Emergencies in Space

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Manned spaceflight is inherently risky and results in unique problems from a trauma and medical perspective. Emergency care under these special physiologic and environmental conditions calls for novel techniques for diagnosis and therapy. [Ann Emerg Med. 2005;46:177-184.]

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INTRODUCTION

Despite the immense technological feats associated with human extraterrestrial travel, there is always the potential need for emergency medical attention. Historically, the difficulties associated with illness and injury have accounted for the failures of more expeditions on Earth's frontiers than any other single technical or environmental reason.[1] It is reasonable to believe the same would also be true for the exploration of space.

In space, as in most remote inhabitations, most medical problems are manageable locally until definitive diagnosis and treatment are available. However, when the problem is an emergency and the closest medical facility is thousands of miles away, then there are significant risks of an adverse outcome. Evacuation from space is costly and arduous and may not be possible in a timely manner. Fortunately, astronaut selection, medical screening, and the short duration of most missions have made medical emergencies rare. As space exploration progresses to longer missions, interplanetary travel, and possible extraterrestrial colonization with diverse and older populations, the need for improved medical preparation will become increasingly important. Providing emergency medical care to this group will undoubtedly be the most difficult obstacle in any operations and contingency planning. This article examines the current state of emergency medical care for those exploring the frontier of space.

History of Emergencies During Space Flight

In more than 60 person-years of manned spaceflight involving more than 400 astronauts and cosmonauts, there have been only 21 fatalities from 5 events.[1] However, there have been multiple near catastrophes. Most mishaps that involved injuries have occurred during liftoff or reentry and include near drownings, cabin decompression, and blunt trauma. In one incident, after landing 1,200 miles off target in 5 feet of snow, a cosmonaut of the Russian Voskhod 2 was attacked by wolves when he tried to exit the spacecraft. Because these medical events were all essentially ground-based accidents, the traditional emergency medical principles could be applied for rescue, injury evaluation, and acute treatment. However, there have also been in-flight incidents, including fires, vehicular collisions, and loss of environmental controls. These problems represent primarily technical glitches in which the resultant medical complications could have required emergency management. Because these events happened while the vehicle was still in orbit, the emergency approach required consideration of the conditions of microgravity, the remote environment, and the limitation of resources. While reviewing the history of space medical urgencies and emergencies, one must remember that the direction of space exploration is constantly changing, and different and unforeseen emergencies could also arise.

Risk of an Emergency

To date, the majority of space exploration has involved healthy young individuals (average age approximately 40 years; approximately 20% are female astronauts) who have undergone intensive medical screening and remain in space for only short periods. In considering longer missions with more diverse crews, such as the extended occupancy of the International Space Station or a possible voyage to Mars, then it is increasingly important to plan for a medical emergency.

Risk analysis is the first step in any medical contingency planning. Using actuarial data, it is possible to estimate the risk of an emergency medical event during space flight.[1-3] In the general population, the emergency incidence rate is usually considered to be about 0.06 events per person-year. If a 7-member crew were to travel for 2.4 years to Mars (the approximate expected duration of such a trip), then we could expect 0.06 events per person-year×7 persons×2.4 years=1.0 emergency.

This finding is consistent with the analysis from the Longitudinal Study of Astronaut Health and data from the Russian Space Program.[4] Although this calculation may be reasonable for estimating risk during future space travel when the general population is involved, the current medical screening criteria for astronauts may make such a prediction unrealistic for routine mission planning.

On examining evacuation rates for medical emergencies from the Antarctic McMurdo Station, we can calculate an incidence of 0.036 events per person-year. The general crew health and the environment of isolation at such a station may reflect the conditions faced by the astronauts, although the potential for an emergency medical event may be somewhat different. In the Figure is a summary of all nonfatal severe medical events during spaceflight from 1961 to 1999 (total=17).[1,2] In reviewing the Figure, note the relative lack of trauma in the events recorded. This finding is in sharp contrast to the 48% trauma as a reason for evacuation from McMurdo Station.[1,2]

A retrospective review of records from the National Aeronautics and Space Administration (NASA) Johnson Space Center Longitudinal Study of Astronaut Health was conducted in 1999 to estimate the occurrence, type, and severity of general illness in the astronaut population while they were not on active duty.[4] Each event was classified according to medical significance, particularly with regard to whether it would have required emergency evacuation or could have been managed by the health maintenance facility planned for the International Space Station had the event occurred in flight.[5] After subtraction of the events that were unlikely to occur in microgravity or would have been detected in preflight screening, an anticipated medical evacuation incidence of 0.02 events per person-year was determined from the data. Using the onboard health maintenance facility to treat less severe medical conditions would have reduced the likelihood to 0.01 events per person-year for this group of astronauts. This estimation is consistent with the extensive data from the Russian program in which 3 cosmonauts have been evacuated in 41.5 years of space flight and in which the Mir Space Station had 1 medical evacuation in 31 person-years.[1,2]

Trauma
Ophthalmology 1
Second-degree burns 1
Cardiopulmonary
Arrhythmias 2
Pneumonitis 4
Reactive airways 1
Internal Medicine
Chronic headaches 1
Cellulitis of arm 1
Other unspecified 1
Genitourinary
Renal stone 1
Urinary retention 1
Prostatitis 1
Urosepsis 2

Figure. Summary of nonfatal spaceflight severe medical events (1961-1999), Total=17.

Physiology and Pharmacology of Microgravity

A microgravity environment results in such significant physiologic changes that in the early years of space exploration, it was uncertain whether humans could even survive in space. All physiologic and pharmacologic aberrations in response to microgravity should be considered when any therapeutic responses to medical emergencies are contemplated during spaceflight.

On entering microgravity, there is an immediate shift of dependent fluids cephalad, with a resulting diuresis and a decrease in systemic plasma volume of 10% to 20% and a transient increase in pulmonary and cardiac volumes.[6-8] Paradoxically, there is an eventual mild decrease in central venous pressure and an anemia of limited importance.[7,8] The initial larger stroke volume seen in microgravity elevates systolic pressure, and a reflex compensatory vasodilatation reduces systemic vascular resistance and widens the pulse pressure. Arterial baroreflexes are blunted because they adapt to these shifts with a decrease in pulse rate and blood pressure. During prolonged space travel, the low afterload resistance and reduced sympathetic outflow has been postulated to result in cardiac atrophy and loss of function.[9] More recent evidence suggests that changes in ventricular volumes may be due to fluid redistributions instead of atrophy.[10] Despite an accentuation in lung blood flow, there is no increase in alveolar fluid. Lung volumes are changed with a 15% decrease in tidal volume and an 18% decrease in alveolar and physiologic dead space. As a result, there is small increase in the respiratory rate.[7,8] During prolonged exposure to microgravity, astronauts lose a small percentage of total body calcium and bone density, which results in an increase in urinary calcium.[6-8] Muscles can also atrophy, with up to a 20% loss in strength and with associated neuroplastic changes.[6-8] There is also a decrease in lymphocyte numbers, with an increase in leukocytes but with a reduced ability for phagocytosis.[8,11] Circadian rhythms and sleep patterns are usually disrupted and can induce psychophysiologic responses to stress.[8,12]

More than 75% of all shuttle astronauts have taken some form of medication for conditions typically considered nonemergency (motion sickness, headache, sleeplessness, and back pain) during their missions.[13,14] Gastrointestinal motility appears to be significantly reduced during the first 72 hours of a mission. Furthermore, space motion sickness symptoms, which include nausea and vomiting, may also affect drug absorption when drugs are taken orally. The changes in extracellular fluid volume and distribution may alter bioavailability, drug distribution, and clearances. Some medications also appear to have an exacerbation of adverse effects in microgravity. A cardiac dysrhythmogenic effect caused by an increase in myocardial irritability has been noted with some common medications.[8,13,15,16] As the time spent in space is extended, then more research will be necessary to define the effects of a microgravity environment on pharmacokinetics.

POTENTIAL EMERGENCIES

All the possible emergencies that might occur in a given population of similar adults could also occur in space. Medical screening has greatly reduced the likelihood of many common medical risks, but the unique problems associated with microgravity and the space environments have introduced a whole new group of potential emergencies. Some of the more important of these emergencies unique to space travel are outlined as follows.

Environmental

Radiation belts extend from about 400 miles above the surface to beyond 48,000 miles into space because of the magnetosphere.[6-8] Galactic radiation amounts to about 10 millirem per day, and the total exposure from a trip to the moon is estimated to be about 0.5 rem. Solar flares can increase this dose to 100 millirem or more and could have a toxic effect by accumulation during the months of a long spaceflight. Because most of the radiation is close to Earth, there is a greater concern for lower-Earth-orbit missions, especially if there are plans for extended habitation. In practice, there have been no reports of significant acute radiation toxicity.

The environment of a spacecraft has the potential for exposure to a variety of toxic chemical and gases. In 1975, 3 American crewmembers on an Apollo-Soyuz mission were accidentally exposed to nitrogen tetroxide gas and required 100% oxygen and subsequent hospitalization because of chemical pneumonitis.[1] Several small fires on previous missions have also resulted in episodes of mild smoke inhalation.

The greatest risk for dysbarism is during extravehicular activity.[6-8] The comparatively lower pressure within the suits used for extravehicular activity can precipitate decompression illness. Cabin pressures are sometimes reduced in preparation for extravehicular activity, and crewmembers may breathe 100% oxygen for a period before leaving the spacecraft. Even with these preventive measures, emergency decompression may be necessary, and contingency plans are required.

Orthopedics

Despite the notable bone demineralization in microgravity, there have been no reports of fractures during spaceflight. There is little opportunity in the weightless conditions and small cabin spaces for a significant impact that could cause bone injuries. In the event that a fracture is sustained, the slow healing of bone in microgravity may be a reason for emergency evacuation to prevent disunion. Therefore, it is important to be able to accurately determine the presence or absence of a suspected fracture. Typical radiograph equipment is impractical in the cabin environment. Dulchavsky et al[17] have explored the use of compact ultrasonographic devices for detecting fractures. They found that this methodology was highly sensitive and moderately specific for detecting long-bone fractures. Muscle and ligamentous injuries are much more likely in the space workplace, and ultrasonography may also be used to determine the extent of this damage.

Reduction of fractures or dislocations require counterforces.[6,18] In microgravity, these maneuvers can be difficult, and there has been some effort to develop restraining devices that could be used for providing traction. Splints chosen for space missions are selected for versatility, low volume, and mass and should be well tolerated for an extended period.

Cardiovascular

The symptoms associated with the large cardiovascular fluid shifts experienced during microgravity exposure have also been some of the most prevalent. Although there are usually no specific in-flight emergency conditions related to these fluid changes, postflight orthostatic hypotension as a result of capacitance alterations and resetting of baroreceptors remains one of the most common and potentially serious problems associated with space travel and could limit interplanetary exploration. Cardiac dysrhythmias consisting primarily of isolated premature atrial or ventricular contractions have been observed during spaceflight, but the physiologic significance of these events has not been determined.[16] Rarely do they limit astronaut performance or affect the mission.

Trauma

The greatest risks for significant trauma are thought to be present during an extravehicular activity.[6,18] Blunt and penetrating injuries can occur during the performance of space-station construction, satellite repair, vehicle docking, and payload deliveries. There is also the potential for chemical and electrical burns. Although most of the usual principles for the diagnosis and management of in-flight trauma apply, there are the serious limitations of available tools to consider. Research into the extraterrestrial management of hemorrhage and possible emergency surgery is being performed to address these problems.[6,18-21]

Infectious Disease

Confinement within a spacecraft is conducive to cross-infection of astronauts, and crews are typically quarantined from the general population for a period before launch. Isolation also limits the exposure to many types of organisms. Therefore, culture data from astronauts and their surroundings indicate a simplification of the indigenous microbial flora, with a decrease in the different strains of bacteria but an increase in the total number.[8,11] The weightless environment is thought to increase the potential for spread of infectious material through aerosolization of bacteria and viruses, which would make these agents more likely to collect on body surfaces and is consistent with reports of a 10-fold increase in the flora of the throat and skin.[8,11] There have been several instances of significant in-flight respiratory tract infections over the years and some reports of superficial cellulites.[8,11] Genitourinary infections are a well-known space-related medical problem, including the well-publicized case of urosepsis developing in an astronaut on

Apollo 13.[1,8] Without the normal gravitational forces to assist proper urine flow, in combination with the limitations of renal filtration, a condition of urinary stasis increases the risk for infection.

Neurologic

Complaints of headaches are common during space travel and are thought to be caused by a cephalad shift of body fluids.[8] Fortunately, most of these headaches can be readily controlled with acetaminophen or a nonsteroidal antiinflammatory drug. However, there have been instances in which astronauts have been severely incapacitated by uncontrollable and persistent headaches.

Space motion sickness affects at least 70% of astronauts on their first flights.[8] These same astronauts are also at risk for recurrence of space motion sickness with repeated exposures to microgravity. Most of the symptoms abate within 72 hours but can recur when the astronaut returns to Earth (*mal de barquement*), particularly for missions lasting several months, and may be an important consideration in planning interplanetary voyages. Although space motion sickness is not fully analogous to terrestrial motion sickness, they share many common features with no specific electroencephalogram changes. Space motion sickness is thought to occur when change-of-axis head movements are made during rotation, which can generate unusual stimulation of the semicircular canals, known as Coriolis cross-coupling stimulation. The most common clinical feature of space motion sickness is the sudden onset of vomiting without clear prodromal signs. These episodes are short and are usually controlled with intramuscular injections of promethazine.[7,8,13,14] Although symptoms of space motion sickness are rarely life threatening, they can be incapacitating, severely affect performance, and possibly result in operational risks.

Urologic

Surprisingly, genitourinary complications have been among the most frequent medical problems experienced during spaceflight.[1,8] After the initial diuresis and dehydration on exposure to microgravity, the astronaut must maintain adequate fluid intake to ensure normal urine flow, which may be difficult because of the work demands, logistics of drinking, and the anorexia of space motion sickness. Poor urine flow coupled with an increased calcium excretion as a result of bone loss can result in a precipitation of renal stones.[8] Nephrolithiasis has occurred in several astronauts, although it has rarely affected the mission.[1]

Psychiatric

Psychiatric issues have always been considered important, but research in this area has been limited because of the priorities of other biomedical problems associated with space flight.[12] However, longer flights and extended confinement on the International Space Station will certainly bring many of these issues to the forefront. The isolation and confinement models of the submarine crews and the Antarctic explorers have often been used to predict the psychological effects of space flight. These models usually involve a state of sensory deprivation, with the classical findings of sleep disturbance and irritability that could lead to expressed anger and hostility. Although isolation is a hallmark of long missions, the astronauts in short space flights typically experience a state of sensory overload and hyperarousal. Prolonged hyperstimulation can result in impaired concentration and deterioration in coordination and performance. Conditions of sensory overload and deprivation can be present during a space mission and may develop into perceptual abnormalities such as hallucinations.

COUNTERMEASURES TO PREVENT EMERGENCIES

On the last Mercury flight, an astronaut experienced a near-syncopal episode on return due to orthostatic hypotension caused by microgravity-induced cardiovascular changes after only 30 hours in space. Since then, this condition has remained one of the most problematic medical emergencies associated with space travel and has even been implicated in the uncertain deaths of 2 of the cosmonauts during reentry.[22] It appears most frequently in female astronauts but is almost always more severe the longer the flight.[23] Some astronauts returning after a prolonged mission (ie, Mir) are essentially incapacitated, requiring supportive care for days before recovery. Therefore, it will be imperative to solve this problem before there can be any reasonable interplanetary missions (Mars' gravity is about three eighths of Earth's). In the past, countermeasures have included applying lower-body negative pressure and giving the astronauts fluid loads immediately before leaving orbit to return to Earth.[8] Florinef has been tried in an attempt to restrict the loss of this fluid load but with very limited success.[8] The Russians have used leg binders in a method similar to the emergency use of military antishock trousers.[8] Midodrine, a selective α_1 receptor agonist that increases peripheral resistance and decreases venous capacitance, has been considered for pretreatment for reentry syncope.[24] However, the physiologic adaptations to microgravity such as a loss of extracellular fluid volume, possible cardiac muscle deconditioning and the down-regulation of vascular capacitances suggest that the problem may require a more complex and integrative solution.[25]

When medical conditions require an emergency need to return to Earth's gravity, it may be possible to artificially create gravity. Rotation of a module or area of the spacecraft at a speed sufficient to create an angular momentum that would generate a centrifugal force comparable to that of 1*g* is feasible, although logistically somewhat difficult.[1,8]

TRIAGE AND THE OPERATIONALLY ORIENTED APPROACH TO EMERGENCY MEDICAL MANAGEMENT

Decisionmaking about triage and emergency care may differ considerably from the usual standards when the nearest physician is thousands of miles away.[26] Medical contingency plans exist to first ensure successful completion of the mission.

Second, they must also protect the medical well-being of the individual, balanced by the needs of the crew as a whole. This approach is commonly known as "operational" medicine and is based on the principles typically used by the military for the functions of a medical team during a combat mission. These principles are based on the concept that the medical group functions as one component of a team that has a specific mission. However, crew safety is a top priority at NASA, and there is considerable redundancy in the system to ensure astronaut health and protection. In a time of smaller crews and short missions, the medical support focuses on appropriate preventive measures and ground-directed management of in-flight emergencies. As missions become longer, the need for an onboard medical presence and contingency planning will also become more important.[26]

Vital Signs and Arrhythmia Monitoring

Continuous monitoring of vital signs rarely occurs outside of the context of an experimental study, although blood pressure, temperature, and cardiac rhythms are typically recorded periodically during the mission for analysis by the ground-based flight surgeons. Although a finding of significant bradycardia is common in these conditioned astronauts, potentially serious arrhythmias (supraventricular and ventricular tachycardias) have been observed on occasion.[16] The arrhythmias are usually short and of unknown physiologic or clinical significance. Advanced monitoring for indicators thought to portend emergency risks (T-wave alternans, QT prolongation) are being considered, but technical obstacles such as noise interferences have limited their usefulness.[1,8] Many of the medications taken by astronauts to treat nausea and insomnia associated with spaceflight can affect cardiac repolarization.[15] This interaction highlights the possible consequences of unrestricted access to prescription medications by laypersons.

Emergency "Room" in Space

When considering where emergencies should be handled aboard the space shuttle or International Space Station, it is clear that instead of an emergency department we are truly referring to an emergency "room" at best and more likely an emergency compartment or module.[27]

The limited available area within the shuttle would severely restrict almost any emergency care. Of the 2 major deck areas aboard the shuttle, the lower compartment contains the toilet and sleeping facilities. It may be necessary to use the sleeping pods to restrain a critically ill astronaut who would otherwise float freely in the compartment and potentially receive more injury. Likewise, the proximity of the toilet may be important, depending upon the problem. Fortunately, the shuttle has some flexibility for a rapid reentry in case of an emergency, and the time spent in the shuttle emergency "room" would be short. Nevertheless, in the case of an emergency, early in-flight resuscitation and stabilization may be necessary.

It would be more difficult to execute a rapid evacuation of a severely injured or critically ill individual from the International Space Station until a better method for emergency return is established. Therefore, greater consideration of an area for prolonged emergency management is required. The modular nature of the station makes specialization of designated areas more feasible. When the needs of the emergency patient are considered, the human research vehicle (where experimental studies are to be performed) may contain the necessary monitoring equipment and tools for intravenous access.

Restrictions in storage capacity of most spacecraft have also restricted what the in-flight medical kit can contain.[28] Most of these therapies are for symptomatic relief of common complaints, and only a few are really what would be considered "emergency" drugs. Space medical kits also contain first-aid supplies, including bandages and splints. Usually, normal saline is the only fluid available on most shuttle missions and aboard the International Space Station. Colloid solutions and blood substitutes may be considered in future kit additions. Currently, inclusion of emergency therapeutics is centered on the concept of resuscitation, stabilization, and early evacuation.

To maintain an onboard emergency facility certain core medical diagnostic, imaging, and laboratory equipment should also be present. Point-of-care laboratory testing using handheld devices is used to rapidly obtain information on a variety of electrolyte, chemical, and hematologic variables. Some more advanced laboratory devices, including a self-contained portable Gram staining apparatus, have already undergone testing in microgravity by NASA.[29]

Noninvasive testing with the use of pulse oximetry, end-tidal CO_2, impedance cardiography, and echocardiography are tools that has been used during spaceflight. Even the focused assessment with sonography for trauma examination has been demonstrated to be feasible in the microgravity environment, although with limited sensitivity.[30] The cost to launch and recover equipment aboard the International Space Station has been estimated to be $10,000 per pound and is a limiting factor for outfitting such a medical facility.[26] In recent years, many monitoring and diagnostic technologies have been condensed in size and can potentially be used during spaceflight.

Emergency Procedures in Space

If emergency procedures are required because of trauma or any major medical condition in which significant blood loss is expected, special consideration must be given to prevent contamination of the cabin environment.[19-21,31] Likewise, the loss of traction and dependent forces in microgravity could greatly complicate an already technically difficult procedure. Several groups have developed specialized surgical chambers that could be used in microgravity. These chambers typically consist of an expandable clear plastic covering with arm ports fitted with surgical gloves. Velcro straps can be used to restrain the patient. Suction equipment cannot use the typical drop-container principles used on Earth and require a centrifugal cylinder to separate liquid from gas. Temporizing procedures and medical alternatives to surgery until evacuation to definitive care is possible and may provide a better option in the microgravity environment.[31,32]

Advanced Cardiac Life Support, Advanced Trauma Life Support, and Resuscitation at Zero Gravity

When the possibility of medical resuscitation in the microgravity environment is considered, it becomes immediately evident that the usual physiologic conditions and advanced cardiac life-support protocols applied on Earth may not be relevant.[6,19,33,34] Using a porcine model in conditions of simulated microgravity aboard a KC-135 aircraft in a parabolic flight, Johnston et al[33] found that it was possible to perform effective cardiopulmonary resuscitation (CPR) in a manner that could maintain $ETCO_2$ levels above that previously reported to be predictive of survival. However, they found that CPR could be performed in the 0*g* environment only if there is a method of restraint of the patient, CPR provider, and all equipment. The provider also fatigued rapidly using a conventional stance for chest compressions because of the lack of the usual counteracting forces. An unconventional vertical-inverted positioning with the CPR provider placing his feet on the ceiling as a brace for a counterforce was found to be more effective and less tiring.

The effects of cardiac stimulatory and vasoactive therapies such as epinephrine and norepinephrine may be unpredictable because of baseline variations and neurohumoral adaptations.[8] Because peripheral resistance is already decreased in microgravity, the arterial pressure changes observed may not be an adequate guide for titration of treatment. Advanced noninvasive monitoring techniques such as $ETCO_2$ and pulse oximetry may be more important indicators of a successful resuscitation in this setting.

Most common advanced trauma life support procedures, including chest-tube insertion and tracheostomy, have also been shown to be feasible in the weightless environment.[34] Judging fluid requirements during resuscitation in space is complicated by the physiologic hypovolemia associated with microgravity exposure.[19] If the patient is being evacuated to Earth and reexposed to gravity, then the volume requirements will certainly be in excess of those needed for the typical terrestrial resuscitation. Alternatively, if care is continued in space, then less fluid will be required. If there is a significant head injury, then fluids must be used very cautiously because of the already elevated cephalad pressures in this environment. Additionally, all fluid resuscitation in space will require a pressure pump apparatus to infuse properly because of a lack of dependent forces. In the case of an injury resulting in hemorrhage, an astronaut with the usual microgravity-induced anemia may be more vulnerable to small losses in blood volume. Because it is impractical to store autologous blood for all crewmembers during a mission, hemoglobin-based oxygen carriers and blood substitutes have been considered as alternatives.

When an operational approach to CPR/advanced cardiac life support/advanced trauma life support is formulated, it is important to consider the variable and potentially limited skills of the appointed crew medical officer. An environment of restricted resources and uncertain availability of assisting personnel are also taken into account in the planning. The standard acute algorithms have been modified to reflect these special considerations, with an emphasis on simple decisive actions. Laryngeal Mask Airways (LMA), although not optimal, may be preferred for airway control because of the greater probability of success for nonskilled providers and the difficulties of procedural logistics associated with weightless conditions. Ventilators will probably not be available, and it is assumed that the patient will have to be bag-valve-mask ventilated. Once an LMA is inserted, the protocol provides that appropriate drugs be preferentially injected down the tube rather than that an intravenous access be placed because of the time and effort required to place it. Exact termination criteria are also used in which no more epinephrine is given after 45 minutes, which is important to limit risks to the crew and overall mission in situations where there is no chance for patient survival.

Rescue: Emergency Medical Services (EMS) From Space

Typically, at least 1 member of a shuttle crew receives the equivalent of paramedic training before a mission.[27,35,36] In the event of an emergency on the shuttle, the mission could be aborted and the patient returned promptly to Earth to receive expert medical attention.[1,27,35,36] The crew member with the medical training would be responsible for stabilization of the patient before and during reentry. The situation is different for an emergency that occurs aboard a space station. Currently, the International Space Station may have more space and resources to stabilize acute medical conditions than previous vehicles. In the event that an astronaut must be returned to Earth in an emergency, the approximate time required for a shuttle to be readied for a low-Earth orbit evacuation attempt is about 45 days, at a cost estimated to be in the range of $100 million.[1,18] Hence, it was important that International Space Station planning include consideration of an emergency return vehicle.[36,37] Currently, the International Space Station is using a modified Russian Soyuz capsule attached to the station to be used in the event of an emergency evacuation. The capsule has a habitable volume of approximately 3 m^3 shared among 3 crewmembers. The capsule is severely limited in allowable medical equipment and may not permit adequate musculoskeletal support for severely injured patients. To meet the minimum US standards for ambulance medical care, any space-based rescue vehicle should have the capability for first-responder CPR, oxygen delivery, intravenous therapy, electrocardiographic monitoring, defibrillation, suction, airway management, mechanical ventilation, splinting, and bandaging.[37,38] A rescue vehicle from a space outpost should also contain some limited hyperbaric and decontamination capabilities. Although a much larger crew return vehicle has been designed by NASA, budgetary considerations have prevented further development,[37,38] which has also limited the maximum number of crew allowed on the station at any one time. For realization of the full potential of the International Space Station, the development of an appropriate EMS system is imperative.

FUTURE CONSIDERATIONS

Defining the future biologic consequences and medical needs of space explorations is a challenge.[39,40] Research in this area is limited and difficult. Parabolic arc flights in the NASA KC-135 aircraft have served as the microgravity laboratory for many biomedical experiments in preparation for emergencies in space.[23,25] Unfortunately, each parabolic cycle generates only approximately 25 to 45 seconds of high-quality microgravity and may be inadequate to test emergency interventions and for the evaluation of medical contingency plans for missions without realistic possibilities for immediate evacuation. Innovative methods using telemedicine and diagnostic support systems may also be incorporated in the process.[41,42]

Much of our knowledge about what will happen to humans on long missions must be extrapolated from data obtained from the Mir and International Space Station experiences. NASA has also been exploring the possibility of using complex computer models of human physiology adapted to the setting of microgravity to simulate the potential pathologic consequences of long-term spaceflight and devise medical treatment and countermeasure plans.[25] Ultimately, consideration of the maximal use of unmanned technology to reduce potential human risks should always be an important part of future planned explorations.

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