Trauma (mechanical hazards) Burn/Smoke inhalation Aerospace
USN aircraft carrier (CVN)	Marine	5500	5 physicians (2 flight surgeons) 1 PA 2 Nurses Psychologist Physical Therapist Radiation Health Medical Admin. 40 Corpsmen	4-9 months	Fixed-wing (Hours to Days)	Trauma (mechanical hazards) Burn/Smoke inhalation Radiation exposure Aerospace
USN surface combatant (CG or DDG)	Marine	329-330	1 IDC (medic) 2 corpsmen	4-9 months	Helicopter (Days)	Trauma (mechanical hazards) Burn/Smoke inhalation
USN submarine (SSBN)	Sub-marine	135	1 medic 2 EMT	6 months	(Days)	Trauma (mechanical hazards) Radiation exposure Long duration in confined area
Special Forces: USN SEAL platoon or US Army Ranger ODA	Sea, Land, Air Mountain Marine Sub-marine	12-16	2 medics	Days-weeks	Helicopter (Hours)	Trauma (GSW, shock/blast). High altitude Cold/heat exposure Diving injuries Climate extremes
International Space Station	Space	3-6	1-2 CMO	4-6 months	Return capsule (Hours to Days from LEO)	Vacuum Temperature extremes Microgravity Radiation exposure Long duration in confined area Aerospace
Exploration Class Mission to Mars (hypothetical)	Space and planetary surface	4-100	1-5 physicians 0-2 nurses 0-1+ medics All crew first responder trained	Months to years	Powered abort for VASIMR (months) Ballistic return for BFR (months to years)	Vacuum Temperature extremes Microgravity and low gravity Radiation exposure Long duration in confined area Dust exposure Aerospace

Discussion:

Broad levels of medical qualifications seen in the teams examined included physician, mid-level, nurse, medic, and first responder. A common theme seen in the teams was personnel with training to the level of medic and first responder for smaller elements (summit teams, Navy SEAL platoons and Army Ranger ODA's, ISS CMO), and training to the level of physician and mid-level, augmented by nurses, medics, EMTs and first responders, at larger bases of operation or teams prepared for extended remote operation with limited options for evacuation over a period of months (Everest ER, Antarctic bases, aircraft carrier, submarine). Extensive surgical capability was based aboard the largest US Navy vessels expected to provide near-definitive care for large numbers of patients subject to mechanical combat trauma (amphibious assault ship, aircraft carrier).

Common principles used before deployment of the teams included medical pre-screening of members, selection or training for desired skills, and cross training and layering of capabilities. A premium was placed on team members using flexibility, adaptability, and improvisation especially if resources and carrying capacity is limited (summit teams, small units of special operators). Cross training is often necessary, especially in smaller teams, to preserve medical capability even if the team is split up or a particular crew member with the preponderance of medical expertise and skill is injured (Stanton, 2009). Integrated surgical and more robust medical capability was reserved for very large contingents of personnel and/or patient populations likely to sustain trauma (aircraft carrier, amphibious assault ships). However, it is notable all the teams examined, even the ISS crew and Antarctic winter personnel, have the possibility of evacuation to definitive medical care within days or weeks even in the most extreme cases (Mills & Mills, 2008). Obviously, this will not be available to our hypothetical mission.

Lastly, special medical training programs for unique hazards, such as TCCC to swiftly mitigate gunshot or IED trauma amongst special operators, should be started early and maintained within the community to minimize avoidable losses. Analogous hazards encountered in space include microgravity, vacuum, radiation, and temperature extremes. Medical professionals and team members must be cognitive of these hazards, trained to handle them, and continuously updated with new treatment protocols and lessons learned during cases encountered during earth-based training, previous missions and even ongoing missions.

Mars Mission Parameters

We now examine two mission architectures for a human Mars mission. These two mission architectures are chosen to represent the extreme estimates of expected mission duration, number of personnel, and launch technology in order to provide a representative range of mission payload, personnel and duration for consideration.

In the first mission architecture, a crew departs to Mars for a "speedboat" mission aboard a rocket using plasma propulsion (VASIMR®), travels outbound to Mars over a 90 day period, stays for 30 days on the planet surface, and a returns to Earth in 90 days for a total mission duration of 7-8 months (Chang-Diaz & Seedhouse, The VASIMR(R) nuclear-electric mission architecture, 2017; Chang-Diaz, Hsu, Braden, Johnson, & Yang, 1995).

The number of crew is highly dependent on and can scale based on the initial mass low earth orbit (IMLEO), trajectories of greater duration, and efficiency of the rocket. The VASIMR® "speedboat" scenario presents a highly efficient rocket with relatively low IMLEO optimized for a shorter mission duration. It is designed for a swift initial human exploration of Mars and a minimal crew size. In short, larger crews may be launched on larger rockets or rockets designed for longer missions. For the initial human landing on Mars, a crew of 4-6 people is proposed as has been planned in the NASA Design Reference Mission for Mars (Portree, 2001).

In the second mission architecture, a crew of 100 people departs to Mars for a longer duration mission using a SpaceX rocket (Big Falcon Rocket or BFR) taking 3-6 months for each leg, and a stay on the planet of 2 years or longer (Musk, 2017). The use of more traditional ballistic trajectories requires a surface stay of slightly less than one Martian year, or about 687 days, before the positions of Mars and earth are suitable for a return launch to earth, when Mars and the sun are in opposition.

Both mission architectures envision launch of cargo vehicles to the surface of Mars two years prior to the human mission. These cargo vehicles allow prepositioning of supplies, power plants, and even robotic mining and atmospheric mining and assembly of habitats before the subsequent arrival of the human crew. The prepositioned supplies launched 2 years earlier could include more, and perhaps more elaborate medical equipment than would be available on the crew transit vehicle launched later.

Mission architectures for human space missions vary widely in their details depending on the assumptions such as IMLEO, launch windows, and mission goals. As an example, VASIMR® technology can achieve either short mission durations for the initial human landing on Mars, or long-duration heavy lift missions for establishment of a permanent human presence on Mars. Because of the vagaries of orbital mechanics, it is very resource intensive to achieve 1-way journeys to Mars in fewer than 90 days. And with current propulsion technologies, once the launch window for the return trip passes, the mission will need to remain on Mars for roughly two years before the next return to earth opportunity. Although some proponents of Mars exploration suggest a permanent human presence, or a one-way trip for explorers, most proposed missions involve an eventual return to earth. Therefore, the two mission architectures presented show the initial mission duration will range from many months to a few years, and the crew could range from 4-100 people.

Mission aborts with a return to earth may be possible. Since VASIMR® is a continuously firing plasma rocket, a powered abort is possible. For example, if a critical engineering failure or MCI occurred in a VASIMR®-powered spacecraft 30 days in to the outbound journey to Mars, it would be possible to reorient the trajectory for a relatively swift return to earth of 150 days. (Chang-Diaz, Hsu, Braden, Johnson, & Yang,

1995) It contrast, free-return ballistic trajectories such as those proposed for BFR could take years to accomplish a return to earth.

Medical Professionals on a Mars mission

Additional hazards possibly encountered on a long duration space mission include microgravity, radiation, vacuum, temperature extremes, and psychiatric challenges. Time of exposure to these hazards could require certain medical specialties for mitigation. Extensive pre-screening of the crew and cross-training would be a given.

At the low end of the range of crew size estimates, it is hard to imagine one of the 4-6 crew would not be a physician, based on the remoteness and duration of the mission[10]. (Kuypers, 2013) The remainder of the crew would be trained to the first responder level, with additional focus on equipment and skills particular to the low- or zero-g, vacuum or near-vacuum, and high-radiation environment of space and Mars. This training level for the rest of the crew would be analogous to TCCC training given to all special operations troops.

With a crew of 100 personnel, the number of medical practitioners would be more flexible. However, the endpoints of the spectrum discussed above in smaller missions would still apply. There would be physicians on the mission, and all team members would at least be trained to a first responder / TCCC level. The medical team members would need to provide both depth and coverage to span both the medical skills deemed necessary on the expedition, and provide timely availability of appropriate level of medical care during all elements and sub-elements of the mission to mitigate medical risk to the required level.

Use of telemedicine in less time-sensitive cases could leverage the knowledge of doctors back on Earth. However, with round-trip communications delays lasting up to 45 minutes depending on the position of Earth and Mars, the current near real-time telemedicine capabilities used with astronauts in LEO would not be possible, supporting a need for a higher level of training for medical practitioners on such a mission. (Foale, et al., 2005)

Regardless of the specialties of the physicians and practitioners on the mission, additional training would be necessary in procedural skills, which might not be represented in the skillet of the crew's medical team. In addition to considering the level of training of medical professionals on a Mars mission, it is very helpful to ensure the skills and experience of the medical team provide enough depth and coverage to handle expected and unanticipated medical contingencies during the mission. Given the use of telemedicine and databases of medical information brought along on the mission, it would be reasonable to include physician specialties and experience leaning towards emergency, trauma, critical care, and procedures. Regular dental care would also be necessary. Medical monitoring and decision making outside of a 1- to 2- hour decision loop could still leverage the use of telemedicine.

Also, as it would be very costly in both money and resources to send large quantities of specialized equipment, crew adaptability and improvisation using multi-purpose and reusable equipment for medical treatment would be a necessity, certainly in contrast to the way allopathic medicine is practiced in large Western hospitals today. One approach would be reducing the use of equipment that is disposable by design, except where needed for hygienic reasons, and in medical kits to be used in emergencies.

Incorporation of more sophisticated surgical capability to provide definitive care will eventually happen dependent on the duration and available payload of future missions, but early missions will likely mitigate the need for surgery by prudent crew screening and prophylaxis, and will have a more basic surgical capability. When more robust surgical capability is eventually provided on subsequent missions, anesthesia equipment and personnel will also be necessary. Initially, an expeditionary approach to surgical requirements would be appropriate (Fosse & Husum, 1992), as opposed to the model of extremely successful but highly specialized surgical teams and operating rooms of modern hospitals. Surgical equipment and capability will increase in proportion to the population sent to Mars, and will be limited by the payload sent to Mars.

Observing the team makeup of the two earthbound missions with the closest number of personnel to the 100-person crew of the BFR, we might expect one physician (submarine configured for special operations mission) or one physician and a mid-level plus other practitioners (Antarctica winter-over at McMurdo Station). However, these numbers are deceptive and certainly unrealistically low for the Mars mission scenario, as we have already observed teams on Earth and in low earth orbit (LEO) invariably have much more favorable evacuation durations in all scenarios. (Mills & Mills, 2008; Summers, Johnson, Marshburn, & Williams, 2005)

As noted in the aftermath of the 2005 collision of the USS San Francisco with an undersea mountain, redundancy and cross-training is necessary to provide a sufficiently deep roster of medical personnel and capability in the event of an MCI (Multicasualty Incident). On a Mars mission, MCI's similar to the USS San Francisco's collision are conceivable, in scenarios such as sub-catastrophic structural damage to the lander during aerobraking or reentry, a hard landing, or explosive decompression of a crew habitat.

Training a mid-level or physician is very time-intensive, so having too many experienced physicians or mid-levels could detract from the readiness of the crew in other necessary skills. A reasonable approach might be to determine the smallest acceptable number of mid-levels and physicians, then add a safety margin, then augment the crew's medical capability by training some of the rest of the crew to the medic level, and all of the remaining crew to the first responder level. In addition, the physicians and mid-levels themselves would certainly be cross-trained, likely in necessary skills involving the biological and physical sciences. For example, a doctor trained in Infectious Diseases may assist with efforts to search for extraterrestrial life on Mars.

Another useful exercise when determining the makeup of a 100-person crew is projecting how the crew would be split up into elements for different missions on the Martian surface, such as rover-based explorations or construction of infrastructure and ensuring the diluted medical capability per element would be acceptable. Furthermore, planning for contingencies, such as MCI's, based on an Operational Risk Management (ORM) matrix would be helpful in determining whether the medical capability is sufficient. The flexible ERSS structure discussed in the US Navy Medicine section, as well as medical contingencies planned for during Special Operations missions, provide instructive examples of how to ensure the proper crew skill set and distribution over the course of the surface exploration mission.

<u>Crew Training in specific mission hazards</u>

As crew of exploration class missions are exposed to the additional extremes of microgravity, vacuum, radiation, and temperature extremes, they must be trained and educated in these hazards. The first line of defense will be education about the hazards and adherence to crew procedures to mitigate them and prevent injuries. Moreover, every crew member must be trained and periodically refreshed in the immediate care of teammates who may become casualties to trauma, occupational injuries, or hazards specific to space exploration.

The medical response training for all crew would likely include CPR in the microgravity environment, and immediate care for decompression injuries or radiation or extreme temperature exposure. CPR in space is a useful example to focus upon, as research has shown possible ways CPR could be performed without the benefit of earth gravity, using creative techniques such as the handstand method or bear hug method (Hinkelbein, Russomano, Hinkelbein, & Komorowski, 2018). Although CPR is a relatively common skill on earth, and ubiquitous amongst the teams previously described, CPR in space would be a novel and unpracticed skill for the crew. Training is necessary for crew to handle medical emergency situations, as new and unpracticed technique such as CPR in space must become familiar and reflexive through the use of mnemonics, checklists, and practice to supplement understanding of the environment.

Despite prudent inclusion of medical professionals on the crew, it is probable the first responder to a casualty will be a teammate trained only to the first responder level. Training of crew to understand hazards and respond to medical emergencies would be an important responsibility of the medical professionals both on and supporting the mission.

An Antarctic analogue of a Martian base has been suggested in the past as a good training simulation for both the spaceflight to and surface mission on Mars. Training and conducting scenarios in such an environment, already discussed here as a remote and extreme environment, could illuminate further guidelines and requirements for the medical mission, and highlight shortages of medical training during various stages of the mission (Andersen, McKay, Wharton, & Rummel, 1990).

Conclusion:

Since the crew of a human mission to Mars would likely be very dense in their skill sets and varied in their experience, the number of medical practitioners in the crew will vary from mission to mission. It will be important to have clearly defined mission parameters, such that proper prioritization of medical conditions can be performed, and planned for. Review of similar teams of medical professionals operating in remote and extreme environments on earth and in LEO provide instructive principles to consider when planning the medical capability for a human mission to Mars.

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Appendix 1: Wilderness First Responder (WFR) schedule

This appendix gives an overview of the schedule for the 10-day National Outdoor Leadership School (NOLS) WFR course. The material was downloaded on April 23, 2018 from:

https://www.nols.edu/media/filer_public/be/0d/be0da7bd-e8e2-4e49-bb54-3467c39be19a/wfr_schedule_november_2016.pdf

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NOLS WILDERNESS MEDICINE
Wilderness First Responder Course Schedule

November 2016

DAY 1

Morning
Introductions: Wilderness vs. Urban Patient Assessment System

Afternoon
Patient Assessment System Documentation
Readings: Ch 1

DAY 2

Morning
Spinal Cord Injury
Lifting and Moving
Spinal Protection & Litter Packaging

Afternoon
Chest Injury Shock
Readings: Ch 2, 3, 4

DAY 3

Morning
Focused Spine Assessment Head Injury

Afternoon
Athletic Injury Fracture Management

Evening
Dislocations
Readings: Ch 4, 5, 6

DAY 4

Morning
Wilderness Wound Management

Afternoon
Hypothermia, Frostbite and Non-Freezing Cold Injury Heat and Hydration
Readings: Ch 7, 8, 9, 10, 23

DAY 5

Morning Altitude Illness Bites and Stings

Afternoon
Lightning
Submersion
Leadership, Teamwork, Communication Stress First Aid
Readings: Ch 11, 12, 13, 14, 26

DAY 6 DAY OFF (No day off for 9-Day Format)

DAY 7

Morning Cardiac CPR

Afternoon
CPR
Respiratory
Altered Mental Status
Readings: Ch 17, 19

DAY 8

Morning
Acute Abdomen
Allergies and Anaphylaxis

Afternoon
Diabetes
SAR, Evac and Emergency Plans

Evening
Mock Rescue
Readings: Ch 16, 18, 19, Appendix B

DAY 9

Morning Decision-making
Mental Health
Urinary and Reproductive

Afternoon
Poisoning Communicable Disease Medical Legal
Readings: Ch 12, 20, 21, 22, 27, 28, 29

DAY 10

Morning
Common Problems Wrap-up Wilderness Drug and First Aid Kits Pain Management in the Wilderness Written and Practical Exams
Readings: Ch 24, 25, Appendix A

Afternoon
Written and Practical Exams Closing Ceremony
Textbook: NOLS Wilderness Medicine

Appendix 2: Diploma of Mountain Medicine (DiMM) topics

This appendix gives an overview of the topics covered during each of the four weeklong DiMM field sessions. The material was downloaded on April 23, 2018 from the Wilderness Medical Society (WMS) website: https://wms.org/education/dimm.asp

Annual WMS Winter and Summer Conferences

Topics covered**:

- High altitude
- Hypothermia
- Cold injuries (frostbite and trench foot)
- Heat and solar radiation, hyperthermia
- Nutrition
- Pre-existing medical conditions in the mountains
- Medical problems in remote areas
- Children in the mountains
- Avalanche & weather
- Rescue organization
- Communications during rescue
- Patient assessment
- Search and rescue techniques
- Patient packaging
- Patient transport
- Helicopters
- Field treatment
- Field trauma treatment
- Analgesia
- Mountain navigation

Alpine Skills and Rescue – Mount Rainier National Park, WA

Topics covered**:

- Expedition food planning
- Mountaineering gear review
- Climbing knots
- Snow travel considerations
- Personal safety systems
- Crampons and ice axe use
- Self-arrest, self-belay, safe glissading practices
- Patient transport on snow/rock/ice
- Snow anchors
- Ice anchors
- Raising/lowering systems
- Roped team travel
- Glacial camp craft
- Self/team crevasse rescue
- Avalanche awareness/rescue
- Glaciology and glacier navigation
- Belaying

- Ice climbing
- Rescue team organization
- Helicopter considerations
- Improvised raising/lowering techniques
- Terrain management strategies
- Short roping/short pitching
- Snow shelters
- Medical kits
- Advanced rescue techniques
- Scenarios (ongoing to reinforce practical skills)
- Medical treatment discussions
- Mount Rainier summit attempt (weather dependent)

Rock Skills and Rescue – Wasatch Range, UT
Topics Covered**:

- Personal safety systems
- Climbing knots
- Belaying
- Movement on rock
- Rappelling
- Lowering
- Ascending
- Rock Anchors (natural and artificial)
- Double rope rescue systems
- Pick-offs
- Mechanical advantage
- Low-angle litter lowers and raises
- High-angle litter lowers and raises
- Local SAR team cache tour
- Mountain Weather
- Navigation
- Patient transport
- Improvised rescue techniques
- Bivouac techniques
- Rock climbing
- Risk management in exposed terrain
- Short roping/short pitching
- Rescue team organization
- Helicopter considerations
- Medical treatment discussions
- Scenarios (ongoing to reinforce practical skills)
- Local technical summit attempt (weather dependent)

** Curriculum topics may change slightly depending on overall course organization

Appendix 3: Himalayan Rescue Association (HRA) orientation topics and altitude illness protocol

This appendix gives an overview of the multi-day orientation and altitude illness protocols for volunteer physicians with the Himalayan Rescue Association (HRA). The information was provided via email correspondence of April 16, 2018 with Dr. Ken Zafren, MD, FAAEM, FACEP, FAWM, Associate Medical Director of the Himalayan Rescue Association, and Clinical Professor at Stanford Department of Emergency Medicine.

Volunteer Physicians with the HRA receive a multi-day orientation including topics such as:

Fever in Asia
Diarrhea in Asia
Dentistry
High Altitude

The manual provided to volunteers includes coverage of:

Destination decisions for patients being evacuated

The HRA has adopted protocols for diagnosis and treatment of altitude illness to minimize variation in approach using documents such as the following example:

HIMALAYAN RESCUE ASSOCIATION
PROTOCOLS FOR THE MANAGEMENT OF HIGH ALTITUDE ILLNESS:
ACUTE MOUNTAIN SICKNESS (AMS), HIGH ALTITUDE CEREBRAL EDEMA (HACE) AND HIGH ALTITUDE PULMONARY EDEMA
Effective: Pre-monsoon season 2015

AMS and HACE

DIAGNOSIS

AMS is the cerebral form of acute altitude illness. For research purposes, AMS is defined as headache and at least one other symptom – gastrointestinal disturbance or anorexia, dizziness, fatigue and sleep disturbance - in the setting of recent ascent to altitude and in the absence of another more likely diagnosis such as viral syndrome, exhaustion or dehydration. AMS can occur without a headache. There are no neurological signs in AMS.

HACE is a severe form of AMS. HACE is distinguished from AMS by the presence of confusion, altered mental status or ataxia (inability to walk heel-to-toe in a straight line).

HAPE often occurs in conjunction with HACE.

HAPE is the pulmonary form of acute altitude illness. Patients with shortness of breath at rest, cough or an SpO2 about 10 points or more lower than expected at a given altitude should be diagnosed with HAPE in the absence of another more likely diagnosis such as pneumonia or asthma exacerbation. A precipitous drop in SpO2 with mild exercise can also help identify HAPE. Crackles can often be heard on auscultation of the lungs, but HAPE can occur without this finding.

Crackles are first heard in the right auscultatory area (right axilla). The doctor should listen carefully in this area.

HACE often occurs in conjunction with HAPE.

TREATMENT
Use the Lake Louise AMS Score to classify severity of symptoms:
Mild AMS: 2-4; moderate-severe AMS: 5-15.

AMS with mild symptoms:
No further ascent until symptoms resolve (with or without treatment) or descend until symptoms improve.
Acetazolamide 125-250 mg orally twice daily to speed acclimatization.
Treat symptoms: paracetamol (acetaminophen) for headache; ondansetron for nausea.

AMS with moderate-severe symptoms:
Consider oxygen (1-2 L/min) or portable hyperbaric chamber
Dexamethasone 4 mg orally, IM or IV every 6 h (not for pediatric use)
Patients taking dexamethasone for treatment should not be allowed to ascend further until 1-2 days after stopping dexamethasone.
Treat symptoms: paracetamol (acetaminophen) for headache; ondansetron for nausea.
Acetazolamide 125-250 mg orally twice daily can be given concurrently with dexamethasone if the patient is not dehydrated.

HACE
Oxygen or portable hyperbaric chamber to raise SpO2 to >90%
Dexamethasone 8 mg orally, IM or IV initially then 4 mg every 6 h, orally, IM or IV.
Descent if feasible and patient not improving.
Treat for HAPE if the patient has concurrent HAPE.
Patients given dexamethasone for HACE should not be allowed to ascend further.

HAPE
Use oxygen or a portable hyperbaric chamber to raise SpO2 to >90%. Some patients may require supplemental oxygen in a portable hyperbaric chamber. An oxygen cylinder can be brought into the chamber or the tubing of an oxygen concentrator can be used to provide supplemental oxygen from outside the chamber. Once the chamber is inflated, the head end of the chamber will usually need to be elevated.
Nifedipine extended release 30 mg orally every 12 h (or 20 mg extended release every 8 h).
If diagnosed or suspected concurrent HACE or if patient not improving despite above treatment: dexamethasone 8 mg po, IM or IV initially then 4 mg every 6 h, po, IM or IV.
Descent if feasible and patient not improving.
If patient is allergic to nifedipine: sildenafil 50 mg every 8 h or tadalafil 10 mg every 12 h may be used.
SILDENAFIL OR TADALAFIL SHOULD NOT BE USED IN CONJUNCTION WITH NIFEDIPINE.
Use of multiple pulmonary vasodilators is not recommended.
ACETAZOLAMIDE SHOULD NOT BE USED IN PATIENTS WITH HAPE.
Acetazolamide can worsen dehydration by its diuretic effect, can exacerbate symptoms of HAPE by its effect as a respiratory stimulant and causes metabolic acidosis, which could be dangerous in a patient with HAPE. Patients with HAPE may be able to continue ascent cautiously after recovery.

REFERENCE
Luks AM, McIntosh SE, Grissom CK, et al. Wilderness medical society practice guidelines for the prevention and treatment of acute altitude illness: 2014 update.
Wilderness Environ Med. 2014;25(4 Suppl):S4-S14.

Appendix 4: United States Antarctic Program (USAP) Basic Field First Aid Manual

This appendix gives an overview of the Basic Field First Aid Manual chapter from the USAP Continental Field Manual. The material was downloaded on April 23, 2018 from the USAP website: https://www.usap.gov/USAPgov/travelAndDeployment/documents/FieldManual-FirstAid.pdf

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Basic Field First Aid Manual

- Hygiene
- Sprains and Strains
  - Signs and symptoms
  - Treatment
- Bleeding and Wounds
  - Treatment of external bleeding
  - Foreign bodies
  - Treatment of wounds
- Carbon Monoxide Poisoning
  - Signs and symptoms
  - Treatment
  - Prevention
- Hypothermia
  - Prevention, Signs and symptoms, treatment
- Frostbite
  - Prevention
  - Mild frostbite signs and symptoms (pre-thaw)
  - Full-Thickness frostbite signs and symptoms (pre-thaw)
  - Full-thickness frostbite signs and symptoms (post-thaw)
  - Frostbite treatment
  - Superficial frostbite treatment (frost nip)
  - Partial-thickness frostbite treatment
  - Full-thickness frostbite treatment
- Immersion Foot
  - Prevention, Signs and symptoms, treatment
- Altitude Sickness
  - Prevention
  - Signs and symptoms
    - Mild/Moderate AMS
    - Moderate AMS
    - Severe AMS
  - Altitude Sickness Treatment
  - HACE Treatment
  - HAPE Treatment - URGENT
- Eye Injuries
  - Tent Eye
  - Snow blindness
    - Signs and symptoms
    - Treatment
    - Prevention
- Skin Injuries
  - Sunburn and windburn
    - prevention
- Dental Health
  - Oral hygiene
- Controlled Medications
  - Issue of restricted drugs
  - Chain of custody

Appendix 5: Surface Warfare Independent Duty Corpsman (IDC) curriculum

This appendix gives the summary of topics and hours for the 12-month, 2000-hour Surface Warfare IDC course curriculum as of fiscal year 2012. The material was downloaded on April 23, 2018 from the Surface Warfare Medicine Institute (SWMI) website:
http://www.med.navy.mil/sites/nmotc/swmi/Documents/OPMED/New%20Curriculum%20Brief.ppt
Definitions of Navy-specific acronyms are added in parentheses.

Unit	Hours	
•Intro to A&P	11	(Anatomy & Physiology)
•Med Hx	16	(Medical History)
•Pharmacy	38	
•Cardio	60	
•BLS-C	8	
•BLS-I	28	
•ACLS	16	
•Heme-Lymph	28	
•Respiratory	5	
•Gastrointestinal	64	
•Genitourinary	74	
•Neurology	65	
•HEENT	64	
•Dental	24	
•Integumentary	46	
•Endocrine	21	
•Musculoskeletal	84	
•Radiology	8	
•Psychiatric	39	
•Infectious Dx	24	
•Emergency	36	
•TCCC	24	(Tactical Casualty Combat Care)
•Trauma	84	
•3-M	16	(Maintenance and Material Management)
•CBRNE	20	(Chemical, Biological, Radiological, Nuclear and Enhanced Conventional Weapons)
•TAV	48	
•FEP	40	(Fitness Enhancement Program)
•Core Admin	8	
•Lab	66	
•NAVOSH	29	(Navy Occupational Safety & Health)
•Preventive Med	65	
•Clinicals	520	
•MDA	20	
•SAMS	16	(Shipboard Non-tactical Automated Data Processing Program (SNAP) Automated Medical System)
•SMDR	57	(Senior Medical Department Representative)
•Mentorship	101	

Appendix 6: Submarine Independent Duty Corpsman (IDC) curriculum

This appendix gives a summary of the 58-week Submarine IDC course curriculum. The material was downloaded on May 1, 2018 from the Navy Medical Operational Training Center website: http://www.med.navy.mil/sites/nmotc/numi/Pages/IDCCurriculum.aspx

Submarine Independent Duty Corpsman Curricula

The curriculum consists of a 58 week course of intensive, fast-paced study and includes 6 weeks of initial training at the Basic Enlisted Submarine School (BESS), and subsequent training at the Naval Undersea Medical Institute (NUMI) in topics covering Radiation Health (8 weeks) and Clinical and Operational Medicine (44 weeks). A myriad of topics involving all facets of leading the medical department onboard an operational submarine are covered: administering the radiation health and atmosphere control programs, conducting atmosphere sampling, performing laboratory procedures, and diagnosing and treating a variety of illnesses and injuries, to name a few. Throughout the course of study, each student is assigned a faculty mentor for a unique one-on-one preceptorship. This mentor provides academic advisement and assignments, career counseling, etc., and is a constant, readily available resource for the student.

Opportunities exist for off-site training during the 12 weeks of clinical rotations, which follow the didactic phases. Currently, clinical partnerships exist with the United States Coast Guard Academy Medical Clinic, Naval Ambulatory Care Centers in Groton, CT, and Newport, RI, as well as Yale New Haven Hospital. These rotations offer invaluable training in areas including anesthesia, trauma and critical care medicine, emergency medicine, and other real-world aspects of operational medicine.

Appendix 7: Special Operations Combat Medic (SOCM) course description

This appendix is the course description for the SOCM course. The material was downloaded on April 23, 2018 from the Special Operations Command (SOCOM) website:
http://www.soc.mil/swcs/_pdf/FY17_AcademicHandbook.pdf

Special Operations Combat Medic

***Course Number**:* 300-ASIW1 ***Location**:* Joint Special Operations Medical Training Center, Fort Bragg, N.C.
***Clearance**:* Secret ***Class Size**:* 87 ***Iterations**:* 8 per year ***Course Duration**:* 36 Weeks

***Prerequisites**:* Must be a volunteer in any enlisted rank of the Army. ARMY: Complete the Test of Adult Basic Education (TABE, Level D) within six months of course entry date. Pass the Army Physical Fitness Test with a minimum of 60 points in each event and an overall score of 240 or above (scored in the students' age group standards IAW TC 3-22.20) or service equivalent. Hold or be designated for assignment to a Special Operations medical position or be selected to attend the 18D (SF Medic) Course. *(NOTE: See ATRRS for class dates and other course prerequisites.)*

***Navy Prerequisites**:* Personnel must be enlisted (E3-E5) and a graduate of the Basic Reconnaissance Course in the HM 8427 Special Amphibious Reconnaissance Corpsman training pipeline. Naval Special Warfare: Personnel must be a special operator or special warfare boat operator to attain the NEC 5392. (NOTE: See CANTRAC and MILPERSMAN 1306-983 for other course prerequisites.)

***Scope**:* The SOCM course is subdivided into individual modules, all of which are designed to ensure inclusion of the cognitive, psychomotor and affective learning domains required of the Advanced Tactical Practitioner and National Registry-Paramedic Committees. The SOCM student is proficient in the following areas/objectives upon completing the course. Basic Life Support certifies students through the American Heart Association approved curriculum; Emergency Medical Technician prepares students to sit for the National Registry for Emergency Medical Technician exam and culminates with NREMT certification; Medical Math – instructs how to prepare, calculate, and administer medications; Anatomy and Physiology instructs the structures and functions of the 11 organ systems and how to identify the anatomical structures and their functions on cadavers in the laboratory; Physical Examination – instructs patient interaction, history taking, physical examination techniques, clinical decision making, and documentation and introduces students to radiology and laboratory procedures; Clinical Medicine instructs pathophysiology, pharmacology and preventive medicine; Advanced Cardiac Life Support certifies students in ACLS through the AHA approved curriculum; Pediatric Education for Prehospital Professionals certifies students in PEPP through the approved PEPP curriculum; Military Medicine instructs medical

planning in support of tactical operations, preventive medicine and weapons of mass destruction; Trauma instructs pathophysiology, assessment, and management of traumatic injuries; Advanced Trauma Practical Skills instructs intravenous and intraosseous access, endotracheal intubation, needle decompression, tourniquet application, nasogastric intubation, urinary catheterization and Extended Focused Assessment with Sonography in Trauma examination; Trauma Patient Assessment instructs assessment and management of a trauma casualty; Combat Trauma Management instructs additional life-saving trauma interventions including hemorrhage control, cricothyroidotomy, venous cutdown and tube thoracostomy and further enhances overall trauma management skills; Tactical Combat Casualty Care instructs TCCC, triage, casualty collection point operations, and multi-purpose canine emergency and trauma care; Prolonged Field Care instructs medical leadership and utilization
of additional resources in the management of complicated trauma patient scenarios through the use of patient simulators; Advanced Tactical Paramedic Examination certifies students as Advanced Tactical Paramedics; Field Training Exercise serves as the culmination exercise for the SOCM course and is a comprehensive assessment of training received throughout the course; Clinical Rotation Field Internship is a clinical practicum designed to integrate didactic knowledge with practical experience in both prehospital settings with emergency medical services and in clinical settings at various medical centers.

Course Description*:* Special Operations Combat Medic Course (300-ASIW1) is a 36-week (180 training days) course that teaches eight, 87 student classes per year and is based on an approved critical task list which is reviewed and updated by the Joint Medical Enlisted Advisory Committee as directed by the USSOCOM Command surgeon IAW USSOCOM Directive 350-29. The course consists of a series of didactic and performance-based learning objectives presented in a logical sequence, enabling the students to progress through the training both individually and as a collective group. The target audience for SOCM is Army and Navy enlisted service members who hold, or are designated for, assignment to a special operations medical position. The course qualifies these enlisted service members as highly trained combat medics with the necessary skills to provide initial medical and trauma care and to sustain a casualty for up to 72 hours if needed before evacuation occurs.

Special Information*:* The SOCM must take the Advanced Tactical Paramedic examination, which is a cumulative, externally promulgated written exam administered by the USSOCOM ATP Certification Committee and the National Registry-Paramedic exam. Students must pass the ATP examination in order to graduate the course and to deploy as a USSOCOM medic.

Appendix 8: Tactical Casualty Combat Care (TCCC) curricula

This appendix gives an overview of the curricula for TCCC for both medical personnel and for all combatants. The material was downloaded and the content summarized on April 23, 2018 from the National Association of Emergency Medical Technicians (NAEMT) website:
https://www.naemt.org/education/naemt-tccc

The Committee on Tactical Combat Casualty Care (CoTCCC)

- 42 members from all services in the Department of Defense and civilian sector
- Trauma Surgeons, Emergency Medicine, and Critical Care physicians, combatant unit physicians; medical educators; combat medics, corpsmen, and PJs (pararescue jumpers)
- 100% deployed experience as of 2017
- Meet periodically; update TCCC as needed

Tactical Combat Casualty Care for Medical Personnel (TCCC-MP) Curriculum 1708

- Intro to TCCC
    - Goals
    - Key factors influencing combat casualty care
    - Evidence documenting lifesaving impact of TCCC
    - Battlefield objectives of TCCC
    - Phases of care in TCCC
- Care Under Fire
    - Role of firepower supremacy in the prevention of combat trauma
    - Techniques that can be used to quickly move casualties to cover while the unit is engaged in a firefight
    - Rationale for early use of a limb tourniquet to control life-threatening extremity bleeding during Care Under Fire
    - Appropriate application of a CoTCCC-recommended limb tourniquet to the arm and leg
    - Why immobilization of the cervical spine is not a critical need in combat casualties with penetrating trauma to the neck
- Tactical Field Care #1
    - Common causes of altered states of consciousness on the battlefield.
    - Why a casualty with an altered state of consciousness should be disarmed.
    - Progressive strategy for controlling hemorrhage in tactical field care.
    - Correct application of a CoTCCC-recommended hemostatic dressing.
    - Correct application of a CoTCCC-recommended junctional tourniquet.
    - Airway control techniques and devices appropriate to the Tactical Field Care phase.
    - Recommended procedure for surgical cricothyroidotomy.
    - Criteria for the diagnosis of tension pneumothorax on the battlefield.
    - Diagnosis and initial treatment of tension pneumothorax on the battlefield.
    - Appropriate procedure for needle decompression of the chest.
    - Appropriate use of pulse oximetry in pre-hospital combat casualty care.
    - Pitfalls associated with interpretation of pulse oximeter readings.

- Tactical Field Care #2
    - Physical findings suggestive of pelvic fracture.
    - Appropriate procedure for application of a pelvic binder.
    - Appropriate procedure for initiating a rugged IV field setup.
    - Rationale for obtaining intraosseous access in combat casualties.
    - Appropriate procedure for initiating an intraosseous infusion.
    - Rationale for administration of tranexamic acid in cases of combat trauma.
    - Appropriate regimen for battlefield administration of tranexamic acid.
    - Tactically relevant indicators of shock in combat settings.
    - Pre-hospital fluid resuscitation strategy for hemorrhagic shock in combat casualties.
    - How to prevent blood clotting problems from hypothermia.
    - Management of penetrating eye injuries in TCCC.
    - Recommended agents for pain relief in tactical settings along with their indications, dosages, and routes of administration.
- Tactical Field Care #3
    - Rationale for early antibiotic intervention in combat casualties.
    - Management of burns in TFC.
    - Why cardiopulmonary resuscitation is not generally used for cardiac arrest in battlefield trauma care.
    - Procedure for documenting TCCC care with the TCCC Casualty Card.
    - Three ISAF categories for evacuation priority
    - Nine items in a MEDEVAC request
    - Rules of thumb for calling for Tactical Evacuation and the importance of careful calculation of the risk/benefit ratio prior to initiating the call
    - Appropriate procedures for providing trauma care for wounded hostile combatants.
- Tactical Evacuation Care
    - Differences between MEDEVAC and CASEVAC
    - Differences between Tactical Field Care and Tactical Evacuation Care
    - Additional assets that may be available for airway management and electronic monitoring
    - Indications for and administration of Tranexamic Acid during tactical evacuation
    - Management of moderate/severe TBI during tactical evacuation
- Critical Decision Care Studies
    - Bleeding Case Studies
    - Circulation Case Studies
    - Airway Case Studies
    - Breathing Case Studies
    - TBI Case Studies
    - Additional Case Studies
- TCCC Scenarios
    - SEAL Casualty – Afghanistan
    - Urban Warfare Scenario – Battle of Mogadishu
    - Military Operations in Urban Terrain (MOUT) Scenarios
- Direct from the Battlefield
    - Presentation covers real-world examples of opportunities to improve – similar to morbidity and mortality conferences

        - The forgotten tourniquet
        - Opioid analgesics for casualties in shock
        - Untreated pain on the battlefield
        - Opioid analgesics given in combination with benzodiazepines
        - Penetrating eye injuries – patched open globe
        - Tension pneumothorax
        - Combat gauze
        - Junctional hemorrhage
        - TCCC training
- Supplemental Modules
    - 3 types of commercial kaolin- and chitosan-based gauze
    - 3 types of commercial junctional tourniquets
    - Improvised and 3 types of commercial pelvic binders
    - Commercial equipment for securing limb and sternum intraosseous access
    - Commercial tactical tourniquet

TCCC-AC (All Combatants) Curriculum 1708

- Intro
    - Same as in TCCC-MP curriculum 1708
- Care Under Fire
    - Same as in TCCC-MP curriculum 1708
- Tactical Field Care
    - Why a casualty with an altered mental status should have weapons and comms gear removed.
    - Correct application of a CoTCCC-recommended hemostatic dressing.
    - Airway control techniques that can be used in the Tactical Field Care phase.
    - Management of penetrating eye injuries in TCCC.
    - Battlefield assessment for hemorrhagic shock.
    - How to prevent hypothermia in combat casualties.
    - Importance of giving antibiotics soon after a casualty is wounded.
    - Why cardiopulmonary resuscitation (CPR) is not generally used for cardiac arrest in battlefield trauma care.
    - Procedure for documenting TCCC care with the TCCC Casualty Card.
- Tactical Evacuation Care
    - Special considerations that apply to care for the wounded during evacuation.
- Scenarios
    - Abbreviated version of TCCC Scenarios from TCCC-MP curriculum 1708