NASA/TP–2011-216159

Impact of Medical Training Level on Medical Autonomy for Long-Duration Space Flight

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January 2012

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ABSTRACT

As the National Aeronautics and Space Administration (NASA) and its international partners plan for manned interplanetary space exploration missions, the question of how to provide optimum medical care during a long-duration space flight becomes increasingly relevant. A mission beyond low-Earth orbit, especially an expedition to Mars, demands a level of medical autonomy unprecedented for manned space flight.[1] Mission planners must consider that in all the history of human exploration, it has been disease, injury, and the limitations of human physiology that have accounted for more losses than any other factors, including technological failures.[2] Most of the published literature on the subject of the medical requirements for a manned expedition to Mars assumes at least one, if not two, physician-astronaut crewmembers. However, a 2008 NASA ad hoc committee of flight surgeons and space medicine experts observed, "Any additional capability in one area (the medical care system) will require decreased capability in another area."[3] Flying a physician crewmember to Mars implies the exclusion of a crewmember who may possess a greater depth of knowledge or skill in another field such as engineering, geology, or astrophysics. Despite assumptions in the field of space medicine, no study presently exists that quantifies the capabilities of physicians and compares them to the capabilities of persons with lesser levels of medical training with respect to maximizing crew health and well-being on a long-duration, exploration space flight. This paper attempts to answer the following question: what benefits does a mission to Mars gain by including a physician in the crew, and are those benefits essential for crew health and mission success? Is there a medical training level below that of a physician that can meet the needs of the crew while accommodating greater knowledge and skill in another area of expertise?

Table of Contents

Tables

1.0 INTRODUCTION

The Exploration Medical Capability (ExMC) project at NASA's Johnson Space Center falls under the umbrella of NASA's Human Research Program (HRP). The overarching purpose of the HRP is to provide for the health and safety of all astronauts, both current and former, not only during space flight but also during training and after mission completion. The specific task of ExMC is the promotion of crewmember health on long-duration space flights, such as to the moon or Mars. To accomplish this charge, ExMC is responsible for advancing current medical technology, informatics, and clinical capabilities to fulfill the needs of an exploration mission. The members of the ExMC project identify potential risks to crew health, determine which resources are necessary to address those risks, and assess the present capacity to meet those needs. Through this process, the scientists, physicians, and engineers of ExMC describe gaps in current technology, informatics, and clinical capabilities that they must find a way to close before the undertaking of an exploration mission.[4]

To determine current medical capabilities and identify areas to target for future development, ExMC created the Exploration Medical Condition List. This list is a dynamic document produced through analysis of medical incidents over the history of manned space flight, studies of human beings in analogous environments, modeling of projected missions, and expert consensus. The list details 77 medical conditions that could occur during an exploration mission and explains why each condition is of concern, the likelihood of an occurrence, and the potential impact of each event on crew health and mission success. The condition list also catalogues the equipment required to diagnose and treat an affected crewmember.

In 2009, ExMC underwent evaluation by the Standing Review Panel (SRP), a committee chartered by HRP to appraise HRP projects. The 2009 ExMC SRP members included physicians, physician astronauts, and scientists. They assessed the gaps identified by ExMC as well as the tasks outlined by ExMC to fill those gaps. The final report of the panel expressed its opinion that a physician crewmember would be necessary on exploration class missions, but conceded that no quantifiable assessment of the benefit provided by a physician crewmember existed. Therefore, the panel suggested a new gap, "Define impact of inadequate assessment of value of a physician on board," to quantify the risk to crew health and mission success of each of the identified medical conditions with and without a physician.[5]

The task levied by the SRP raises questions about the level of medical training that allows for maximization of crew autonomy. Medical care for a Mars exploration mission requires a paradigm shift. The contingency for potential medical events in low-Earth orbit involves return to Earth and definitive care. The current approach on the International Space Station (ISS) is patient stabilization and transport back to fully equipped terrestrial medical facilities as soon as possible. Providing for crew health on a long-duration mission beyond the moon dictates a transition toward autonomous treatment in space. Although complete care on board the spacecraft is the goal, exploration mission planners must accept that current capacity falls short of this ideal. As such, planners must agree on an acceptable level of risk.[1,6] This paper describes an effort to assess the impact of medical training on crew health outcomes and addresses the issue of which level of medical training best minimizes the health risks of long-duration space flight.

2.0 APPROACH

The current Exploration Medical Condition List[6] is derived in part from the 45-year history of medical events during manned space flight. Revisiting the literature describing and analyzing those events provided a better appreciation for the medical problems already experienced by humans in space. More importantly, a literature review of the medical and health challenges anticipated for a Mars expedition yielded information about the capabilities necessary for an exploration mission. The results of these reviews, in combination with the Exploration Medical Condition List, served as a basis to identify a medical skill set necessary for the accurate diagnosis and appropriate treatment of each foreseeable medical event.

Training guidelines and analogous studies, mostly from military and trauma literature, offered information regarding the competencies of persons with three different medical training backgrounds, namely: crew medical officer, paramedic, and physician. Additionally, these studies supplied evidence regarding the effects of medical training level on patient outcomes. Each task extrapolated from the condition list was categorized by minimum training level required. Those categories were then applied to the condition over all, depending on the tasks needed for diagnosis and treatment.

3.0 HISTORY OF MEDICAL EVENTS DURING MANNED SPACE FLIGHT

In the approximately 50 years since humans first traveled beyond Earth, about 400 men and women have flown in space.[2] While several serious medical incidents have occurred over the course of space exploration, such as the widely publicized case of urosepsis affecting astronaut Fred Haise during the Apollo 13 mission, the most common medical events were self-limited illnesses or exacerbations of chronic conditions requiring only an ambulatory level of care.[1,2] Despite the low acuity of medical events in space, they are quite frequent. Seventy-five percent of shuttle astronauts utilized medication to treat a non-emergent problem.[2] Common ailments included minor trauma to the skin and mucous membranes, exercise-induced overuse injuries, space motion sickness, sleep disturbances, and extravehicular activity (EVA)-associated injuries. Cardiovascular abnormalities, predominantly manifested as dysrhythmias detected on EKG, did not occur infrequently. In fact, on the NASA-Mir missions from 1995 to 1998, EKG monitoring revealed physiologic dysrhythmias in 10 crewmembers, all of whom had a history of at least one abnormal preflight EKG, and only one of whom was symptomatic.[7] Other medical events during manned space flight spanned a variety of ailments and etiologies, including headaches from carbon dioxide exposure, fatigue or other environmental factors, rashes ranging from atopic dermatitis to folliculitis, and even cellulitis, urinary retention, renal stones, pneumonitis, dental caries, behavioral health problems, and medical reactions to human experiments.[2,8]

Minor injuries during space flight are common and encompass mainly abrasions, contusions, and strains. More serious injuries such as dislocations and sprains are exceedingly rare, and despite documented bone density loss, there is no history of a skeletal fracture occurring in space. The following table shows the incidence of overall musculoskeletal injury in comparison to hours of manned space flight through December 2006.[8]

	Male	Female
Total Hours of Manned Space Flight	198,275.5	33,449.4
Injury Incidence (injury/day)	0.021	0.015
Total Hours of EVA	1,087.8	
Injuries Associated with EVA (injuries/day)	1.21	

Table 1. Incidence of Musculoskeletal Injuries in the U.S. Space Program through December 2006. Injuries among astronauts during space flight are common, but are usually mild and are most frequently abrasions, contusions, or strains. The most common causes of crewmember injury are crew activity, such as impacting structures, stowing equipment, or transiting through the spacecraft, the EVA suit, and exercise. These data exclude injuries for which a mechanism could not be determined or which were thought to be an exacerbation of a chronic injury that occurred preflight.[9]

As can be seen from this table, EVA results in a much higher incidence of injury compared to the risk of space flight in general. This becomes relevant for any exploration mission, as the frequency and total number of EVAs is anticipated to exceed current operations.

There are several limitations to using a historical review of medical events during space missions to predict future medical challenges. Methods of data collection and the type of data collected are inconsistent over the history of manned space flight, even within the U.S. program. Furthermore, the data that do exist are stored in multiple formats across many repositories located at a variety of institutions in different countries. The total number of subjects available for analysis is very small, and there is a possibility of underreporting among space program participants. Finally, there is a lack of adequate controls to confirm the validity and significance of the data collected.[9]

4.0 CHALLENGES TO MEDICAL CARE DURING MARS EXPLORATION MISSIONS

Any plans for a long-duration, interplanetary exploration mission must address many conditions not previously encountered during manned space flight. These conditions, which include the logistics of traveling such a great distance away from Earth and the environment faced by astronauts living and working in interplanetary space and on the Martian surface for an extended period of time, impose novel challenges to the delivery of health care to exploration crewmembers.

The technical requirements for a mission to Mars necessitate an expedition of two to three years in duration. No human has yet spent such a consecutive length of time in space. This extended stay in an inhospitable environment increases the likelihood of medical events occurring, both minor and severe. These events may include, but are not limited to, disease, trauma, decompression sickness, burns, toxic exposures, overheating or overcooling, life support failure, depressurization, and meteorite impacts. The distance imposes additional challenges for a Mars exploration mission. As the spacecraft travels away from Earth, there will be increased lengthening of the time needed for a communication signal to travel from Earth to the crew and back. With current technology, it could take as long as 45 minutes to complete a communication loop between mission control on Earth and a crew on the Martian surface, depending on the orbital positions of both planets. Additionally, in the event of a serious medical incident that compelled evacuation of an ill or injured crewmember, Earth and definitive care are four to six months away.[10] The distance renders not only medical evacuation but timely resupply impossible, meaning that the crew must bring with them all of the medical equipment and disposables required for the duration of the mission.

It is difficult to anticipate all of the medical equipment the crew needs to carry for a two- to three-year mission, particularly because of the lack of precedent for such an undertaking. Some variables with potential repercussions for human health during a Mars expedition relate to the impact of the known physiologic changes resulting from space flight over an extended period of time, such as loss of muscle and bone mass, neurovestibular changes, immune suppression, plasma volume loss, reduction in cardiac volume and mass, and effects on metabolism and the endocrine system.[1,3,6,11] Other factors with possible health implications include radiation exposure, multiple gravity transitions, and psychological stressors.[1,7,12] Likewise, Mars surface conditions present distinct challenges for sustaining human life and maintaining the equipment that the astronauts will depend on for their health and safety. The surface of Mars is treacherous and inhospitable, with frequent dust storms and below freezing temperatures. There is a reduced atmospheric pressure of 6.1 mbar compared to Earth's atmospheric pressure of 1,013 mbar, and the lack of a magnetic field places astronauts at continued risk of radiation exposure.[7,10]

Crewmembers of a Mars expedition will face a level and duration of radiation exposure never before encountered in the history of space flight. Multiple authors identify radiation as a principal risk to crew health on an exploration mission.[1,3,7,13] During the six-month journey between planets, there will be nothing to protect the crew but their own spacecraft. As described by Davis in 1999,[13] with exposure models available at the time and assuming an aluminum spacecraft wall 0.75 cm thick (2 g/cm^2), a Mars mission would exceed the 0.5 sievert radiation exposure limits adopted by NASA. Adding thicker shielding to the spacecraft will result in greater mass, thus increasing the amount of thrust necessary to propel the aircraft and, therefore, mission cost. Once on the Martian surface, the planet itself will offer some shielding, but without a magnetic field there will be nothing to dampen incoming radiation.[7]

Complicating the issue of radiation exposure, there remains no reliable way to forecast large radiation events. Approximately 75% of the radiation total dose equivalent the crew will receive will be in the form of galactic cosmic rays (GCR). This radiation originates outside of Earth's solar system and is not well understood. Even radiation emitted from Earth's own sun, called solar particulate radiation, is unpredictable. Current technology enables less than 30 minutes of warning before a solar particle event.[7] Assuming a 180-day surface stay and 65 EVAs, among the lower estimates encountered in the literature, Hamilton et al,[1] describe a 0.2-0.3% risk of a very large solar particle event delivering up to 1 Gray of radiation to blood-forming organs. While the likelihood of acute radiation sickness is low, they estimate a 10% risk of prodromal symptoms, primarily nausea and vomiting.[1] Though these percentages are small, there remains a significant risk of radiation-induced illness. Furthermore, the late effects of radiation exposure, likely to result from GCR, occur months to years after exposure and manifest as an increased incidence of certain tumors, skin cancer, and hematologic cancers, cataracts, and tissue damage or mutations, among other symptoms.[7] Given a multi-year expedition, it is possible that astronauts may begin to show these late effects, with potential mission impact.

Radiation is not the only long-term exposure with which the crew must contend. After six months transiting to Mars in a microgravity environment, it is not clear how the crew will adapt to functioning in the 0.38 gravity of Mars. Even more uncertain is how the crew will tolerate the forces of lift off from the planetary surface following roughly two years of living and working in reduced gravity.[11] The deconditioning of the crew, coupled with the increased demand of multiple, frequent EVAs, may precipitate a variety of musculoskeletal injuries.

While the long-term effects of reduced gravity may have a substantial impact on crew physiology and predispose crewmembers to injury, the long-term effects of the mission itself may have a substantial impact on crew psychology and, in turn, the outcome of the expedition. Space medicine literature contains many descriptions of psychological stressors. Russian literature uses the term "asthenia" to describe a combination of depressive and dissociative symptoms occurring in cosmonauts and defines three stages of psychological adaptation to space flight.[12] These stages include an acute phase of up to two months duration while cosmonauts adapt to their new environment, an intermediate phase characterized by physical and mental tiredness, irritability, and declining motivation, and a long-duration phase during which psychological and somatic symptoms worsen with potential effects on inter-crew relationships and performance.[13] The pressure of the mission, its associated workload and compressed timeline, the lack of privacy, confined living and working area, reduced sensory stimulation, loss of traditional social support, prolonged isolation, and the unique challenges arising from the interactions of a multicultural crew are all factors that can influence behavioral health.[7,11] These stressors will be more severe and of longer duration on an expedition to Mars, worsened by the inability to communicate with physicians, friends, and family in real time, and necessitating additional training for the on-board medical crewmember in psychiatric diagnosis, counseling, and pharmacotherapy.[3,13] Behavioral health is a perceivable 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. Psychiatric issues likely contributed to three Russian cosmonaut evacuations, and even among the prescreened population of U.S. Navy submarines, psychiatric and behavioral health problems are the third leading reason for emergency evacuation (after trauma and surgical necessity).[7]

With consideration of all possible events, both U.S. and Russian models predict one medical emergency per year for a six-person crew.[10] Therefore, as Kozlovskaya and colleagues observe in a 2003 paper[10] on the subject, the crew of a Mars exploration mission must possess the "resources to enable medical prevention, diagnostics, and care without assistance from the outside."[11] These resources may be any combination of a medically trained crewmember, medical equipment, diagnostic and treatment aids, and decision making tools. However, many authors assume a benefit with greater degrees of medical training. Pool and Davis identify knowledge, skill, and proficiency as the three "critical elements" upon which medical capability depends.[11] The remainder of this paper attempts to address in detail the impact of medical training level on capability and the effect that medical training level may have on an exploration mission to Mars.

5.0 MEDICAL TRAINING LEVELS

Analysis of a combination of published articles, accreditation guidelines, and training flow sheets enables a comparison of the clinical capabilities and technical skills of the following three levels of practitioners:

1) Astronaut crew medical officers,
2) Civilian paramedics, and
3) Physicians.

While many training paths exist within the health care fields, such as emergency medical technician, medical assistant, nurse, nurse practitioner, and physician assistant, choosing three distinct levels of training permits a more quantifiable distinction in competencies. Although paramedic and physician education is not standardized, a review of the literature provides sufficient background to generalize the abilities of each practitioner.

The crew medical officer (CMO) is any astronaut chosen by a mission commander to serve as the person that manages medical care for other crewmembers during a given mission. The crew medical officer usually lacks previous medical training or experience. On board the ISS, there are currently two CMOs for each six-person crew.[1] Before launch, each CMO undergoes an additional 40 hours of instruction in the use of the medical equipment on station and basic recognition and treatment of a variety of common conditions. The CMO training flow includes four hours of lecture and practical lessons on medical diagnostics, five hours devoted to medical therapeutics, and 10.5 hours of basic life support (BLS) and advanced cardiac life support (ACLS) training to American Heart Association standards. There is an additional optional clinical component consisting of emergency department shadowing or an ambulance ride-along, for example.[14] Additional resources are available on board ISS to offset the limitations in CMO knowledge and skill. These resources include real-time telemedicine support from flight surgeons in mission control and just-in-time training, which utilizes computer-based tutorials that CMOs access by topic at point of care. Just-in-time training with telemedicine guidance resulted in the acquisition of good quality ultrasonographic images when CMOs without experience in ultrasonography performed examinations on fellow astronauts on board the ISS in 2004.[10] Further attempts at telemedicine-guided ultrasonography and ophthalmoscopy, in addition to other diagnostic and therapeutic procedures over the past several years, also met with success.

In contrast to CMOs, who undergo a standard course of instruction administered by NASA and its partners, the training of paramedics is variable. Much of the literature regarding the skills of paramedics and health outcomes of their patients in comparison to other providers originates outside the country. Even within the United States, certification requirements for paramedics differ by jurisdiction. However, the National Highway Traffic Safety Administration (NHTSA), an element of the U.S. Department of Transportation, produces a curriculum designed to establish minimum requirements for paramedic training, and there is some consensus in the literature and among health care providers regarding the expectations of paramedic performance and their capabilities.[15] The tasks that paramedics generally perform include pharmacotherapy, placing peripheral intravenous catheters and administering intravenous fluids and medications, BLS and ACLS, laryngeal airway and endotracheal tube placement, and needle thoracostomy, in addition to more basic skills such as physical examination and vital sign monitoring. For the most part, paramedics are not able to perform a rapid sequence induction before intubation of conscious patients, and they are not capable of advanced airway procedures, such as a cricothyrotomy. Additionally, paramedics do not perform invasive monitoring, which requires techniques such as placement of arterial or central lines.[16] The focus of paramedic training is short-term, pre-hospital emergency care, and the scope of paramedic practice is limited and specialized. Paramedics are more likely to regularly perform lifesaving interventions, such as intubation, than a general physician but they lack the depth and breadth of knowledge possessed by the average physician.[17]

For the most part, physicians possess all of the skills and capabilities of paramedics, with additional competencies born of their advanced education. However, physician training is even less standardized than that of a paramedic, and a physician's abilities depend largely on his field of specialty, experience, and personal interest.[17] The guidelines and objectives set forth by the Accreditation Council for Graduate Medical Education (ACGME), which accredits all residency and fellowship programs for physicians in the United States, are frequently vague. Nonetheless, examples of training expectations do exist. Emergency medicine is one specialty for which the ACGME maintains specific requirements for types and numbers of procedures necessary for completion of residency training. A selection of those skills includes adult medical and trauma resuscitation, bedside ultrasound, cardiac pacing, central line placement, chest tube placement, conscious sedation, cricothyrotomy, dislocation reduction, intubation, lumbar puncture, and pericardiocentesis.[18] As this list demonstrates, many of the clinical competencies of a physician fall beyond the range of a paramedic's ability.

Despite variability in physician skills and the possibility, as Pool purports,[7] "that physicians who provide care on missions to the Moon and Mars require a breadth of training that does not currently exist in any single physician training program or residency," there are many benefits to flying a crewmember with a physician background on an exploration mission as compared to other levels of medical training.[11] A physician crewmember is an already maximally educated medical provider, and therefore lessens the demands on limited mission preparation time. An increase in the independent functioning of the crew medical provider may decrease the requirements of the medical equipment flown on board the spacecraft, particularly in terms of complexity, automaticity, and redundancy, thereby reducing mass, volume, power, and cost.

In relation to a physician's higher level of autonomy, numerous studies, predominantly in trauma and emergency response literature, demonstrate improved patient outcomes when a physician provided treatment as opposed to a paramedic. A review of studies examining primary helicopter retrieval of trauma patients found in 10 of 12 publications that mortality rates were lower for physician teams compared to paramedic teams, even when a nurse practitioner with the same pharmacotherapy and procedural skills as a physician accompanied the paramedics.[19] The authors attributed this finding to the superior wealth of knowledge and clinical judgment of a physician. Whereas CMOs and paramedics depend heavily on algorithms for patient management, physicians use a different decision making process. Physicians obtain data through history taking and physical examination, then synthesize and interpret that data to determine a diagnosis and formulate a plan of care. Physicians also have a unique perspective and more complete understanding of health care delivery, as they care for patients not only in the immediate and short-term setting, but through the intermediate and long-term stages of an illness or injury, as well as in times of good health.[17,20] This scope of practice is essential for maximizing the health and well-being of astronauts on a long-duration mission. In fact, a group working with the Israeli armed forces found physicians superior to paramedics for military ground operations, with the most pronounced benefit occurring on long-duration missions with limited resources far from definitive treatment.[17] Finally, the perception of a physician as the most highly trained of medical providers cannot be discounted. Physicians are thought of by many as able to deliver the highest standard of care, and this may impact the morale of not only the crew, but their friends and family, and favorably influence public opinion.[17] This reasoning may be why most of the Russian and American papers published assume a physician crewmember on any Mars exploration mission.[1,3,7,11,13]

6.0 DEFINING MEDICAL TASKS BY TRAINING LEVEL

To quantify the impact of flying a physician compared to a crewmember with a lesser level of medical training, analysis was performed based on the current Exploration Medical Condition List, a sample of which appears in Table 2.[6]

	Priority	Rationale	Incidence Data	Likelihood
Kidney Stone	2 – Shall	An untreated kidney stone…can result in severe pain, and may lead to infection, sepsis, and the need for EVAC.	0.002555 events per person-year	2 – Low

	Consequence Data	Consequence	Mitigation	Diagnosis	Treatment
Kidney Stone	An untreated kidney stone could become serious enough to require evacuation…	3 – Moderate	…80 to 85% of kidney stones will respond to conservative treatment…	Vital signs Imaging Modality Stethoscope Urinalysis	Crew Medical Restraint System Lithotripsy Surgical Treatment Antiemetic Carpuject Injector BZK Wipes Gauze Pads Non-sterile Gloves (pair) Sharps Container Narcotic Analgesic Tape IV Fluid Y-type Catheter Lever Lock Cannula IV Pressure Infusor IV Administration Set Iodine Pads Tourniquet CMRS

Table 2. Exploration Medical Condition List. The entries in this table are an abridged example of a condition from the Exploration Medical Condition List. Prioritization is on a scale of 0 to 2, with 0 indicating that mission planners currently do not expect to carry the capacity to diagnose and treat the condition on board the spacecraft during an exploration mission, 1 signifying that the capacity should be manifest if possible, and 2 being the highest level of priority and a condition that the crew will be able to diagnose and treat during the mission. Likelihood and consequence are both rated on a scale of 1 to 5, or very low to very high.

Specific medical tasks necessary to diagnose and treat each condition were identified and described based on the information already in the database. These tasks included the knowledge and skill necessary to properly use the equipment associated with each condition or perform the procedures listed. The medical tasks were added to the condition list in a new column entitled "Skill/Capability," as shown in Table 3.

	Diagnosis	Treatment	Skill/Capability	Training Level
Kidney Stone	Vital Signs Measurement Capability Imaging Modality (Ultrasound, CT, MRI, IV Pyelography or Urography) Stethoscope Urinalysis	Crew Medical Restraint System Lithotripsy Surgical Treatment Antiemetic Carpuject Injector BZK Wipes Gauze Pads Non-sterile Gloves (pair) Sharps Container Narcotic Analgesic Tape IV Fluid Y-type Catheter Lever Lock Cannula IV Pressure Infusor IV Administration Set Iodine Pads Tourniquet CMRS	Vital signs Diagnostic ultrasound Urine dipstick Urinalysis Urine microscopy Urine culture and sensitivity Administer PO Venipuncture Assess fluid status IV fluid administration Surgical capability	Physician

Table 3. Expanded Exploration Medical Condition List. The changes made to the condition list for the purposes of this analysis included the creation of two new fields or columns. The first new column, "Skill/Capability," inventories the various tasks a medical provider must complete to diagnose and treat the condition. These capabilities are not all inclusive, but are based on the information already in the condition list. Each individual task was described further, and a determination of medical training level necessary for performance of that task was made through best clinical judgment with expert agreement. With the second new column, "Training Level", a, either a crew medical officer (CMO), paramedic, or physician, was assigned to each condition based on the lowest level of training required to complete all of the tasks ascribed to that condition.

Each skill/capability identified in the expanded condition list was described further, and a training level was assigned to the task, based on the lowest level of medical training deemed necessary for task completion, by the best clinical judgment of a group of physicians and scientists with a background in aerospace medicine experienced in the delivery of medical care in space. For example, "Vital Signs," was defined as, "Assessment of pulse rate, respiratory rate, blood pressure by manual or automatic sphygmomanometry, temperature, and pulse oximetry," and was determined to be a CMO-level capability. Some tasks mandated further explication, particularly capabilities that CMOs performed on ISS but that were assigned a higher level of medical training in this exercise. The reason such increases in necessary level of training occurred is related to the novel challenges of traveling to Mars as already delineated. For many medical skills, there was a substantial difference in the degree of training required to complete a task with basic telemedicine support in contrast to the training that would enable independent, autonomous, immediate performance of that task.

The expanded condition list assumes current technology, including current image storage and forwarding capability and telemedicine limitations with, at most, a 25-minute one-way communication delay between Mars and Earth. While telemedicine will undoubtedly become more advanced before the undertaking of an exploration of Mars, by assuming no forward development, the Exploration Medical Condition List portrays the worst-case scenario for the management of medical events beyond Earth's orbit. Of the 77 conditions on the Exploration Medical Condition List, 64 (83.1%) are prioritized as "shall" or "should." These are the conditions for which the appropriate diagnostic and therapeutic equipment and supplies will likely fly on a mission to Mars. Thus, the medical provider on that mission must possess the ability to manage a wide spectrum of health problems. According to the new classification of conditions by training level, most anticipated events require a physician for optimum diagnosis and treatment. Table 4 summarizes these conclusions.

	Number	**Percent of Total (77)**
Shall and should conditions	64	83.1
CMO-level conditions	30	39.0
Paramedic-level conditions	12	18.8
Physician-level conditions	47	54.7

Table 4. Summary of Training Level Required to Meet Mars Expedition Medical Needs. Of the 77 conditions described by the Exploration Medical Condition List, 64 are priority 1 or 2, necessitating on-board capability for diagnosis and treatment. Of these 64 conditions, 47 (54.7%) require skills that a consensus of space medicine experts consider physician-level tasks. Only 12 conditions require skills above the training level of CMO but not yet at the level of a physician. A CMO can successfully manage the remaining 30 conditions with a sufficient degree of autonomy, despite the difficulties in telemedicine guidance imposed by long-duration space flight.

7.0 ADDITIONAL BENEFITS OF PHYSICIAN TRAINING

While this analysis attempts to define a discreet skill set for three levels of medical training to quantify the impact of a physician crewmember on an exploration mission to Mars, physicians generally possess qualities that are difficult to enumerate or measure. These are attributes that one cannot learn in medical texts but that physicians develop through years of training and experience. For example, a substantial part of physician training emphasizes cultural competency and interpersonal relationships, which are essential in the comprehensive and compassionate delivery of health care and have a potential impact on crew well-being during an exploration mission.[21] Delay in communication during a journey to Mars and while living on the Martian surface will prevent direct conversation with flight surgeons, and as the 2008 NASA ad hoc committee observes, "will render the interpersonal human interaction and give and take of any needed counseling…useless."[3] This impairment in communication and counseling has possible drastic implications for the behavioral health of the crew that will already be under threat from the many psychological stressors of the mission. However, a physician with sufficient counseling skills can ameliorate the potential negative outcomes for the crew.

The issue of behavioral health is closely intertwined with the general concepts of preventive health and health maintenance. Maximizing crew health for long-duration missions will require more than management of acute or even chronic illnesses or injuries. According to ACGME guidelines, all physician training incorporates elements of preventive medicine, making physicians ideal providers for a healthy crew during an extended mission. Furthermore, physicians receive exposure to health systems and training in the recognition of ways in which systematic improvements can better promote patient health.[21] A physician crewmember is best suited to observe crew habits and performance, identify risks to crew health and well-being, innovate and implement interventions, and monitor the effectiveness of those interventions. Such insights may result in systematic improvements of benefits for future exploration missions to Mars or beyond. In a similar vein, physician crewmembers can facilitate discussions regarding issues relevant to crew health that may better identify problems for which the physician can then implement solutions. In a prospective study of injuries in the neutral buoyancy lab at Johnson Space Center where astronauts train for EVAs, Strauss and colleagues report that involving astronauts in the documenting of injuries precipitates enhanced joint decision making and more thorough discussion of treatment and prevention strategies, leading to better use of countermeasures and reduced symptoms.[22]

A physician's flexibility extends beyond prevention to treatment scenarios. A logical assumption is that a physician's clinical judgment and breadth and depth of knowledge allows a greater level of independence and provides the physician with more advanced real-time problem-solving abilities. No amount of preflight screening will ever preclude every medical event.[10] Even in a prescreened population at McMurdo Station in Antarctica, 0.036 medical emergencies occur per person per year. Excluding those events that are unlikely to occur in microgravity, such as trauma, which accounts for 48% of the injuries at McMurdo, the rate of medical emergencies is 0.02 per person per year.[23] Assuming a crew of six on a three-year mission results in a 36% risk of a serious medical event. While this analogy is imperfect, and the crew may never need to rely on the flexibility and problem-solving of a physician during a two- to three-year mission, in a worst-case scenario, including a physician in the crew could prove to be life or mission saving.

8.0 STUDY LIMITATIONS

There are many limitations to the work presented here, including the basis of this study on modern technology. There is no way to fully anticipate the developments that will occur in medical decision making tools, diagnostic aids, and therapeutic equipment over the decade or more before a long-duration exploration mission is undertaken. As technology becomes more sophisticated and reliable, the level of medical training necessary to attain a given degree of crew autonomy may decrease. Another shortfall of this study is the variability in medical training for paramedics and physicians already described. This variability is not well categorized, and many of the studies assessing differences in the care delivered by physicians compared to paramedics took place outside of the United States and under conditions not entirely analogous to space flight, such as in combat or trauma situations. That variability may increase depending on recency of training. Traditionally, when physician astronauts enter the astronaut training flow, they cease clinical practice. Increasing time since last training and a lack of clinical practice possibly results in a decline in clinical skill. Given these factors, the classification of tasks by training level must still undergo vetting and validation, though it is currently based on the best clinical judgment of several experts in the field of space medicine. The next step in this vetting process is to present the classification to the ExMC advisory group, comprised of physicians, astronauts, and scientists. Additionally, many avenues of medical training were purposefully excluded from this analysis. It is possible that some other training background, such as that of a nurse practitioner or physician assistant, provides the essential autonomy while maximizing crew and mission resources. Another type of independent practitioner may prove valuable during a long-duration mission, but physicians remain the gold standard, particularly in depth and breadth of knowledge and those intangible qualities mentioned above.

9.0 CONCLUSIONS

The medical providers on a long-duration space flight to Mars must be prepared to manage a wide range of clinical quandaries. There are many variables that may affect crew health during an exploration mission, and there is no way to accurately predict or prepare for every eventuality. Literature on the topic of the medical requirements for exploration space flight assumes at least one physician crewmember, a recommendation that is supported by this analysis of the Exploration Medical Condition List. Additional quantification of the impact of a physician on crew health would require more complex modeling or a clinical trial comprised of real-time scenarios and simulations performed by individuals with differing medical training backgrounds.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE January 2012	3. REPORT TYPE AND DATES COVERED NASA Technical Paper	
4. TITLE AND SUBTITLE Impact of Medical Training Level on Medical Autonomy for Long-Duration Space Flight			5. FUNDING NUMBERS
6. AUTHOR(S) Laura M. Bridge, M.D., Georgetown University School of Medicine Sharmi Watkins, M.D., M.P.H., NASA Johnson Space Center			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Lyndon B. Johnson Space Center Houston, Texas 77058			8. PERFORMING ORGANIZATION REPORT NUMBERS S-1106
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER TP-2011-216159
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Available from the NASA Center for AeroSpace Information (CASI) 7121 Standard Hanover, MD 21076-1320 Category: 52			12b. DISTRIBUTION CODE
13. ABSTRACT *(Maximum 200 words)* As NASA and its international partners plan for manned interplanetary space exploration missions, the question of how to provide optimum medical care during long-duration space flight becomes increasingly relevant. In the history of human exploration, disease, injury, and the limitations of human physiology have accounted for more losses than other factors, including technological failures. Most published literature on the subject of the medical requirements for a manned expedition to Mars assumes at least one, if not two, physician-astronaut crewmembers. However, a 2008 NASA ad hoc committee of flight surgeons and space medicine experts observed, "Any additional capability in one area (the medical care system) will require decreased capability in another area." Flying a physician crewmember to Mars implies the exclusion of a crewmember who may possess a greater depth of knowledge or skill in another field. This paper attempts to answer the following question: what benefits does a mission to Mars gain by including a physician in the crew, and are those benefits essential for crew health and mission success? Is there a medical training level below that of a physician that can meet the needs of the crew while accommodating greater knowledge and skill in another area of expertise?long-			
14. SUBJECT TERMS long duration space flight; medical personnel; physicians; flight surgeons; manned Mars missions		15. NUMBER OF PAGES 28	16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited