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WILDERNESS ESSAY

Emergency and Wilderness Medicine Training for Physician Astronauts on Exploration Class Missions

The National Aeronautics and Space Administration (NASA) has been challenged to develop capabilities designed to meet the unique challenges required to explore the solar system and is working toward a goal of landing humans on near-Earth asteroids, the Moon, and eventually Mars.[1] The current plan for NASA is to support the extension of the International Space Station (ISS) through 2020. The ISS will serve as a platform for space life sciences research as well as preparation for future exploration class missions by further increasing our understanding of space physiology.[2,3] The primary objectives in sending humans back to the lunar surface or to Mars are to explore, perform research, and gain knowledge. The safeguarding of human health and performance, using appropriate medical care, is essential to meet these mission objectives. History has shown that during the exploration of frontiers on Earth, human physiologic maladaptation, illness, and injury have accounted for more failures of expeditions than any single technical or environmental factor.[4] Carrying out this bold vision creates many new challenges, including a level of medical autonomy unprecedented for human spaceflight. Because a prompt evacuation back to Earth is not feasible in exploration missions, the capability of delivering medical care on site will be the key to success.[5] However, it will be impossible to provide medical care for all imaginable problems. The crew will, therefore, need improvisational skills and acceptance of a certain amount of risk. This paper focuses on the medical and communication challenges of exploration type missions and explicates the value of combined emergency medicine (EM) and wilderness medicine (WM) training for astronaut physicians.

Communication Challenges and Self-Sufficiency

The time to reach definitive medical care from the ISS may be as brief as 24 hours, but from a lunar base, it would be at best several days. Assuming there are no major developments in propulsion technology, even a Mars "fly-by" with direct return to Earth may represent a 9-month round trip. The entire trip may last as long as 1000 days. Radio communication will require up to 20 minutes to reach Mars from Earth. As a result of the latency involved in planetary mission communications, telemedicine will be primarily conducted in a store-and-forward mode. Real-time consultation during an emergency will not be possible.[6] Extended periods of communication blackout may even leave the Mars explorers without Earth contact for weeks. Crews will therefore need to manage acute medical events autonomously.

Space Environmental Effects on Human Physiology and Psychology

The greatest medical concerns to a crew on an exploration class mission include radiation exposure, physiologic alterations in the reduced gravitational environment, and human behavior.[7,8] Radiation is a major concern for crew health, but most likely we will not venture into deep space before acceptable countermeasures have been developed. The effects of microgravity on the human body include muscle atrophy, bone loss, increased risk of renal stones, immunological changes, neurovestibular system changes that produce motion sickness, significant fluid shifts that affect intracranial pressure, visual changes, and cardiovascular function.[9] The countermeasures that have been developed today help to overcome some of these changes; however, there are still some major hurdles. Again, the majority of these challenges will need to be addressed before any long-duration mission will take place. In the next section, the focus will be on the medical challenges that may need to be tackled during a space exploration mission.

The long duration, the confinement in a small space with a small group of people, and the isolation from Earth may have a substantial impact on crew psychology and, in turn, the outcome of the expedition. Behavioral problems form a realistic threat to crew health and mission success, as it has resulted in substantial mission impact in the past, both in space and in analogous environments. To cite the famous explorer Roald Amundsen: "The human factor is three quarters of any expedition." Psychiatric issues likely contributed to 3 Russian cosmonaut evacuations. Among the prescreened population of US Navy submarines, psychiatric and behavioral health problems are the third leading reasons for emergency evacuation, after trauma and surgical necessity.[10,11] The development of appropriate selection criteria of the crew, as well as the training required to develop the necessary behavioral competencies for long-duration space exploration, will play a critical role.[12]

Medical Challenges of Space Missions

Epidemiological risk data obtained from ground-analog populations, cosmonauts in long-duration space flight, analog military and civilian populations, and data gathered on astronauts by NASA Medical Operations since 1959 provide a source of representative medical events that might occur.[6] In the approximately 50 years since humans first traveled beyond Earth, more than 500 men and women have flown in space. There have been 21 fatalities from 5 events[4] and several near catastrophes. Most mishaps that involved injuries have occurred during liftoff or reentry and include near drowning, cabin decompression, and blunt trauma. The most common medical events thus far have been self-limited illnesses or exacerbations of chronic conditions requiring only an ambulatory level of care.[13,14] Despite the low acuity of medical events in space, these events are quite frequent. Seventy-five percent of shuttle astronauts used medication to treat a nonemergent problem.[14] Common conditions included minor trauma to the skin and mucous membranes, exercise-induced injuries, low back pain, space motion sickness, sleep disturbances, extra-vehicular activity (EVA)-associated injuries, and cardiovascular abnormalities, predominantly manifested as dysrhythmias detected on electrocardiogram.[11] Other medical events during manned space flight spanned a variety of ailments and etiologies, including headaches from carbon dioxide exposure, fatigue, rashes ranging from atopic dermatitis to folliculitis, cellulitis, urinary retention, renal stones, pneumonitis, dental caries, behavioral health problems, and medical reactions to human experiments.[13,15] Minor injuries during space flight are common and encompass mainly abrasions, contusions, and strains.

The profile of expected illnesses and medical emergencies on long-duration exploration missions differs somewhat from data that have been collected in space thus far. Owing to the duration, location (beyond low Earth orbit), and the activities (more EVAs) of exploration type missions, the exposure to the hazards of space will be more severe. The specific health concerns predicted for long-duration exploration missions are stated in Table 1. Serious injuries such as dislocations and sprains have been exceedingly rare, and despite documented bone density loss, there is no history of a skeletal fracture occurring in space to this date. The EVAs result in a much higher incidence of injury compared to the risk of space flight in general. That becomes relevant for any exploration mission, as the frequency and total number of EVAs is anticipated to exceed current operations.[15] Table 2 lists expected ambulatory and acute illnesses and medical emergencies during exploration type missions.

Is There a Doctor On Board?

According to some studies, including a physician in every spaceflight crew would greatly enhance mission safety.[16–18] Although there has been considerable discussion regarding the ideal physician for long-duration missions, the most important medical skill for this type of mission may be the ability to learn novel techniques and solutions to problems not encountered in previous medical training.[19]

Emergency and Wilderness Medicine Training

Imagine this: *You are getting tired, hyperthermic, and hyponatremic from sweating in your spacesuit after hours of collecting Martian rocks. You are having problems with balance and motor control because your vestibular and musculoskeletal systems need time to adapt to the 0.38 G as opposed to 5 months of zero G during your journey through space. You are on unfamiliar and rocky terrain, you slip and fall, and because of the demineralization of your bone, you break your wrist. To your horror, you also notice a leak in your suit, which means decompression illness is lurking if you do not patch it up quickly. Communication with Earth is not possible from your position, and you expect the loss of communication will last the next 14 days. Now who are you going to call?*

This scenario would be quite plausible on a first human mission to Mars. For astronaut physicians venturing into our solar system, a background in EM with a fellowship in WM may be ideal. The emergency physician (EP) is used to functioning in a team, handling stressful and unexpected situations, improvising when necessary, and should be able to communicate efficiently with a vast array of specialists. Furthermore, EPs have a broad knowledge base, are proficient in basic surgical skills, and are competent in the management of the critically ill and injured.[20] The most expected acute conditions in space (Table 2) are within the scope of what an experienced EP should be able to diagnose and treat. If an emergency event should occur, the EP possesses the following specific skills that may save life or limb: medical and trauma resuscitation, procedural

Table 1. Human health concerns during exploration type missions

Radiation
Cancer
Cataracts
Genetic mutation
Microgravity
Immunologic changes
Decreased red blood cell mass
Bone and mineral loss
Muscle atrophy/loss of strength
Neurologic changes
Vestibular/sensorimotor changes
Cardiovascular changes
Visual dysfunction (hyperopic vision shifts)
Isolation and confinement
Mental health problems (depression, anxiety, moral, motivation, conflicts, aggression, decreased cognition, stress)
Fatigue and sleep disturbances (problems with circadian rhythm or work/rest schedules)
Artificial environment
Decreased partial pressure of oxygen (PPO_2)
Increased partial pressure of carbon dioxide ($PPCO_2$)
Inhalation of foreign objects, fluids, or toxic gases
Off-nominal temperature and humidity levels
Bacterial growth
Water contamination
Chemically reactive Mars/lunar surface dust
Noise, vibration, odors, visual sterility, lighting
Nutrition
Vitamin deficiencies

Source: *Medical Aspects of Exploration Missions.* NASA Johnson Space Center Medical Sciences Division, Medical Operations Branch, Houston, TX

sedation and analgesia, intubation, cricothyrotomy, chest tube placement, intravenous/central line placement, cardiac pacing, pericardiocentesis, treatment of external arterial or venous bleeding, wound management, and reduction of fractures and dislocations.[21] Acute psychiatry and the recognition of behavioral problems are also part of this broad palette. The ability of the EP to use ultrasonography as a diagnostic and guidance tool during procedures is another major advantage. Ultrasonography is the only medical imaging modality aboard the ISS, and is likely to remain the leading imaging modality in future human spaceflight programs.[22,23]

Advanced surgical skills are considered less likely to be needed in space because of advanced screening. It is likely that crewmembers for remote long-duration spaceflight would have elective laparoscopic removal of their appendix before flight. Analysis of other remote care medical systems reveals that some surgical diseases can be treated medically in combination with careful and continuous evaluation of the patient.[24–28]

In the end, it is all about the ability to operate autonomously at a remote location. That calls for a doctor who has great improvisational skills on top of a broad skills set. No other specialty focuses more on improvisation than WM.

The fellowship program in WM as offered by the Wilderness Medical Society[29] and several universities[30] may prove to be vital adjunct training. It is a discipline that at its very core teaches medical professionals how to deal with a broad spectrum of medical problems in an austere setting and to deal with problems not previously encountered. Wilderness medicine professionals learn to work with limited supplies and the stressful factors of weather, terrain, and isolation similar to exploration type missions. Even on Earth, owing to the geographic locations, takeoff or non-nominal landing of a space vehicle might position the crew in a desolate and hostile environment. Search operations can be hampered by difficult meteorological and geographical conditions in the region of emergency landing or bailout, as in the case of the Russian crew of Voskhod 2. They landed in an inhospitable part of Siberia, so heavily forested that rescue helicopters could not land.[31] Doctors with WM training learn to keep ahead of the curve; they know that preventing or treating disease or injury before they get serious is of paramount importance when operating in a remote setting far away from definite care. Specific knowledge on topics like thermoregulation, dysbarism, toxicology, wilderness dentistry, improvised splinting, and wound management will be exceptionally advantageous in space. The combined training in EM and WM should equip astronaut physicians with a good set of skills so that they can tackle most of the illnesses and emergencies that are to be expected on their mission.

How To Stay Sharp

Skill erosion will be an important issue worth considering for long-duration space missions. Current countermeasures for procedural skill decay include efficient and structured medical training design.[32] The educational experience can be enhanced by designing realistic simulations, also known as high-fidelity environment analog training (HEAT)—“serious gaming” in a virtual world with avatars or high-fidelity mannequins like the SimMan.[33–36] Similar to flight simulators, medical simulation allows effective training and maintenance of skills and has been successful in improving the training of physicians in safety-critical environments.[37,38] NASA

Table 2. Expected illnesses and medical emergencies during exploration type missions

Trauma	
	Wounds, burns, contusions, sprains, fractures
Cardiovascular	
	Cardiac dysrhythmias, orthostatic intolerance
Respiratory	
	Pneumonitis
Immunologic/allergic	
	Persistent latent viral reactivation, anaphylactic reactions
Dermatologic	
	Cellulitis, dermatitis
Neurovestibular	
	Space motion sickness
Gastrointestinal	
	Gastroenteritis, constipation
Urogenital	
	Renal stones, urinary tract infections and acute urinary retention
Dental	
	Crown fracture, dental infections/abscess
Ophthalmologic	
	Corneal abrasion, corneal infection, foreign body
Psychiatric	
	Depression, anxiety
Environmental	
	Exposure to toxins
	Acute radiation illness (due to solar particle events)
	Decompression sickness

has developed a flight-ready human patient simulator that can operate in simulated microgravity.[39–41]

Summary and Recommendations for Future Study

The medical and operational challenges of exploration class space missions are numerous. One of them is choosing the "right stuff" for an astronaut physician. This essay demonstrates why residency in EM with additional training in WM could be of value in space by highlighting specific attributes of EM and WM education and how they would apply to the expected medical challenges on exploration missions. Furthermore, it discusses how to maintain the skills set during extensive training and the long journey in space. More research needs to be done to find the ultimate skills set for an astronaut physician and ways to cope with skills erosion when boldly going where no man or woman has gone before.

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