Risk of Inability to Adequately Treat an Ill or Injured Crew Member

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Mission architecture limits the amount of equipment and procedures that will be available to treat medical problems. Resource allocation and technology development must be performed to ensure that the limited mass, volume, power, and crew training time be efficiently utilized to provide the broadest possible treatment capability. This allocation must also consider that not all medical conditions are treatable, given the limited resources, and some cases may go untreated. – *Human Research Program Requirements Document*, HRP-47052, Rev. C, dated Jan 2009.

The promotion of crew health and safety in space requires the provision of necessary resources, despite limitations in mass, volume, power, and crew time, and must be directed toward the treatment of the conditions with high likelihood or severe consequence. The care of the crew begins with thorough pre-flight health status assessments and appropriate medical training in procedures and equipment to allow care to be crew-administered, and under certain circumstances, completely autonomous. Autonomous, crew-administered care is exemplified here, as Scott Parazynski (left) prepares to withdraw blood from the arm of John Glenn (right) while on the shuttle middeck.

Executive Summary

A review of published and non-published (e.g., NASA Longitudinal Study of Astronaut Health database) information on medical conditions that occurred during space missions (including the Russian partner experience), as well as a review of relevant information from harsh analog environments (e.g., submarine fleet health databases, Antarctic expeditions, mountaineers' expeditions) provides evidence that medical conditions of different complexity, severity, and emergency will inevitably occur during long-term Exploration missions. Depending on the medical problem, the resources that are available, and the time that is necessary for returning to Earth, different levels of medical care are required. Providing medical care for these conditions will be challenging in the resource-constrained environment of space. Plans for care to support both the health and the safety of astronauts and mission success must be made with regard to balancing the most likely conditions with those that pose the most catastrophic outcome. All medical problems have the potential to affect the mission, but significant illnesses or trauma will result in a high probability of mission failure or loss of crew. These considerations justify postulating and addressing the "risk of the inability to adequately treat an ill or injured crew member" during an Exploration mission, including not only which capabilities will be available but also how medical care will be provided and performed.

Introduction

The specific provision of medical services during space missions is authorized and required by the following documents: NPD 8900.5A, *NASA Health and Medical Policy for Human Space Exploration*; NPD 8900.1G, *Medical Operations Responsibilities in Support of Human Space Flight Programs;* NPD 8900.3F, *Astronaut Medical and Dental Observation Study and Care Program*; and NASA-STD-3001, *NASA Spaceflight Human Systems Standard – Volume 1, Crew Health*.

Medical conditions of different complexity could occur during space missions, especially during long-term space missions to the moon and Mars. An increasing number of possible medical conditions, including trauma, will have to be addressed for these missions since emergency returns become unlikely or impractical as the distance from Earth increases. Return will be nearly impossible during Mars missions and severely limited for many lunar situations. Even teleconsulting will have certain limitations due to significant delays in real-time communication on Exploration missions to Mars. Thus, health care, including emergency care and psychological support, will have to be self-administered and, under certain circumstances, completely autonomous.

Genuine difficulties in providing medical care in space include, but are not limited to: (a) resource constraints resulting from the boundaries of the mission design and architecture (volume, mass, power) and dictating that only the most critical medical equipment can be stored on board the space vehicles and delivered to the space habitats; (b) lack of trained medical professionals among the crew members; (c) limited pre-flight crew training time, necessitating the restriction of the training to only medical knowledge, techniques, and procedures that address the medical situations that are most likely to occur or that are most critical; (d) the probability that the crew members on the vehicle or in the habitation module may have to respond to emergency medical conditions without real-time support from Earth; (e) limited shelf-life of medical therapeutics and supplies; and (f) the possibility of encountering unpredicted illnesses and ailments that may be unique to the space exploration environment.

The most optimal way to achieve adequate support for crew health and to secure mission success on extended-duration missions is to establish a thorough pre-flight health status assessment, including all new technological

approaches (genomics, proteomics, etc.), and develop a systematic approach to a more comprehensive autonomous health care system in space.

Evidence

The evidence that is needed to postulate the possibility and estimate the probability of the occurrence of medical conditions during space missions can be drawn from different sources. Some sources include: (a) records of medical problems that were encountered in previous space flights by U.S. and Russian crews as well as other international partners; (b) information on the medical conditions that occurred during short- and long-term Earth expeditions (submarine, alpine, Arctic and Antarctic expeditions, expeditions to other remote ground-based locations, etc.); (c) general population studies addressing the age-related probabilities of different diseases and incidence of trauma; and (d) pre- and post-flight records of the health status and medical conditions of astronauts and cosmonauts.

Space flight evidence

In-flight illness incidence rates are partially summarized in several publications (Stewart et al., 2007; Summers et al., 2005; Davis, 1999). Evidence can also be obtained from the Longitudinal Study of Astronaut Health database that is maintained at NASA JSC. Tables 8-1 through 8-3, which are taken from a collaborative review report that was edited by John Ball and Charles Evans, are illustrative of the conditions that could occur and some estimates of the probabilities (Ball and Evans, 2001).

Table 8-1. ***In-flight Medical Events for U.S. Astronauts during the Space Shuttle Program (STS-1 through STS-89, April 1981 to January 1998)***

Medical Event or System by ICD-9[a] Category	Number	Percent of Total
Space adaptation syndrome	788	42.2
Nervous system and sense organs	318	17.0
Digestive system	163	8.7
Skin and subcutaneous tissue	151	8.1
Injuries or trauma	141	7.6
Musculoskeletal system and connective tissue	132	7.1
Respiratory system	83	4.4
Behavioral signs and symptoms	34	1.8
Infectious diseases	26	1.4
Genitourinary system	23	1.2
Circulatory system	6	0.3
Endocrine, nutritional, metabolic, and immunity disorders	2	0.1

[a]*International Classification of Diseases, 9th Ed.*

Table 8-2. ***Medical Events Among Seven NASA Astronauts on* Mir, *March 14, 1995, through June 12, 1998***

Event	Number of Events
Musculoskeletal	7
Skin	6
Nasal congestion, irritation	4
Bruise	2
Eyes	2
Gastrointestinal	2
Psychiatric	2
Hemorrhoids	1
Headaches	1
Sleep disorders	1

Note: Data from the Russian Space Agency indicate that there were 304 in-flight medical events on board the space station *Mir* from February 7, 1987 through February 28, 1998. The numbers of astronauts at risk or the incidence per 100 days was not reported.

Table 8-3. ***Medical Events and Recurrences Among Astronauts of All Nationalities on* Mir, *March 14, 1995, through June 12, 1998***

Event	Number of Events
Superficial injury	43
Arrhythmia	32
Musculoskeletal	29
Headache	17
Sleeplessness	13
Fatigue	17
Contact dermatitis	5
Surface burn	5
Conjunctivitis	4
Acute respiratory infection	3
Asthenia	3
Ocular foreign body	3
Globe contusion	2
Dental	2
Constipation	1

As most of these conditions do not represent medical emergencies, they could be treated by merely taking medications while on board, if available. About 75% of all astronauts have taken some form of medication during shuttle missions for nonemergency conditions such as motion sickness, headache, sleeplessness, and back pain. Other nonemergency conditions that the shuttle astronauts have experienced include minor trauma, burns, dermatologic and musculoskeletal conditions, respiratory illnesses, and genitourinary problems, etc.

More important is the existing evidence of potential medical emergencies during space flight, such as potentially fatal and nonfatal arrhythmias, heart attack, stroke, embolism, massive hemorrhage, emergencies that are related to renal stone formation, infection, and thrombotic complications. Among these conditions, only arrhythmias, renal colic, and infections have been documented. The documented arrhythmias were mostly mild abnormalities, such as occasional premature atrial contractions (PACs) and premature ventricular contractions (PVCs). PACs or PVCs were present in 30% of astronauts at some point during periods of strenuous activity.

Potentially serious arrhythmias (supraventricular and ventricular tachycardia) have also been reported. For example, during Apollo 15, one crew member experienced ventricular bigeminy; ventricular ectopy was reported on Skylab; and on *Mir*, a crew member experienced a 14-beat run of ventricular tachycardia (Fritsch-Yelle et al., 1998). No manifestation of coronary artery disease (CAD) was registered during any human space flight; however, considering the risk of cardiovascular events in older people and the increasing age of crew members, the possibility of such complications during long-term space missions cannot be ignored. Other medical emergencies that have been observed in space include rare, but real, cases of urological (Berry, 1974; Lebedev, 1983) and dental emergencies (Newkirk, 1990; Brown et al., 1977), as well as behavioral and psychiatric problems.

Additional evidence and consideration substantiates the risk of the inability to treat crew members on Exploration missions. For example, in a few cases in the past, episodes of renal colic and arrhythmia have required that crew members (Russian cosmonauts) be brought back to Earth, shortening their stays in space and possibly compromising the missions (Summers et al., 2005).

Radiation exposure could also cause other potential medical problems; for example, it might affect general health and cause radiation-specific pathological processes, especially given the proposed length of missions to Mars. If such emergencies were to occur, they would most likely be catastrophic and mission ending.

Moreover, when designing space medical care systems, the potential for crew exposure to toxic chemicals and gases as well as to chemical and electrical burns must be considered. There are also risks for significant trauma, both on board the spacecraft and during EVAs, due to the nature of operational activities and the closed environmental systems.

Lastly, given the length of Mars missions, there is also a certain age-related probability of the development of diverse medical conditions that are similar to those in the general population. These probabilities can be assessed based on general population health statistics as well as from information that is found in the astronaut pre- and post-flight health databases (Peterson et al., 1993; Hamm et al., 1998).

Ground-based evidence

The ground-based incidence of illness data are derived from publications and the available databases summarizing the occurrence of different medical conditions that are encountered in groups of individuals who are exposed to harsh environments that could be considered as analogs of the space environment. A sample of this information is presented in Tables 8-4 through 8-6 (Ball and Evans, 2001). As can be seen from the tables, the incidence of different medical conditions in these environments was, in general, relatively low (from 10 to ~50 events per 100,000 person-days) and mostly these were non-emergent conditions. Even these illnesses (trauma, infections, psychiatric disorders) required an evacuation that would be difficult, if not impossible, to provide in space, however, especially on future missions to the moon and Mars.

Table 8-4. ***Incidence of Health Disorders and Medical-Surgical Procedures during 136 Submarine Patrols***

Disorder	Number/ 100,000 Person-days
Injury (includes accidents)	48.8
Respiratory	24.6
Skin or soft tissue	19.0
Ill-defined symptoms	10.5
Infections	10.0
Procedure	**Percentage of All Procedures Performed**
Wound care, splinting	42.0
Suturing	18.7
Cleansing	8.2
Nail removal	6.8
Fluorescein eye examination	4.2
Incision and drainage of abscess	2.9
Tooth restoration	2.0

Table 8-5. ***Reasons for 332 Medical Evacuations from All Submarines, U.S. Atlantic Fleet, 1993 to 1996***

Reason for Evacuation	Number of Cases
Trauma	71
Psychiatric illness	41
Chest pain	34
Infection	40
Kidney stone	23
Appendicitis	21
Dental problem	31
Other	71
Total[a]	332

[a]Rate = 1.9 to 2.3 per 1,000 person-months

Table 8-6. ***ANARE Health Register Illnesses in Antarctica from 1988 to 1997***

Disorder	Number	Percent of Total
Injury and poisoning	3,910	42.0
Respiratory	910	9.7
Skin, subcutaneous	899	9.6
Nervous system or sensory organs	702	7.5
Digestive	691	7.4
Infection or parasitic	682	7.3
Musculoskeletal or connective tissue	667	7.1
Ill-defined symptoms	335	3.6
Mental	217	2.3

It is important to emphasize that crews that were living and working in harsh environments (Antarctic expeditions, submarines, and undersea habitats) also had medical emergencies, such as intracerebral hemorrhage,

stroke, myocardial infarction, appendicitis, and bone fractures. There were also cases of cancer and psychiatric illness. However, the overall rate of these serious medical or surgical emergencies was low. The most common emergencies were dental. For instance, in 100 British Polaris submarine patrols, crew members required 30 fillings and seven extractions due to intolerable pain (Glover and Taylor, 1981). Dental problems had been the cause for a transfer at sea in the U.S. Polaris submarine program (Tansey et al., 1979). Extractions and fillings have also been required in Antarctica (Lisney, 1976).

The calculated rate of significant illness or injury that is based on the meta-analysis of data from submarines, Antarctic expeditions, military aviation, and U.S. and Russian space flight experience was found to be approximately 0.06 event/person-year (Billica, 1996). Extrapolation of these data to a 2.5-year Mars mission involving six crew members provides an expected rate of a significant medical event of 0.9 people/mission (Billica, 1996). In other words, one significant medical event could be expected per Mars mission. It is understandable that risk estimations that are made by using the data from analog populations have certain limitations for Mars mission risk assessments. These estimates are likely to be conservative, as they do not account for the unique problems that are associated with the spacecraft environments, possible radiation effects, as well as exposure and physiological adaptation to low gravity (Buckey, 2006).

Of particular interest is the incidence of cardiovascular events in the harsh-environment populations. For example, the reported 5-year annual cardiac events rate by age group among USAF aviators was: 0.0054% (30–34 years), 0.018% (35–39 years), 0.038% (40–44 years), 0.14% (45–49 years), and 0.13% (50–54 years) (Osswald et al., 1996). Of all of these events, 21% were cases of sudden death and 61% were diagnosed and treated as myocardial infarction. Therefore, despite the rigorous screening that USAF aviators undergo, very often the first manifestation of CAD in this population was a significant cardiac event (Buckey, 2006). It is believed that these data are applicable to the Astronaut Corps as well, despite the fact that astronauts undergo a more-extensive medical assessment. In fact, this information emphasizes the risk of occurrence of sudden death or heart attack in space despite thorough screening (Buckey, 2006).

In the submarine program, the most common general surgical condition has been appendicitis (Tansey et al., 1979), and even a case of death due to appendicitis has been reported among the participants of the Antarctic expeditions (Ball and Evans, 2001). Other serious conditions that were also reported in the submarine program were traumatic amputations, fractures, and dislocations (Buckey, 2006). Furthermore, depression and anxiety reactions are found to be the most common two psychiatric diagnoses that are made on submarines (Tansey et al., 1979), and are also frequent among researchers who are enduring long Antarctic winters (Lugg, 2000).

Computer-based Simulation Information

Computer-based simulation of the likelihood and consequences of medical conditions is a decision tool that is used to assess medical risks. Although this methodology has not yet been used effectively to develop a probabilistic approach to support the medical management decision process, it is a promising tactic. Based on the premise that an optimal resolution is needed to synthesize the many incongruous factors and circumstances that are involved in providing medical care in space, this methodology could be used as a planning tool to address the likelihood of occurrence of different medical conditions and identify the required resources to treat these conditions. The integrated medical model (IMM), a tool of this type that quantifies the probability and consequences of medical risks, is in development.

Risk in Context of Exploration Mission Operational Scenarios

A review of the medical conditions that occurred during space missions in the past, as well as a review of relevant information from harsh analog environments, provides sufficient evidence that medical conditions of different complexity, severity, and emergency may inevitably occur during long-term Exploration mission. Understandably, the type and severity of the risks that would contribute to these conditions might fluctuate depending on the actual configuration of a mission, its longevity, and the complexity of the tasks that are to be performed on it. The major goals of the Exploration medical support system for the Constellation Program are to define the levels and specifics of risk factors for each mission to ensure that adequate health monitoring and maintenance systems are developed and implemented. The medical support system should also ensure that medical care, if needed, could be delivered with support from Earth or autonomously when communications with support personnel on Earth are excessively delayed or unavailable. The need for autonomous medical care puts additional emphasis on astronaut training and the development of computerized guides to facilitate the delivery of care. The identification of risks must be derived from a comprehensive analysis of all of the available sources of information, including analog environments. Medical care for Exploration missions will be based on the current understanding of the pathogenesis of the anticipated conditions in reduced gravity and on state-of-the-art diagnostic and treatment capabilities that are available on Earth. These diagnostic and treatment capabilities have to be modified and adjusted to the specifics of the space environments and comply with the NASA space flight health standards.

The development of appropriate risk context and the goals that are laid out within the ExMC Element necessitate identification of the “gaps” that exist between the anticipated in-flight medical conditions and the ability to mitigate or treat the conditions adequately. Documented in-flight conditions and conditions that are derived from comparable terrestrial populations will provide the basis for the Exploration medical condition list. This list will be prioritized based on the projected occurrence, possibility of being adequately diagnosed and treated on Exploration-class missions, consequences, and constrained resources (mass, volume, power, shelf-life, etc.) to diagnose and treat illnesses and injuries. This gap identification will facilitate the ability to articulate these difficult and complex problems and risk characterizations as well as to seek innovative solutions.

Conclusion

The review of the available published and non-published (JSC database) medical information that is related to astronaut health and in-flight medical conditions as well as records of medical conditions occurring in analog environments provides strong support for risk justification for both emergent and non-emergent medical events in space. At the same time, the data analysis reveals significant gaps in risk assessment, knowledge concerning potential medical conditions, and diagnostic and treatment capabilities on Exploration missions.

An Exploration medical condition list is being developed, in close collaboration with the Space Medicine Division at JSC, to focus the ExMC Element work further. This list will be further specified by Exploration mission design to assist with the planning of research and development activities so that Constellation Program development milestones and Space Life Sciences standards and requirements are met by the space vehicles. The identification and documentation of Exploration medical conditions and the associated gaps is essential for focusing and prioritizing ongoing studies in this field and for guiding the NASA HRP strategy.

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